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IDAUP Coordinator Prof. Theo ZAFFAGNINI

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**DATA MERGING FOR A DIGITAL LANDSCAPE
Creative Integration of GIS, BIM and Computational Tools
in the Landscape Design Process**

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Candidate

Beatrice, MAGAGNOLI

Supervisor DA

Prof. Luca, EMANUELI

(UniFe Matr. N. 119323)

(Polis Univ. Reg. N. PL581N110011)

Supervisor POLIS

Prof. Xhimi, HYSA

External Expert

Prof. Gianni, LOBOSCO

Years 2022-2026

DATA MERGING FOR A DIGITAL LANDSCAPE.

**Creative Integration of GIS, BIM and Computational Tools
in the Landscape Design Process**

Thesis Supervisor:

Prof. Luca Emanuelli

Architecture Department - University of Ferrara (Italy)

Thesis Co-Supervisor:

Prof. Xhimi Hysa

POLIS University of Tirana (Albania)

External Expert:

Prof. Gianni Lobosco

Interuniversity Department of Regional and Urban Studies and Planning (DIST) - Politecnico of Torino
(Italy)

Abstract

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The construction sector is undergoing a profound digital transformation, increasingly shaped by requirements for interoperability, transparency and collaborative practices. In Italy, this transition has been accelerated by the national normative framework, particularly the *Decreto BIM* (D.M. 560/2017), which mandates the progressive adoption of Building Information Modelling (BIM) in public works. While architecture and engineering have already established consolidated digital procedures, the landscape discipline remains only marginally represented within these workflows, revealing a structural limitation in current practice.

The thesis addresses this lack of integration by proposing an interoperable design approach that brings landscape architecture to the same level of digital integration as other design fields. This new workflow enables landscape architects to employ BIM in a way that responds to environmental data needs while preserving the centrality of design reasoning, allowing data to inform proposals without replacing the interpretative and decision-making role of the designer.

Landscape projects rely on spatial analyses traditionally conducted within Geographic Information Systems (GIS), which are essential for managing territorial scales, environmental data and spatial heterogeneity. GIS also enables the processing of Earth Observation (EO) datasets, yet despite its recognised value, it remains insufficiently connected to BIM, which is primarily oriented towards object-based modelling at the building and infrastructural scale.

The research investigates how landscape architecture can be effectively incorporated into BIM workflows through direct interoperability with GIS. It examines how environmental data originating from EO platforms, processed and classified within GIS, can be systematically transferred into BIM as both geometry and information. This interoperable approach enables BIM to operate as a dynamic, data-driven environment in which parameters do not merely document design choices but actively inform them, reflecting the evolving nature of ecological systems. The proposed approach was tested across a multiscale application on three territorial areas within the Site of National Interest (SIN) of Bussi sul Tirino, demonstrating how EO and GIS data can support different landscape design objectives, from identifying strategic areas to informing planting strategies and topographic modifications.

The impact of the research operates on two levels. Operationally, it demonstrates how environmental data can move beyond preliminary assessments to directly support design scenarios within BIM environments. Disciplinarily, it provides landscape architecture with a transferable approach that strengthens its role within interdisciplinary collaboration, ensuring that ecological and territorial knowledge becomes fully integrated into shared digital platforms.

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Publications

The research activities carried out throughout the Doctoral path of the last 3 years and the base of the first findings of this thesis have been partially disseminated through national and international journal articles and conference proceedings. Several sections of the dissertation are based on previously published work. Notably, part of the methodological framework presented in this doctoral work has been refined and validated through its application to different case studies and through collaborative research conducted within Sealine (Research Centre of the Department of Architecture, University of Ferrara) in which I actively participated.

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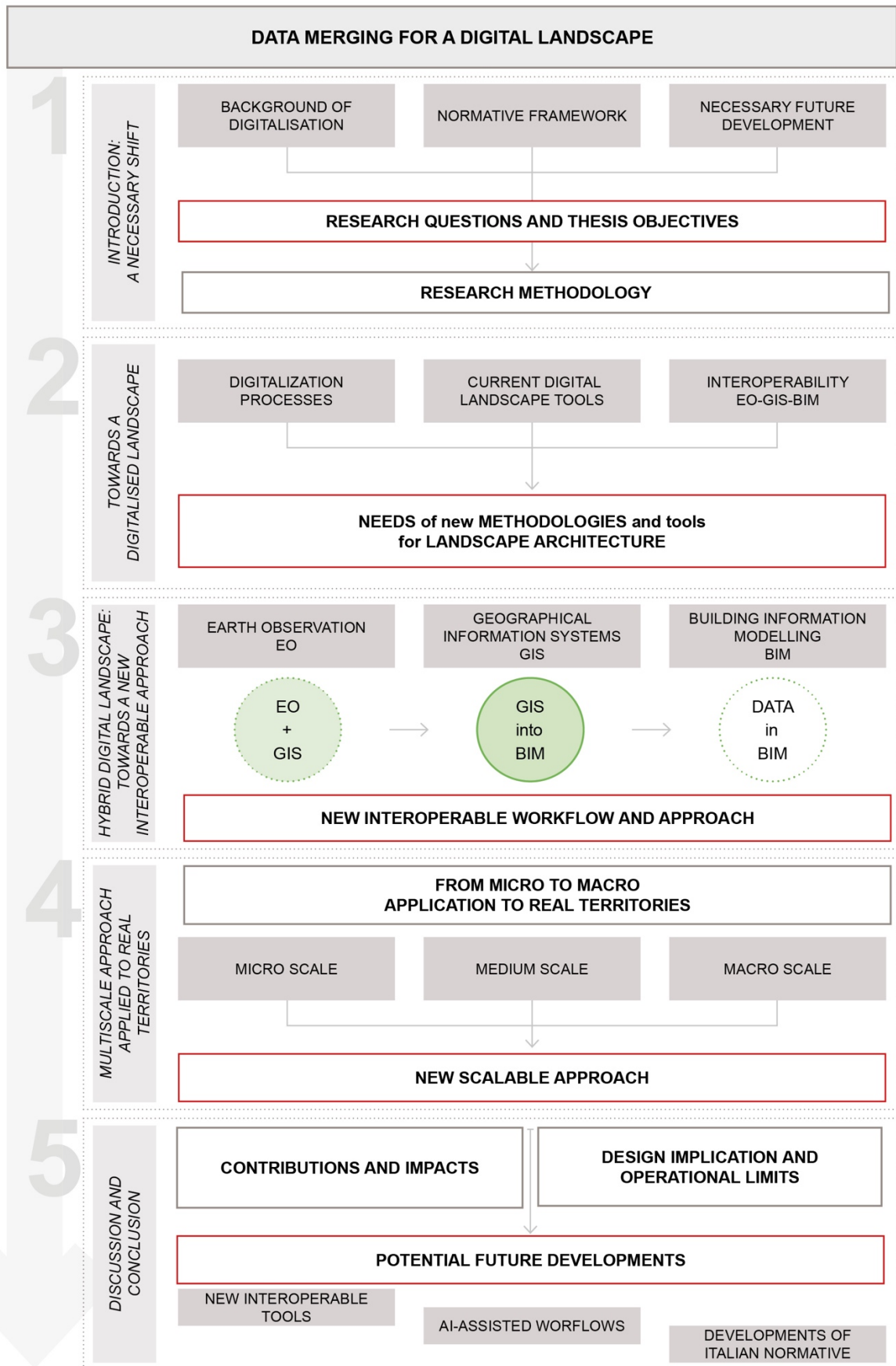
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Figure 0.1 - Graphical representation of the thesis structure



Thesis structure

The thesis is organised into five chapters, progressively outlining the development and application of an interoperable digital workflow for digital landscape design.

Chapter 1 introduces the motivations for the research, framing the digitalisation of landscape practice as a necessary evolution in response to increasing data availability and regulatory demands. It situates the study within the Italian and European normative context, formulates the research questions and objectives, and presents the methodological strategy adopted to test the integration of environmental data within design processes.

Chapter 2 reviews the main digital tools currently used in landscape-related disciplines, tracing the shift from analogue representation to computational environments. It examines the functions and limitations of GIS, Earth Observation and BIM, highlighting the current lack of integration between platforms and the marginal role of landscape within BIM-based procedures. The chapter concludes by discussing interoperability as a key condition for future development.

Chapter 3 defines the proposed workflow, showing how EO-derived information is processed, structured and transferred across GIS and BIM environments. It illustrates the operational steps required for data translation and presents three core applications, strategic area identification, data-driven planting design and topography-informed grading, demonstrating how environmental parameters can inform design decisions within a parametric model.

Chapter 4 tests the workflow on real territorial cases at Micro, Medium and Macro scales, assessing scalability and design implications. The results show how environmental data can support both detailed project configurations and broader territorial interpretations, while revealing benefits and current constraints of data-driven approaches.

Chapter 5 concludes by outlining the main contributions of recognising landscape as an information layer within BIM processes. It discusses operational limits, identifies barriers to implementation and highlights future developments related to interoperability, AI-assisted design workflows and potential regulatory evolutions, closing with reflections on the transition towards a data-merged landscape practice.

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1 Introduction: A Necessary Shift

Landscape architecture faces a moment of profound transformation. Contemporary landscapes are shaped by accelerated ecological change, socio-territorial pressures and new forms of environmental instability. Climate impacts, biodiversity decline, soil degradation and shifting land-use regimes demonstrate that landscapes behave as dynamic, interdependent systems rather than static spatial containers (Forman, 1995; Wu, 2013). As landscape ecology has long argued, spatial patterns and ecological processes operate across multiple scales, influencing one another in ways that challenge linear or object-centred approaches to design (Ahern, 2011; Turner, 2005). Designing within this complexity requires methods capable of understanding relationships, gradients and systemic behaviours. Landscape architecture, rooted in systems thinking and landscape ecology, operates at the intersection of environmental processes and territorial transformations. At the same time, the modalities through which planning and design are conceived are themselves undergoing a digital transition. Over the past two decades, expectations for transparency, interoperability and coordinated information have redefined the way public works and territorial transformations are managed (Eastman et al., 2011; Succar, 2010). Digital models are increasingly considered not merely as representational tools but as decision environments in which data, knowledge and design intent converge. Among these models, Building Information Modelling (BIM) has become a central methodology, understood not simply as 3D modelling but as an information framework where geometric components are associated with attributes, performance data, construction logic and collaborative workflows. BIM enables multidisciplinary teams to operate within shared environments, improving coordination, traceability and the structuring of project information across the entire lifecycle of a work (Barazzetti et al., 2020). This shift is reinforced by European environmental and digital agendas (European Commission, 2021) which emphasise the use of evidence-based criteria, spatial data infrastructures and measurable environmental performance in design and planning processes. Italy has institutionalised this transition through the BIM Decree (DM 560/2017) and the new Public Procurement Code D.Lgs. 36/2023 (Repubblica Italiana, 2023), mandating progressive adoption of BIM in public works. Yet landscape architecture remains only marginally represented within this digital transition, despite dealing with territories, ecologies and spatial systems that inherently depend on datasets and multi-scalar interpretations.

It is in this context that the present doctoral research is situated. This thesis investigates how landscape architecture can meaningfully participate in the digitalisation of the construction and planning sectors by proposing a multi-scalar methodology that connects environmental data, spatial analysis and modelling environments. More specifically, the research explores how information traditionally processed in GIS and environmental analysis platforms can be translated into modelling frameworks capable of supporting iterative, parametric and data-informed decision-making.

This research is grounded on two core conceptual notions that guide both its theoretical positioning and methodological development: landscape as an information layer and territorial intelligence. In this thesis, landscape as an information layer refers to the understanding of landscape not only as a physical or visual system, but as a structured spatial entity capable of storing, transmitting and generating environmental information within digital environments (Forman, 1995; Steinitz, 2012). Territorial intelligence, in turn, denotes the capacity to interpret and organise spatial data in order to transform environmental information into actionable knowledge that supports multi-scalar landscape decision-making (Girardot, 2009). These concepts inform the way EO, GIS and BIM are integrated and operationalised within the proposed design workflow.

The need for such an approach becomes evident when considering the historical foundations of landscape design practice. For much of the twentieth century, landscape architecture relied on an intuitive, iterative and often empirical process: designers generated alternatives through drawing, manual or digital and evaluated them qualitatively in the later phases of the project (Corner, 2011; Steiner, 2011). Although this approach preserves the creative and interpretive intelligence of design, it limits the capacity to engage with the increasing volume of environmental information now available through remote sensing, spatial databases and modelling infrastructures (Lu & Weng, 2006). As a result, a gap has emerged between what we know about landscapes (through data, models and analyses) and what we are able to use within the early stages of the design process.

This disconnect is further amplified by the division between disciplinary tools. The data that support landscape decisions, environmental indicators, territorial analyses and spatial classifications, are often dispersed across separate platforms, formats and workflows. This fragmentation limits their ability to inform design processes in a continuous, operable and interoperable way.

GIS environments offer powerful capabilities for analysing land systems, ecological functions and spatial heterogeneity (Zölch et al., 2016), but these analyses remain largely separate from the object-based, parametric and collaborative environments of BIM, which were originally conceived for buildings and infrastructures. Because landscape projects frequently intersect with public space, territorial governance and environmental regulation, the capacity to structure information within shared modelling environments becomes essential, not only for design coordination, but also for ensuring transparency and accountability in public decision-making. As highlighted by recent research (Ma & Ren, 2017; Schubert et al., 2023) interoperability between GIS and BIM remains a central challenge, especially for landscape modelling, where territorial variability, complex semantics and ecological processes must be represented in a consistent digital format.

This doctoral thesis responds to these challenges by proposing a workflow that bridges environmental data, GIS-based modelling and BIM environments. The research aims to enable landscape architecture to operate within digital construction ecosystems without losing its ecological specificity. By connecting multi-source environmental data to modelling environments, the workflow supports the development of design strategies that are transparent, scalable and grounded in measurable environmental conditions responding directly to contemporary demands for accountability, adaptability and interdisciplinary coordination.

This introduction chapter examines the broader context in which the research is positioned, outlining the disciplinary and operational conditions that make a new approach necessary and helping to clarify the motivations that guide the development of the proposed workflow.

The chapter is articulated into five sections. Section 1.1 outlines the digitalisation of landscape practice, tracing the shift from intuitive, drawing-based methods to GIS- and BIM-enabled workflows and highlighting the emerging need for interoperable, data-informed design.

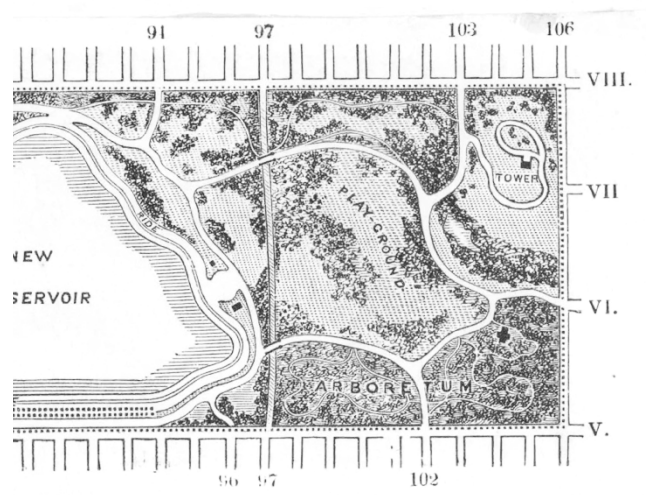
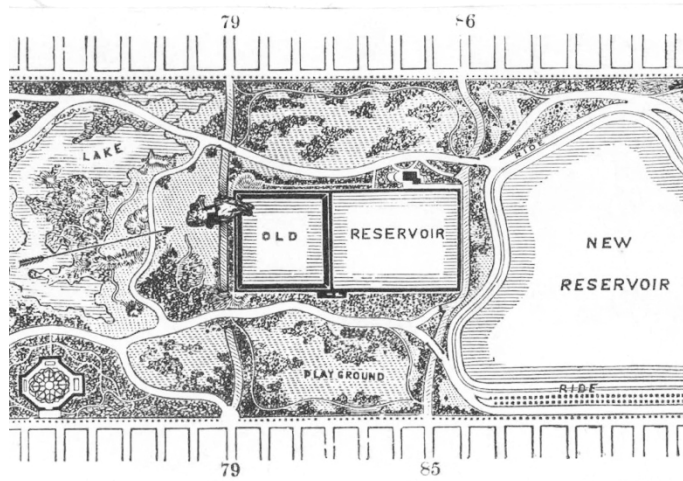
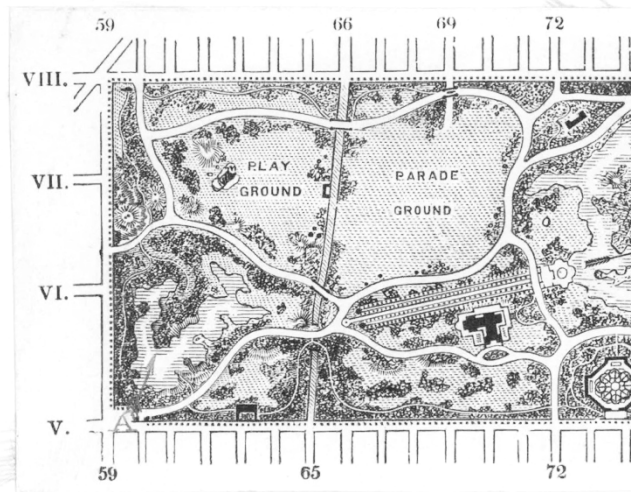
Section 1.2 frames this evolution within the international, European and Italian normative context, showing how parallel BIM and GIS regulations shape public works and expose a structural gap for landscape architecture.

Section 1.3 discusses why future developments must focus on integrating EO, GIS and BIM, arguing that territorial intelligence produced in geospatial environments should become a generative driver within modelling processes.

Section 1.4 defines the overall research objective and formulates the questions that guide the thesis, focusing on how an EO-GIS-BIM workflow can support multi-scalar landscape design within current regulatory demands.

Finally, Section 1.5 presents the methodological structure of the thesis, explaining how literature review, workflow construction, multi-scalar applications and critical discussion are organised across the subsequent chapters.

Figure 1.1 - The drawing illustrates the early analytical interpretation of landscape as a system of hydrological, vegetative and spatial relationships, Olmsted's technical plan for Central Park, New York (ca. 1868). Source: Olmsted Archives, National Park Service.



1.1 Background of Digitalisation of Landscape Practice and New Potential

Traditionally, the architectural and landscape design process has been conceived as a creative and decision-making practice grounded in exploration, intuition and iterative refinement. Designers typically respond to site-specific constraints by generating alternative solutions through drawing, whether manual or digital, which serves as a cognitive tool to externalise thoughts and test emerging ideas (Corner, 2011; Schon, 1983). In landscape architecture, these alternatives are then evaluated in terms of functional, aesthetic and ecological performance, as well as their capacity to address the initial requirements of the project (Steiner, 2011). When one or more options are deemed satisfactory, they are developed further, when they are not, the process is restarted, sometimes repeatedly, until a viable equilibrium is reached.

However, assessments of performance and suitability often take place relatively late in the design process, once most major decisions have already been taken. This limits the ability to revise or reconsider fundamental aspects of the project without restarting the entire workflow. As a result, the success of a design is heavily influenced by the designer's initial intuition and experience, which shape the early conceptualisation of the problem. The traditional process is therefore inherently empirical, relying on personal expertise and prioritising the alternatives that designers already know or perceive as appropriate for the context. While such an approach preserves the interpretive intelligence of design practice, it constrains the capacity to test multiple scenarios early on and reduces the integration of structured, evidence-based knowledge. This structural limitation becomes more pronounced today, as landscapes are increasingly shaped by complex interactions, multiscale dynamics and rapidly changing environmental conditions. These complexities challenge intuition-based methods and demand more systematic ways of engaging with the data-rich context in which contemporary landscape decisions unfold.

Over the past four decades, the digitalisation of design disciplines has progressively redefined how information is generated, structured and communicated. Early Computer-Aided Design (CAD) systems introduced during the 1980s improved drafting efficiency but did not fundamentally transform the cognitive processes underlying design (Eastman et al., 2011). A deeper shift occurred with the advent of three-dimensional modelling and parametric systems, which moved the focus from representing forms to modelling relationships, dependencies and iterative rules (Terzidis, 2006; Woodbury, 2010). These developments laid the foundation for an emerging “algorithmic thinking”, in which design is approached as a dynamic system governed by parameters and continuous feedback loops. In parallel, Geographic Information Systems (GIS) have become foundational to landscape analysis and planning. The conceptual foundations of GIS are deeply rooted in landscape architecture itself. McHarg (1969) method of layered ecological analysis provided one of the earliest systematic frameworks for evaluating landscape suitability through the overlay of environmental criteria. Before the advent of these analytical digital systems, projects such as Olmsted's design already demonstrated a structured understanding of hydrological, vegetative and spatial relationships, revealing the landscape as a dynamic and interconnected system (Figure 1.1).

Figure 1.2 - Ian McHarg analytical ecological overlay for the Delaware River Basin. Source: University of Pennsylvania Archives, Ian L. McHarg Collection, 1969

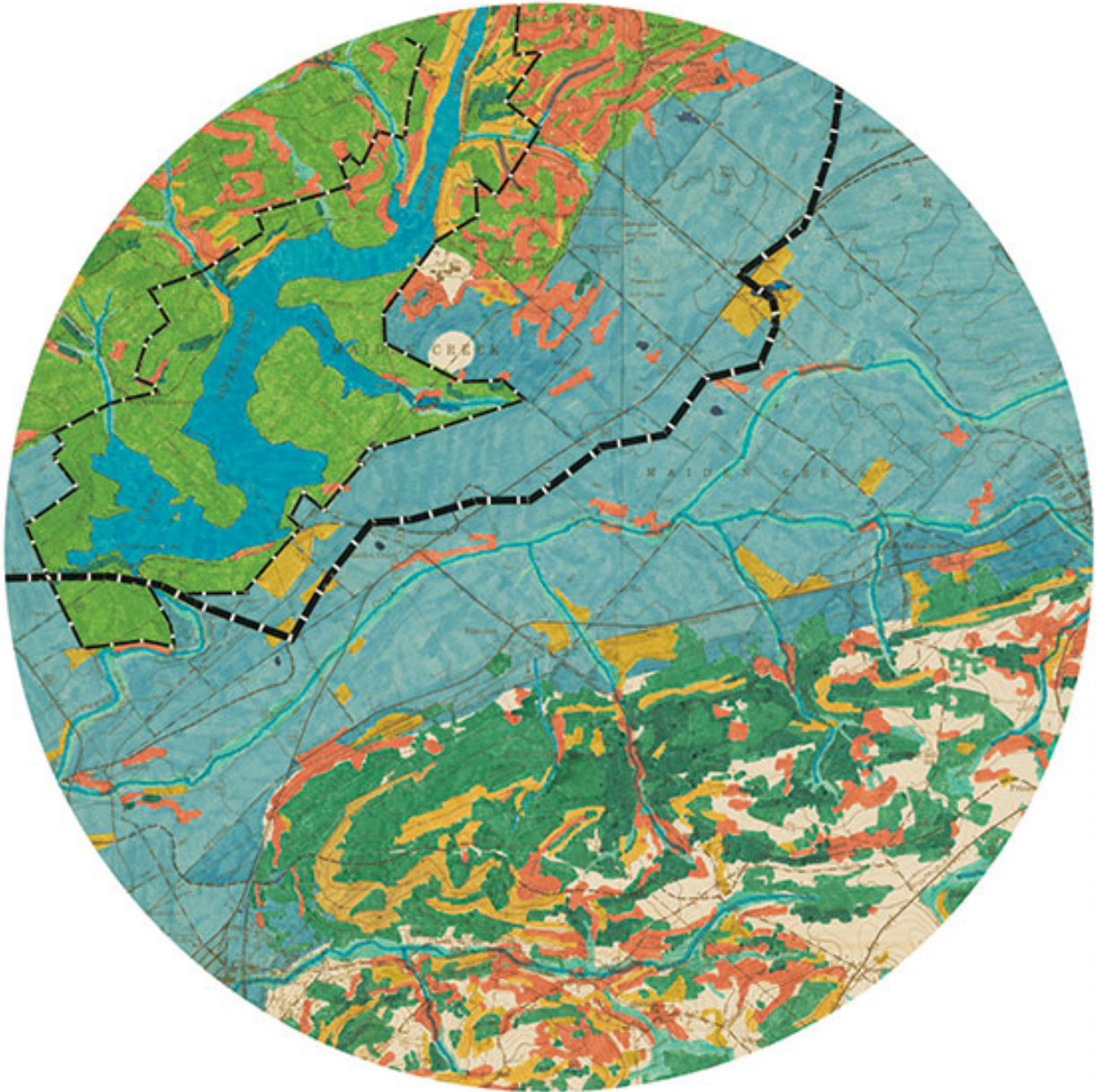


Figure 1.2 shows an analytical composite map for the Delaware River Basin, created through the manual superimposition of environmental layers (soils, hydrology, vegetation, landform) combined to inform regional suitability mapping. This method anticipated the multilayer logic later formalised in GIS technologies. Although originally developed through manual cartographic techniques, McHarg's approach anticipated the digital logics of spatial layering, weighting and suitability modelling that later became formalised within GIS technologies (Steiner, 2011; Yang & Li, 2016). Since their emergence in the 1960s, GIS platforms have evolved into powerful environments capable of integrating heterogeneous datasets (topography, land cover, hydrology, climate, soils, etc.) and supporting complex spatial modelling (Coppock & Rhind, 1991; Longley et al., 2015).

For landscape architecture, GIS has become essential to understanding ecological patterns, territorial processes and spatial heterogeneity. As remote sensing and Earth Observation technologies expanded, GIS became the primary interface through which environmental evidence is translated into spatial knowledge (Weng, 2012). Programmes such as Copernicus, with their multi-temporal and multi-scalar datasets, further strengthened the role of GIS in monitoring land-use transitions, ecological performance and climate-related phenomena.

Within this evolving digital landscape, Building Information Modelling (BIM) has emerged as a central methodology for organising project information. Rather than a geometric drafting tool, BIM is an object-oriented and information-rich modelling paradigm in which elements are defined by semantic attributes, functional relationships, parameters and lifecycle data (Succar, 2010). Its relational structure enables coordinated updates, data consistency information flows and multi-disciplinary collaboration across the entire lifecycle of a project, such as design, construction and maintenance (Eastman et al., 2011).

Despite its potential, BIM currently offers limited native support for continuous, dynamic and ecologically defined landscape components. Terrain is often reduced to a single surface, lacking soil stratification, hydrological behaviour or geomorphic logic. Vegetation is represented through symbolic or generic objects without ecological semantics, growth patterns or environmental performance attributes (Hijazi & Donaubauer, 2017; Ohori et al., 2018). Open spaces, ecological infrastructures and natural systems are frequently simplified into categories that fail to reflect their temporal evolution or interdependencies (Landscape Institute, 2016).

Crucially, these limitations are not only the result of insufficient landscape-specific objects but of a deeper structural gap: BIM environments are not natively connected to GIS-based spatial analysis, meaning that the environmental evidence on which landscape architecture depends cannot be directly integrated into modelling workflows. This lack of GIS-BIM interoperability is one of the main obstacles preventing landscape disciplines from fully entering digital design and construction ecosystems (Ma & Ren, 2017; Schubert et al., 2023).

While BIM is well established in architecture and engineering, with applications ranging from clash detection to cost estimation, scheduling and lifecycle management, its adoption in landscape architecture remains limited. International and national frameworks¹ primarily address building and infrastructure domains, offering only partial support for the ecological, dynamic and continuous components typical of landscape projects (ok). This gap has contributed to the perception, still common in the profession, that BIM is “immature” or “unsuitable” for landscape applications (Goldman, 2011).

¹ Major international and national BIM frameworks and standards remain predominantly oriented toward buildings and infrastructures. These include the ISO 19650 series on information management using BIM; the CEN/TC 442 standards on Building Information Modelling; the Italian UNI 11337 standard on digital processes in construction; the COBie (Construction-Operations Building Information Exchange) schema for structured asset data; and the European MEPContent Standard (EMCS) for uniform mechanical, electrical and plumbing data.

Figure 1.3 - Coordination BIM Model of various disciplines. Image courtesy of LAND Italia Srl.



BIM is therefore not limited to buildings. The same advantages of automation, visualisation and analysis that BIM software offers in construction can be applied to landscape architecture. In this sense, the current immaturity or lack of discipline-specific content can be overcome by recognising that Building Information Modelling is not about walls, doors or windows, but about intelligent data-driven objects that encode performance and relationships. Figure 1.3 represents a coordination model where buildings, infrastructures and open spaces are modelled together on the same platform.

As a result, landscape projects frequently rely on GIS for environmental analysis and BIM for modelling, yet the two environments remain disconnected, forcing designers to manually bridge the gap through fragmented and non-interoperable workflows. Yet these limitations do not diminish the methodological potential of BIM for landscape architecture, rather, they highlight the need to reinterpret BIM through ecological, environmental and multi-scalar modelling logics.

In reality, many of the strengths of BIM align closely with landscape needs. BIM environments allow the modelling of terrain, earthworks and surface modifications, the integration of soil and plant attributes, the simulation of water demand and hydrological behaviour and the coordination of extensive planting schemes using parametric rules. Plant species can be associated with tolerances, soil requirements or ecological functions, supporting decisions on irrigation, phytoremediation or suitability. BIM thus becomes a platform for linking environmental evidence with design reasoning. Research demonstrates that advanced landscape operations, such as parametric grading, earthworks optimisation, soil layering and drainage modelling, are feasible in BIM but require custom semantics, rule-based extensions and deeper integration with GIS workflows (Kang, 2018; Noardo et al., 2022).

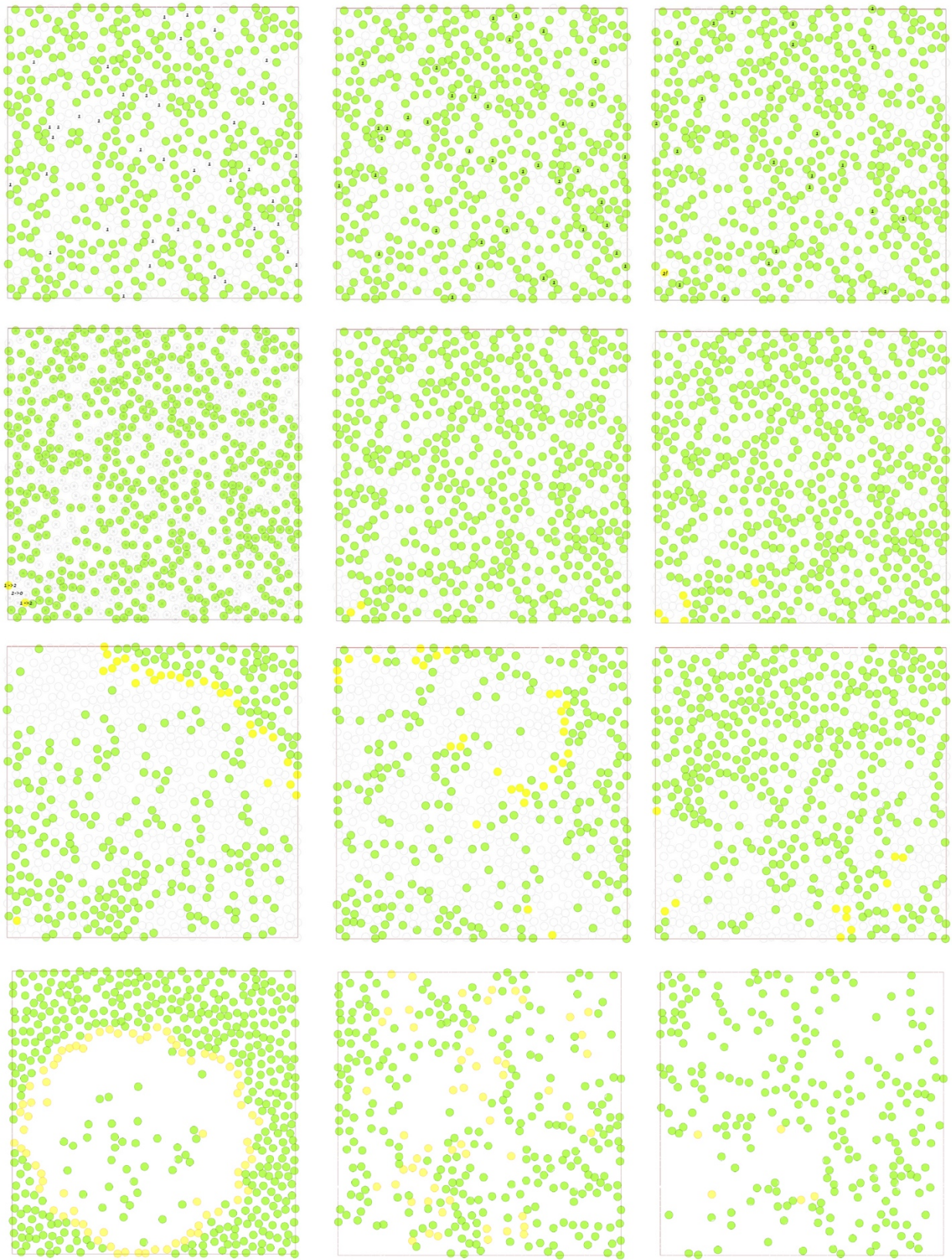
For BIM to meaningfully support landscape architecture, domain-specific semantics, improved representations of continuous surfaces and deeper interoperability with GIS-based environmental modelling are required.

Moreover, BIM offers significant advantages in automation, analysis and communication:

- parametric relationships ensure that changes in one component propagate across the model;
- databases allow queries for plant counts, material quantities or water needs;
- simulations can assess performance and spatial conflicts;
- 3D visualisations enhance communication with stakeholders.

BIM tools provide enhanced project control and the full advantages of an information-rich environment. Object-based modelling links the data describing an element to its geometry, a principle that landscape architects have likewise begun to adopt. Parametric functionality is central to BIM processes: any modification to an object propagates across all its associated views. What distinguishes BIM tools is their capacity to operate intelligently, establishing relationships between objects and information, when used through parameters, relational logics and collaborative modelling. Moreover, BIM enables data-driven simulation, as objects are stored within a queryable database structure.

Figure 1.4 - Example of a Generative Landscape design through the application of computational tools. Source: generative-landscapes.com



These advantages can be summarised in five fundamental processes:

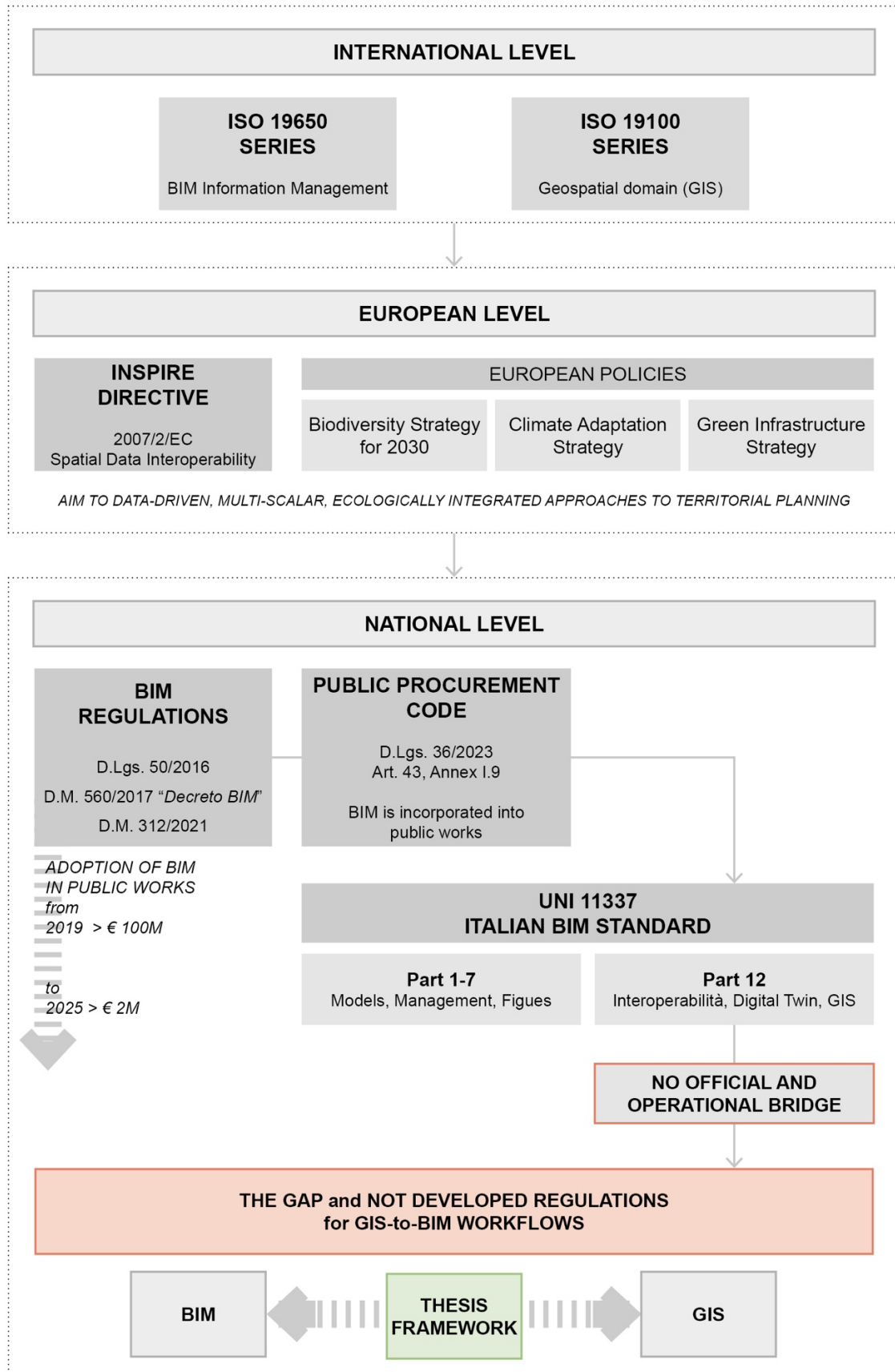
- Collect, acquiring landscape information that enables the measurement, identification and attribution of objects and supports the overall BIM process.
- Generate, introducing specific elements into the design, such as topography, vegetation or urban furnishings, by defining their location, level of detail and performance characteristics.
- Analyse, identifying clashes between elements during the design phase, predicting in-use performance, running simulations and anticipating problems.
- Communicate, producing 3D representations that are more realistic and easier to interpret than 2D drawings, both for designers and stakeholders.
- Realise, supporting the creation of the final asset and its components during construction.

The development of visual computational tools further expanded the potential of design computation (e.g. Grasshopper and Dynamo). These tools allow designers to automate tasks, encode custom rules and build data-driven workflows without advanced programming skills (Peters & Thon, 2019). Computation thus becomes not a specialised activity but a widespread mode of reasoning that enhances design exploration, expands the capacity to test alternatives and enables real-time feedback between intention and performance. Figure 1.4 shows an example of computational tools use for generative ecological forest scenarios.

The core logic of computational design, iteration, dependency, branching structures and rule definition, resonates strongly with principles of landscape ecology, in which systems evolve through interacting processes across scales (Wu, 2013). In both domains, the goal is to understand how relationships change over time: in ecology, between organisms and environments; in computation, between geometries, parameters and information. Taken together, GIS-based environmental modelling and computational design tools represent complementary dimensions of contemporary digital landscape practice: the former structuring ecological and territorial evidence, the latter modelling relationships, behaviours and generative rules. Their integration provides the conceptual and operational foundation for data-informed and adaptive landscape workflows.

When interpreted not as a catalogue of architectural objects but as a digital environment for structuring relationships and information, BIM has the potential to become a powerful substrate for environmental, multi-scalar and evidence-based landscape design. This conceptual repositioning of BIM, as a data-rich, relational and extendable modelling environment, is essential for aligning landscape design with contemporary digital processes and for enabling the GIS-BIM workflows explored throughout this thesis. Altogether, these developments indicate that the digitalisation of landscape architecture requires environments in which environmental evidence, spatial reasoning and parametric modelling converge. The lack of such integrated workflows, particularly between GIS and BIM, constitutes the core methodological gap that this research addresses.

Figure 1.5 - Regulatory framework for the digitalisation of the built and territorial environment and adoption of BIM across international, European and national levels



1.2 Context of Application: A Normative Framework

Contemporary digital practices in landscape architecture do not evolve in isolation but are strongly shaped by the regulatory frameworks that govern how public works are conceived, designed and delivered. Normative structures, whether International, European or National, do not simply prescribe procedural obligations, they actively steer technological development by defining which tools, data formats and information processes are considered valid within institutional workflows. As a result, the regulatory environment becomes a decisive driver of innovation, determining the conditions under which digital methods such as BIM, GIS and geospatial infrastructures can be adopted, integrated or scaled across disciplines. Understanding this framework clarifies not only the legal obligations associated with digital public works, but also the strategic direction in which technology is being steered, such as interoperability, transparency, environmental accountability and the long-term management of digital information. In this sense, analysing the normative ecosystem is a prerequisite for positioning landscape architecture within the broader digital transition and for identifying the structural gaps that must be addressed to enable coherent GIS-BIM integration. Figure 1.5 provides an overview of the Italian normative framework and its international relationships, while the subsequent sections illustrate their progressive development.

At the international level, the digitalisation of the built environment is framed by the ISO 19650² series, which establishes global principles for organising and exchanging information through Building Information Modelling. The standard defines how information should be structured across the entire asset lifecycle and introduces a clear hierarchy of information requirements: Organisational Information Requirements (OIR), Asset Information Requirements (AIR) and Exchange Information Requirements (EIR). These information requirements establish the framework for how the project will be managed and their implementation is subsequently carried out within the Common Data Environment (CDE), where all project information is created, coordinated and maintained. The BIM Execution Plan (BEP) sets out how the project team will manage information and collaborate throughout the delivery process, in response to the EIR (Shilton, 2018). The BEP is a live working document that is continually updated as the project evolves, reflecting the responsibilities and contributions of the disciplines involved at each stage. ISO 19650 therefore provides the procedural backbone for BIM-based information management, shaping roles, workflows and digital deliverables. Parallel to this, the geospatial domain relies on the ISO 19100³ family, which regulates how territorial, environmental and spatial data are modelled and exchanged. Standards such as ISO 19115 (metadata), ISO 19107 (spatial schema) and ISO 19166 (Earth Observation data) underpin national spatial data infrastructures, environmental monitoring and GIS-based analysis.

² EN ISO 19650 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using BIM. Available at <https://www.iso.org/standard/68078.html>

³ EN ISO 19100 - Geographical Information Systems and Geospatial analysis. Available at <https://www.iso.org/standards.html>

However, these two standardisation frameworks operate in parallel rather than in integration. ISO 19650 governs BIM processes, while ISO 19100 governs geospatial information and no existing ISO standard defines operational procedures for connecting GIS-based environmental analyses with BIM-based modelling workflows. For landscape architecture, where decision-making depends on geospatial evidence, yet public procurement increasingly requires BIM deliverables, this absence represents a structural gap. It is within this unresolved space between the BIM and GIS standardisation ecosystems that this thesis positions its methodological contribution.

In the European Union, the convergence of environmental policies, digital strategies and spatial data infrastructures has established clear expectations for evidence-based planning and interoperable information systems. The INSPIRE Directive (2007/2/EC - Infrastructure for Spatial Information in the European Community) established the foundational structure for this transition, defining shared data models, metadata standards and interoperability rules for geospatial information across Member States (Craglia & Annoni, 2007). More recent strategies, including the European Green Deal, the EU Biodiversity Strategy 2030 and the EU Climate Adaptation Strategy, reinforce the expectation that spatial interventions be grounded in reliable environmental evidence, long-term monitoring and transparent digital processes (European Commission, 2021a).

The introduction of BIM in Italy has not been a sudden event but the outcome of a structured regulatory process that has progressively expanded the obligation to adopt digital methods in public works. This process was first framed by the Public Procurement Code D.Lgs. 50/2016 (Repubblica Italiana, 2016), which encouraged the adoption of electronic tools and digital procedures, creating the institutional foundation for subsequent regulatory developments. The turning point was the publication of Ministerial Decree 560/2017 (Ministero delle Infrastrutture e dei Trasporti, 2017), widely known as the *Decreto BIM*, which represented the first national attempt to formalise digital methods within public procurement. Rather than imposing an immediate and universal transition, the decree introduced a gradual roadmap, reflecting an awareness that the adoption of BIM requires organisational maturity, technical competencies and clearly defined information requirements.

The first enforcement phase, effective from 1 January 2019, applied to complex public works with a exceeding €100 million, positioning BIM as a requirement for major infrastructural projects already characterised by high coordination. This gradual transition was later confirmed and refined by Ministerial Decree 312/2021 (Ministero delle infrastrutture e dei trasporti, 2021) , which progressively extended the mandate to works of lower value, compelling an increasing number of public authorities and design teams to adopt digital methodologies. The reduction of economic thresholds not only expanded the range of projects subject to BIM, but also initiated a broader organisational reconfiguration within the Italian public procurement system. With each enforcement step, contracting authorities were required to adjust their internal workflows, establish dedicated digital roles and redefine responsibilities related to information management.

Central to this transformation was the introduction of the *Capitolato Informativo* (CI), the Italian document defining modelling requirements, information deliverables and coordination procedures, corresponding to the Exchange Information Requirements (EIR) in the ISO 19650 framework. Equally significant was the mandatory adoption of the *Ambiente di Condivisione dei Dati* (ACDat), the Italian equivalent of the Common Data Environment (CDE), where project information is created, managed and shared throughout the lifecycle. As thresholds progressively lowered, the digital transition expanded from major national authorities to municipalities and smaller public bodies, requiring investment in training, organisational restructuring and interoperable platforms. This incremental mandate ensured that digitalisation permeated the public sector, transforming BIM from a tool for large infrastructures into a standard component of ordinary administrative practice.

This phased introduction reaches full maturity in the new Public Procurement Code (Codice dei Contratti Pubblici) D.Lgs. 36/2023 (Repubblica Italiana, 2023), which replaces the original logic of descending economic thresholds with a clearer and more comprehensive regulatory framework. Under the new Code, BIM is incorporated into the broader concept of *Gestione Informativa Digitale delle Costruzioni* (GID), the official Italian term used to define the overall digital information management framework governing the planning, design, construction and lifecycle of public works. It is regulated by Article 43, which requires all contracting authorities to adopt interoperable platforms aligned with national and international standards. In addition, Annex I.9 specifies the operational methods, requirements and implementation conditions for digital information management across project phases.

The decisive milestone was set for 1 January 2025, from which date the use of BIM becomes mandatory for all new public works and for interventions on existing assets whose estimated construction cost exceeds €2 million. For works involving buildings protected under the *Codice dei beni culturali e del paesaggio* (D.Lgs. 42/2004)⁴, the Italian Code of Cultural Heritage and Landscape, the relevant threshold corresponds to the European public procurement threshold for works, currently €5,382,000. BIM is thus no longer associated exclusively with large or specialised projects but becomes the ordinary condition for the planning, design, construction and management of public works. However, the expansion of the mandate has not been matched by uniform implementation capacity, particularly among smaller municipalities, where digital readiness, technical expertise and infrastructural resources remain uneven despite the requirement already in force (Raj et al., 2025).

The *Decreto BIM* was therefore not simply a technical regulation, but an instrument for systemic cultural change. By binding the obligation to progressive thresholds, the decree ensured that the transition permeated the entire national procurement ecosystem, making BIM not a tool for specialised projects but a structural requirement of ordinary public practice. Public Procurement Code D.Lgs. 36/2023 (Repubblica Italiana, 2023), also elevates digital processes from a growing obligation into a fundamental principle of

⁴ Italian Code of Cultural Heritage and Landscape, which regulates the protection, conservation and management of cultural assets and landscape areas of public interest.

procurement. The Code defines digital models as official contract documents, formalises the CDE as a legal component of the information workflow and strengthens Feasibility Document of Design Alternatives (Documento di Fattibilità delle Alternative Progettuali - DOCFAP) and the Technical-Economic Feasibility Study (Progetto di Fattibilità Tecnico-Economica - PFTE) as multidisciplinary, georeferenced and data-rich phase in which environmental, territorial and infrastructural evidence must be integrated in a coherent digital structure. The Code consolidates a cultural and operational shift: digital information is no longer an optional enhancement but a structural requirement that guides the entire lifecycle of public works.

Parallel to legislative developments, the Italian standard UNI 11337⁵ has provided the technical backbone for digital transformation. Across its many parts, the standard defines terminology, modelling levels, classification systems, data structures and collaborative procedures relevant to digital building and infrastructure processes. Particularly notable is the extension of the standard to infrastructures, which recognises that digital models must align with geospatial reference systems and national spatial data infrastructures. Within this regulatory evolution, UNI 11337 - part 12, published in its updated edition in June 2025, builds upon the draft framework developed in 2022, which represents a key advancement, as it explicitly addresses the digital representation of infrastructures and their alignment with territorial reference systems. Unlike earlier parts of the standard, which focused primarily on buildings, Part 12 introduces requirements for georeferencing, spatial consistency and the integration of digital models with national geospatial frameworks. As highlighted in recent technical analyses (Perego, 2025), the standard mandates that infrastructure models be positioned within official reference systems, harmonised with the *Repertorio Nazionale dei Dati Territoriali* (RNDT) and compatible with the *Database Geotopografico* (DBGT). However, despite this progress, UNI 11337-12 does not define operational procedures for integrating environmental analyses, raster data or multi-layer geospatial models typical of landscape architecture. The standard strengthens spatial alignment between infrastructure BIM and national geodata but leaves unresolved the methodological integration of GIS-based environmental evidence into BIM workflows, reinforcing the central gap that this thesis addresses.

What emerges is a regulatory landscape that is coherent yet structurally dual. On the one hand, BIM is now mandatory for all phases of public works and constitutes the official environment through which digital project information must be produced, coordinated and delivered. On the other, the environmental, ecological and territorial knowledge that underpins landscape architecture continues to be governed by geospatial standards and spatial data infrastructures rooted in the GIS domain. These two ecosystems, BIM for project modelling and GIS for territorial evidence, are both mature, highly regulated and indispensable, yet they remain formally disconnected. No Italian or European regulation currently provides operational

⁵ UNI 11337 - Gestione digitale dei processi informativi delle costruzioni, part 1-7, part 12. Available at <https://www.uni.com/>

mechanisms, shared data structures or standardised procedures for integrating GIS-based environmental analyses into BIM-based modelling environments. As highlighted in recent professional national reports (Perego, 2025), this gap obliges practitioners to rely on ad-hoc conversions, custom scripting or discipline-specific workarounds to transfer information between systems. This structural separation has profound implications for landscape architecture, a discipline whose decision-making processes rely on the continuous integration of territorial evidence, ecological dynamics and spatially explicit environmental data. Unlike architecture or linear infrastructures, landscape projects operate across gradients, continuities and evolving ecological processes, which cannot be adequately represented within BIM environments conceived primarily for discrete, static, construction-oriented objects. As a result, landscape architecture remains structurally disadvantaged within the current regulatory and technological ecosystem: it is required to operate within BIM to comply with public procurement procedures, yet its analytical foundations remain anchored to GIS-based geospatial frameworks that lack formal integration pathways.

It is precisely within this regulatory and methodological misalignment that the present doctoral research is situated. Rather than treating GIS-BIM integration as a technical refinement, the thesis positions it as a strategic necessity for enabling landscape architecture to participate fully, consistently and effectively in Italy's evolving digital transition. By addressing the absence of operational bridges between the two normative ecosystems, the research responds to a systemic digital gap, offering a workflow capable of aligning environmental evidence, spatial analysis and BIM modelling within a coherent and interoperable framework.

Taken together, these normative frameworks create both an opportunity and a constraint. On one hand, the legislative push toward structured, interoperable, information-driven processes places Italy at the forefront of digital transformation. On the other, while the BIM-oriented regulatory framework now requires georeferencing and alignment with national spatial data infrastructures, it does not define how territorial and environmental data should be operationally integrated into modelling environments. Environmental evidence, remote sensing products and territorial analyses are regulated within the geospatial domain, whereas digital project information is regulated within the BIM domain. No current legislation provides an operational bridge between the two, leaving interoperability largely dependent on ad-hoc procedures, custom scripting or discipline-specific workarounds (Perego, 2025).

In this context, the development of rigorous GIS-BIM workflows becomes not merely an opportunity but a necessity. The regulatory framework requires public projects to be delivered through BIM, while the knowledge base underpinning landscape architecture is produced, validated and governed through GIS. Bridging these domains is therefore essential to align environmental evidence with the digital processes mandated by current Italian legislation. The methodological framework proposed in this thesis is situated precisely within this normative condition: it responds to a structural digital gap by offering a coherent workflow capable of integrating environmental data, spatial analysis and BIM modelling within the contemporary regulatory ecosystem.

1.3 Necessary Future Development

Contemporary landscape architecture operates within a profoundly transformed digital condition. As highlighted by Picon (2013), digital culture does not merely introduce new tools, it reshapes the ways in which designers perceive, interpret and engage with places, memory and time. This is particularly relevant for a discipline working with processual, unstable and time-dependent systems, where landscapes are understood as evolving configurations shaped by environmental and anthropic forces (Emanuelli & Lobosco, 2016b). Within such a framework, digital tools become active mediators: they influence what designers see, what they value and which futures they can imagine. At the same time, the increasing digitalisation requested by European and national regulations reinforces the need for structured and interoperable workflows capable of supporting such interpretative practices.

This evolution is particularly evident in the proliferation of data-rich environments, where remote sensing, Earth Observation (EO), Geographic Information Systems (GIS) and Building Information Modelling (BIM) together generate unprecedented volumes of spatial and environmental information. Nikologianni et al. (2022) highlight that the challenge is no longer the availability of data but the capacity of design disciplines to convert digital evidence into meaningful, situated decisions. In this sense, the digital turn in landscape architecture is as much cultural and epistemological as it is technological.

The last decade has often been described as the era of “Big Data”⁶, marked by the rapid expansion of environmental datasets, satellite imagery, multi-sensor recordings and large geospatial repositories. Yet, as Goldstein & Nost (2022) and Cao et al. (2021) both suggest, the simple accumulation of information does not necessarily translate into improved design outcomes. Data becomes valuable only when it is structured, interpreted and embedded within coherent workflows capable of supporting informed decision-making. BIM and GIS, originally conceived for distinct purposes, are now increasingly understood as complementary frameworks within this broader transition from data abundance to “Insight-Driven” design⁷. This perspective aligns with the view that the landscape architect acts as a constructor of scenarios, someone who evaluates alternatives, assesses impacts and degrees of reversibility and translates numerical projections into spatial strategies (Di Giulio et al., 2018; Emanuelli & Lobosco, 2016a). The shift from data accumulation to insight-driven processes therefore directly resonates with the evolving professional identity of the landscape architect. BIM provides a structured, parametric and relational environment, GIS contributes territorial knowledge, ecological patterns and multi-scalar evidence, EO adds temporal depth and continuous monitoring of environmental dynamics (Eastman et al., 2011; Sayed Emara, 2022).

⁶ Big Data refers to extremely large, heterogeneous and rapidly accumulating datasets, typically characterised by volume, velocity and variety, which require advanced analytical techniques to extract patterns and meaning. In design disciplines, the term identifies the shift from intuition-driven to evidence-rich processes enabled by availability of spatial, environmental and sensor information.

⁷ Insight-Driven Design describes the methodological transition from merely collecting or visualising data to transforming them into actionable insights capable of informing decisions, workflows and project scenarios. The cultural value of data emerges only when they become interpretable and operational within design reasoning, bridging analytical evidence and spatial intention.

Taken together, these three domains define the contemporary digital ecosystem in which landscape architecture is called to operate. Yet, despite their complementary potential, GIS, EO and BIM have historically evolved as separate ecosystems, generating a persistent methodological fragmentation. GIS contributes essential spatial intelligence for understanding environmental implications (Schaller et al., 2017), while BIM supports structured information flows and iterative decision-making processes (Cao et al., 2021). EO adds the ability to observe gradual transformations, vegetation stress, hydrological variations, microclimatic phenomena, otherwise invisible within traditional modelling environments (Wang et al., 2024).

For landscape architecture, this disconnection is particularly problematic. The discipline increasingly works with performative and reparative landscapes, where design is inseparable from ecological functioning, adaptation to risk and long-term environmental processes (Lobosco, 2019). Such contexts demand workflows capable of operating across time, scale and data types, capabilities that no single system currently provides. As a consequence, designers rely on GIS for analysis, BIM for modelling and EO for environmental evidence, without a unified methodological space capable of connecting these layers.

The lack of interoperability has direct implications for design. If the core value of BIM lies in structuring information for informed decisions, the absence of GIS and EO based evidence within modelling environments limits the capacity to evaluate spatial, ecological and temporal conditions. Conversely, when GIS and EO remain confined to preliminary analytical phases, their potential to guide design adaptations or simulate long-term scenarios is significantly reduced. This is particularly limiting in a field where the designer often acts as a cartographer of hidden structures, revealing diffuse systems, ecological corridors, hydrological networks and latent spatial infrastructures, that are not immediately visible yet are essential for territorial decision-making.

Although the international research landscape has produced a substantial body of work on BIM and GIS interoperability, most contributions remain oriented toward a predominantly BIM-to-GIS direction. As extensively discussed in recent systematic reviews (Ma & Ren, 2017), the prevailing objective is to export BIM geometry and semantics into GIS environments in order to enhance large-scale urban analyses, 3D city modelling and digital-twin applications. This orientation reflects the needs of architecture, engineering and construction, where design models (IFC⁸, native BIM formats) are treated as the primary source of information to be contextualised within territorial datasets. The majority of tools, schemas and conversion pipelines therefore support the passage of information from the detailed, object-based domain of BIM toward the geospatial, territory-oriented domain of GIS.

⁸ IFC, acronym of Industry Foundation Classes, is an open, non-proprietary data schema developed by buildingSMART to support interoperable exchange of BIM information defining geometry, attributes and relationships of building and infrastructure elements across different software platforms.

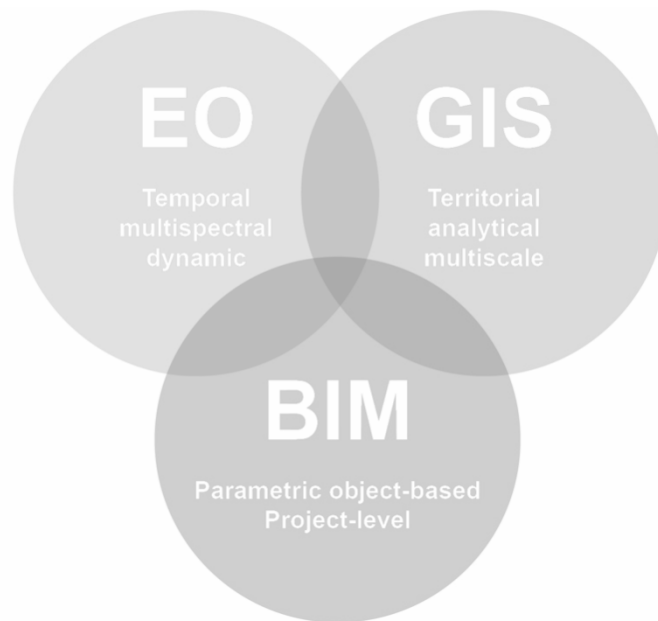
However, this research adopts the opposite viewpoint, motivated by the specific epistemology and workflow of landscape architecture. Here, the design process does not originate from the building or the artefact but from the territorial evidence, environmental conditions, ecological dynamics, gradients, multispectral signatures, hydrological behaviours, that are inherently produced, governed and structured in GIS. For landscape architects, the foundational question is not how to project the building model into a geographical context, but how to ensure that territorial knowledge enters the BIM environment as a generative and decision-driving component of the project. This reversal is particularly urgent in the current Italian normative context, where public procurement requires BIM deliverables even for landscape works, whereas the disciplinary reasoning of landscape architecture remains rooted in geospatial analysis.

The necessity for integrated digital ecosystems is therefore not merely technological, it is disciplinary. Numerous authors highlight the lack of adequate data flows, shared structures and standards at the intersection of GIS-to-BIM direction (Borkowski & Wyszomirski, 2021; Nikologianni et al., 2022; Zhu & Wu, 2022). While EO continues to expand as a primary source of environmental monitoring, its integration into design workflows remains largely untapped. For a discipline working across gradients, continuities and evolving ecological processes, this fragmentation is incompatible with contemporary design challenges.

In parallel with these conceptual and methodological challenges, the practical landscape of software tools further shapes the possibilities of interoperability. Landscape architects today may operate across multiple platforms: open-source environments such as QGIS, proprietary geospatial suites such as ArcGIS Pro, Building Information Modelling tools (e.g. Autodesk Revit, Vectorworks Landmark, etc.) and a growing range of cloud-based or AI-augmented analytical services. Each of these environments embodies different data structures, coordinate systems, modelling logics and collaborative protocols, which in turn influence how effectively environmental knowledge can be transferred across systems. As highlighted by Andrianesi & Dimopoulou (2020), the divergence between object-based parametric modelling in BIM and the geospatial databases typical of GIS represents a core barrier to integration. Moreover, the software most commonly used within professional practice, particularly Revit for BIM and QGIS or ArcGIS for GIS, tends to prioritise architectural, engineering or territorial planning workflows, often leaving landscape-specific needs underrepresented (Borkowski et al., 2023; Borkowski & Wyszomirski, 2021).

Although a detailed examination of these tools will be provided in the Chapter 0, it is important to acknowledge that any viable EO-GIS-BIM workflow must engage with the technical and commercial ecosystems available to landscape architects. The feasibility of interoperability is therefore shaped not only by conceptual alignment and regulatory pressures, but also by the practical selection of software environments capable of supporting ecological data structures, multi-scalar modelling strategies and collaborative information exchanges.

Figure 1.6 - Conceptual diagram illustrating the complementary roles of EO, GIS and BIM: the three domains intersect to highlight how Earth Observation provides temporal and multispectral data, GIS offers territorial and analytical multi-scalar capabilities and BIM delivers parametric, object-based modelling at the project level.



Within this context, the relevance of this research becomes evident. As Zhang (2023) suggests, system-based logics acquire meaning only when aligned with human intentionality. Similarly, digital augmentation should be understood as an enrichment rather than a replacement of embodied and cultural experiences (Dai & Liu, 2024). The methodological ambition of this thesis follows this trajectory: the integration of EO, GIS and BIM is conceived not as a technological substitution but as a means to strengthen the designer's interpretative capacity, enabling richer readings of territories, more informed scenario construction and more adaptive design strategies.

Therefore, this thesis positions EO-GIS-BIM interoperability as a strategic necessity for enabling landscape architecture to operate effectively within data-rich, multi-scalar and digitally regulated contexts. By proposing a coherent workflow capable of aligning environmental evidence, spatial analysis and information modelling, it aims to enhance the discipline's ability to contribute meaningfully to ecological adaptation, infrastructural transformation and territorial governance. By enriching BIM with territorial intelligence, derived from GIS and EO tools, the research allows the BIM to become a responsive, data-informed environment aligned with the analytical foundations of the discipline. This shift reframes interoperability not as a matter of technical convergence alone, but as a disciplinary necessity for supporting landscape architecture in the digital transition mandated by contemporary European and Italian regulations. What emerges is the need for a design culture able to navigate, combine and reinterpret fragmented digital ecosystems. By proposing a structured workflow that brings EO, GIS and BIM into dialogue (Figure 1.6), this research advances the idea of *Data Merging for a Digital Landscape*, a new approach where territorial intelligence becomes an active driver of design reasoning and ecological transformation.

1.4 Research Questions and Objectives

The overarching objective of this research is to develop and test an integrated EO-GIS-BIM workflow capable of embedding territorial intelligence within information-modelling environments, thereby supporting landscape architecture in addressing the increasing digitalisation mandated by current European and Italian regulations. Within this framework, the thesis seeks to understand how environmental evidence, traditionally produced, structured and interpreted within GIS and EO domains, can become an active driver of decision-making inside BIM, a modelling space that is rapidly becoming mandatory for public works yet remains poorly equipped to handle landscape-specific data structures and ecological logics.

To achieve this, the research pursues four interconnected objectives, which guide its structure and methodological development:

- (1)** To conceptualise and define the role of EO and GIS data as generative drivers within BIM, identifying how environmental indices, ecological patterns and territorial structures can support parametric modelling, rule-based design logics and scenario testing.
- (2)** To develop and formalise an operational workflow for transferring, structuring and embedding environmental data, derived from satellite imagery, raster analyses and vector-based classifications, directly within BIM using computational tools and scripts.
- (3)** To evaluate how this integrated workflow performs across multiple spatial scales, from territorial strategic planning to detailed planting and micro-topographic modelling, reflecting the inherently multi-scalar nature of landscape architecture.
- (4)** To situate the workflow within the contemporary regulatory context, verifying its compatibility with the Italian Public Procurement Code and exploring how this new approach can anticipate and support future developments in digital regulations and design technologies.

Taken together, these objectives outline a research trajectory that is at once conceptual, methodological and applicative. They reflect the need to move beyond generic claims about digital innovation and instead articulate how landscape architecture can meaningfully operate within an increasingly regulated and data-intensive design environment. By focusing simultaneously on the nature of environmental data, on the operative mechanisms required to embed such data within BIM and on the multi-scalar implications of this integration, the research defines a coherent framework for understanding both the opportunities and the constraints of current digital tools. At the same time, these objectives highlight that the challenge is not merely technical. The question is how digital evidence can reshape design reasoning, support ecological adaptation and align with the responsibilities of landscape architects working within dynamic and fragile territorial systems.

Developing an EO-GIS-BIM workflow therefore requires asking not only how interoperability can be achieved, but also why such integration matters and what forms of knowledge it enables.

From this ambition emerge a set of research questions that articulate the specific issues the thesis addresses:

RQ1 - How can GIS and EO derived environmental data be systematically transferred, structured and operationalised within BIM environments in a way that preserves their spatial and ecological meaning?

RQ2 - What approach and computational workflows are required for these data to function as generative drivers, informing modelling rules, design alternatives and scenario-based processes?

RQ3 - To what extent can an EO-GIS-BIM workflow support the specific responsibilities of landscape architecture, including ecological adaptation, risk mitigation and long-term environmental management, across different spatial scales?

RQ4 - How might the proposed EO-GIS-BIM workflow anticipate and support future developments in the regulatory landscape, such as the Italian Public Procurement Code and emerging European standards for environmental data, thereby contributing to the definition of new operational models for landscape architecture?

RQ5 - How can this integrated workflow be expanded in the near future through new interoperability plugins, AI-driven environmental modelling and automation tools and what opportunities could these technologies open for more adaptive, predictive and ecologically responsive landscape design?

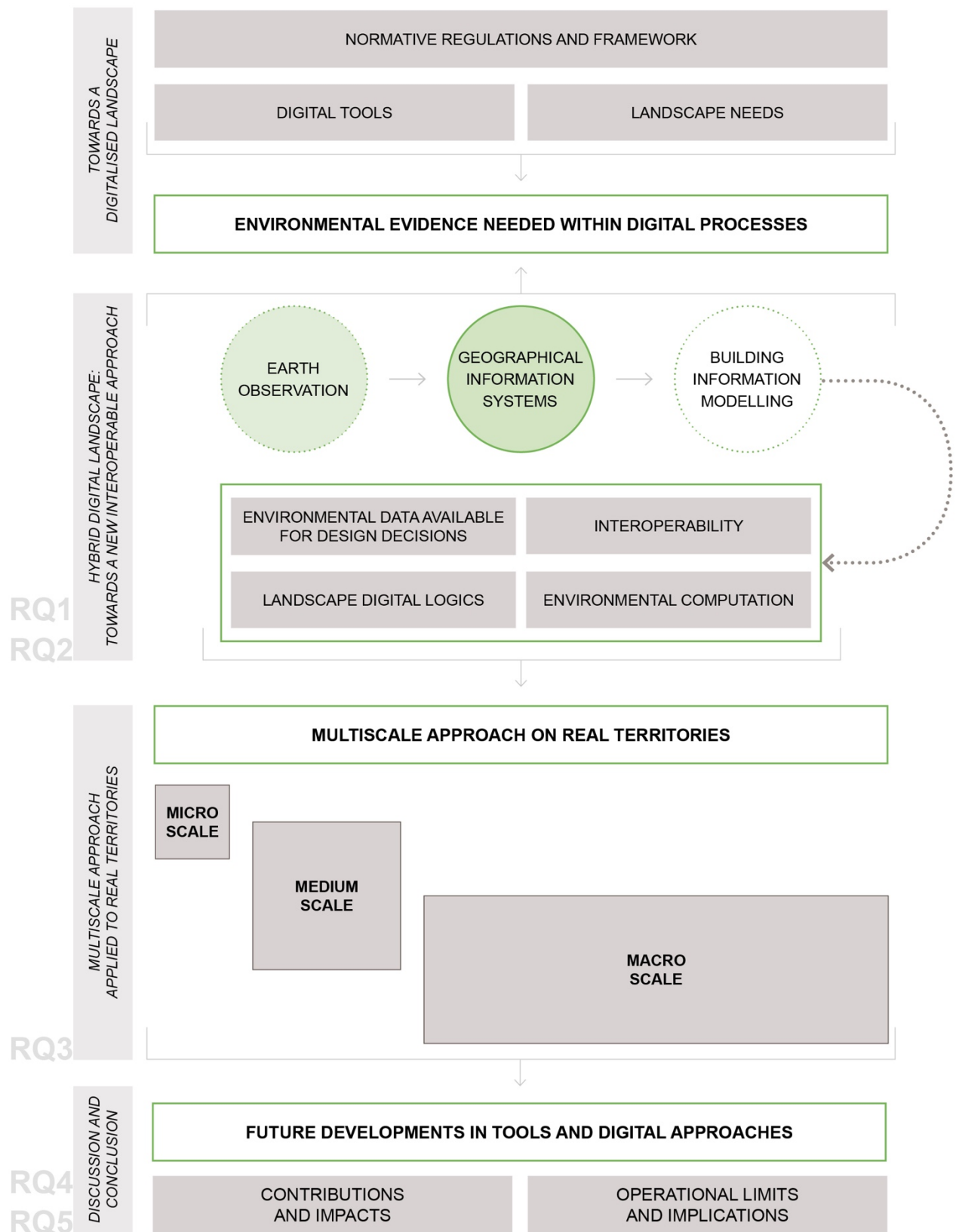
These questions structure the thesis across its three main methodological chapters.

RQ1 and **RQ2** are addressed in Chapter 3, where the workflow is defined, implemented and tested through computational procedures for transferring and operationalising environmental data within BIM.

RQ3 is explored in Chapter 4, which applies the workflow across different spatial scales, demonstrating how it supports scenario building, ecological reasoning and design decision-making in practical contexts.

Finally, **RQ4** and **RQ5** are discussed in Chapter 5, where the broader implications of the workflow are examined in relation to regulatory frameworks, future technological developments and the long-term evolution of digital landscape practice. Together, these chapters provide a coherent response to the research questions and articulate a structured path toward data merging for a digital landscape.

Figure 1.7 - Methodological flowchart of the thesis: the diagram illustrates the structure of the research methodology, showing how regulatory frameworks, digital tools and landscape needs converge toward an EO-GIS-BIM workflow, which is then tested across multiple spatial scales and projected toward future developments



1.5 Methodology

The methodological framework of this research is designed to operate across conceptual, technical and applicative dimensions, reflecting the hybrid nature of the challenges posed by digitalisation in landscape architecture. The study does not approach EO-GIS-BIM integration as a purely technical exercise, but rather as a design-driven investigation grounded in environmental evidence, computational reasoning and normative constraints. For this reason, the methodology combines theoretical reflection, data analysis, computational development and multiscale testing grounds, allowing the workflow to be both conceptually robust and operationally verifiable, as represented in Figure 1.7.

Within this Chapter 1 “Introduction: A Necessary Shift” the scientific motivation of the research has been introduced by outlining the current fragmentation between GIS-based environmental analysis and BIM-centric design practices in landscape architecture.

The methodological structure of this thesis is articulated through a progressive sequence of chapters, each performing a specific function within the overall research design. Rather than presenting methodology as a separate technical section, the thesis embeds methodological reasoning directly into its organisation, allowing the development, testing and evaluation of a new workflow to unfold in a coherent and cumulative manner. The chapters therefore operate as distinct but interdependent stages.

Chapter 2 “Towards a Digitalised Landscape” establishes the scientific and disciplinary baseline by reviewing the state of the art. It examines how Earth Observation, GIS and BIM are currently used within landscape architecture, highlighting both their individual potentials and the structural gaps produced by their separate evolution. The chapter evaluates existing workflows, interoperability schemas, data-conversion techniques and computational approaches documented in the international literature. Particular attention is given to the limits of existing BIM-GIS integrations, which remain predominantly oriented toward architecture and engineering. By situating the research within contemporary debates and technological trends, this chapter defines the knowledge gap that the thesis addresses and clarifies why a new methodological framework is required for landscape-specific needs.

Chapter 3 “Hybrid Digital Landscape: Towards a New Interoperable Approach” develops the core methodological contribution of the thesis represented by an extended EO-GIS-BIM workflow.

This chapter is the core of the research and it establishes the conceptual principles guiding interoperability, defines the structure of environmental datasets and formalises the operative steps through which GIS and EO derived evidence can be transformed into actionable information within BIM environments. The chapter proceeds through four integrated layers of method development:

- Data foundation: acquisition and processing of EO data, computation of spectral indices, classification of territorial parameters and structuring of vector-raster information for GIS-to-BIM interoperability.
- Interoperability principles: definition of coordinate strategies, attribute structures, spatial units and classification logics required to ensure that environmental information retains meaning when transferred into BIM.
- Computational implementation: development of scripts and parametric procedures (Dynamo, Python, custom nodes) enabling automated data transfer, parameter creation, rule-based modelling and information embedding.
- Modelling logic: construction of a BIM environment capable of receiving, interpreting and operationalising environmental evidence through decision rules, thresholds, parametric objects and scenario-generation strategies.

In this chapter, the workflow is not theoretical but constructive. Each step is defined and tested and reasoned following the main research objectives.

Chapter 4 “Multiscale Approach Applied to Real Territories” tests the methodological framework through a multiscale application developed within the Municipalities of Bussi sul Tirino and Piano d’Orta, located in the Abruzzo region (Italy), which forms part of the National Interest Sites (Siti di Interesse Nazionale - SIN). Recognising that landscape architecture operates simultaneously at territorial, infrastructural, ecological and site-specific scales, the workflow is applied across three design resolutions, Micro, Medium and Macro. This chapter evaluates the performance of the EO-GIS-BIM workflow through real environmental conditions, design scenarios and modelling challenges. It examines how the workflow can support: planting models, detailed grading and localised design decisions (Micro scale), ecological structures, intervention typologies and morphological adaptations (Medium scale), territorial pattern identification and strategic-area selection (Macro scale).

The multiscale testing demonstrates how environmental evidence flows through the entire modelling process and verifies the operational relevance of the workflow for landscape practice. Although the workflow is tested using EO-derived datasets and land-use information, this choice reflects their availability across the entire study area and, more broadly, their global open-source accessibility. These datasets represent only a limited subset of the information required in real landscape projects. In practice, the availability and resolution of environmental data vary significantly between countries, regions and municipalities and additional layers, such as soil typologies, groundwater depth, hydrogeological conditions, contamination levels or site-specific microclimatic measurements, may be integrated whenever accessible within the context under examination.

In this thesis, the use of EO-based data does not imply a reductive understanding of landscape information, but responds to the methodological objective of testing the workflow under conditions of reproducibility

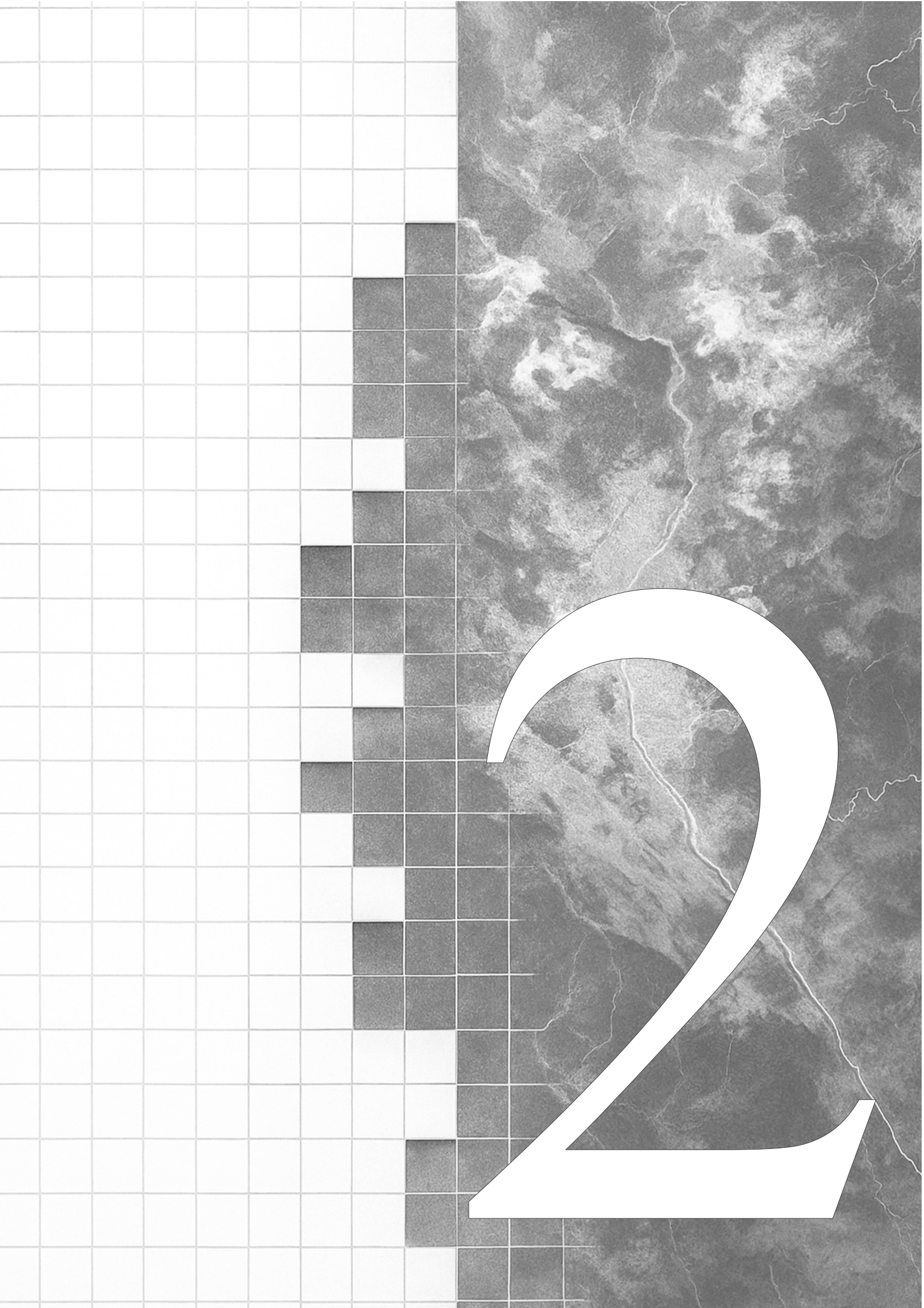
and transferability. The application developed for the SIN of Bussi sul Tirino in Abruzzo region therefore employs EO-derived indicators as the primary environmental input, while acknowledging that future implementations may incorporate more detailed datasets depending on data availability and project requirements.

Chapter 5 “Discussion and Conclusion” expands the methodological implications toward future developments. It situates the workflow within the current and emerging Italian regulatory frameworks, evaluating its compatibility with the Public Procurement Code (D.Lgs. 36/2023) and the future evolution of European standards for environmental data and digital construction. The chapter also examines how the workflow could evolve through AI-assisted modelling, new interoperability plugins, automation tools, digital-twin infrastructures and predictive environmental simulations. It projects the workflow into future disciplinary trajectories.

Across these chapters, the research methodology integrates four complementary dimensions:

- Conceptual reasoning, grounded in digital culture, landscape theory and environmental design;
- Analytical processing, based on EO extraction, GIS modelling and environmental classification;
- Computational development, through scripts, parametric logics and data-driven modelling environments;
- Applied experimentation, validating the workflow through real spatial contexts and multi-scalar design tasks.

Together, these dimensions define a methodological path that moves from understanding to construction, from construction to testing and from testing to critical reflection. The thesis is therefore structured as a methodological progression in which each chapter extends and consolidates the previous one, ultimately enabling a coherent framework for data merging for a digital landscape.



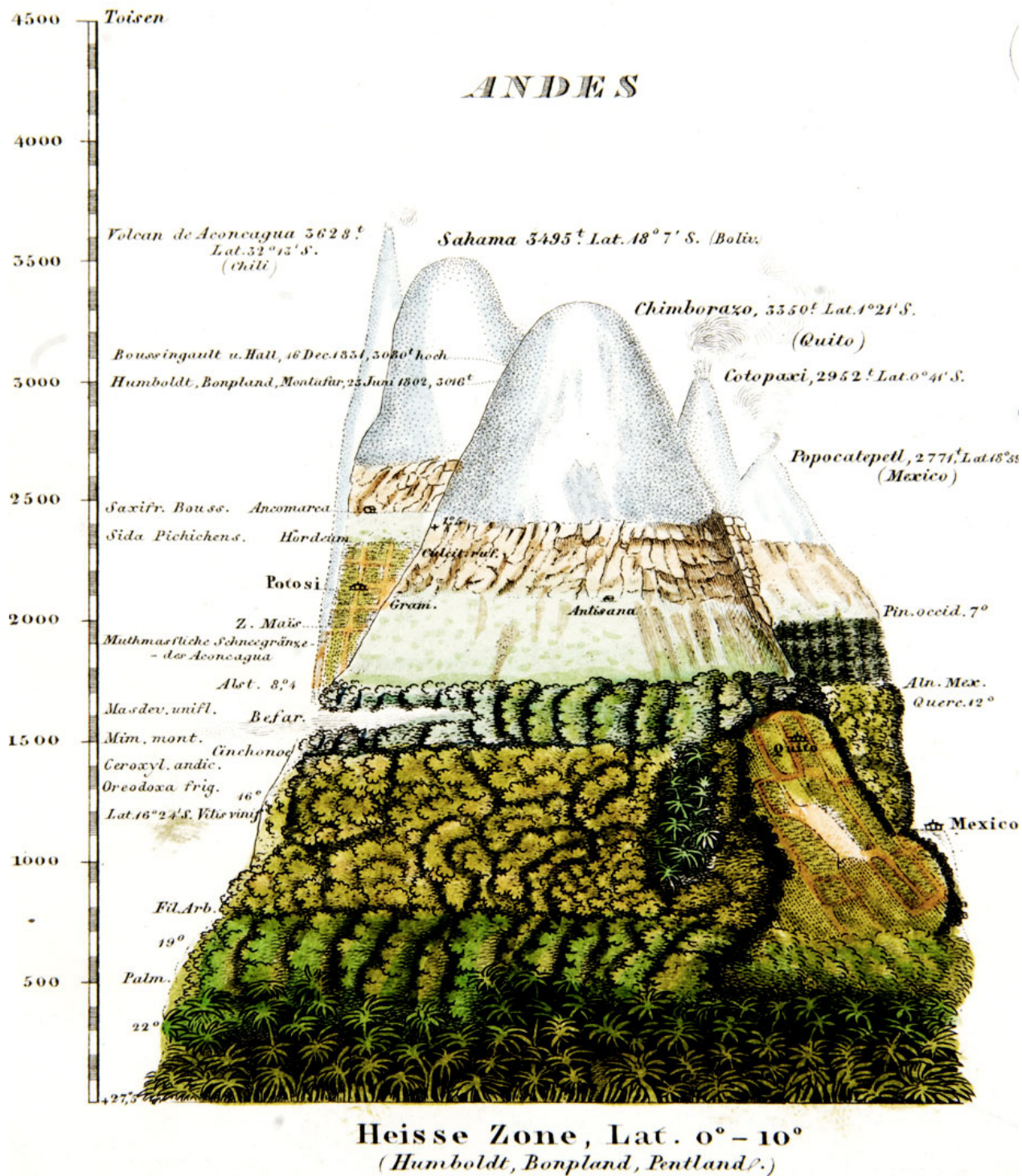
2 Towards a Digitalised Landscape

The purpose of this chapter is to locate the research within the broader evolution of digital practices that are reshaping contemporary landscape architecture. While Chapter 1 serves as an introduction of the research context and it has outlined the regulatory framework and the conceptual motivations for developing new data-integrated workflows, this chapter examines the technological and methodological landscape in which such workflows must operate. It does so by tracing the transformation of representation techniques, reviewing the main digital tools currently employed in landscape analysis and design and analysing the state of interoperability between their respective ecosystems.

The chapter is articulated into four parts. Section 2.1 retraces the evolution of representation techniques, from analogue cartography to parametric and data-driven modelling, highlighting how each technological shift has influenced the way landscapes are read, interpreted and transformed. Section 2.2 provides an overview of the digital tools that structure contemporary landscape practice, focusing on three main domains: Geographic Information Systems (GIS), Earth Observation (EO) and Building Information Modelling (BIM). Each tool is discussed in terms of its capabilities, limitations and relevance for landscape-specific workflows. Section 2.3 examines the current state of GIS-BIM interoperability, including reviewing scientific literature and existing tools to identify both the potentials and the persistent obstacles that prevent seamless data integration across systems. Section 2.4 explores analogies between digital processes and environmental dynamics, reflecting on how computational logics, such as parametric relations, networks and continuous fields, resonate with ecological processes shaping territorial systems. In addition, it discusses the new potentials of landscape digitalisation, outlining the opportunities that emerge when EO, GIS and BIM are considered not as separate tools but as components of an integrated digital ecosystem.

Together, these sections provide the conceptual and technical foundation required for Chapter 3, where the thesis proposes an operational workflow for a hybrid digital landscape.

Figure 2.1 - Alexander von Humboldt's Naturgemälde (1807), derived from his ascent of Mount Chimborazo in 1802, representing botanical, climatic and altitudinal data into a single visual model, representing one of the earliest attempts to conceptualise the landscape as an interconnected ecological system. Source: Ansichten der Natur (von Humboldt, 1807/2018).



2.1 Evolution of Representation Techniques

Representation has always played a foundational role in landscape architecture. It is not merely a means of illustrating a proposal but a way of constructing knowledge, selecting what matters and giving form to relationships that are otherwise invisible. As Cosgrove (2008) argued, every representational technique embodies a specific worldview and shapes the way landscapes are imagined and transformed. Understanding how representation has evolved is therefore essential for situating the current transition toward digital, data-rich methodologies and for recognising both the opportunities and constraints they introduce. Representation therefore shapes not only how designers visualise space but also how they understand ecological processes, relationships and transformations. This perspective aligns with Harley (1992) and Corner (1999) argument that mapping practices actively influence decision-making, embodying values, priorities and interpretative frameworks rather than simply depicting reality. From the first territorial sketches to contemporary geospatial modelling, each era has interpreted the landscape through the instruments available to it, shaping not only how designers visualise space but also how they understand ecological processes, relationships and transformations. Representation has never been a neutral act: it has historically mediated the relationship between humans and the environment, influencing decisions, values and forms of intervention.

Alexander von Humboldt's ascent of Mount Chimborazo in 1802 marked a turning point in the understanding of nature, introducing the idea of an interconnected, multiscale system of environmental relations, often described as the birth of ecological visualisation (von Humboldt, 2018). His synoptic drawings *Naturgemälde*, depicting vegetation zones, climatic gradients and altitudinal shifts, anticipated the systemic perspective later embedded in ecological analysis and GIS. Humboldt reframed representation not as a mirror of the world but as a device for revealing hidden patterns and linking phenomena across time and space. Figure 2.1 illustrates this conceptual breakthrough: through the combination of scientific measurement and graphic synthesis, Humboldt's visualisation transcended mere depiction and became a comparative model capable of revealing systemic relationships across scales and climates. These early insights prepared the ground for McHarg's ecological overlays, which turned environmental relationships into visual layers, inaugurating a methodological lineage in which the map becomes an instrument of ecological reasoning.

For much of the twentieth century, landscape representation was grounded in analogue cartography, descriptive mapping and perspectival drawings. These tools positioned the landscape as a static composition whose identity could be captured through spatial abstraction and visual synthesis. Classical planning traditions, from Lynch (1960) cognitive mapping to McHarg (1969) layered suitability method, expanded this representational repertoire by introducing analytical readings of the territory.

From this moment onwards, representation progressively expanded its analytical potential. Nineteenth-century topographic surveys and thematic atlases enabled increasingly accurate depictions of geomorphology, soils, hydrology and climate. The emergence of photogrammetry and aerial photointerpretation in the mid-twentieth century introduced new forms of territorial evidence, enabling multi-scalar readings of geomorphology, land use and settlement patterns. These analogue techniques paved the way for the digital revolution of the 1980s and 1990s, leading to the construction of geographic databases and the consolidation of Geographical Information Systems (GIS). As Goodchild (1992) noted, GIS transformed mapping into a computational activity where the landscape could be queried, measured and modelled through spatial datasets. This transition profoundly affected landscape practice. The GIS paradigm introduced layering, classification and spatial analysis as central operations, enabling designers to reveal gradients, constraints and opportunities with unprecedented precision. At the same time, it shifted representation from a static illustration to a dynamic system of relations in which the ecological and territorial structures of the landscape could be explored, compared and evaluated.

A further representational transformation emerged with the rise of computational and parametric design tools, such as Grasshopper, Dynamo and other algorithmic modelling platforms. Parametric modelling replaced form-making with rule-making: relationships, dependencies and behaviours could be encoded and adapted dynamically. As Picon (2013) notes, computation moves design from the production of fixed objects to the definition of systems capable of responding to external inputs. For landscape architecture, this shift is particularly significant: environmental processes, solar exposure, runoff, microclimates, can be simulated, compared and integrated into adaptive design strategies. Representation becomes predictive rather than descriptive.

In parallel to the emergence of computational methods, Building Information Modelling (BIM) introduced information-rich environments structured around objects, attributes and relations. Unlike CAD, which relies on geometric primitives, BIM organises projects as relational databases embedded in spatial models, where each component carries not only form but also behaviour and semantics. However, as several authors have noted (Borkowski & Wyszomirski, 2021; Shilton, 2018), BIM evolved primarily within architectural and construction contexts. Its object-based logic, built around discrete elements, remains ill-suited to the continuous gradients, diffuse systems and ecological processes characteristic of landscape architecture. This produces a representational tension: although BIM has become mandatory for public works, it still lacks native structures for modelling multi-scalar and dynamic landscape conditions.

In response to these limitations, contemporary practice is beginning to experiment with hybrid forms of representation that place GIS, computational modelling and BIM side by side, rather than fully integrated. Despite these emerging tendencies, it is important to acknowledge that GIS, computational modelling and BIM continue to operate as largely independent ecosystems. Their combination in practice often results in parallel workflows rather than true integration, highlighting the absence of shared standards, data structures or modelling logics, precisely the gap that this research seeks to address.

The evolution of representational techniques thus prepares the ground for the emergence of integrated digital ecosystems. The convergence of GIS, EO and BIM, each with its own representational grammar, signals a shift toward models capable of linking territorial evidence, temporal phenomena and projective design strategies. This trajectory forms the conceptual basis for the transition described in this chapter and sets the foundation for the integrated methodological approach developed in the subsequent sections.

These developments reveal a long-standing trajectory in which landscape representation moves from depiction to explanation, from objects to processes and from drawings to data-rich analytical environments (Shen et al., 2024). Yet this historical evolution also exposes a structural discontinuity: while each tool offers partial forms of territorial intelligence, they remain technically and conceptually fragmented. Understanding this lineage is therefore essential for recognising why interoperability has become an unavoidable frontier in contemporary landscape practice. It is precisely within this historical and representational trajectory that the present research positions itself, proposing a methodological framework capable of reconnecting these separate digital ecologies into a coherent approach for landscape design.

To fully understand how this representational evolution shapes contemporary digital practice, the following subsection examines the three principal technological domains that today structure landscape information: Geographical Information Systems (GIS), Earth Observation (EO) and Building Information Modelling (BIM). Each of these environments embodies a distinct way of organising, analysing and modelling territorial knowledge and their characteristics are essential for understanding the logic of interoperability developed later in this thesis.

2.2 An Overview of Current Digital Landscape Tools

The progressive digitalisation of landscape practice has led to the consolidation of three technological domains: Geographical Information Systems (GIS), Earth Observation (EO) and Building Information Modelling (BIM). Each tool presents contributes distinct analytical, representational and operational capacities. While historically developed as separate ecosystems, these tools now form the core of contemporary data-driven approaches to territorial analysis and design. Understanding their principles, structures and methodological implications is therefore essential for situating the integrated workflow proposed in this thesis.

GIS provides the spatial framework through which territorial patterns, ecological dynamics and environmental processes can be analysed, classified and visualised. EO expands this perspective by introducing multi-temporal, spectral and synoptic observations capable of revealing landscape changes, vegetation conditions, hydrological behaviours and climatic variations at multiple scales. BIM, in turn, offers a parametric and information-rich environment where design components, rules and relationships can be structured, evaluated and managed across the project lifecycle.

Although each of these systems operates according to its own logic: GIS grounded in geospatial databases, EO in remote-sensing acquisition and processing, BIM in object-based modelling and information collection. The combined potential for landscape architecture lies precisely in their complementarity. Together, they can provide analytical depth, environmental evidence and structured modelling capabilities required to link territorial intelligence with design decision-making.

This section therefore outlines the foundational characteristics of these three domains and discusses their relevance for landscape practice. The following subsections examine:

- 2.2.1 Geographical Information Systems: Principles, data structures and analytical functions supporting territorial understanding.
- 2.2.2 Earth Observation in Landscape Studies: The role of satellite imagery, spectral indices and temporal monitoring in identifying environmental patterns and changes.
- 2.2.3 Building Information Modelling: Core concepts of BIM, including parametric logic, object-based structures and information management.
- 2.2.4 BIM for Landscape: Emerging applications, limitations and methodological challenges of applying BIM within landscape architecture, application of modelling landscape elements within the Revit Autodesk software.

Together, these components establish the technological and conceptual foundations required to understand the interoperability challenges addressed within the innovation approach proposed by this research.

2.2.1 Geographical Information Systems

Geographical Information Systems (GIS) are computer-based frameworks designed to capture, store, manipulate, analyse and visualise geographically referenced data. As Burrough (1986) states in his early and influential definition, GIS comprises “a set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world”. This dual nature, simultaneously a database technology and an analytical environment, positions GIS as a critical instrument for disciplines concerned with spatial reasoning, including landscape architecture, territorial planning and environmental assessment.

The conceptual origins of GIS are closely intertwined with the evolution of landscape planning in the 1960s. McHarg (1969) in *Design with Nature*, articulated a methodological shift based on the systematic overlay of thematic maps (geology, hydrology, soils, land use, etc.) anticipating the later computational formalisation of spatial layering and suitability analysis. In parallel, research at Harvard’s Graduate School of Design laid methodological foundations for spatial modelling and regional planning. These contributions converged with technological developments by Howard Fisher, whose SYMAP (Synagraphic Mapping and Analysis Program) in 1965 demonstrated the potential for automated thematic mapping despite the limitations of early computing hardware.

The term Geographical Information System itself was introduced shortly after by Tomlinson (1968), who conceptualised GIS as an integration of four computational domains: image processing, Computer-Aided Design (CAD), cartographic mapping and database management. This integration remains a defining characteristic of GIS today: the capacity to connect heterogeneous information, composed by raster imagery, vector geometries and tabular attributes, through spatial location and to derive relationships, patterns and processes that are otherwise analytically inaccessible (Goodchild, 2018; Longley et al., 2015).

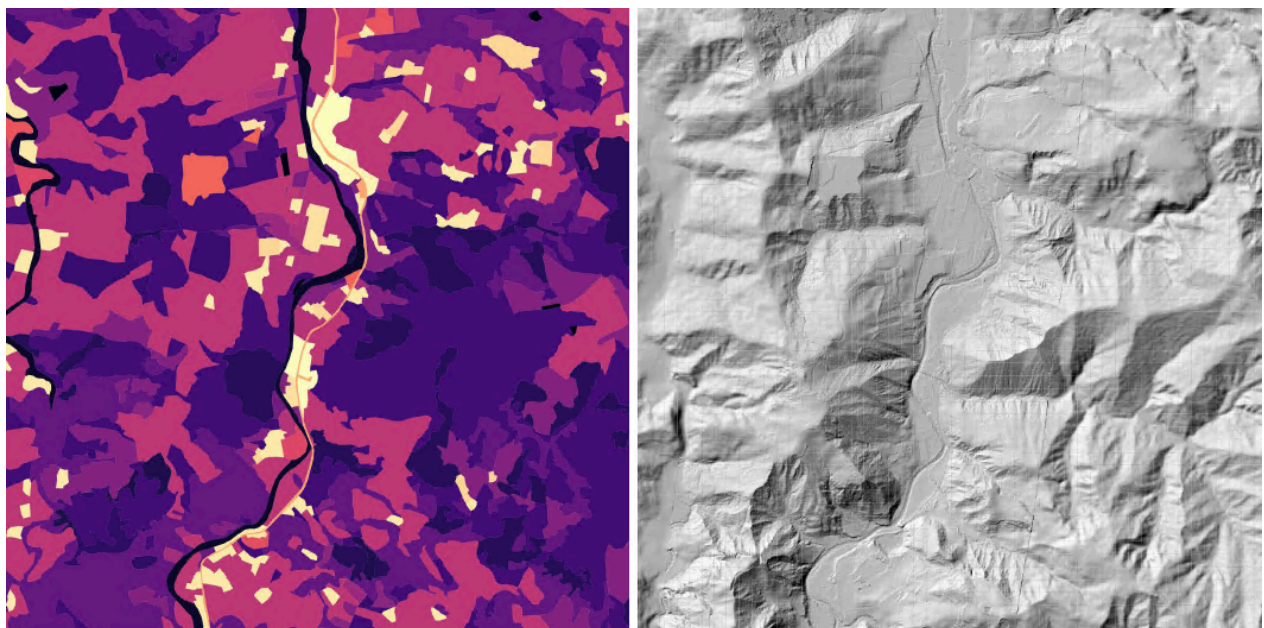
What makes GIS particularly suited to landscape architecture is its ability to represent space not merely as geometry, but as a layered, relational system. Landscapes are composed of interacting physical, ecological and socio-cultural processes whose spatial patterns cannot be reduced to lines or surfaces alone. Unlike Computer-Aided Design (CAD), which organises space through discrete geometric primitives and is primarily concerned with form-making, GIS encodes the landscape as a network of relationships, between terrain and hydrology, soil and vegetation, infrastructure and settlement patterns. In this sense, GIS aligns with the systemic nature of landscape by allowing designers to understand how conditions vary across gradients, how processes unfold over time and how multiple layers of information converge to shape place. By integrating spatial reasoning with environmental data, GIS provides an interpretive framework that supports both analytical and design-oriented understandings of landscape complexity.

Despite the diversity of modern platforms, all GIS environments rely on four interactive subsystems: (1) data input, which transforms maps, sensor data or surveys into digital formats; (2) data storage and management, typically through relational or object-relational databases; (3) spatial analysis, where geoprocessing operations generate new knowledge; (4) output, enabling cartographic, numerical or three-dimensional representation.

These subsystems support the three essential forms of information embedded in any GIS dataset: geometric (location, shape, extent), topological (adjacency, connectivity, containment) and attribute (descriptive or quantitative characteristics).

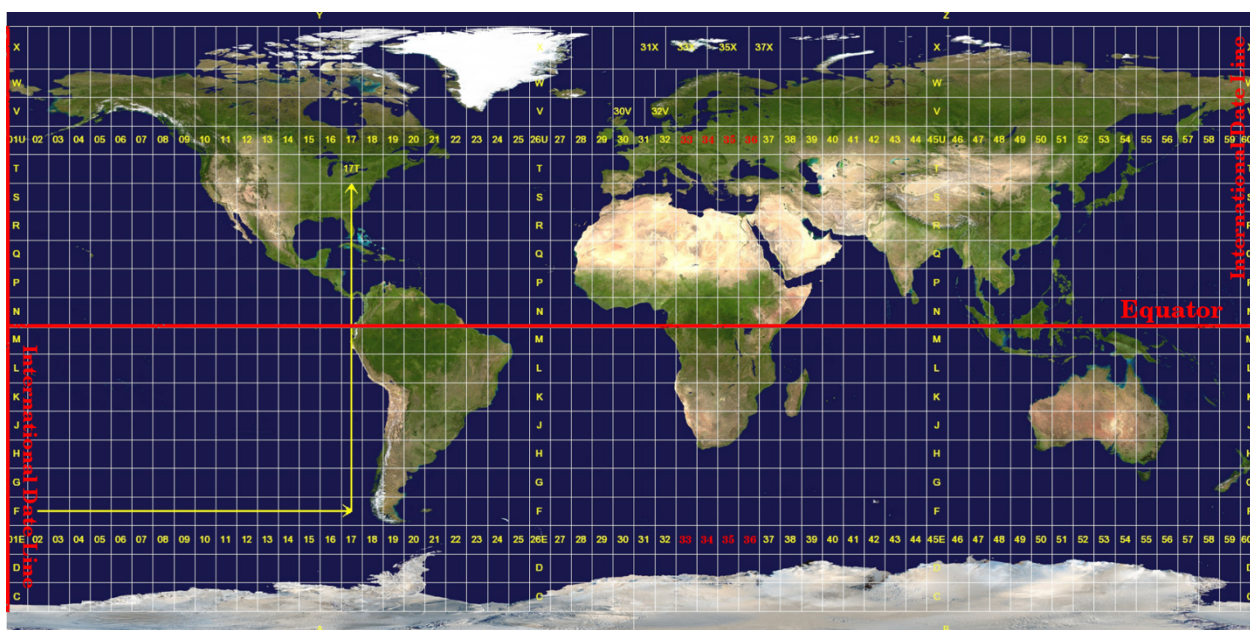
Spatial entities are represented using two main data models. Figure 2.2 shows the main differences in the same territorial portion. Vector data store discrete features (points, lines and polygons) whose coordinates are arranged into geometries linked to attribute tables. This model is appropriate for phenomena with clear boundaries, such as land parcels, vegetation patches or infrastructures. Raster data, in contrast, model continuous surfaces through a matrix of cells (pixels), each with a value representing an environmental variable. Raster formats are suited to phenomena such as elevation, vegetation indices or soil moisture, which vary gradually across space and are often derived from Earth Observation (EO) imagery. The resolution (pixel size) determines the granularity of analysis and the degree of generalisation. Many landscape-relevant datasets adopt raster structures, especially Digital Elevation Models (DEMs). Their two principal variations are: Digital Terrain Model (DTM), representing the bare ground surface and Digital Surface Model (DSM), including vegetation and built objects. These provide essential information for geomorphology, hydrological modelling, microclimate studies and visibility analysis.

Figure 2.2 - Comparison between vector and raster data in a GIS environment: on the left, vector representation of land use, structured as polygons; on the right, raster representation derived from a Digital Elevation Model (DEM), illustrating the terrain as a continuous surface composed of regular grid cells



An essential component of any GIS dataset is the Coordinate Reference System (CRS), which defines how locations on the Earth’s surface are mathematically described and related to one another. CRS have two main families. Geographic coordinate systems express positions using latitude and longitude referenced to a specific datum (e.g., WGS84 or ETRS89). They describe the Earth as a curved surface and are suitable for global or large-scale representations, but their angular units (degrees) are not ideal for distance or area analyses. Projected coordinate systems, by contrast, translate the curved Earth onto a planar Cartesian grid through a map projection (e.g., UTM, Web Mercator), allowing the use of linear units such as metres. Different projections preserve different geometric properties (area, distance, direction or shape) and their selection directly affects the reliability of spatial measurements and comparisons. Because datasets from surveys, national mapping agencies and Earth Observation platforms frequently adopt different CRSs, ensuring consistent reference systems is crucial to prevent spatial misalignment and to maintain analytical accuracy, particularly when integrating GIS outputs into BIM environments. Figure 2.3 illustrates the projected CRS, in which the combination of longitudinal zones and latitudinal bands forms a global grid enabling the unambiguous localisation of points on the planet. This system provides a practical alternative to geographic coordinates, particularly when accurate distance and area measurements are required. Furthermore, GIS data are inherently spatio-temporal: every record carries a *where*, a *what* and a *when*. This allows analysts to examine landscape dynamics, compare historical baselines, model future scenarios or integrate near-real-time environmental data from EO platforms. As data acquisition becomes increasingly sensor-based, through satellites, drones and Internet of Things (IoT) networks, GIS functions as a nexus where heterogeneous streams can be synthesised into structured knowledge.

Figure 2.3 - Projected Coordinate Reference System: global map of UTM (Universal Transverse Mercator) zones showing how the Earth is divided into sixty longitudinal zones, organised sequentially from west to east, providing a consistent framework for metric measurements and spatial analysis



The distinct value of GIS lies not merely in representing spatial data, but in enabling integration and analysis across multiple layers of information. Through techniques of overlay, spatial interpolation, neighbourhood analysis, cost-distance modelling and network analysis, GIS reveals relationships that are inherently spatial, such as ecological gradients, settlement patterns, accessibility, exposure and suitability for interventions (Goodchild, 2018). This integrative capacity differentiates GIS from CAD environments, which prioritise geometric accuracy and design representation but lack the relational structure needed to model spatial processes. While CAD excels in precision, GIS excels in relational reasoning, allowing the user to move from descriptive mapping to interpretative analysis. This distinction is central for landscape architecture, where understanding the interplay of ecological, geomorphological and socio-cultural processes is indispensable.

Landscape architecture has long relied on mapping as a way of structuring spatial thinking and communicating design intent. GIS strengthens this tradition by offering rapid, iterative and scalable tools for understanding the spatial logic of landscapes. In addition, GIS enables designers to construct explicit models of landscape systems, test hypotheses, explore constraints and opportunities and evaluate alternative design scenarios (Steinitz, 2012).

Yet within the discipline, GIS has often been confined to planning-oriented and analysis tasks (e.g. inventory, suitability mapping, constraint analysis, etc.) rather than embraced as a design intelligence tool. Literature in landscape research suggests that GIS's potential for design exploration remains underused, despite its capacity to represent complex spatial relations and support reasoning across scales (Llobera, 2003; Pettit et al., 2018).

In practice, GIS supports three main families of operations that directly contribute to landscape thinking:

- Modelling, which transforms raw data into conceptual or digital representations of terrain, ecological structure or spatial processes;
- Analysis, where relationships, thresholds and patterns are derived from spatial layers;
- Representation, through maps or 3D visualisations that communicate landscape structure and meaning.

These operations form a continuum between observation and proposition: GIS is not only a tool for documenting the existing landscape but a medium for constructing spatial hypotheses and design principles grounded in environmental evidence.

2.2.1.1 Applications of GIS in Landscape Architecture

The relevance of Geographical Information Systems (GIS) to landscape architecture emerges from their ability to synthesise heterogeneous forms of spatial information and transform them into actionable knowledge. While GIS is often described as an analytical tool, its role within landscape practice extends far beyond computation: it operates as an integrative platform capable of assembling environmental, social and infrastructural datasets, modelling spatial processes and supporting design reasoning across scales. In this sense, GIS enables landscape architects to move from isolated observations to a systemic understanding of place, aligning analytical insight with projective thinking (Forman & Godron, 1986; Steinitz, 2012).

A defining characteristic of GIS is its ability to operate seamlessly across spatial scales, each of which corresponds to distinct landscape questions and design tasks.

At the local and project scale, GIS supports detailed assessment of terrain, microclimate, soil conditions, hydrological behaviour, vegetation patterns and land-use constraints. These analyses inform the early phases of design, enabling decisions on layout, planting, drainage and ecological restoration.

At the urban or peri-urban scale, GIS facilitates the study of accessibility, ecological connectivity, demographic patterns, mobility flows, environmental stressors and landscape fragmentation. Such analyses allow strategic visions for green-blue networks, nature-based solutions and sustainable mobility systems.

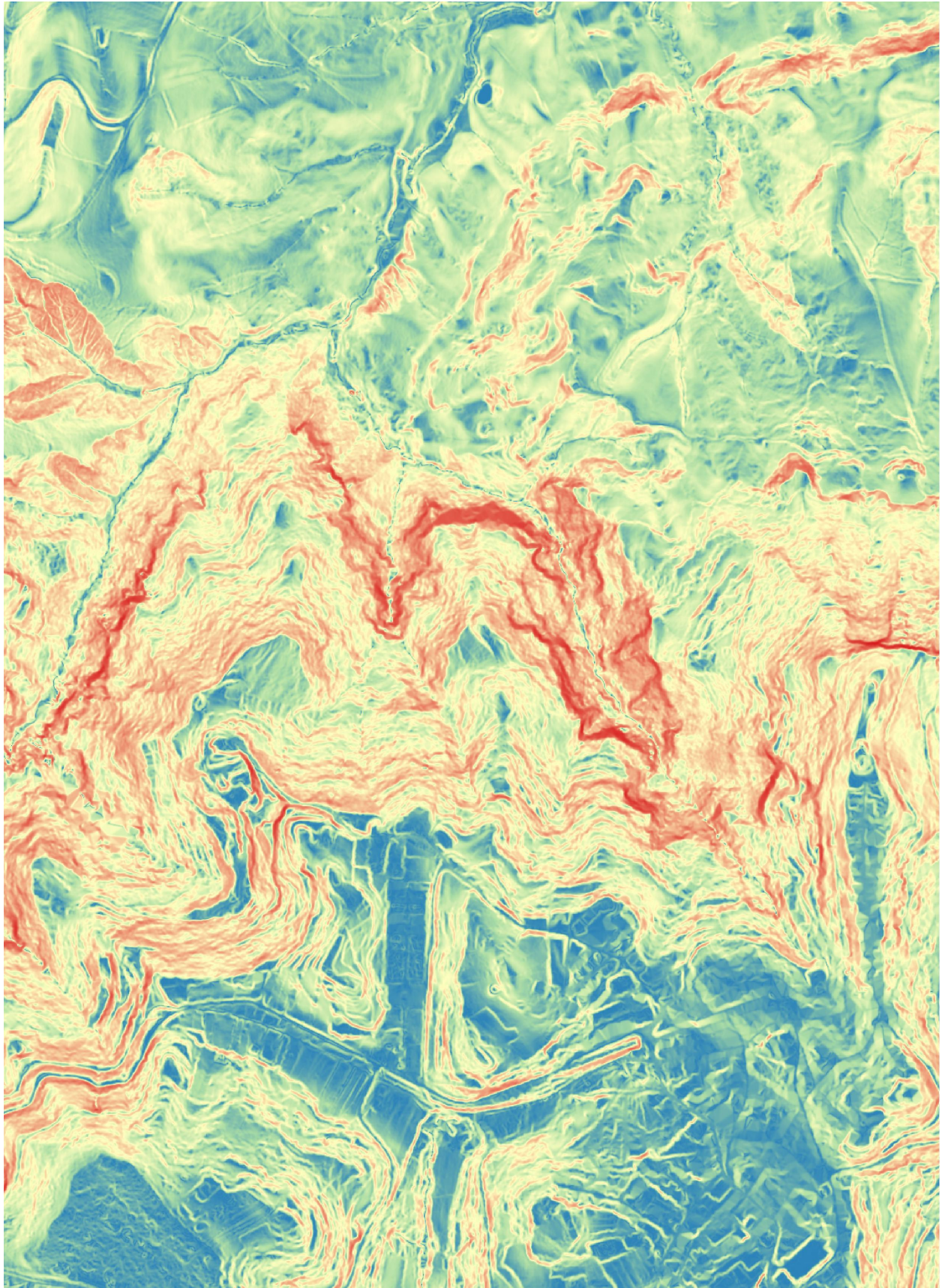
At the territorial or regional scale, GIS enables the modelling of broad landscape processes watershed functioning, wildfire regimes, agricultural suitability, ecological corridors, land-use transitions or climate impacts. This scale is essential for long-term planning, resilience strategies and integrated regional policies. By maintaining coherent spatial structures across these levels, GIS creates a continuous analytical framework capable of accommodating both local interventions and regional strategies.

The value of GIS does not lie solely in its capacity to process spatial data, but in its ability to integrate, relate and reinterpret heterogeneous information.

Beyond specific applications, GIS offers landscape architects a unique advantage: the ability to merge, relate and reinterpret data from multiple domains, such as ecology, hydrology, geology, climate science, land-use policy, socio-economic indicators and cultural heritage. Digital models combined with ecological simulations can reconstruct past landscapes, visualise urban development trajectories, or estimate landscape performance under alternative scenarios. In this integrative sense, GIS provides a unified framework in which dispersed forms of knowledge become comparable, layered and projectively meaningful.

The following sections illustrate how these capabilities translate into concrete advantages for landscape architecture, enabling informed analysis, scenario-building and decision-making across different spatial scales and specific applications.

Figure 2.4 - GIS-based slope analysis derived from a Digital Elevation Model (DEM), illustrating spatial variations in terrain steepness, with blue tones indicating areas of lower slope and red tones corresponding to steeper gradients



Environmental and ecological analysis

GIS is widely used in landscape architecture for environmental diagnostics and ecological modelling. Raster-based operations allow the calculation of slope, aspect, solar radiation and moisture indices, supporting terrain interpretation and microclimatic assessment. Ecological models integrate topography, vegetation and climate variables to identify sensitive habitats and restoration priorities (Turner & Gardner, 2015). Digital terrain and surface models further support hydrological analysis, visibility studies and erosion assessments. Together, these tools help designers understand ecosystem functioning and embed proposals within scientifically grounded environmental conditions. Figure 2.4 shows a DEM slope analysis.

Risk assessment, vulnerability and climate adaptation

GIS plays a key role in modelling environmental risks and supporting climate-adaptation strategies. Hydrological models (e.g. flow accumulation, flood susceptibility, etc.) inform water design, while multi-criteria analyses map exposure to erosion, landslides, wildfire or urban heat. Climate-related datasets enable the assessment of sea-level rise, drought vulnerability and shifting temperature regimes. These spatial insights support the planning of resilient green-blue infrastructures and the priority measures of adaptation.

Land-use planning, scenario modelling and geodesign

GIS is fundamental in land-use planning and scenario modelling, enabling designers and planners to explore the consequences of alternative development trajectories. Within geodesign frameworks, GIS supports collaborative and iterative design processes where stakeholders engage with spatial data, test interventions and evaluate their performance. This integration of spatial evidence, design intent and scenario evaluation positions GIS as a core instrument for decision-making in complex landscape systems (Pettit et al., 2018).

Landscape management and long-term monitoring

GIS is equally central to landscape management, where the analysis of temporal change is essential. Combined with Earth Observation data, GIS supports the monitoring of vegetation dynamics, soil degradation, deforestation, coastal processes and post-disturbance recovery. In parks, protected areas and cultural landscapes, GIS enables the tracking of habitat conditions, species distribution, maintenance needs, visitor flows and environmental quality. These capabilities strengthen long-term stewardship by providing continuous, spatially explicit evidence on landscape performance.

Taken together, these applications illustrate how GIS functions not only as an analytical environment, but as a connective platform capable of integrating heterogeneous forms of territorial knowledge. These applications share the same goal: to translate spatial information into structured knowledge that can guide sustainable and context-sensitive landscape design. GIS establishes the spatial framework through which external analyses, field observations, sensor networks and modelling tools can be meaningfully related to the landscape project. The next section examines the role of Earth Observation (EO) data and their accessibility, which constitute a fundamental source of environmental information. Together, EO and GIS form the analytical foundation for the interoperable, data-driven workflow developed in Chapter 3.

2.2.2 Earth Observation in Landscape Studies

Earth Observation (EO) refers to the systematic acquisition of information about the Earth's surface through satellite, aerial and UAV-based sensors⁹. Over the last two decades, EO has become a cornerstone of environmental sciences, territorial planning and landscape analysis, offering continuous, multiscale and standardised datasets that support the interpretation of ecological and socio-environmental dynamics. EO is particularly valuable for landscape architecture because it expands the analytical capacity introduced by GIS, enabling designers to observe processes that unfold over large spatial extents and long temporal horizons. As the remote-sensing literature highlights, such datasets provide an indispensable empirical foundation for understanding vegetation dynamics, land-use change, environmental stress and the behaviour of landscapes as complex systems (Campbell & Wynne, 2011; Chuvieco et al., 2002).

The development of Earth Observation (EO) has its roots in the post-war period, when aerial photography and early remote-sensing experiments laid the foundations for systematic environmental monitoring. The launch of Landsat-1 in 1972 marked a turning point, providing the first continuous, multispectral record of the Earth's surface and establishing remote sensing as a scientific discipline (Campbell & Wynne, 2011). Throughout the 1980s and 1990s, advances in sensor technology, atmospheric correction and digital image processing expanded the analytical potential of EO, allowing the monitoring of land-use change, vegetation dynamics and large-scale ecological processes.

The early 2000s saw a shift towards operational global monitoring, thanks to the consolidation of long-term missions (e.g., Landsat 7-8, MODIS), the emergence of radar programmes (e.g., Envisat ASAR) and the increasing integration of EO into environmental policy frameworks (Herold et al., 2016). The introduction of the European Copernicus Programme in 2014, with its philosophy of free and open data, represented another milestone. The Sentinel constellation democratized access to high-quality imagery, enabling not only scientific research but also planning, environmental governance and design-oriented applications. Today, EO provides one of the most comprehensive records of terrestrial processes, combining large-scale coverage with high-frequency updates and an expanding suite of spectral, thermal and radar measurements (Chuvieco, 2020).

The rapid evolution of EO capabilities is closely tied to major institutional programmes that provide free and continuous access to satellite imagery. Among these, the European Copernicus Programme, coordinated by the European Commission and the European Space Agency (ESA), has played a transformative role.

⁹ UAV-based sensors refer to measurement devices mounted on Unmanned Aerial Vehicles (UAVs), commonly known as drones. These sensors enable the acquisition of high-resolution environmental, geospatial and structural data through low-altitude, flexible and cost-effective aerial surveys, complementing satellite and ground-based monitoring techniques.

Copernicus follows an open-data philosophy that ensures long-term data continuity, standardised processing chains and global spatial coverage. Its Sentinel constellation includes several missions relevant to landscape studies:

- Sentinel-1 (C-SAR) all-weather radar imaging, supporting surface deformation monitoring, flood mapping and land-cover change detection;
- Sentinel-2 (MSI) high-resolution multispectral imagery across 13 spectral bands, essential for vegetation monitoring, soil assessment and water quality analysis (Drusch et al., 2012);
- Sentinel-3 (OLCI/SLSTR) large-scale monitoring of ocean colour, land surface temperature and atmospheric dynamics.

In particular, Sentinel-2, equipped with a multispectral instrument covering 13 spectral bands, enables high-resolution monitoring of land cover, vegetation, soil and water dynamics (ESA, n.d.; GISGeography, 2023). These data have been extensively applied in fields such as agriculture, forestry, urban planning and risk assessment, supporting both large-scale monitoring and local interventions (NASA EarthData, 2023; Farmonaut, 2024). For landscape architecture, EO imagery represents a valuable opportunity to integrate ecological and territorial dynamics into the design process, providing a bridge between spatial analysis and project decisions. Parallel to Copernicus, the Landsat programme, jointly managed by NASA and the United States Geological Survey (USGS), provides a dataset extending back to 1972, making it essential for long-term landscape change detection. Other missions, such as MODIS, AVHRR or commercial constellations (e.g., Planet, Maxar), further broaden the range of spatial and temporal resolutions available to researchers and designers (Wulder et al., 2008).

One of the greatest advantages of EO is its capacity to provide synoptic coverage of territories. This allows designers and planners to observe patterns that are invisible from ground-level field surveys or limited-scale datasets. At the regional scale, EO supports the interpretation of ecological corridors, settlement dispersion, agricultural trends and hydrological networks. At finer scales, high-resolution imagery and UAV surveys allow the examination of vegetation conditions, land cover changes, soil degradation or the performance of specific interventions.

Temporal continuity is equally important: EO datasets are updated at intervals ranging from a few days (Sentinel-2) to hours (geostationary sensors), enabling the construction of time series that reveal trends, cycles and anomalies. This temporal dimension is critical for understanding phenology, drought cycles, thermal behaviour, vegetation recovery after disturbance or long-term land-use trajectories (Li & Roy, 2017).

GIS provides the structural environment in which these datasets are organised, queried and related, while EO supplies the observational dimension that describes landscape processes as dynamic, evolving phenomena. The integration of these two domains supports a deeper and more systemic understanding of landscape functioning, which is essential for evidence-based decision-making in design and planning.

Although EO is often perceived as a resource for scientific or planning-oriented analysis, its relevance for design is increasingly recognised. EO enriches early project phases by offering a comprehensive understanding of the ecological, geomorphological and climatic frameworks in which interventions will be situated. Satellite-derived indices help identify constraints (flood risk areas, degraded soils, heat-stressed zones) and opportunities (vegetation corridors, cool islands, recharge zones), enabling designers to shape proposals that respond to existing territorial logics (Herold et al., 2016).

In regional or metropolitan contexts, EO-based land cover and land-use analyses support strategic visions for ecological networks, watershed-scale interventions, green infrastructure and climate adaptation. At smaller scales, high-resolution imagery informs site-specific planting, microclimate design, soil remediation strategies and water-sensitive planning.

By grounding design choices in environmental evidence, EO supports a transition from intuition-driven to data-informed landscape practice, strengthening the scientific robustness and long-term resilience of interventions. EO data are accessible through a growing ecosystem of online platforms and processing tools. Key infrastructures include:

- Copernicus Data Space Ecosystem (Copernicus Browser) for Sentinel imagery;
- USGS EarthExplorer for Landsat data and global DEMs;
- Google Earth Engine (GEE) for cloud-based analysis at both local and planetary scales;
- ESA SNAP Toolbox, commonly used for preprocessing, atmospheric correction and spectral processing.

Access to raw data often requires several preprocessing steps (e.g. cloud masking, radiometric calibration, atmospheric correction) which ensure that datasets are consistent and suitable for quantitative analysis. Increasingly, platforms like Copernicus Browser¹⁰ and GEE¹¹ offer ready-to-use collections that simplify these operations. For landscape architecture, these tools reduce the technical barrier to integrating EO into analysis workflows, making satellite data a practical component of day-to-day project development.

Despite its advantages, EO presents limitations that must be acknowledged. Spatial resolution may be insufficient for highly detailed design tasks, cloud cover can sometimes compromise optical imagery and spectral signatures require careful interpretation. However, the trend towards higher spatial resolution, increased revisit frequency and expanded spectral capabilities, combined with machine learning and automated segmentation, is rapidly enhancing EO's relevance for landscape research and practice (Belgiu & Drăgu, 2016). Emerging approaches, such as data fusion between multispectral sensors, deep-learning-based classification and near-real-time monitoring, including recent AI-driven initiatives such as the AlphaEarth Foundations project¹², are expanding the scope of EO-supported landscape analysis.

¹⁰ Copernicus is an intuitive interface to view and analyse satellite imagery. Available at <https://browser.dataspace.copernicus.eu>

¹¹ Google Earth Engine is a planetary-scale platform for Earth science data & analysis. Available at <https://earthengine.google.com>

¹² AlphaEarth Foundations helps map our planet in unprecedented detail, project by Google DeepMind, July 2025

2.2.2.1 Applications of EO in Landscape Architecture

Earth Observation (EO) platforms generate a wide set of biophysical indicators that are essential for interpreting the structure, functioning and temporal dynamics of landscapes. Rather than focusing on individual missions, it is useful to group EO-derived datasets into thematic categories that reflect the main landscape processes they describe. These categories support different phases of landscape planning and design, from preliminary diagnosis to scenario evaluation and monitoring. Figure 2.5 shows examples of different satellite indices related to vegetation, soil moisture and stress over the same territorial area.

Vegetation and phenology

Spectral vegetation indices are among the most widely used EO-derived metrics for landscape analysis. The Normalised Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Soil Adjusted Vegetation Index (SAVI) capture variations in canopy greenness, biomass, stress and phenological behaviour. Their temporal profiles allow designers to detect ecological gradients, identify degradation patterns and analyse seasonal cycles that influence species selection, water demand and habitat quality. Vegetation indices have long been used in ecology and landscape research to monitor productivity dynamics, assess drought stress and map succession processes (Huete et al., 2002; Tucker, 1979). In the context of landscape architecture, they support the identification of restoration priorities, the delineation of ecological corridors and the evaluation of green infrastructure performance.

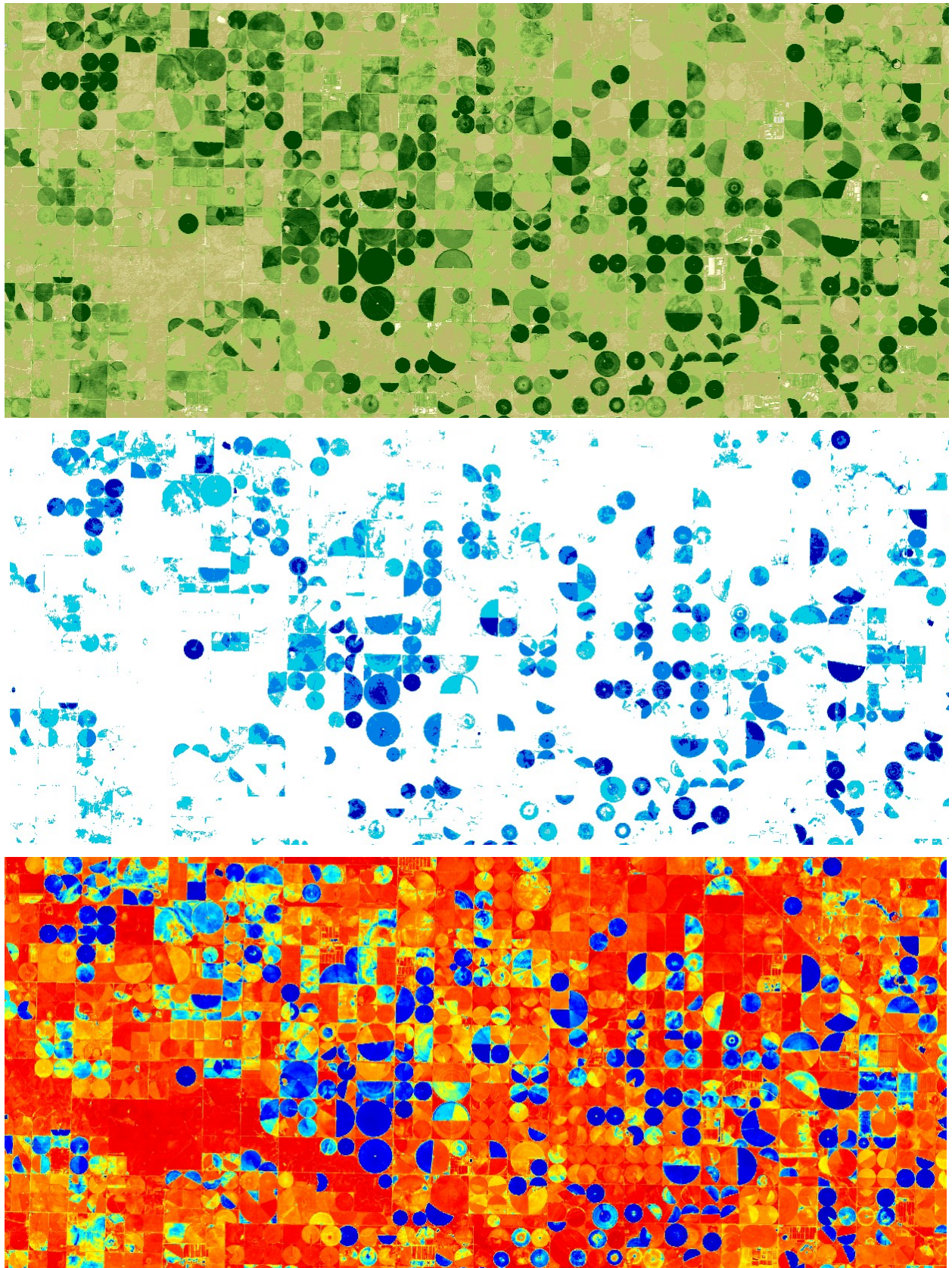
Soils and moisture

Soil-related indicators, such as the Normalized Difference Moisture Index (NDMI), Moisture Stress Index (MSI), surface albedo and bare-soil indices, provide essential information about soil water content, organic matter, salinity and overall degradation. These parameters influence vegetation health, erosion susceptibility, infiltration capacity and the resilience of ecosystems under climatic stress. Moisture sensitive indices have been widely employed to study soil and vegetation interactions, drought risk and land degradation processes (Gao, 1996; Whiting et al., 2005). For landscape architects, these indicators help prioritise soil remediation, plan drought-resistant planting strategies and assess the feasibility of nature-based solutions that rely on soil and water interactions.

Surface conditions and thermal patterns

Thermal datasets, including Land Surface Temperature (LST) and surface emissivity, are central for analysing microclimates and identifying heat-stress conditions. LST derived from EO allows the mapping of Urban Heat Islands (UHI), the assessment of cooling potential in open spaces and the evaluation of material performance at neighbourhood and city scales. EO-based thermal analyses have become a key instrument in climate-sensitive design, with numerous studies demonstrating their role in assessing thermal comfort, heat vulnerability and the performance of vegetation-soil-surface interactions (Weng, 2009).

Figure 2.5 - Earth Observation visualisations extracted from the Copernicus Browser, showing different satellite-derived analyses of the same agricultural landscape tile: from top to bottom the EVI, MSI and NDMI indices



Water and hydrological dynamics

Indices such as the Normalized Difference Water Index (NDWI) and the Modified NDWI (MNDWI) are used to detect surface water, turbidity, wetness gradients and seasonal fluctuations. When combined with DEMs or DSMs, EO supports watershed delineation, flood analysis, wetland mapping and the identification of areas with high hydrological sensitivity. EO hydrological indicators play a crucial role in water management, with documented applications in drought monitoring, flood forecasting and wetland conservation (McFeeters, 1996; Xu, 2006). For landscape architecture, they inform the design of water-sensitive urban interventions, ecological corridors, restored riparian systems and flood-resilient public spaces.

Land cover and land-use change

EO supports robust land-cover classification and change detection through datasets such as CORINE Land Cover, Copernicus Land Monitoring Service products and Landsat historical series. These datasets enable the identification of fragmentation patterns, urban expansion, agricultural decline, surface sealing or the long-term evolution of green-blue networks. Land-use change analysis is foundational in landscape ecology and planning (Coppin et al., 2004). For designers, these datasets provide strategic information about territorial dynamics, helping contextualise interventions within broader socio-ecological transformations.

Morphology

EO-derived Digital Elevation Models (DEMs) and Digital Surface Models (DSMs) support geomorphological analysis, hydrological modelling, slope-aspect calculations, solar exposure analysis and visibility studies. These models help interpret landform processes, erosion susceptibility, microclimate patterns and geomorphological constraints. Terrain modelling is a long-established part of remote sensing and geomorphology, with DEMs used to describe watershed behaviour, assess geomorphic stability and model ecological niches (Hengl & Reuter, 2009). Within landscape architecture, these morphological analyses guide spatial layout, planting strategy, circulation planning and the integration of design with landform structure.

Collectively, these EO indicators form a multilayered, dynamic representation of landscape systems, complementing the spatial reasoning capabilities of GIS and extending them into the temporal and ecological domain. EO provides a continuously updated, multi-scale representation of environmental conditions, offering insights that support both strategic and site-specific landscape design. When integrated within GIS environments, EO data enrich spatial reasoning with temporal and ecological depth.

This conceptual foundation is essential for the EO-GIS-BIM workflow introduced in Chapter 3, where EO serves as the initial analytical layer upon which spatial modelling and design-related decision-making are constructed.

2.2.3 Building Information Modelling

Building Information Modelling (BIM) is a data-driven methodology for creating, organising and sharing structured digital information across the life cycle of built and landscape assets. Rather than a specific software environment, BIM should be understood as a set of processes, standards and modelling principles that integrate geometry and metadata within a coordinated and collaborative digital environment (Eastman et al., 2011; Succar, 2010). International frameworks such as ISO 19650, together with the Italian normative system represented by UNI 11337, position BIM as a cornerstone of contemporary digitalisation strategies in architecture, engineering and infrastructure. However, its application within landscape architecture remains comparatively underdeveloped, with limited standards, modelling conventions and information requirements tailored to landscape-specific components.

The distinctive feature of BIM is its use of parametric objects that combine geometric description with performance data, construction attributes, classifications, costs or maintenance requirements. This semantic structure differentiates BIM from traditional CAD, where drawings are composed of isolated lines without embedded meaning. In BIM environments, any modification to an element, whether a pavement layer, a retaining wall, a planting bed or a drainage component, automatically propagates across views, schedules and analytical models, ensuring internal consistency and reducing the risk of errors (Smith & Tardiff, 2009). This shift from 2D drafting to model-based reasoning supports faster iterations, coherent documentation and a more integrated understanding of how components function within a wider spatial system.

BIM requires a Common Data Environment (CDE) in which all stakeholders contribute and retrieve information in a controlled and traceable way (ISO, 2018; Succar, 2010). The CDE facilitates interdisciplinary coordination, enabling the integration of architectural, structural, infrastructural, mechanical and landscape models. Tools such as clash detection, compliance checking and federated model reviews help anticipate conflicts before construction, reducing delays and fragmentation (Koo & Fischer, 2000; Kymmel, 2008). This collaborative dimension echoes many of the advantages traditionally associated with GIS, particularly the integration of heterogeneous datasets as seen in previous sections, but operates at the level of constructible and maintainable components.

Many of the advantages traditionally listed in BIM practice can be reframed into four conceptual families, aligned with the scientific literature and the methodological aims of this thesis:

1. Integrated information and reduced redundancy - The transition to BIM significantly decreases the need to duplicate drawings across disciplines. A shared model consolidates geometric and non-geometric information, enabling automatic updates, real-time quantity take-offs. This minimises errors and provides an analytical base for decision-making.
2. Analysis, simulation and decision support - BIM environments integrate a wide range of analytical tools (e.g. energy modelling, solar exposure analysis) allowing designers to explore scenarios rapidly. These capacities translate into more informed design choices.

3. Coordination - Through federated models, clash detection and multi-disciplinary reviews, BIM enables the early identification of spatial or functional conflicts. This improves collaboration and ensures that landscape interventions can be coordinated with underground utilities, architectural elements and other infrastructures.
4. Representation and communication – A unified 3D environment supports clear and accurate visual communication. Sections, axonometries, diagrams, 3D views and even animations can be generated directly from the model, accelerating design exploration and improving communication with clients, public authorities and multidisciplinary teams. This strength is particularly relevant for landscape architecture, which relies heavily on visual, spatial and experiential representations to communicate design intent.

Landscape projects involve elements, such as vegetation, soils, water systems, pavements and ecological structures, whose behaviour and maintenance needs evolve over time. The long-term performance of these elements requires a structured and reliable information environment and BIM is increasingly recognised as an effective framework for supporting such continuity (Ervin, 2020). Within a BIM landscape model, data concerning planting species, dimensions, life-cycle conditions and maintenance regimes can be stored, updated and queried systematically, enabling a more accurate understanding of how living systems change throughout seasonal and multi-year cycles.

Similarly, infrastructure layers such as irrigation networks, drainage systems or soil remediation interventions can be modelled with their associated technical attributes, performance parameters and maintenance histories. This allows designers and managers to link each landscape component to relevant metadata (e.g. warranties, supplier specifications, documentation, inspection reports or operational guidelines) thus consolidating fragmented information into a single, coherent repository (Eastman et al., 2011). The ability to structure and interrelate such data supports coordinated long-term operations across institutional actors, whether public authorities or private owners and facilitates proactive, rather than reactive, approaches to landscape management. To support long-term asset management, BIM integrates progressive layers of information commonly referred to as “BIM dimensions”, which extend beyond spatial representation and become relevant at different stages of the project life cycle. In BIM fundamentals, seven main dimensions are recognised: 3D spatial and geometric representation, 4D time-based construction sequencing, 5D cost estimation and budget management, 6D sustainability and performance analyses, 7D asset and maintenance management.

A defining characteristic of BIM is its extension across all phases of a project, from conceptualisation to construction and long-term management. This life-cycle perspective is essential to landscape architecture, where built elements coexist with living systems whose conditions evolve over time.

Planning and design phases: modelling of existing conditions (terrain, vegetation, infrastructure); 3D conceptual modelling and spatial programming; cost estimation (5D); sequencing (4D) and sustainability assessments (6D); interdisciplinary analysis and coordination.

Construction phase: fabrication information, construction sequencing and site coordination; integration of as-built updates into the federated model.

Operational phase: transition of the design model into an Asset Information Model (AIM); monitoring of vegetation, pavements, furniture, soils and drainage systems; planning of maintenance operations, lifecycle assessments and space management.

These phases align structurally with the diagram shown in Figure 2.6, which illustrates how BIM uses expand and diversify through the project life cycle.

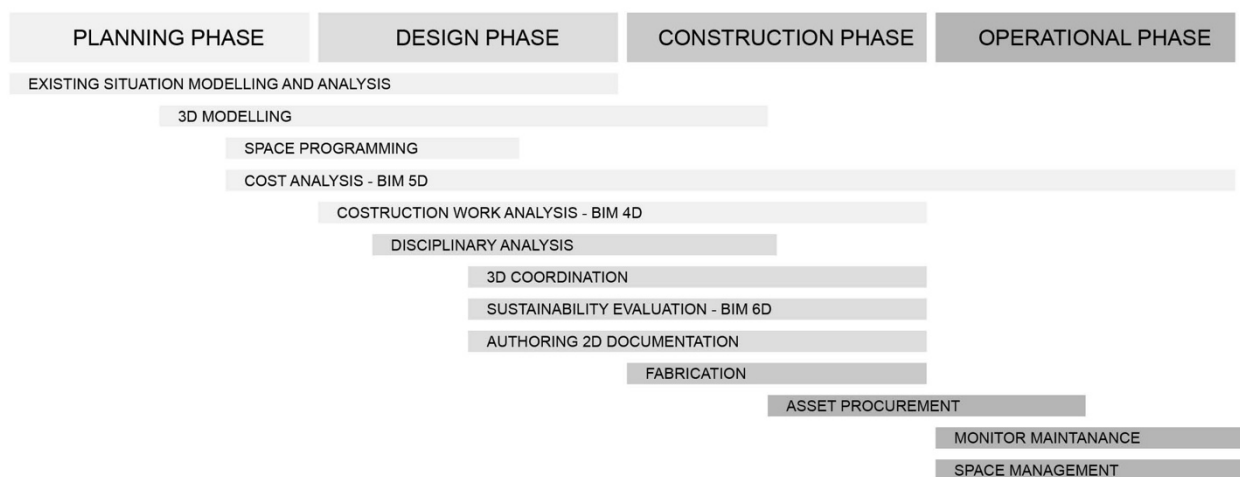
In this perspective, BIM functions not simply as a design tool but as a knowledge infrastructure that enhances the capacity to monitor, maintain and adapt open spaces over extended time frames. By embedding ecological, technical and operational information into a unified digital model, BIM strengthens the integration between design intentions and the long-term stewardship of landscape assets.

When compared to GIS, which is focused on spatial relationships, environmental patterns and territorial logic, BIM operates at the scale of components, assemblies and construction systems.

In the EO-GIS-BIM continuum, BIM represents the constructive and operational layer, where insights derived from remote sensing and GIS analysis become materialised into actionable, buildable and maintainable design information.

The next section (2.2.4) examines how BIM can be specifically adapted for landscape architecture, exploring modelling strategies, data structures and interoperability requirements for integrating environmental intelligence into the BIM environment.

Figure 2.6 - BIM uses across planning, design, construction and operational phases. The diagram highlights the progressive accumulation of information and the differentiation of BIM applications over time



2.2.4 BIM for Landscape

Landscape architecture operates at the intersection of ecological processes, spatial systems and constructed environments. Its objects, composed of terrain, vegetation, water, infrastructure and soils, are dynamic, interdependent and often diffuse across scales. For this reason, the integration of Building Information Modelling (BIM) into landscape practice is not a contradiction, but a natural evolution of the field toward data-informed, interoperable and life-cycle oriented approaches to design. As several authors argue (Ervin, 2020; Landscape Institute, 2016), the “B” of BIM has historically constrained its application to buildings, yet its real potential lies in the I (Information) and the M (Modelling). These dimensions make BIM an appropriate environment for modelling complex systems whose behaviour changes over time, much like ecological and landscape systems do.

In a BIM workflow, each discipline contributes to a common digital environment where geometric and non-geometric information are coordinated. This logic is inherently compatible with landscape architecture, a field where interdependency among elements is a defining characteristic. As in an ecological system, elements within a BIM model respond to changes in context: when design decisions influence grading, vegetation, drainage or infrastructure layouts, corresponding components adjust parametrically, ensuring consistency across representations. The adaptability that characterises ecological processes finds a methodological parallel in the parametric and relational nature of BIM, which enables coordinated updates across architectural, structural, infrastructural and landscape models (Smith & Tardiff, 2009; Succar, 2010).

The literature and emerging professional practices point to a number of BIM uses that are particularly relevant for landscape architecture (Brückner et al., 2019; Hijazi & Donaubauer, 2017). These include the capacity to organise and query information, reduce errors, analyse spatial and environmental conditions and support coordinated design and management.

First, BIM supports quantification and material assessment, enabling automatic calculation of quantities for hard landscape (pavements, retaining structures, furniture, infrastructures) and soft landscape (plants, soils, mulches, turf, substrates). This reduces the risk of human error in complex projects and supports cost estimation and workflows (Kymmel, 2008).

Second, BIM facilitates the management of structured data. Information regarding plant species, sizes, maintenance requirements, soil types, slopes or drainage typologies can be stored within parametric families, generating a coherent information system that integrates ecological and technical knowledge. This transforms BIM into a repository of site-specific knowledge, allowing the landscape model to function not only as a design tool but as an information hub throughout the project life cycle.

Third, BIM improves visualisation and representation. Parametric vegetation families, phasing tools and visualisation engines allow designers to simulate the spatial configuration of planting at maturity, explore seasonal variations and present conceptual ideas to clients with improved clarity.

Even though these visualisations do not capture ecological complexity in full depth, they significantly enhance communication during the design process.

Fourth, BIM allows the integration of terrain modelling, including grading design, cut-and-fill calculations, slope analysis and the modelling of multilayered substrates. This is essential in landscape projects where earthworks, hydrology and accessibility depend on accurate representation of topographic conditions.

Finally, BIM supports coordination with architectural and infrastructural disciplines, reducing the risk of conflicts with underground utilities, building interfaces, lighting, irrigation or mobility systems. By integrating all models into a federated digital environment, landscape architects gain visibility on project-wide dependencies and can adapt their decisions early in the process.

Across these uses, BIM contributes to a more structured, evidence-based and multidisciplinary landscape practice, particularly when paired with GIS and EO datasets, which provide the environmental conditions that inform modelling decisions.

Although numerous software platforms support BIM methodologies, each presents strengths and limitations when applied to landscape contexts. The comparative analysis presented in Table 2.1 highlights the diversity of BIM and BIM tools currently available for landscape design.

Landscape-specific platforms (e.g., Vectorworks Landmark, Edificius-LAND) provide accessible environments for planting design and graphical production, yet they present limitations in parametric control, customisation, data structuring and interdisciplinary interoperability. Although Vectorworks Landmark can import Revit files, category and class correspondence remains partial, reducing the reliability of translated objects. Moreover, exports toward other BIM platforms rely almost exclusively on IFC, which limits the preservation of information richness and behavioural properties across disciplines. While IFC (Industry Foundation Classes) is the essential open standard for BIM data exchange, its use in everyday multidisciplinary collaboration remains inefficient. This limitation reinforces the importance of adopting a shared BIM authoring environment across disciplines to ensure consistency, reduce fragmentation and support collaborative design. The IFC standard is valuable for client deliverables and long-term data archiving, but it is far less effective for interdisciplinary and continuous collaboration between teams. For this reason, IFC ensures openness, but cannot provide the fluid interoperability required in collaborative design workflows.

Conversely, generalist BIM authoring tools such as Autodesk Revit and Civil 3D offer higher modelling robustness, advanced parameterisation and more reliable integration within multi-disciplinary workflows. Revit, in particular, benefits from the embedded Dynamo environment, which enables the creation of automated routines, data-driven modelling processes and connections with external sources. This computational tool is essential for developing landscape information models aligned with the interoperability goals of this research.

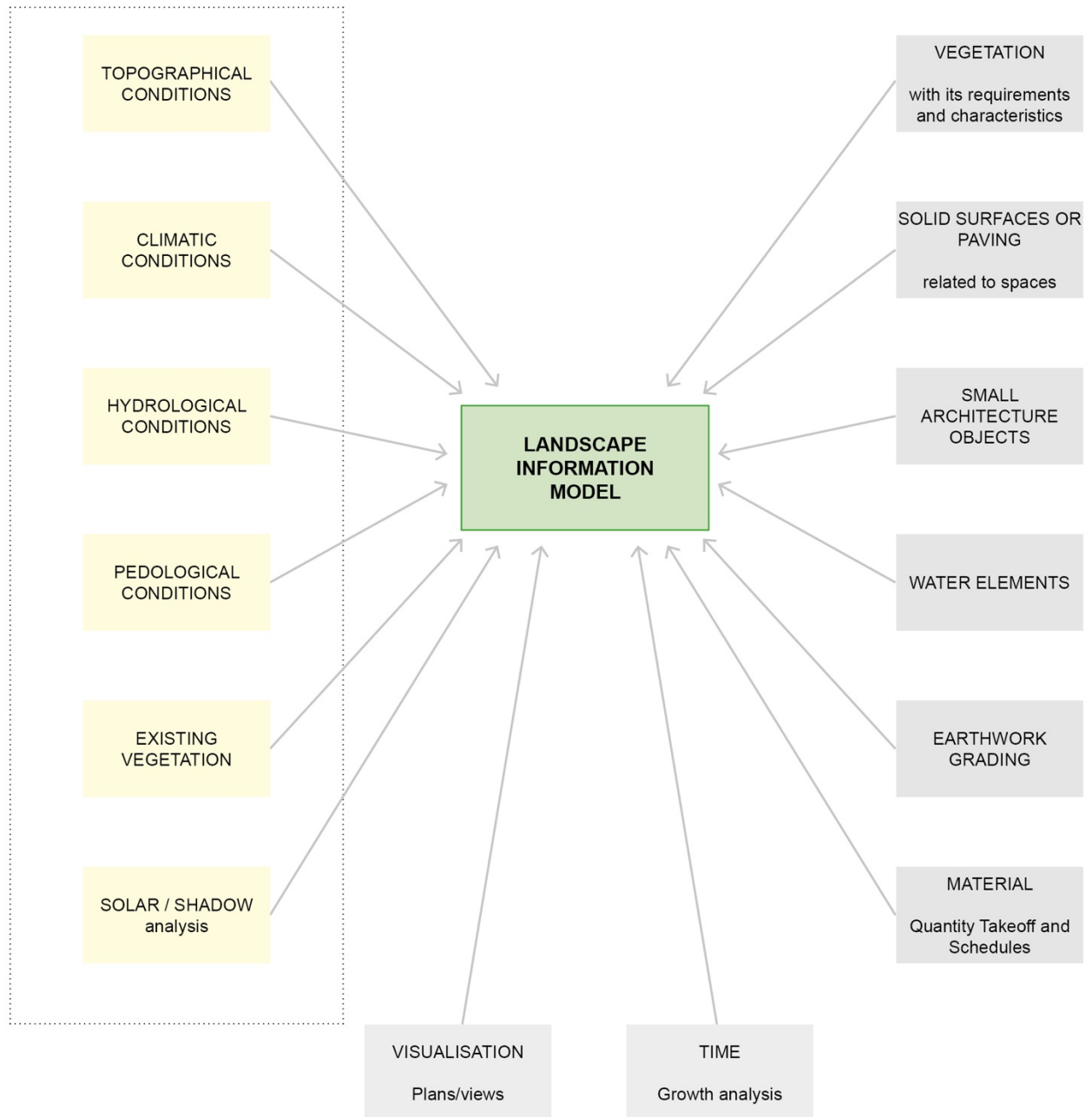
Table 2.1 - Overview of BIM Software and Tools Relevant to Landscape Modelling

BIM Software	Main Characteristics / Relevance for Landscape Architecture
Autodesk Revit + Dynamo	Multidisciplinary BIM authoring platform (architecture, structure, MEP); direct connection to Dynamo for visual programming; high customisation; strong interoperability with Autodesk ecosystem; enables detailed modelling of site elements and integration of external datasets.
Autodesk Civil 3D (+ Dynamo)	BIM platform for civil and infrastructural engineering; widely used for terrain modelling and grading; supports import/editing of shapefiles; limited use of Dynamo; good interoperability with Revit via Autodesk 360 workflows.
Autodesk InfraWorks (+ Model Builder)	Conceptual-scale BIM environment for infrastructure and landscape masterplanning; low LOD modelling; supports shapefile integration; 3D terrain extraction via cloud-based Model Builder; useful for early-stage studies but not suitable for detailed BIM coordination.
Archicad, Allplan, AECOSim	BIM authoring platforms with no native landscape-specific tools; partial integration with Grasshopper (e.g. Archicad); limited suitability for complex site modelling and interdisciplinary coordination involving terrain and vegetation.
Edificius-LAND	Landscape-oriented BIM software; limited project scale and customisation; interoperability restricted to IFC; not suitable for multidisciplinary collaboration.
Vectorworks Landmark	Landscape-oriented BIM toolset; supports shapefile import and different native files import (e.g. Revit models) but with limited category/class correspondence); IFC-only interoperability; suitable for planting design but weak in complex modelling and coordination.
Site Designer, Topo from Lines, Rhino. Inside Revit, Topo Align, CS ArtisanRV, Environment for Revit	Add-ons and plug-ins for Revit that assist with site modelling (topography, paths, grading, plant placement); substantially expand Revit's landscape modelling capabilities.
Lumion, Enscape, Twinmotion	Real-time rendering tools with integrated vegetation libraries; useful for visualisation of landscape design proposals; not BIM-authoring tools.
Autodesk Navisworks, Solibri, Synchro	Coordination and project-management environments (4D/5D BIM); widely used for clash detection, scheduling and quantity take-off; crucial for multidisciplinary integration including landscape packages.

Given the widespread adoption of Revit across architectural, infrastructural and engineering sectors, its use as a common authoring environment significantly reduces fragmentation between disciplines. Moreover, its native integration with Dynamo enables the development of custom, data-driven workflows that are essential for linking EO-GIS inputs with BIM models and for handling the parametric complexity typical of landscape systems. The choice of Revit as the primary platform for BIM-based landscape modelling in this research provides the most coherent, interoperable and future-oriented solution.

Figure 2.7 - Diagram illustrating how essential GIS-derived environmental information informs a Landscape Information Model, enabling the parametrisation of vegetation, materials, water features and earthwork within BIM, together with visualisation and temporal simulations. Source: re-elaboration of Borkowski & Wyszomirski (2021)

NECESSARY GIS LAYERS



Within this fragmented landscape of tools, this research adopts Revit Autodesk as the primary platform for developing a BIM-based methodology for landscape architecture. The choice reflects methodological, technical and interoperability considerations. Revit is today one of the most widely adopted BIM platforms across architectural and engineering workflows (Kaur et al., 2025). Its growing use within landscape architecture further demonstrates its capacity to support accurate, information-rich landscape models and to maintain coordinated datasets across disciplines (Bhattacharjee, 2024; Nikologianni et al., 2022).

For landscape architects, this widespread use offers two strategic advantages:

1. Interoperability and coordinated workflows - Revit is natively integrated into the wider Autodesk ecosystem (Civil 3D, InfraWorks, Navisworks), enabling seamless exchange of data related to terrain modelling, infrastructure, drainage, utilities and structural systems. This reduces fragmentation and allows landscape models to be developed in close coordination with other disciplines.
2. Parametric modelling enhanced by Dynamo - Revit incorporates Dynamo, a visual programming environment that significantly expands modelling and data processing capabilities. Through Dynamo, designers can connect BIM objects to external datasets. This supports the creation of data-driven rules, automated placement of components, parametrization of planting and integration of environmental attributes directly into BIM families.
3. Shared modelling conventions and industry standards - by adopting the same platform used by architects and engineers, landscape models remain readable, editable and maintainable by other project partners, avoiding the risk that landscape information becomes siloed into a discipline-specific tool.
4. Flexible representation of terrain and environmental systems - when combined with Civil 3D or InfraWorks Model Builder, Revit allows the import and refinement of topographic surfaces, grading operations, alignments, volumes and multilayered soil structures, elements which are essential to landscape design.

For these reasons, Revit offers the most robust environment for the integrative and data-informed landscape workflows developed in this research, as represented in Figure 2.7. Its ability to host parametric, multidisciplinary and dynamically updated information provides a stable foundation upon which landscape models can be constructed, interrogated and adapted throughout the project cycle. This establishes a coherent basis for the modelling strategies illustrated in the following section. In this context, Revit becomes not merely a tool for representation, but a dynamic environment for building adaptive and evidence-based landscape information models aligned with the methodological framework developed in Chapter 3.

2.2.4.1 Modelling the Landscape in Revit Autodesk

The modelling of landscape systems within Building Information Modelling (BIM) environments requires an approach that is conceptually aligned with ecological thinking: relational, multi-scalar and responsive to changing conditions. Although Revit was originally conceived for architectural and engineering purposes, its parametric structure, database logic and integration with visual programming make it increasingly suitable for landscape applications (Ervin, 2020; Hijazi & Donaubaauer, 2017). What matters is not the “building” component of BIM, but its capacity to represent information-rich systems whose behaviour varies over space and time, an aspect that resonates strongly with landscape architecture.

A landscape-oriented BIM workflow begins with the establishment of an appropriate template, defining view configurations, graphic standards and classification systems tailored to site-scale design. In landscape architecture, plan views, sections and 3D views constitute the core representational framework. Plan views articulate spatial organisation, technical layers, planting distributions and construction boundaries across different levels. Sections, both territorial and detail-scale, reveal grading logic, soil stratigraphy, hydrological interfaces and the relationships between built and vegetated systems. 3D views play an increasingly central role in landscape representation, as they enable designers to visualise complex spatial structures, communicate grading transitions, assess the interaction between hard and soft components and support iterative design discussions with stakeholders. Within BIM workflows, 3D views also act as analytical environments, allowing the verification of slopes, elevations, visibility conditions and the spatial coherence between disciplines. They ensure that landscape models can be read and understood at multiple scales and levels of abstraction, strengthening both design communication and coordination.

To enable structured collaboration, landscape models are typically organised into worksets that follow the logic of coordinated discipline-based BIM. A pragmatic structure distinguishes between:

- Site (existing/proposed topography, existing vegetation, context, masses),
- Hard Landscape (pavements, walls, kerbs, ramps, stairs, drainage elements, street furniture),
- Soft Landscape (trees, shrubs, herbaceous layers, planting beds).

This organisation reflects best practices in multidisciplinary BIM coordination (Eastman et al., 2011; Smith & Tardiff, 2009), ensuring that landscape information remains readable, controllable and aligned with architectural, infrastructural and engineering models.

In landscape BIM workflows, project parameters are essential for organising information consistently across the model. They allow attributes to be shared among different Revit categories or instances, creating a unified structure for classification and analysis. These parameters can store botanical data, soil types, construction layers, maintenance information or, eventually, spatial labels derived from GIS.

Within this framework, landscape components can be constructed through a combination of system families (e.g., Floors, Planting, Railings, Stairs), site-modelling tools (Topography/Toposolid) and custom modelling strategies such as Model-In-Place sweeps for drainage or kerbs. The aim is not to replicate architectural conventions, but to use Revit's parametric and informational capabilities to build adaptive, evidence-based landscape information models capable of integrating data from Earth Observation (EO) and GIS, an aspect further developed in Chapter 3.

A distinguishing advantage of BIM for landscape architecture is the ability to convert geometric elements into quantifiable, information-rich schedules. Revit's scheduling system enables landscape components to be interrogated, aggregated and analysed according to project requirements, providing a bridge between design intentions, environmental data and maintenance planning. Schedules are essential for several reasons:

1. Quantification and Material Estimation - Floor schedules can report pavement areas, layers, materials and construction types; planting schedules aggregate species counts, sizes, conditions and rootball volumes. These outputs support cost estimation and align with BIM workflows (Kymmel, 2008).
2. Environmental Attributes - Schedules become particularly powerful when populated with environmental attributes, allowing the landscape model to become a container for environmental intelligence.
3. Maintenance, Lifecycle and Management Data - Planting schedules may include pruning cycles, watering needs, botanical classifications, expected canopy spread, carbon sequestration potential or maintenance frequencies. This transforms the BIM model into a long-term management tool, aligning landscape practice with asset-management principles (Abideen et al., 2022; Zhao et al., 2022).
4. Coordination with Other Disciplines - Schedules also help verify consistency across models, for example, identifying mismatches in levels, materials, slopes or intersections with utilities, thus supporting conflict detection.
5. Scenario Testing and Parametric Logic - When combined with Dynamo, schedules can drive parametric rules, such as assigning species types based on EO indices, filtering planting by site typology or generating automated warnings for slopes exceeding accessibility requirements.

The following Table 2.2 provide a visual and methodological overview of the main modelling components used in landscape BIM, distinguishing between Hard Landscape and Soft Landscape. Each entry summarises the modelling logic, interoperability considerations and the type of information that should be embedded to support downstream uses such as coordination, scenario analysis or environmental evaluation.

Table 2.2 - Hard and Soft Landscape Elements in Revit (Visual and Modelling Overview)

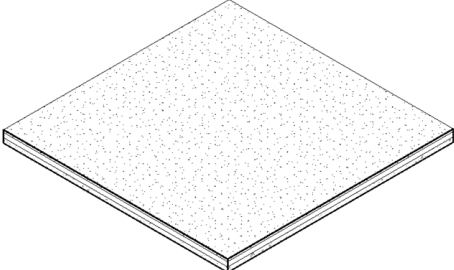
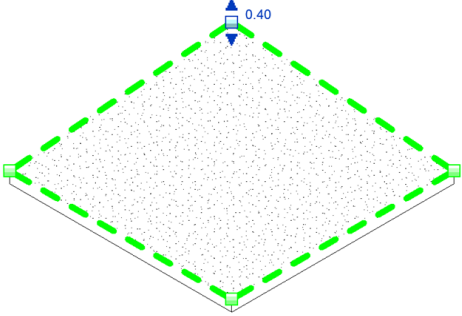
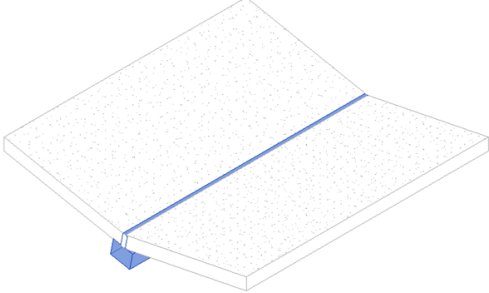
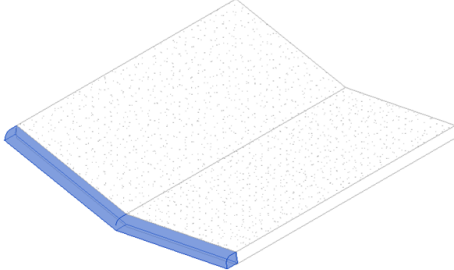
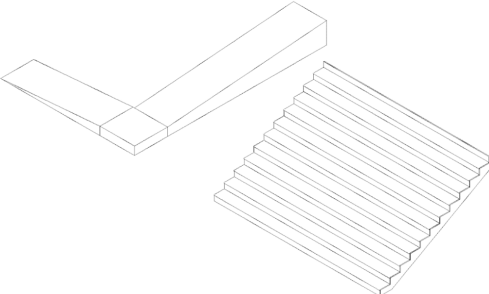
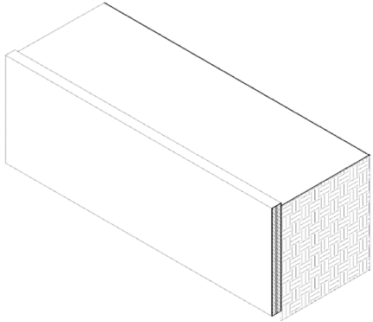
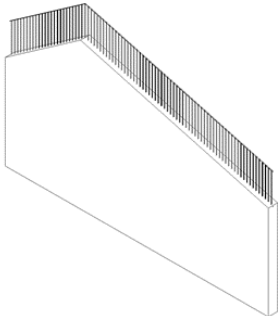
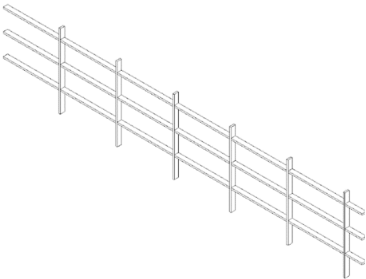
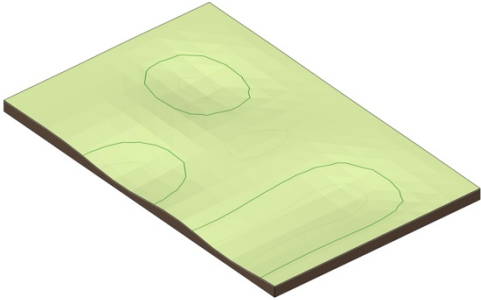
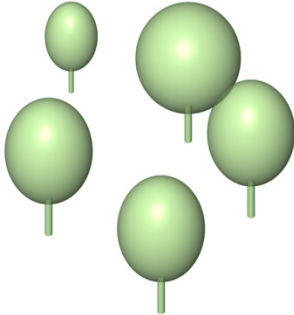
Element	Modelling Strategy in Revit	Figure
Pavements / Surface Layers	<p><u>Hard and Soft Elements</u></p> <p>Modelled using <i>Floor</i> families due to flexibility in hosting families, multilayer construction and 2D representation; supports stratigraphy, materials and construction logic; preferable to <i>Roof</i> for exterior ground modelling.</p>	
Grading and Slopes	<p><u>Hard and Soft Elements</u></p> <p>Slopes defined using <i>Modify Sub-Elements</i> with point-based elevation control; supports drainage gradients, accessibility and multi-directional grading; essential for coordinating hard/soft edges.</p>	
Drainage Channels / Runnels	<p><u>Hard Elements</u></p> <p>Created using <i>Model-In-Place</i> sweeps or extrusions following pavement slopes; allows bespoke geometries for water conveyance; integrates with grading operations.</p>	
Kerbs and Edges	<p><u>Hard Elements</u></p> <p>Modelled as <i>Slab Edges</i> when using <i>Floors</i>; as <i>Gutter</i> when using <i>Roof</i>-based pavements; custom geometries via <i>Model-In-Place</i> for curved or non-standard profiles; tied to pavement slope.</p>	
Stairs and Landscape Ramps	<p><u>Hard Elements</u></p> <p><i>Stairs</i> tool for conventional flights; <i>Ramp</i> tool limited to single slopes, <i>Floors</i> with sub-elements provide more flexible ramp modelling for outdoor spaces; slope constraints align with accessibility codes.</p>	

Table 2.2 - Hard and Soft Landscape Elements in Revit (Visual and Modelling Overview)

Element	Modelling Strategy in Revit	Figure
Retaining Walls and Edges	<p><u>Hard Elements</u></p> <p>Constructed using <i>Wall</i> families with top/bottom profile editing, or via in-place components for terraced systems; must coordinate with grading and sub-surface layers.</p>	
Railings	<p><u>Hard Elements</u></p> <p>Created using the <i>Railing</i> tool; customisable posts and rails; can be hosted on Floors or Walls; automatically adapts to host geometry (e.g., retaining wall profiles).</p>	
Fences	<p><u>Hard Elements</u></p> <p>Modelled with <i>Curtain Wall</i> systems; mullions use custom profiles and panels can be set to empty or material-based; supports insertion of gates by replacing panels with Door families.</p>	
Topography / Earthworks	<p><u>Soft Elements</u></p> <p>Existing or proposed topography represented through <i>Toposolid</i> or via imported Civil 3D surfaces; supports cut-and-fill analysis, subregions, site modification and visibility control.</p>	
Trees	<p><u>Soft Elements</u></p> <p>Loadable <i>Planting</i> families with parametric attributes (species, height, crown diameter, rootball size); symbolic 2D representation coordinated with 3D geometry; supports scheduling and maintenance data.</p>	

Although BIM provides a powerful environment for modelling, coordinating and managing landscape components, it is not sufficient on its own to grasp the ecological and territorial dynamics that shape landscape systems. Its full strength emerges only when combined with GIS, capable of structuring spatial relationships and environmental logic and with Earth Observation (EO), which introduces temporal depth, synoptic vision and continuous monitoring.

Ultimately, BIM provides landscape architects with a modelling environment that mirrors the relational and dynamic nature of landscape systems. By structuring geometry, data and analytical logic within a single, interoperable model, Revit creates the conditions for linking environmental evidence to design decisions.

Within this research, BIM operates as the design and decision-making environment, while EO and GIS supply the evidence base: vegetation indices, moisture conditions, microclimate signals, soil classifications, hydrological patterns and other environmental indicators that determine the spatial logic of interventions.

The integration of these domains supports a methodology in which:

- Earth Observation: measures and monitors territorial processes
- Geographical Information Systems: structures and interprets spatial relationships
- Building Information Modelling: materialises data into parametric design models

This triad establishes an interoperable, data-informed workflow through which landscape architecture can evolve into a discipline capable of grounding design decisions in environmental intelligence. The next chapter expands on this integration, showing how EO and GIS datasets can be embedded into BIM to support an increasingly predictive, scenario-based and ecologically grounded approach to landscape design.

2.3 Interoperability Between EO, GIS and BIM

The previous sections have outlined the conceptual foundations and technical characteristics of Earth Observation (EO), Geographical Information Systems (GIS) and Building Information Modelling (BIM). Having examined these domains separately, this section shifts the focus to how they operate together. The aim is to understand not only the capabilities of each system in isolation, but the conditions under which their integration becomes meaningful for landscape architecture, where environmental data, spatial analysis and parametric modelling must converge into a coherent, interoperable workflow.

Landscape architecture operates at the intersection of ecological processes, territorial systems and constructed infrastructures, requiring a design workflow that is spatially explicit, data-rich and capable of responding to environmental variability. Traditional BIM environments, although powerful for the modelling of buildings and infrastructural assets, remain insufficient when used alone to understand the ecological and territorial dynamics that shape landscape systems (Nikologianni et al., 2022). Their core strength lies in parametric representation, coordination and lifecycle information, but BIM lacks the spatial intelligence, environmental semantics and territorial context essential for landscape decision-making.

Conversely, Geographic Information Systems (GIS) offer multi-scale spatial reasoning, environmental modelling, geostatistical analysis and a direct connection to territorial datasets such as soils, hydrology, vegetation, exposure, climate or land-use patterns. GIS provides planners and designers with the ability to interpret spatial relationships, monitor environmental change and assess site suitability, playing a crucial role in informed decision-making during the early phases of design (Goodchild, 2018; Schaller et al., 2017). Yet GIS alone cannot support the detailed, object-based, parametric modelling required for construction documents, quantity take-offs, clash detection or multidisciplinary coordination.

The integration of BIM and GIS therefore represents a necessary evolution toward data-driven landscape design. As highlighted by multiple authors, the real value of BIM emerges when it is paired with structured environmental datasets that inform its modelling logic (Biljecki & Tauscher, 2019; Cao et al., 2021). BIM provides a robust information environment in which ecological data can be embedded into parametric elements and propagated throughout the project's lifecycle, from conceptualisation to construction and long-term management.

However, despite the recognised potential of GIS-BIM integration, current workflows remain fragmented and technologically constrained. The vast majority of existing approaches operate in a unidirectional direction BIM-to-GIS most commonly for the publication of models in web-GIS platforms or for territory-scale visualisation (Ma & Ren, 2017; Zhu & Wu, 2022). By contrast, GIS-to-BIM interoperability, which would enable environmental data to actively shape design choices, remains significantly underdeveloped.

For landscape architects, this gap is particularly problematic. Landscape projects depend on environmental evidence, such as soil moisture, thermal patterns, vegetation indices, slope conditions, hydrological dynamics, that typically originate from GIS or Earth Observation (EO).

Without an interoperable workflow, these datasets remain external to the BIM modelling environment, forcing designers into traditional linear processes where GIS supports only pre or post verification rather than driving decision-making design.

Although both domains operate on spatial data, their conceptual foundations, data models and operational paradigms differ substantially, creating barriers to seamless interoperability. A review of existing literature reveals a fragmented landscape of methods, tools and theoretical frameworks, with relatively few contributions explicitly addressing the needs of landscape architecture.

GIS and BIM have evolved with distinct epistemologies. BIM focuses on object-based, parametric modelling and is primarily concerned with the micro-scale representation of buildings, components and construction systems (Andrianesi & Dimopoulou, 2020). GIS, conversely, operates at macro-scale, structuring territorial relationships, environmental patterns and large-scale datasets relevant to planning and ecological assessment (Brückner & Remy, 2021).

Other overview researches highlight some divergences:

- Data Models: BIM adopts IFC or native schemas, whereas GIS typically uses CityGML or geospatial relational databases (Kutzner et al., 2020; Lam et al., 2024; Ohori et al., 2018).
- Coordinate Reference: BIM uses local coordinate systems; GIS uses geographic or projected reference systems (Zhu & Wu, 2022).
- Semantics: BIM embeds object attributes related to construction, while GIS embeds environmental semantics such as soils, hydrology, exposure, ecological sensitivity (El-Hallaq et al., 2019; Fosu et al., 2015).
- Purpose: BIM is optimised for design, coordination and construction, while GIS for environmental analysis and territorial governance (Andrianesi & Dimopoulou, 2020; Ma & Ren, 2017).

These foundational differences complicate interoperability, particularly when attempting to move GIS-derived environmental semantics into BIM environments. There are three main categories of integration generally identified (Ma & Ren, 2017; Zhu et al., 2022).

GIS to BIM: it can be used when environmental datasets inform site modelling, early design, resilience and accessibility assessments. Remains the least developed pathway due to semantic and geometric incompatibilities.

BIM to GIS: Currently the most mature workflow. Used to publish BIM models into GIS platforms, enabling web-based visualisation, territorial analysis or asset management.

GIS and BIM to a Third System: Integrations into Digital Twins or 3D city models using intermediate data models such as CityGML or semantic ontologies (Sun et al., 2019).

In all three cases, authors agree that geometry transfer tends to be unidirectional BIM-to-GIS due to the difficulty of converting lightweight surfaces into solid parametric objects.

2.3.1.1 Practical Interoperability Between GIS and BIM Software

The practical integration between GIS and BIM environments depends not only on conceptual alignment but also on the technical interoperability of the software ecosystems through which landscape architects operate. For this reason, the research first examined the most widely adopted GIS platforms (QGIS, ArcGIS Pro, AutoCAD Map 3D) and BIM authoring tools (Revit, Civil 3D, InfraWorks, Vectorworks Landmark), assessing their capacity to exchange geometry, attributes and coordinate information. This analysis reveals that, although numerous tools exist for spatial analysis and digital modelling, true interoperability remains limited, fragmented and highly tool-dependent, confirming what recent reviews also emphasise (Andrianesi & Dimopoulou, 2020; Zhu & Wu, 2022).

A key milestone in the evolution of GIS-BIM integration is the strategic partnership signed in 2017 between Autodesk and Esri, the global leaders in digital design and geospatial systems. Their stated ambition was to bring together geographic information systems and BIM to support planning, design, construction and operations across the full lifecycle of built assets, enabling users to design anything, anywhere by connecting environmental context with digital construction models (Esri & Autodesk, 2017; Perego, 2025). The core idea behind the partnership is a bi-directional flow of information:

- GIS to BIM, can provide environmental, geospatial and regulatory datasets needed for early-stage design decisions;
- BIM to GIS, feeding back as-built models, asset information and construction updates into GIS platforms for long-term management.

In practice, this partnership produced a set of software-level workflows, as illustrate in Table 2.3 below.

Table 2.3 - Overview of key relationships between BIM and GIS through Esri and Autodesk software platforms.

BIM and GIS Software Relation	Main Characteristics
ArcGIS to InfraWorks	BIM users can connect directly to ArcGIS Online datasets. The data remain connected, not imported, ensuring live synchronisation of geospatial layers.
InfraWorks to ArcGIS	Infrastructure models can be published back to ArcGIS Online, transferring simplified geometry and attributes for planning and public engagement.
ArcGIS to Civil 3D	ArcGIS Online layers can be imported and edited within Civil 3D, effectively allowing the software to act as an ArcGIS editor for engineering workflows.
Revit to ArcGIS	Revit BIM models can be imported and visualised inside ArcGIS Pro, allowing geospatial contextualisation of architectural and infrastructural models.

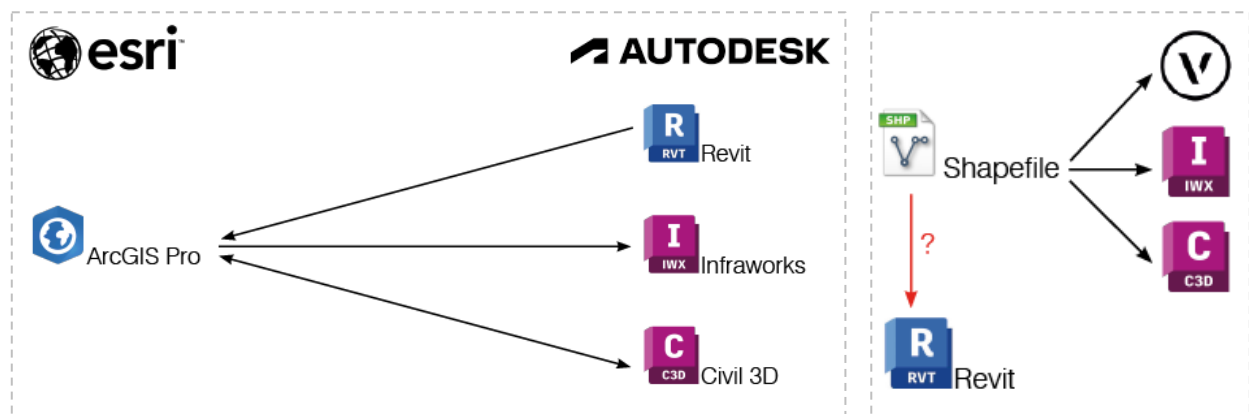
While these Autodesk-Esri collaboration workflows represent substantial progress, the integration remains asymmetric. As noted by multiple studies (Hjelseth & Thiis, 2008; Kari et al., 2016), the current ecosystem strongly favours BIM-to-GIS rather than GIS-to-BIM. No direct method exists today for importing GIS datasets, especially vector/raster datasets with attributes, directly into Revit in a parametric and information-preserving form. The GIS data inside the softwares InfraWorks and Civil 3D typically lose part of their attribute structure when are eventually transferred to Revit.

As outlined in the introduction, the aim of this research is to enable the integration of GIS data within BIM environments so that such information can be used both as a design analysis layer and as a tool to support project evaluation. Given the absence of direct software interoperability, the only viable alternative is interoperability through file formats. Among GIS datasets, the most relevant for design purposes are vector formats, particularly the Shapefile, which encodes primitive geometries (points, lines and polygons) alongside tabular attributes containing textual or numerical information. Although the open-source Shapefile format (as opposed to the proprietary Esri version) can be imported into BIM tools such as InfraWorks or Civil 3D, the collaborative limitations with Revit remain unchanged. Shapefiles can also be imported into Vectorworks Landmark, a BIM software previously discussed. However, adopting this platform would introduce further coordination challenges (IFC import and export, interoperability and data loss across disciplines) that would be difficult to manage within multidisciplinary workflows.

From this perspective, GIS data are available, but the central issue lies in how these datasets can be manipulated, imported and structured once inside the BIM model. Several workflows appear, at first glance, to support GIS-to-Revit integration, yet these processes merely transfer geometry, stripped of all attribute information resulting in points, lines or polygons with no data attached. The core challenge, therefore, is determining how to ensure that attribute information effectively reaches Revit in a usable form.

Figure 2.8 illustrates how GIS-BIM interoperability differs between the Autodesk-Esri collaboration and the Shapefile-based workflow, where methodological gaps remain evident.

Figure 2.8 - Overview of data exchange pathways between GIS and BIM environments: on the left, the Autodesk-Esri collaborative ecosystem; on the right, the workflow based on Shapefiles, highlighting existing methodological gaps

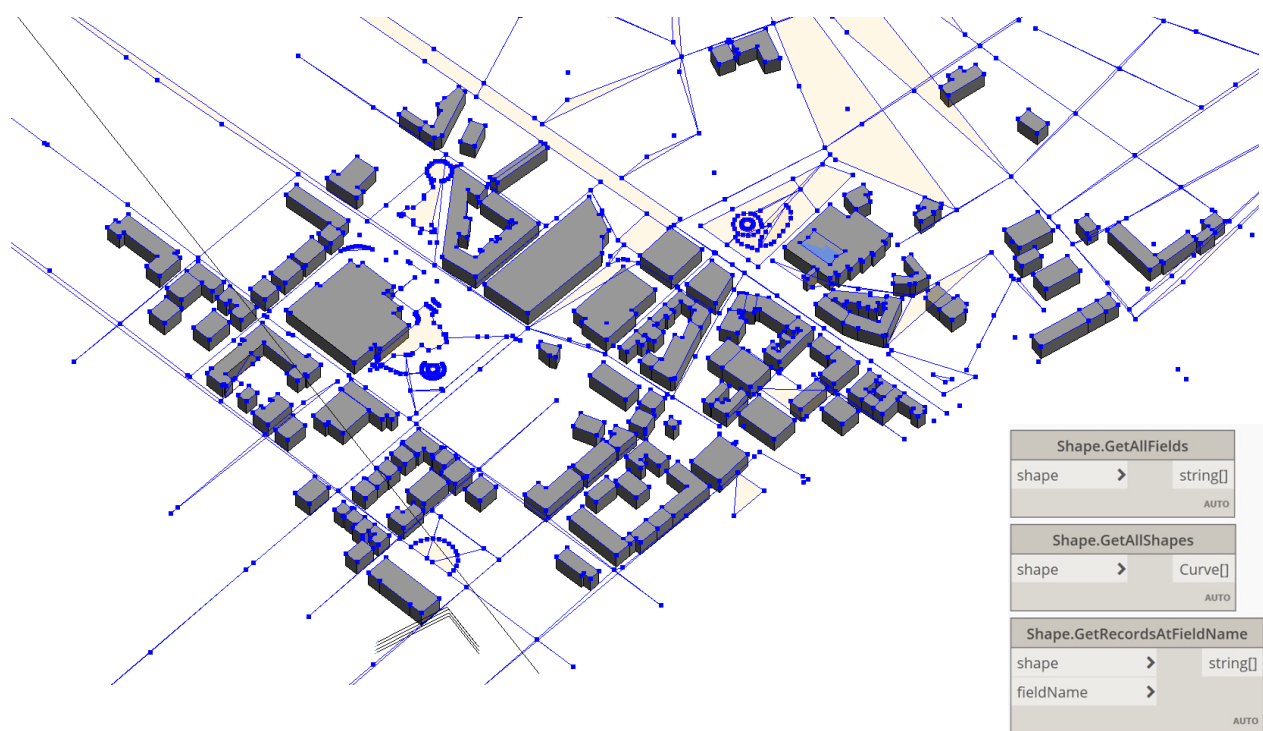


Given the current constraints of commercial software, the only viable path for achieving meaningful GIS-to-BIM data transfer today is through workflow automation and custom scripting. Within Revit's Dynamo environment, the *DynamoGIS* package offers a partial solution, enabling the extraction of both geometry and attribute information directly from GIS datasets (Figure 2.9). This tool can process vector formats, specifically Shapefiles, as well as raster data. It is from this capability that the present research begins to develop an operational workflow for integrating GIS data into BIM models, focusing on how such data can be visualised, structured and translated into meaningful elements within the Revit modelling environment.

In conclusion, the review of current GIS-BIM ecosystems highlights a persistent limitation: although several commercial platforms advertise interoperability, existing workflows rarely enable the transfer of attribute-rich geospatial information into BIM authoring environments. In practice, exchanges remain largely geometry-based. The Autodesk-Esri partnership has improved connectivity at the platform level, yet its operational focus continues to privilege architectural and infrastructural use cases rather than the ecological and multiscale needs of landscape architecture. As a result, landscape models remain weakly integrated within current BIM-GIS toolchains and no existing workflow allows direct ingestion of GIS datasets into Revit while preserving full informational richness.

Against this backdrop, the methodological ambition of this thesis becomes evident: to address the underdeveloped GIS-to-BIM direction by defining a workflow capable of importing, structuring and operationalising geospatial data within BIM environments. By enabling environmental information, such as EO analysis, to inform design decisions directly, rather than merely validating them after the fact, the research contributes to the development of a more integrated, data-informed landscape practice.

Figure 2.9 - Import of GIS vector data as volumetric elements in Revit through DyanamoGIS.. Source: forum.dynamobim.com



2.4 New Potentials: Analogies Between the Digital and the Environment

Having examined the main digital tools used in contemporary landscape practice, including GIS, EO and BIM, this section explores how their combined logics open new conceptual and operational potentials when viewed in parallel with the functioning of environmental systems.

Digital models and environmental systems share a fundamental conceptual parallel: both evolve through continuous flows of information, feedback mechanisms and adaptive processes. Ecological systems adjust dynamically to variations in climate, soil, vegetation or hydrological conditions, while digital and computational systems evolve through updates, parametric rules and real-time data inputs. As several literature highlights (Cao et al., 2021; Nikologianni et al., 2022), the real value of BIM lies not in its use as a static modelling environment, but in its capacity to host and manage information that changes over time. This thesis builds on that analogy. By integrating Earth Observation, GIS and BIM, the goal is to transform the BIM environment from a static container into a dynamic, data-informed landscape model, one that evolves in parallel with the processes occurring on the ground. The idea is not to mimic ecological behaviour literally, but to align the digital workflow with the logic of environmental systems: incremental, responsive and continuously updated.

Environmental systems operate as complex information networks: vegetation indices reveal plant health, hydrological patterns express soil-water dynamics and topographic gradients determine movement and flow. EO and GIS already treat the landscape in these terms, translating ecological processes into structured data layers. GIS literature emphasises that spatial datasets constitute an evolving knowledge base supporting modelling, scenario generation and decision-making across multiple territorial scales (Longley et al., 2015). EO adds temporal depth, revealing seasonal or long-term dynamics such as drought, vegetation stress or soil moisture fluctuations. These systems demonstrate that the environment itself is informational: a dynamic archive of processes that can be measured, classified and projected. For landscape architects, this means that environmental intelligence can become an active agent in design, informing decisions rather than merely validating them after the fact (Ma & Ren, 2017).

Digital models and especially parametric modelling environments such as Revit Autodesk, also operate through relationships, dependencies and feedback loops. Changes in one parameter propagate through the system, reshaping geometry, attributes or classifications, much like ecological dependencies trigger systemic adjustments. Thus, both digital and ecological systems share structural properties: they are dynamic, data-driven and sensitive to change. This similarity provides the conceptual foundation for integrating EO, GIS and BIM into a single methodological framework.

The integration of EO, GIS and BIM redefines the role of BIM in landscape architecture. Instead of being a final-stage representational tool, BIM becomes a living information system that evolves as new environmental data enter the workflow.

GIS contributes spatial intelligence, managing large datasets and interpreting territorial relationships (Schaller et al., 2017). EO contributes temporal intelligence, monitoring vegetation health, soil moisture or microclimatic conditions. BIM contributes design intelligence, materialising information into parametric components governed by rules, constraints and performance criteria.

Zhu & Wu (2022) describe BIM-GIS integration as an information flow system, where datasets acquire meaning as they move through different modelling environments. Within landscape architecture, this flow becomes an ecological-digital feedback loop:

- EO measures environmental processes;
- GIS structures and interprets spatial relationships;
- BIM transforms those inputs into adaptive design models.

In this perspective, landscape modelling becomes a dynamic operation aligned with the changing conditions of the physical environment. The digital landscape is no longer a static representation: it becomes a responsive model capable of integrating long-term monitoring, scenario simulations and data-driven decision-making.

This thesis adopts precisely this view, by connecting environmental intelligence with BIM, it proposes an approach in which digital tools mirror the logic of nature, adaptive, interconnected and continually updated, opening new potentials for resilient, evidence-based and context-responsive landscape design.

3

3 Hybrid Digital Landscape: Towards a New Interoperable Approach

The third chapter develops the core interoperable approach framework of this research by demonstrating how Earth Observation (EO), Geographic Information Systems (GIS) and Building Information Modelling (BIM) can be progressively integrated into a coherent, multiscale and interoperable workflow. Building on the technical foundations outlined in Chapter 2, this chapter illustrates how environmental data are generated, structured, interpreted and finally embedded into parametric BIM environments to support a new form of evidence-informed landscape design. The aim is to transition from raw territorial information to a design-ready digital landscape capable of connecting analytical insight with project decision-making across scales. As clarified in the methodological outline presented in Chapter 1.5, the datasets employed in this phase serve to test the workflow and represent only a limited portion of the broader range of information required in real landscape projects, which may include additional layers such as soil characteristics, groundwater conditions or ecological inventories depending on data availability within the specific context.

The chapter is organised into six sections. Section 3.1 presents the Earth Observation analysis, detailing the selection of the most relevant datasets, the derivation of spectral indices and their relevance for interpreting the environmental dynamics of the case study. Section 3.2 examines the transfer from EO to GIS, explaining the structuring of raster data into a regular grid, the use of zonal statistics and the classification of environmental values to support downstream interoperability. Section 3.3 expands the analytical framework through GIS-based interpolation and the integration of additional thematic layers, such as slope, land use, hydrological risk and planning constraints, supporting a multidimensional reading of the territory. Section 3.4 addresses the crucial passage from GIS to BIM, illustrating both territorial-scale and project-scale workflows, the preparation of BIM parameters and the challenges linked to coordinate systems, data loss and non-dynamic interoperability. Section 3.5 explores the new potentials opened by embedding environmental data into BIM, showing how classified parameters can inform planting strategies, soil restoration, hydrological design and topographic modelling through dedicated Dynamo-based simulations. Section 3.6 concludes the chapter by outlining the methodological transition toward the testing ground applications, demonstrating how the interoperable framework developed in the previous sections constitutes the foundation for the multiscale applications explored in Chapter 4.

To test this workflow, a pilot experiment was carried out on a small portion of the case study area.

These sections demonstrate how the proposed workflow enables a progressive convergence of EO, GIS and BIM into a hybrid digital landscape. Through this integrated structure, environmental data, spatial organisation and design intentions can be connected and negotiated iteratively, supporting evidence-informed decision-making and expanding the operational capabilities of the landscape architect.

3.1 Earth Observation analysis

Earth Observation (EO) represents the first operational step in the proposed methodological workflow, as it provides a consistent and scalable foundation for understanding the environmental and anthropogenic dynamics of the landscape. By offering synoptic coverage and temporal continuity, satellite-based data allow processes such as vegetation dynamics, soil degradation, hydrological change and thermal stress to be captured at multiple scales, from regional to site-specific (Weng, 2012). Within the broader framework of landscape digitalisation, EO delivers quantitative and georeferenced layers that can be systematically integrated into GIS and BIM environments, thus ensuring that subsequent design stages are informed by robust environmental evidence. Rather than serving only as tools for monitoring, EO datasets are here interpreted as generative inputs, capable of supporting both analytical interpretation and creative modelling in the landscape design process (Sudmanns et al., 2023).

In the following paragraphs, Sentinel-2 imagery accessed through Copernicus Browser¹³ are used to derive a set of spectral indices relevant for vegetation, soil, water and moisture monitoring, while additional metrics such as Soil Organic Carbon and Urban Heat Island are computed within Google Earth Engine¹⁴. Together, these datasets provide the baseline environmental layers that will be further structured in GIS and subsequently tested within BIM, forming the foundation of the interoperable workflow.

Data from Copernicus Browser

Earth Observation (EO) data represent the first layer of information in the proposed methodological framework, providing consistent multi-temporal and large-scale insights into environmental processes. Among the most widely used sources is the Copernicus Browser, which grants access to the imagery acquired by the Sentinel constellation. In particular, Sentinel-2 is designed for high-resolution optical monitoring and offers thirteen spectral bands across visible, near-infrared (NIR) and short-wave infrared (SWIR) regions, with spatial resolutions ranging from 10 to 60 meters (European Space Agency - ESA, n.d.; GISGeography, 2023).

Each band has specific analytical potential. The visible spectrum (B02 Blue, B03 Green, B04 Red) enables the creation of true colour composites for natural landscape visualization, while their combinations are essential for vegetation indices such as NDVI and EVI. The red-edge bands (B05, B06, B07) are particularly relevant for detecting subtle variations in chlorophyll content and early vegetation stress, which are crucial for assessing ecological health in contaminated or degraded areas. The NIR bands (B08, B8A) are widely applied in vegetation monitoring, biomass estimation and land cover classification. Finally, the SWIR bands

¹³ For more details about Copernicus Browser see Chapter 2.2.2. Available at <https://browser.dataspace.copernicus.eu>

¹⁴ For more details about Google Earth Engine see Chapter 2.2.2. Available at <https://earthengine.google.com>

(B11, B12) provide information on soil and vegetation moisture, burned areas and geological substrates, factors central to evaluating soil degradation and industrial brownfields such as those present in Piano d’Orta. Atmospheric bands (B01, B09) support correction processes, cloud detection and water vapor mapping, ensuring higher reliability of analyses (European Space Agency - ESA, n.d.).

The complete configuration of Sentinel-2 bands and their main applications is summarized in Table 3.1, which illustrates the connection between raw spectral information and landscape analysis. All the raw data layer have been downloaded in August 2025.

Table 3.1 - Sentinel-2 Raw Bands and Main Applications

Band	Common Name	Central Wavelength (nm)	Spatial Resolution	Main Applications
B01	Coastal aerosol	443 nm	60 m	Atmospheric correction, coastal/aerosol studies.
B02	Blue	490 nm	10 m	Water quality, chlorophyll detection, vegetation indices (EVI, NDWI).
B03	Green	560 nm	10 m	Vegetation vigour, land cover mapping.
B04	Red	665 nm	10 m	Vegetation indices (NDVI), land cover, crop monitoring.
B05	Red Edge 1	705 nm	20 m	Chlorophyll content, early vegetation stress detection.
B06	Red Edge 2	740 nm	20 m	Crop health monitoring, vegetation analysis.
B07	Red Edge 3	783 nm	20 m	Water stress, precision agriculture, species differentiation.
B08	Near Infrared (NIR)	842 nm	10 m	Biomass, NDVI, vegetation mapping.
B8A	Narrow NIR	865 nm	20 m	Advanced vegetation studies, species discrimination.
B09	Water vapour	945 nm	60 m	Atmospheric correction (water vapor).
B11	SWIR 1	1610 nm	20 m	Soil and vegetation moisture, burned area mapping, fire detection.
B12	SWIR 2	2190 nm	20 m	Geology, mineral mapping, urban areas, severe fire/burn analysis.

The primary advantage of Sentinel-2 lies in its 10-20 m resolution, which offers a compromise between territorial-scale coverage and the level of detail required for project-oriented applications. While datasets such as MODIS (250-500 m) remain suitable for global or regional monitoring, Sentinel-2 imagery is particularly effective for multiscale landscape projects, enabling territorial strategies while capturing site-specific details, as required in the case study area illustrated in the next chapter (Drusch et al., 2012).

For this research, a focused set of indices was calculated from the Sentinel-2 raw bands, rather than relying on the visualised layers provided by Copernicus Browser, which only retain RGB values and are therefore unsuitable for GIS-based analysis. This choice ensures analytical robustness and comparability across scales, while maintaining usability within interoperable GIS-BIM workflows. The decision to concentrate on vegetation, soil and moisture indicators reflects the dual nature of the study area, which combines highly anthropized industrial land with sensitive fluvial and ecological systems.

Vegetation indices such as the Normalised Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI) and the Soil Adjusted Vegetation Index (SAVI) were included for their consolidated role in ecological monitoring and assessment (Huete, 1988; Rouse et al., 1973; Sentinel Hub, n.d.). Moisture-related indices, namely the Normalised Difference Moisture Index (NDMI), the Normalised Difference Water Index (NDWI) and the Moisture Stress Index (MSI) are particularly relevant in relation to both agricultural dynamics and the detection of drought and contamination effects on vegetation (Farmonaut, 2024; Gao, 1996; Hunt & Rock, 1989; NASA EarthData, 2025). These indices were included as they provide direct insights into hydrological processes and vegetation stress, which are highly pertinent to the dual fluvial-industrial character of the site. In particular, NDWI allows a clear separation of water bodies from built-up areas and dry surfaces (McFeeters, 1996). The Bare Soil Index (BSI), introduced and applied in several studies for soil degradation and land cover discrimination (Nguyen et al., 2021), provides critical information on degraded and industrial surfaces, supporting the identification of brownfields and compromised soils.

The indices were not only selected for their consolidated role in vegetation, soil and water monitoring, but also for their suitability to be transformed into parameters usable in downstream digital workflows. Their ability to be discretised, classified and associated with spatial units makes them particularly appropriate for transfer into structured environments such as GIS and BIM, ensuring that the environmental evidence can effectively inform subsequent modelling and design steps.

This methodological choice, therefore, prioritises scientific accuracy and design applicability, ensuring that the selected indices can serve as meaningful inputs for ecological assessment and for subsequent integration into landscape-oriented BIM models. Table 3.2 reports the raw bands used, simplified formulas and main applications in landscape and GIS analysis. As an illustrative example, Figure 3.1 shows the raster calculator expression used in QGIS to compute the Enhanced Vegetation Index (EVI), chosen here because of its relatively more complex formulation compared to other indices. Figure 3.2 illustrates an example of the processed raster data, presenting selected EO analyses applied to the portion of the pilot test area.

The indices used in this study represent only an initial subset of the much wider range of environmental data available. They do not capture the full scope of information required for a landscape project, rather, they were intentionally selected to reduce the volume of data to be processed, since the focus of this research is on the methodological approach and workflow rather than on data exhaustiveness.

Table 3.2 - Sentinel-2 Indices Calculated from Raw Bands and Their Applications

Index	Raw Bands Used	Formula (simplified)	Main Application in Landscape / GIS	Reference
NDVI (Normalised Difference Vegetation Index)	B08 (NIR) B04 (Red)	$(B08 - B04) / (B08 + B04)$	Vegetation vigour, biomass monitoring	Rouse et al. (1973)
EVI (Enhanced Vegetation Index)	B08 (NIR) B04 (Red) B02 (Blue)	$2.5 \times (B08 - B04) / (B08 + 6 \times B04 - 7.5 \times B02 + 1)$	Canopy density, effective in dense vegetation	Sentinel Hub (n.d.)
SAVI (Soil Adjusted Vegetation Index)	B08 (NIR) B04 (Red)	$((B08 - B04) / (B08 + B04 + 0.5)) \times 1.5$	Vegetation in high soil-reflectance areas	Huete (1988)
NDMI (Normalised Difference Moisture Index)	B08 (NIR) B11 (SWIR1)	$(B08 - B11) / (B08 + B11)$	Vegetation water content, drought stress	Gao (1996)
NDWI (Normalised Difference Water Index)	B03 (Green) B08 (NIR)	$(B03 - B08) / (B03 + B08)$	Water detection in urban/industrial contexts	McFeeters (1996)
MSI (Moisture Stress Index)	B08 (NIR) B11 (SWIR1)	$B11 / B08$	Vegetation moisture stress, drought detection	Hunt & Rock (1989)
BSI (Bare Soil Index)	B11 (SWIR1) B04 (Red) B08 (NIR) B02 (Blue)	$((B11 + B04) - (B08 + B02)) / ((B11 + B04) + (B08 + B02))$	Detection of bare soil, land degradation and industrial areas	Nguyen et al. (2021)

Note: All indices were recalculated from Sentinel-2 raw bands to ensure quantitative values suitable for GIS analysis. Each index highlights a specific environmental component relevant for the dual fluvial and industrial character of the case study area.

The calculated Sentinel-2 indices (Table 3.2) provide a quantitative, GIS-ready foundation for interpreting vegetation dynamics, soil exposure, moisture conditions and disturbance processes in the study area. Their consistency across space and time ensures comparability and facilitates subsequent integration into interoperable GIS-BIM workflows. However, not all environmental dimensions relevant to landscape interpretation are directly covered by Copernicus datasets. This limitation motivates the inclusion of additional metrics computed through Google Earth Engine (GEE), which extend the analytical scope of EO-derived layers.

Figure 3.1 - Example of the calculation of the EVI index inside the QGIS platform using the raw bands of Copernicus Browser

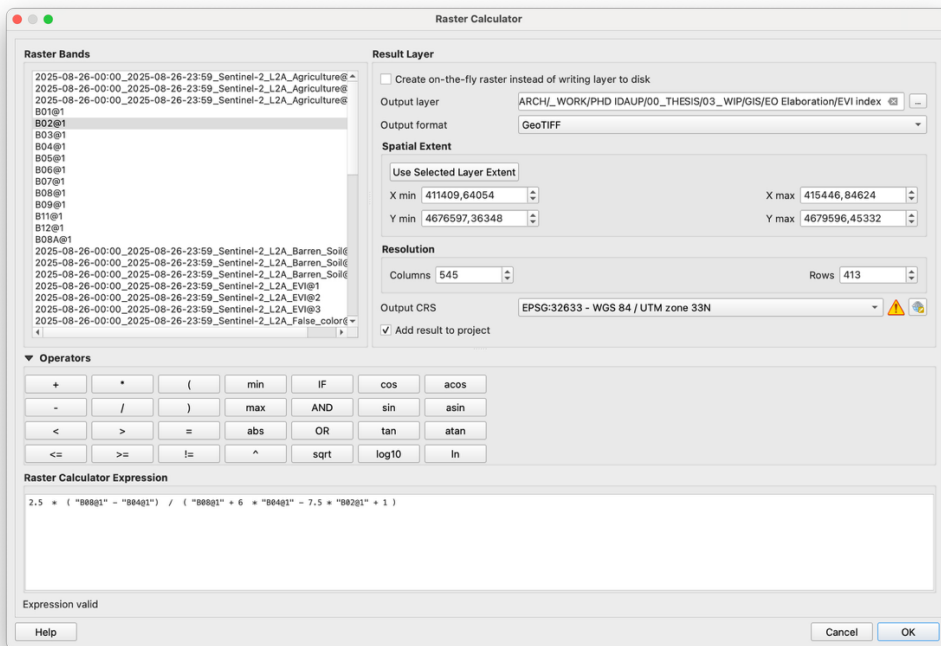
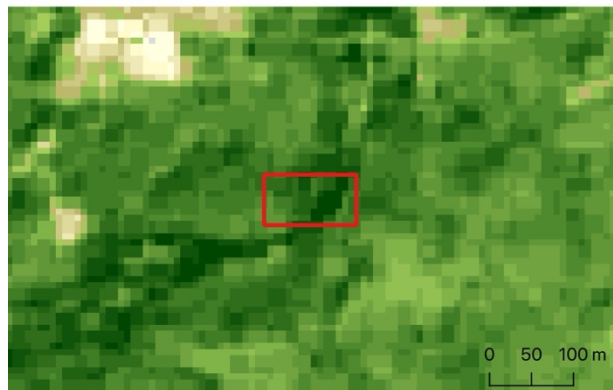
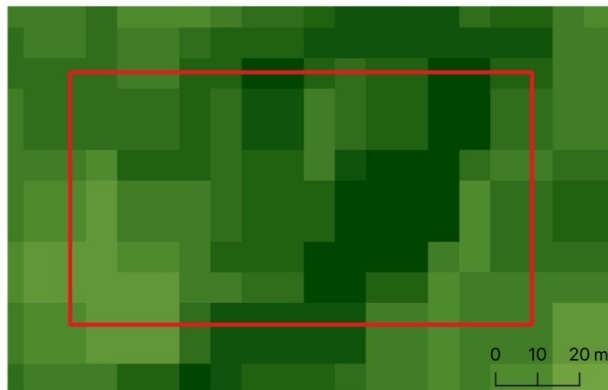


Figure 3.2 - EO-derived spectral indices from Copernicus data: EVI (top) and MSI (bottom) calculated for the study area, presented at full-tile extent (left) and as a zoomed portion of the pilot area (right); the red outline indicates the selected test pilot project area used for subsequent spatial analysis and data integration

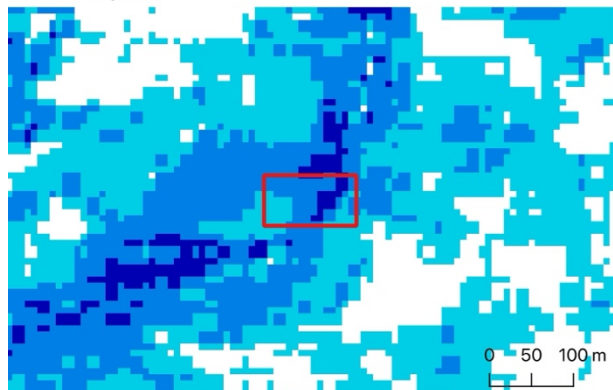
EVI - EO Copernicus



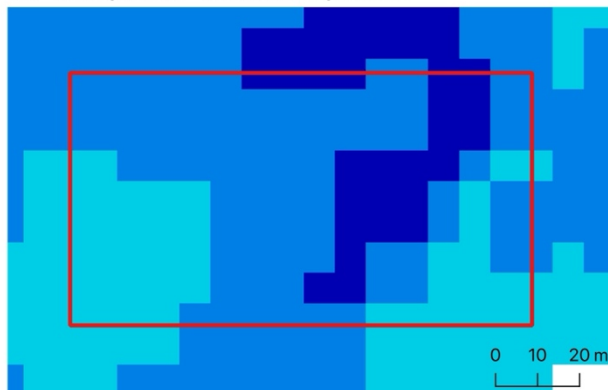
EVI - EO Copernicus - Portion of test pilot area



MSI - EO Copernicus



MSI - EO Copernicus - Portion of test pilot area



Data from Google Earth Engine

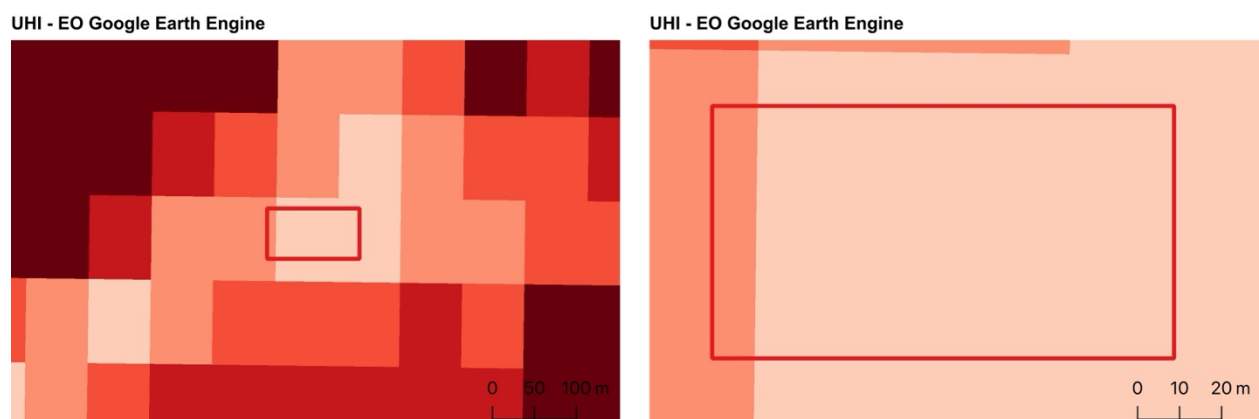
Some environmental datasets relevant to the case study are not directly available through Copernicus Browser or other open-source repositories. For this reason, specific calculations were carried out within Google Earth Engine (GEE), which provides access to an extensive data catalogue and computational tools for deriving additional indicators. Through the web-based platform and the use of concise scripts only datasets with national coverage for Italy and complementary to the Copernicus-derived analyses were selected. In this research, two datasets were particularly important: Soil Organic Carbon (SOC) and Urban Heat Island (UHI) metrics.

The estimation of Soil Organic Carbon was derived from the OpenLandMap Soil Organic Carbon Content database, available in GEE. This dataset provides predictions of SOC content (5*g/kg) based on a global compilation of soil sampling points, covering the period 1950-2017. It offers a spatial resolution of 250 m and an 8-day temporal frequency, ensuring robust spatio-temporal coverage for soil quality assessments (Hengl & Wheeler, 2018). SOC values were extracted and reclassified for the case study area to highlight potential soil degradation and ecological restoration needs.

To evaluate the Urban Heat Island effect, the methodology proposed by Naim & Kafy (2021) was implemented using a GEE script made available by the authors on GitHub (Ahrari, 2024). The analysis was conducted for July and August 2024, corresponding to the hottest months in Italy. Using the ST_10 thermal band from Landsat 8 imagery, land surface temperatures were retrieved and averaged for the study area. Subsequently, the Urban Thermal Field Variance Index (UTFVI) was computed, which is widely recognised as a robust indicator for detecting and quantifying the Surface Urban Heat Island effect. This dataset complements Copernicus-derived indices by adding information on thermal stress, which is particularly relevant in post-industrial and urbanised contexts.

Figure 3.3 shows how the UHI data retrieved from GEE are provided at a 100 × 100 m spatial resolution, making the change in EO data definition clearly visible when compared at different scales.

Figure 3.3 - EO-derived spectral indices from Google Earth Engine data: panels display UHI presented at full-tile extent (left) and as a zoomed portion of the pilot area (right); the red outline indicates the selected test pilot project area used for subsequent spatial analysis and data integration



Thematic Groups for Landscape Analysis

The indices derived from Copernicus Browser Sentinel-2 and the metrics calculated in Google Earth Engine (GEE) were selected not only for their consolidated scientific validity, but also for their direct applicability to the environmental conditions of the case study. This integrated classification combines spectral indices (vegetation, moisture, soil, disturbance) with soil carbon and thermal environment metrics, thereby expanding the analytical scope while maintaining a coherent framework for multiscale decision-making. Such an organisation provides a comprehensive basis to interpret the dual nature of the case study, characterised by both fluvial and post-industrial landscapes. To facilitate their operational use, the indices and metrics have been grouped into broader thematic categories that reflect the main dimensions of landscape analysis. This classification, summarised in Table 3.3, transforms single spectral measurements into integrated layers of knowledge, bridging the technical domain of remote sensing with the interpretative needs of design practice.

Table 3.3 - Macro-Thematic Grouping of Sentinel-2 Indices for Landscape Interpretation

Macro-theme	Indices / Maps Used	Applications
Vegetation & Ecology	NDVI, EVI, SAVI	Monitoring of vegetation vigour, canopy density and ecological restoration processes
Water & Moisture	NDMI, NDWI, MSI	Assessment of vegetation water content, drought stress and water dynamics in riverine/industrial contexts
Soil & Urban Areas	BSI, SOC	Identification of bare soil, contaminated sites and industrial brownfields, baseline soil carbon condition
Disturbance & Risk	UHI	Assessment of thermal stress and urban microclimate risk

This thematic structure ensures that EO data are directly connected to the landscape design process, transforming raw satellite imagery into meaningful layers for GIS integration and subsequent BIM modelling. In this way, indices and metrics move beyond their role as mere technical outputs and become operative tools for the landscape architect. They enable the interpretation of ecological, hydrological, soil and climatic dynamics within a multiscale framework, where quantitative evidence directly informs design reasoning. This transition from measurement to meaning represents the true added value of EO integration in the proposed methodology. The datasets and macro-theme groups used in this thesis represent a selective subset chosen to test the workflow approach. As stated in Methodology Chapter 1.5, they are not intended as the only values through which the landscape can be described or designed, but rather as an initial sample used to demonstrate the applicability of the method.

The following section will illustrate how these EO datasets derived from Copernicus and GEE are structured and organised within GIS, preparing them for interoperability with BIM workflows.

3.2 From EO to GIS: Interoperability and Data Structuring

Once derived from Earth Observation (EO), raw spectral indices require further processing to become operationally useful within a design-oriented digital workflow. Geographic Information Systems (GIS) constitute the pivotal environment for this transformation, as they provide the spatial infrastructure needed to store, visualise, analyse and integrate data layers of heterogeneous origin (Longley et al., 2015).

In the broader digital landscape, GIS can act as the interface between remote sensing and Building Information Modelling (BIM), ensuring that environmental data are not only mapped but also structured into interoperable formats that can support subsequent modelling and design (Billen et al., 2014). Within the scope and objectives of this thesis, this passage through GIS represents a fundamental point of interaction: EO-derived information is transformed from raw spectral values into datasets that are structured, interpretable and transferable. In this sense, GIS does not operate merely as an intermediate step but as the methodological cornerstone that makes possible the effective integration of environmental knowledge into BIM-based landscape design workflows. This interaction is where the digital landscape begins to take shape through data interoperability.

In this section of the interoperable approach, the open-source software QGIS was employed as the primary environment for data integration and processing. QGIS was selected because it is a widely accessible tool, freely available to the scientific and professional community and capable of handling both raster and vector formats. Its interoperability with multiple geospatial standards (e.g., GeoTIFF, Shapefile, GeoPackage) makes it particularly suitable for managing heterogeneous datasets such as those derived from EO and GEE. Furthermore, the availability of advanced geoprocessing algorithms and plug-ins ensures the possibility of transforming raw spectral indices into structured, interpretable and transferable datasets. This combination of accessibility, flexibility and analytical robustness positions QGIS as a pivotal tool in the proposed workflow, enabling the transition from remote sensing outputs to design-oriented geoinformation.

The indices calculated from Copernicus Sentinel-2 imagery and obtained from GEE, i.e. NDVI, EVI, SAVI, NDMI, NDWI, MSI, BSI, SOC, UHI (see previous section within Table 3.2 and Table 3.3), were imported into QGIS as georeferenced TIFF raster files and verified for correct spatial alignment with national coordinate systems and localisation within the study area.

In order to establish a robust framework for the subsequent importation of environmental components into BIM software, it was necessary to define from the outset an appropriate analytical structure for EO data. Two methodological steps were prioritised: (1) the generation of a regular reference grid, discretising the study area into spatial units; (2) the classification of EO-derived indices into thematic classes, which simplifies interpretation and facilitates the transfer of data to design-oriented BIM platform.

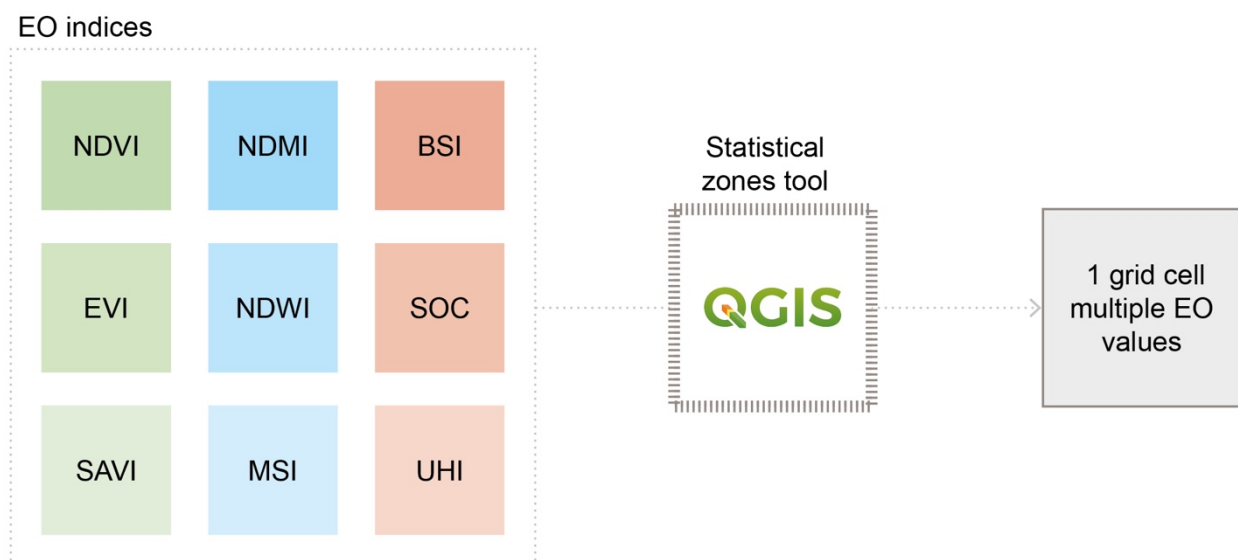
Regular Grid and Zonal Statistics

A regular grid with a 10 × 10 m cell size was generated, corresponding to the maximum spatial resolution of Sentinel-2. This grid functioned as the vector framework onto which EO-derived raster values were discretised for subsequent analysis. For each cell, the “Zonal statistics” algorithm in QGIS was applied. This tool calculates summary statistics (the function “mean” has been utilised) of a raster layer for each polygon unit of an overlapping vector grid. As a result, each grid cell became a container of information, storing multiple environmental attributes extracted from EO indices, as shown in the Figure 3.4.

The adoption of a regular grid and the use of zonal statistics do not simply serve to simplify the numerical values of EO indices. This step establishes the dual structure of the data, geometry and information, which is essential for ensuring that values can later be associated with parametric objects in BIM. By aggregating EO values into discrete cells, the methodology secures both spatial coherence and attribute transferability, thus reducing the risk of data loss when shifting between different modelling environments.

The size of the discretization grid depends both on the input data and on the scale of the project under development. For instance, in the case of a territorial or municipal-scale project, the grid may consist of larger cells. Conversely, for a detailed project concerning a specific area, the grid may employ smaller cells in order to allow a finer differentiation of information.

Figure 3.4 - Workflow for aggregating EO indices using QGIS: Earth Observation indices (NDVI, EVI, SAVI, NDMI, NDWI, MSI, BSI, SOC and UHI) processed through the Statistical Zones tool in QGIS to assign multiple EO values to a single grid cell



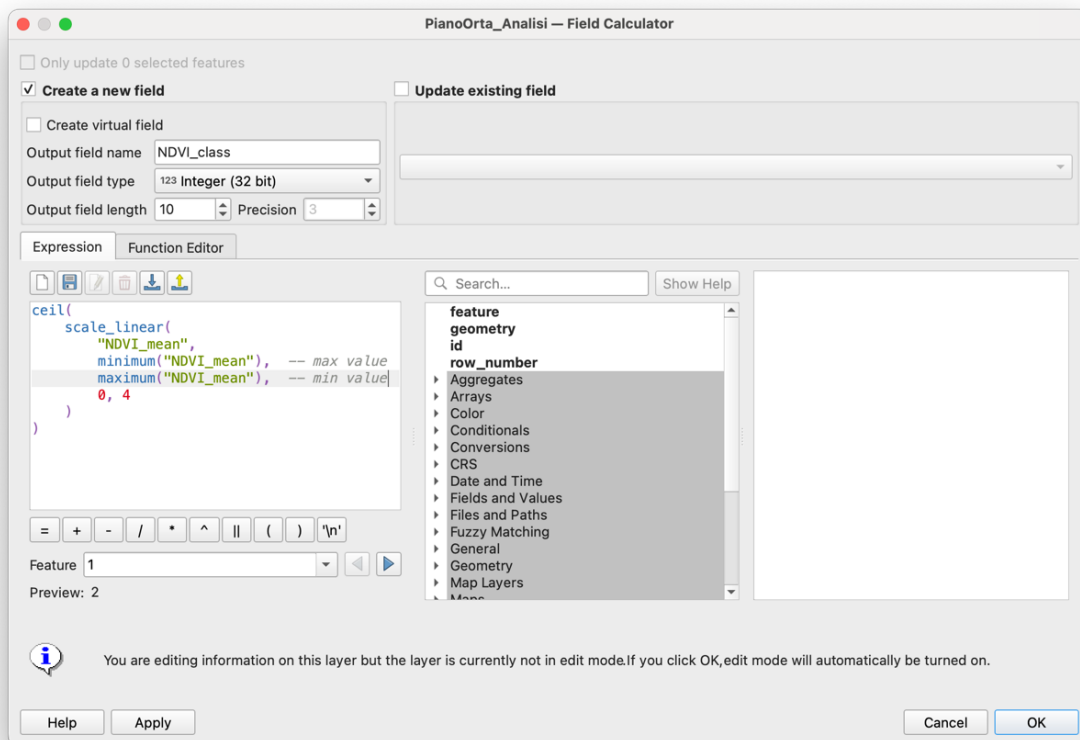
Classification of values

To enhance interpretability and facilitate future BIM integration, raw numerical values were reclassified into classes. This step reduces data complexity, provides a more legible output for non-specialist users and enables categorical attributes to be directly linked to BIM parametric objects. The reclassification into four classes follows established practice in remote sensing and landscape analysis, allowing continuous spectral values to be transformed into discrete levels of environmental meaning (Congalton & Green, 2019).

This step is crucial not only for simplifying data interpretation but also for ensuring compatibility with BIM parametric environments, where discrete attributes can be directly assigned to design elements.

To ensure comparability across indices, all values were normalised into a four-class system, where Class 1 always represents the least favourable condition (e.g., vegetation stress in NDVI, low soil fertility in SOC, high degradation in BSI/UHI) and Class 4 the most favourable one (e.g., dense vegetation, high fertile soils, comfortable microclimate). For indices where higher raw values indicate stress or degradation, such as MSI, BSI and UHI, the classification thresholds were inverted, so that the highest classes correspond to positive conditions. This standardisation enables different environmental indicators to be interpreted within a coherent framework and ensures that the resulting classes can be seamlessly associated with BIM parametric attributes. Figure 3.5 shows an example of the formulas used for the classification in the grid layer in QGIS.

Figure 3.5 - Example of the formula used to attribute 4 different classes to the NDVI values



The 4 classes classification system adopted (very low, low-moderate, moderate-high and high) provides a consistent framework across all indices, facilitating comparative analysis and supporting multiscale landscape decision-making, as illustrated in Table 3.4. Unless otherwise specified, references to “High” (Class 4) or “Low” (Class 1) values throughout this thesis correspond to the class-based system presented in the table, rather than to the raw numerical values of each index. This avoids ambiguity where higher raw values signify unfavourable conditions.

Table 3.4 - Classification of EO- and GEE-derived indices into four classes

Index	Value range	Class 1 (Very Low)	Class 2 (Low-Moderate)	Class 3 (Moderate-High)	Class 4 (High)	Interpretation in landscape analysis
NDVI	-1 to +1	<0.2 = Very low vigour	0.2-0.4 = Sparse	0.4-0.6 = Moderate	>0.6 = Dense vegetation	Vegetation vigour and biomass
EVI	-1 to +1	<0.2 = Very low	0.2-0.4 = Low	0.4-0.6 = Moderate	>0.6 = High	Canopy density, vegetation monitoring
SAVI	-1 to +1	<0.2 = Very low	0.2-0.4 = Low	0.4-0.6 = Moderate	>0.6 = High	Vegetation in exposed soil areas
NDMI	-1 to +1	<0 = Very dry	0-0.2 = Dry	0.2-0.4 = Moderate	>0.4 = High moisture	Vegetation water content, drought stress
NDWI	-1 to +1	<0 = Non-water	0-0.2 = Sparse presence	0.2-0.4 = Moderate	>0.4 = High water	Surface water detection in fluvial/industrial areas
MSI	0 to ~2	>1.50 = Very high stress	1.20-1.50 = High stress	1.00-1.20 = Moderate stress	<1.00 = Low stress	Vegetation stress and water availability
BSI	-1 to +1	>0.4 = High bare/industrial soil	0.2-0.4 = Moderate	0-0.2 = Slight bare soil	<0 = Stable soil/vegetation	Soil degradation, industrial land
SOC	0-50 g/kg	<10 = Very low	10-20 = Low	20-30 = Moderate	>30 = High	Soil fertility and ecological quality
UHI	0-1	>0.6 = Very high stress	0.4-0.6 = High stress	0.2-0.4 = Moderate stress	<0.2 = Comfortable	Urban microclimate risk

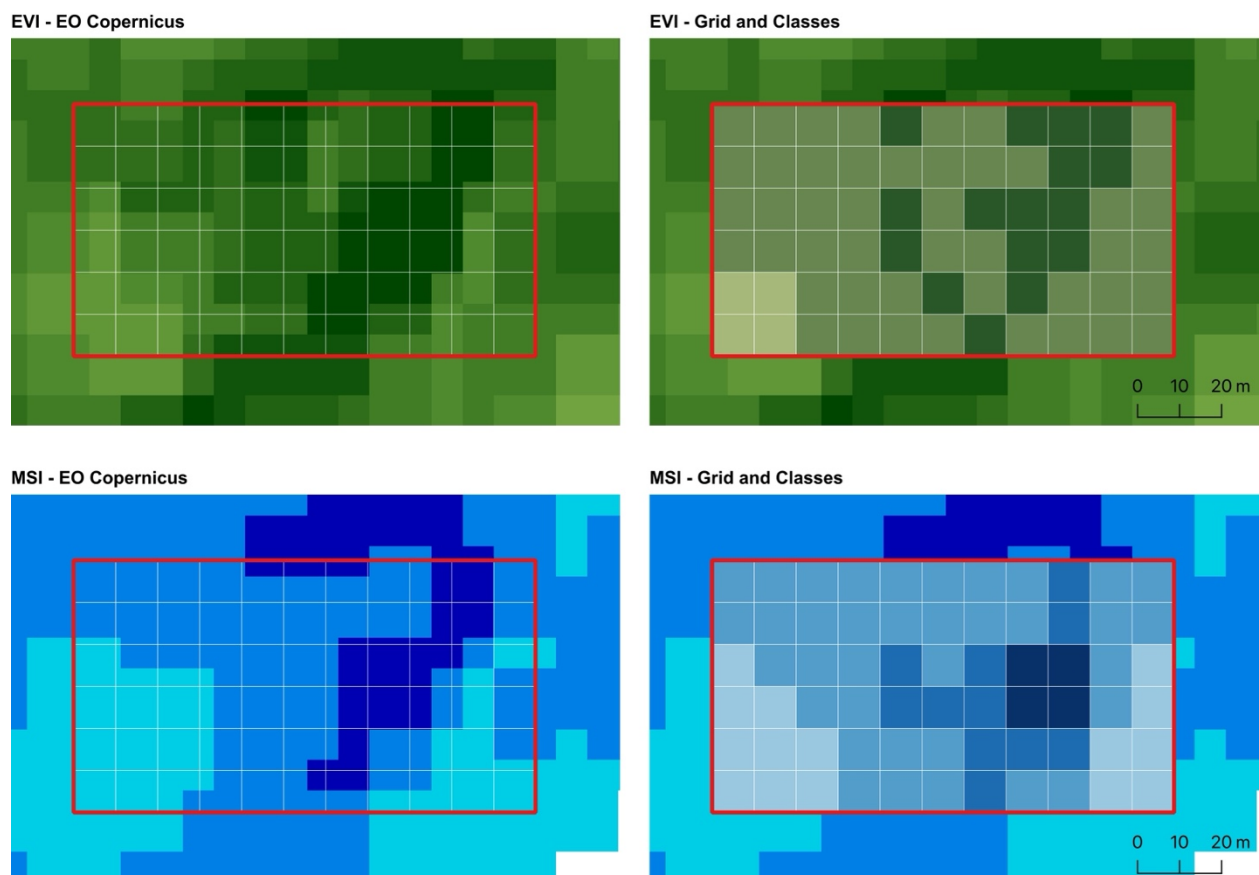
The combination of these two steps results in a structured dataset where each spatial unit (grid cell) holds aggregated and classified information on vegetation, soil, moisture and urban context analysis. This framework ensures that EO data are not only stored in a GIS but also prepared in a form compatible with BIM, thereby strengthening interoperability and enabling environmental parameters to inform landscape design decisions. Figure 3.6 shows how the EVI and MSI indices are converted into a 10 × 10 m grid, allowing EO values to be discretised into classes for use in the downstream BIM workflow.

The grid-based aggregation and four-class reclassification translate complex spectral signals into compact, design-ready knowledge units. This transformation is essential for bridging the gap between environmental monitoring and design practice, providing the landscape architect with interpretable and design-ready information. As noted by Jensen (2013), the value of remote sensing lies not only in the acquisition of raw imagery but in its interpretation and transformation into meaningful indicators, while Goodchild (2007) stresses the role of GIS in structuring such information into knowledge frameworks.

It is important to emphasise that the classification thresholds adopted in this workflow the EO indices are calibrated and classified to the environmental and bioclimatic characteristics of the European context. These thresholds cannot be considered universal, as vegetation reflectance and soil-plant interactions vary across climatic zones, species compositions and seasonal dynamics (Delegido et al., 2011; Pettorelli et al., 2005). Therefore, any application in different geographic contexts should be supported by a dedicated recalibration of value ranges to ensure reliable interpretation of environmental conditions.

Building on this foundation, the next section addresses how these classified datasets are further interpolated, analysed and critically interpreted within GIS, thereby moving from quantitative indicators to qualitative knowledge that can directly inform landscape design decisions.

Figure 3.6 - EO grid classification applied to EVI and MSI datasets: EVI (top) and MSI (bottom) indices with their corresponding grid-based classifications; the red outline indicates the selected test pilot project area used for subsequent spatial analysis and data integration



3.3 GIS as Interpolation and Interpretation of Multisource Information

While Earth Observation (EO) indices constitute the primary layer of environmental information, the GIS environment allows these data to be enriched, combined and critically interpreted with additional sources. In this sense, GIS acts not only as a technical platform for data management, but as an interpretative interface where heterogeneous datasets are structured into meaningful knowledge for the landscape architect (Goodchild, 2007). The grid framework developed in GIS is not conceived as a static repository of EO outputs, but as a dynamic and expandable structure capable of incorporating multiple layers of information. While the initial input is represented by EO-derived indices, the strength of this framework lies in its ability to be progressively enriched with additional datasets that are strategic and necessary for landscape interpretation and design.

At the technical level, GIS enables interpolation and data transformation between different formats, ensuring that raster-based indices and vector-based constraints can be analysed within the same reference system. These operations are essential to guarantee analytical consistency across scales and to make EO-derived metrics directly comparable with planning and regulatory data. From these processes, thematic maps can be derived, expanding the analytical spectrum of the grid. Layers such as slope, aspect, hydraulic risk and vegetation cover become indispensable to evaluate the environmental and morphological constraints of the site. These outputs do not simply enrich the database but provide the foundation for a multidimensional understanding of the territory, where physical, ecological and anthropogenic factors are considered together (Burrough & McDonnell, 1998). The result of the GIS step not only expand the analytical base but also create the preconditions for integrating regulatory and design-driven requirements into the workflow of the thesis.

This distinction highlights two complementary phases in the proposed workflow:

- a technical phase, centred on spatial analysis, interpolation and the production of thematic layers;
- an interpretative phase, where numerical values and cartographic outputs are critically assessed and translated into knowledge that can inform landscape design.

In this perspective, GIS is not limited to a role of technical infrastructure but becomes a tool for critical territorial reading, enabling the landscape architect to connect quantitative metrics with qualitative understanding of landscape processes (Cassatella & Peano, 2011).

Beyond EO products, a wide set of non-EO datasets can be integrated within the GIS framework, further enhancing the richness of the spatial model. As represented in Figure 3.7 the categories of data integrated in GIS to complement EO-derived information are in this way ready for the transfer to the Model environment.

The categories can be grouped into the following areas, which may include:

- Urban planning instruments (e.g., zoning plans, land use regulations, protected areas);

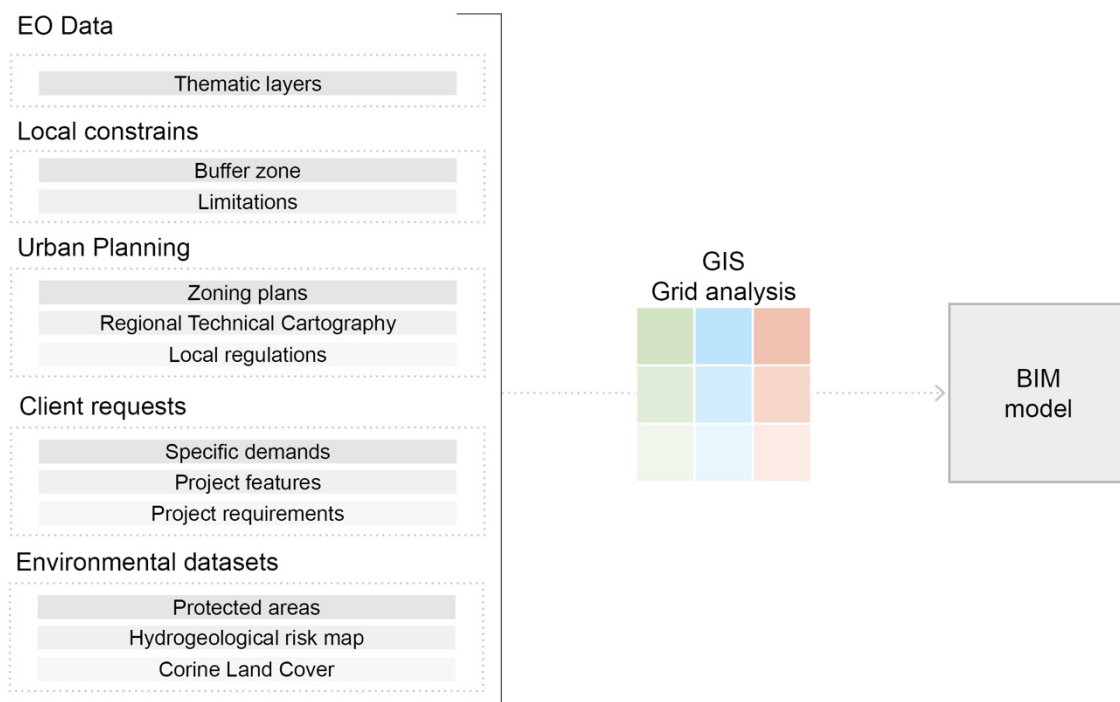
- Environmental databases such as Corine Land Cover, Natura 2000 networks, or hydrogeological risk maps;
- Local-scale data such as buffer zones, easements and infrastructural constraints;
- Client-specific requirements or project-based conditions (e.g., accessibility corridors, landscape restrictions).

The enrichment of the grid with non-EO datasets such as slope, exposure, land use or hydraulic risk maps further consolidates its role as a multidimensional framework. These additional inputs allow the grid to capture not only environmental dynamics but also planning constraints and regulatory requirements, which are equally relevant for landscape design. In this way, the GIS environment becomes the keystone where quantitative EO data, environmental variables and normative conditions are harmonised into a single structure prepared for BIM interoperability.

By allowing the integration of such a wide range of information, GIS becomes a comprehensive repository of territorial knowledge. The structured grid developed in the previous step is therefore not limited to EO indices but can accommodate any type of spatial data, ensuring multiscale and multi-source coherence.

This capacity to organise and harmonise environmental, planning and design-related data marks GIS as the true cornerstone of the methodology. It enables the enrichment of the analytical framework while keeping datasets compatible with further applications. This methodological phase sets the stage for the following step, where the structured and harmonised GIS datasets are prepared for interoperability with BIM, ensuring that environmental knowledge can be transferred into a highly standardised modelling environment.

Figure 3.7 - Integration of multi-source datasets through GIS grid analysis for BIM workflows



3.4 From GIS to BIM: Interoperability Challenges and Opportunities

The transition from Geographic Information Systems (GIS) to Building Information Modelling (BIM) represents the central point of the proposed workflow. While GIS provides the analytical environment for structuring and classifying Earth Observation (EO) and complementary datasets, BIM constitutes the design-oriented platform where such information must be translated into parametric attributes and geometries. This transition is complex and requires a deliberate methodological approach, as the two environments were conceived for different purposes: GIS for territorial analysis and cartographic representation, BIM for object-based modelling and construction documentation (Noardo et al., 2020; Barazzetti, 2016). Despite their differences, GIS and BIM share several common features. Both operate on spatial data, record and manage information about space and enable advanced analysis and spatial visualisation. At the same time, their divergences are significant: BIM typically applies local coordinate systems, while GIS makes use of global reference systems. Furthermore, data presentation in BIM follows architectural and construction norms, while GIS adopts the conventions of cartographic representation (Borkowski & Wyszomirski, 2021).

These commonalities and differences directly affect interoperability. Whereas the shared reliance on spatial data and analytical mechanisms suggests potential for integration, the divergence in data models, coordinate systems and representational standards generates critical barriers. As discussed in the Chapter 2.3, most existing research has focused on interoperability in the opposite direction, from BIM to GIS, mainly to support facility and asset management during the operational phase of projects. The use of GIS-to-BIM workflows for design purposes, however, remains underdeveloped and constitutes a crucial research frontier for landscape-oriented applications (Amirebrahimi et al., 2016; Garramone et al., 2020).

In the context of landscape architecture, the problem becomes even more complex, as the discipline inherently spans across different scales. For this reason, the workflow here proposed experiments with GIS-to-BIM interoperability both at the territorial scale and at the local/project scale, testing both the softwares Autodesk InfraWorks and Autodesk Revit combined with Dynamo. The two approaches are complementary: the first provides a broad territorial framework, the second allows detailed integration of environmental attributes into design-oriented BIM objects.

Before addressing these two scales, it is useful to provide an overview of the different datasets that constitute the foundation of the GIS-to-BIM workflow. Table 3.5 summarises the sources, their processing in the GIS environment and their relevance once transferred into BIM. This framework shows how environmental, topographic, planning and project-specific data can be systematically prepared for parametric use in BIM, thereby establishing the basis for the two subsequent interoperability experiments.

Table 3.5 - Datasets into the GIS framework with BIM relevance

Data source / Layer	Example indices or datasets	GIS processing / Use	Relevance for BIM
Earth Observation (EO)	NDVI, EVI, SAVI, NDMI, NDWI, Moisture Stress, BSI	Raster-to-grid aggregation, classification into 4 classes, thematic mapping	Provides parametric attributes for vegetation health, soil condition and water presence to be attached to BIM elements (e.g., floors, surfaces, site objects)
Topographic data	Slope, aspect, elevation models (DEM/DTM)	Interpolation, raster analysis, vector contour extraction	Controls terrain modelling in BIM (toposurface, grading objects) and informs drainage and accessibility design
Hydrological data	Flood risk zones, river buffers, aquifer recharge areas	Buffering, overlay, hazard mapping	Defines constraint zones and informs BIM site modelling with hydraulic and safety restrictions
Land use / planning	Corine Land Cover, zoning maps, urban planning instruments	Vector reclassification, overlay with EO indices	Translated into BIM site layers and land-use constraints for design compliance
Legal/administrative constraints	Buffer zones (roads, railways, cemeteries, heritage sites)	Distance analysis, overlay operations	Imported into BIM as exclusion or restriction zones for design compliance
Client / project-specific requirements	Project boundaries, functional areas, requested buffer zones, specific requirements	Digitisation, attribute assignment	Directly imported into BIM site plans and used as constraints for scenario modelling

Taken together, the datasets demonstrate how the GIS environment operates as the pivotal interface through which heterogeneous information is translated into structured and interoperable inputs for BIM. Once classified, normalised and organised within a multi-scale grid, these layers acquire a level of abstraction that makes them both comparable and design-ready, enabling their association with BIM elements through shared parameters. This preparatory phase therefore marks the transition from data processing to data integration: environmental evidence is no longer confined to analytical representation but becomes embedded within the modelling environment, where it can inform design reasoning.

In this framework, the next two sections illustrate how these GIS-derived datasets can be transferred into BIM environments at different levels of application.

3.4.1 Territorial Scale

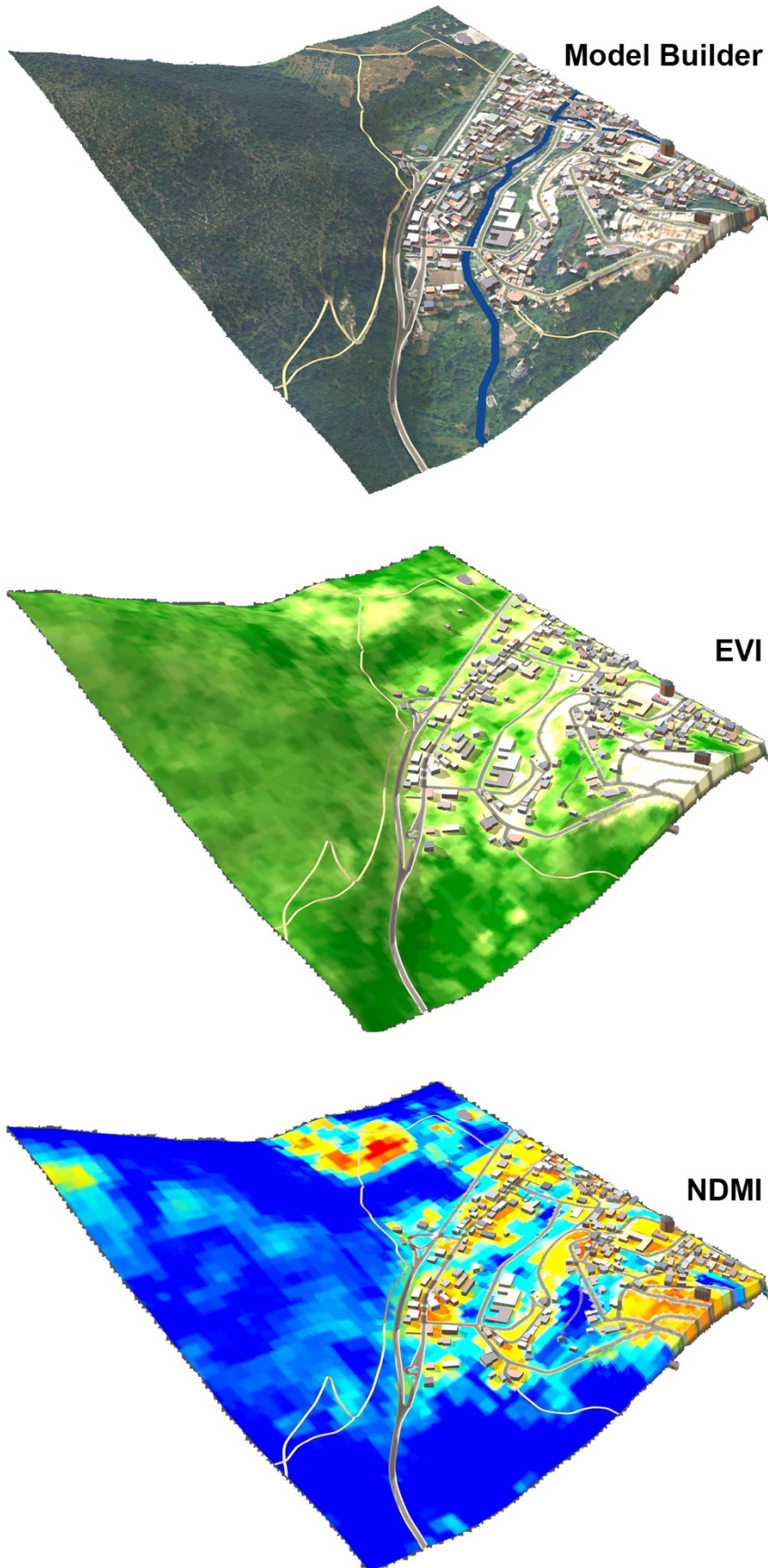
At the territorial scale, GIS-to-BIM interoperability was tested using Autodesk InfraWorks, a platform designed for integrating geospatial datasets within concept-level infrastructural and territorial modelling. One of the main advantages of InfraWorks lies in its native ability to import shapefiles, GeoTIFFs and elevation models (DEM/DTM), allowing environmental and planning information to be displayed directly within a three-dimensional contextual model (Genovese et al., 2023). In this simulation, a small portion of the study area was generated through ModelBuilder, which automatically reconstructed a digital terrain based on existing elevation sources and contextual datasets. Onto this surface, EO-derived raster indices and complementary GIS layers were imported and overlaid, enabling their spatial distribution to be explored within a realistic topographic framework. Figure 3.8 shows the EO indices (EVI and NDMI) overlaid onto a ModelBuilder terrain model, allowing environmental conditions to be visualised directly within a spatial context.

This preliminary test confirms that InfraWorks can effectively support territorial-scale interpretation, providing an immediate understanding of how environmental patterns, such as moisture variability, vegetation vigour or heat exposure, relate to landform and morphological structure. The platform therefore proves useful for communicating geospatial evidence in an intuitive manner and for supporting early-stage strategic reasoning. However, the workflow remains limited to visual superimposition: although the datasets can be displayed on the terrain, no parametric relationship is established between the GIS attributes and the modelled components. Consequently, EO-GIS information cannot be queried, extracted or operationalised for design purposes, nor can it influence the behaviour or properties of model elements.

These limitations are particularly relevant in the context of landscape architecture, where the objective is not only to visualise geospatial conditions but to translate them into design-relevant parameters. While InfraWorks is effective for broad-scale visualisation and decision support, it does not provide the object-based, attribute-driven control required for project-scale modelling within a BIM environment (Hijazi & Donaubaer, 2017). In practice, the platform functions as a transitional and exploratory environment, suitable for preliminary contextual framing and validation of environmental datasets, but its outputs are not directly usable for detailed or parametric design applications.

For this reason, territorial-scale GIS-to-BIM interoperability should be understood as a visual rather than operative integration stage. To achieve a meaningful connection, where environmental attributes become embedded parameters associated with design objects, the workflow must transition to Autodesk Revit combined with Dynamo, which enables the creation, mapping and manipulation of shared attributes and supports rule-based interpretation at the project scale (Ma et al., 2021).

Figure 3.8 - Visual integration of EO indices within InfraWorks: the base Model Builder output (top), the EVI-derived vegetation layer (centre) and the NDMI moisture index (bottom)



3.4.2 Local Project Scale

At the local project scale, GIS-to-BIM interoperability requires more precise and detailed translation of data. Following the preparation of the shapefile of the grid with all the correct information, developed in the previous sections, the crucial step is to set up a BIM template capable of receiving both GIS geometries and attributes in a consistent and accurate way. As anticipated in the Chapter 2 in the sections “An Overview of Current Digital Landscape Tools”, today the BIM domain is largely dominated by Autodesk Revit, which is widely used in architectural and engineering practice. This justifies its adoption in this methodological workflow and approach as the BIM environment for landscape modelling and design. The use of Revit ensures the production of a BIM model that can communicate and collaborate across disciplines, preventing landscape architecture from becoming an isolated, highly specialised domain. A key feature distinguishing Revit from other BIM software is the integration of Dynamo, a visual programming interface that allows customised workflows and facilitates connections with external files, while supporting the exploration of alternative design options. A comprehensive description of all Dynamo nodes, scripts and parameter structures is not included within this chapter. A dedicated appendix at the end of the Thesis (Appendix I - Dynamo Scripts, Packages and Python codes) has been prepared to provide the full documentation, including the complete node lists, script logic and detailed explanations of each computational step. Within this chapter, only representative screenshots and the overarching reasoning behind the workflow are presented, in order to maintain clarity and focus on the methodological framework rather than its technical implementation.

The fundamental steps to achieve effective interoperability are linked to:

- the validity of the BIM model and its preparation to receive GIS information;
- the creation of a workflow capable of transferring both the geometric component and the corresponding attribute information to Revit elements (with the system family *Floors* used as a reference);
- the development of a workflow that allows new data or updates of already imported data to be transferred into the BIM model after the creation of elements, ensuring a complete exchange of information in the future.

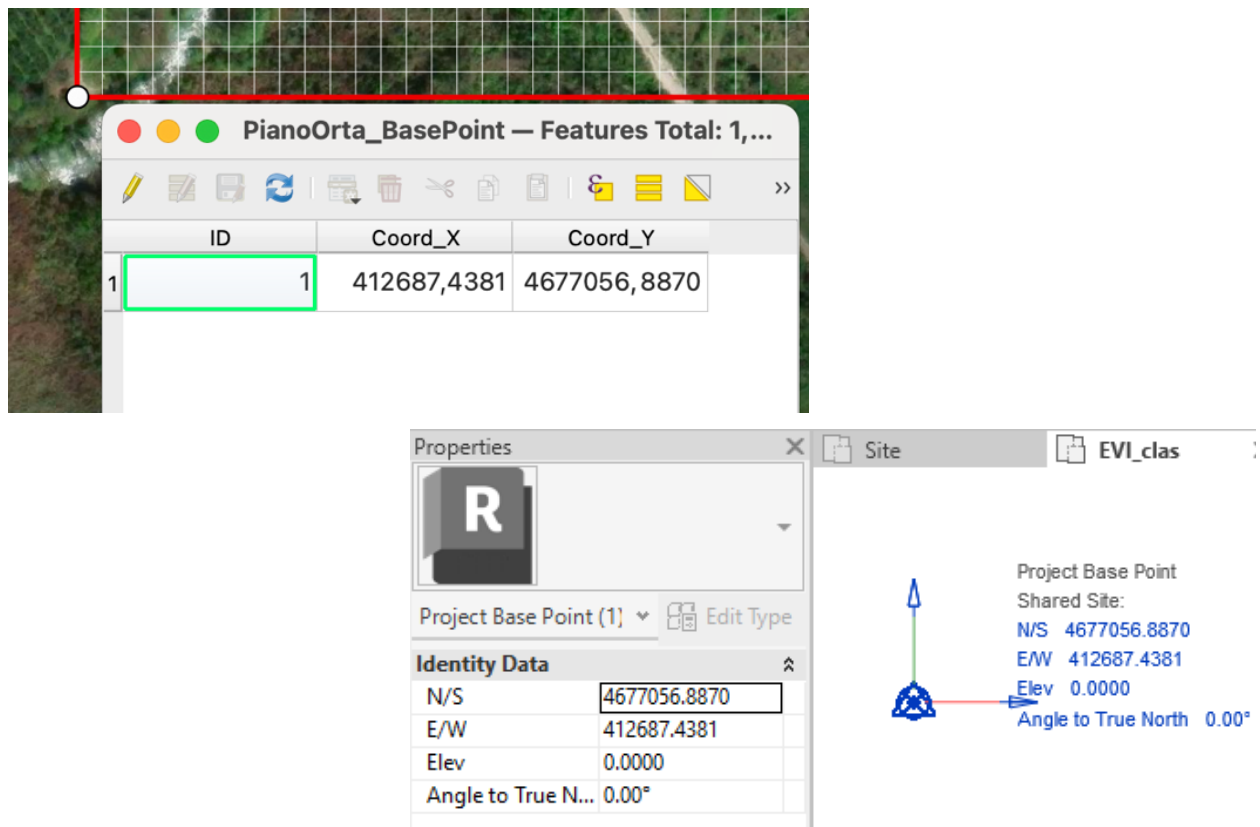
A first implementation of this workflow was tested on a small portion of the case study area, as showed in the EO-GIS preparation analysis grid, allowing the methodology to be validated under controlled conditions before being extended to broader spatial contexts. This preliminary application makes it possible to verify the accuracy of data transfer, assess the behaviour of BIM elements enriched with GIS attributes and define the parametric structure prior to scaling up. The subsequent chapter (Chapter 4) applies the same interoperability framework across the three operational scales, Micro, Medium and Macro, demonstrating how the approach can evolve from detailed project modelling to territorial interpretation.

3.4.2.1 BIM Model Preparation

A crucial aspect for successful GIS-BIM interoperability is the management of coordinates and project origin. Indeed, the shapefile has its own projected coordinate system, which must be correctly aligned with the Revit model. Before any operation, plan and 3D views must be set up. After establishing the units of measurement in metres, the Project Base Point and Survey Point must be positioned to coincide with the coordinates derived from the GIS shapefile. By identifying a reference base point in QGIS, the corresponding X and Y values are extracted and subsequently assigned to Revit's Project Base Point, as illustrated in Figure 3.9.

In the import view, annotations such as Elevations and Levels should be temporarily hidden to avoid confusion and to allow the shapefile geometry to be displayed correctly. Otherwise, the geometry might appear outside the visible extents of the Revit project if the origin points are not properly matched.

Figure 3.9 - Base Point Coordinates: from QGIS (top) into Revit Project Base Point (bottom)



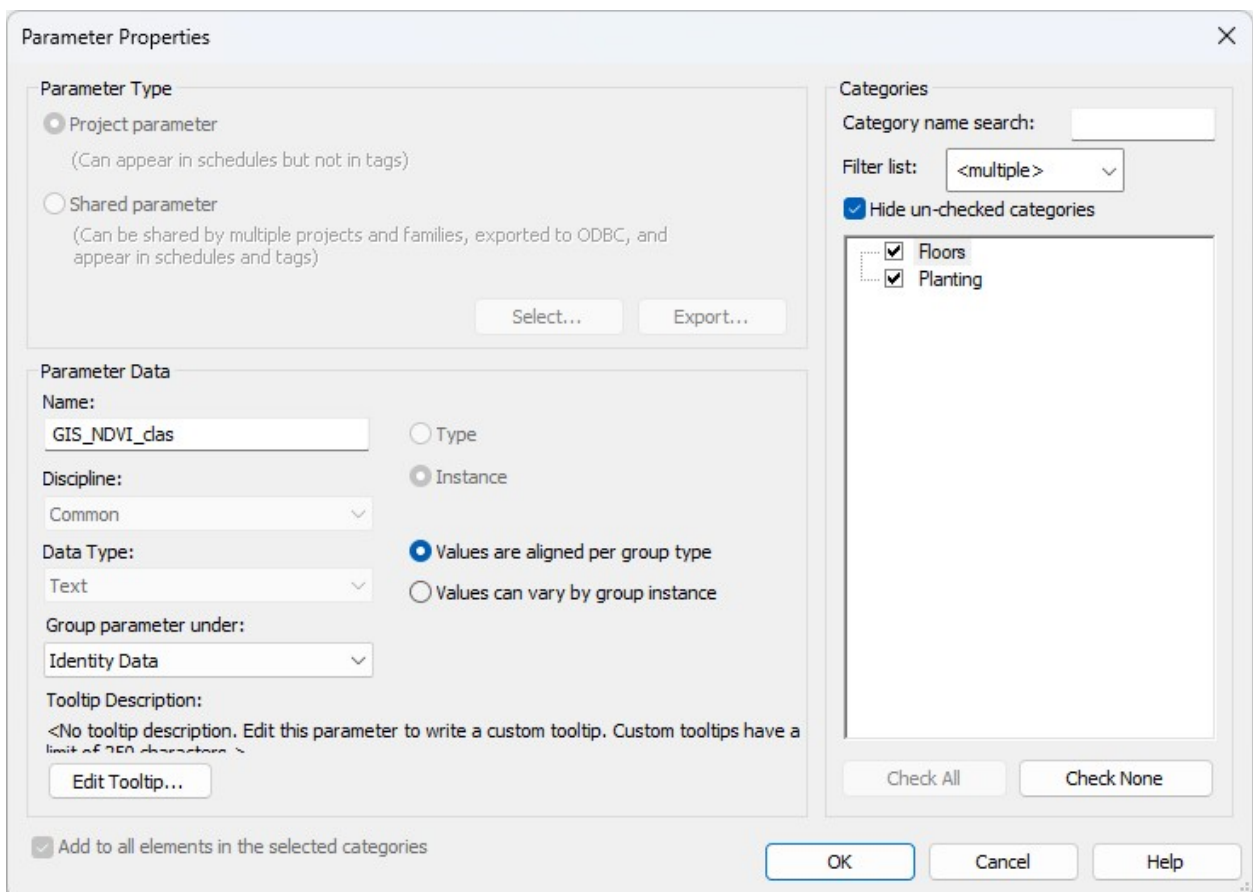
The information within BIM elements is stored in parameters, which must be defined in advance to receive GIS attributes. New Project Parameters should therefore be created and assigned to the relevant BIM categories. In this research, the focus is on system families (Floors) and loadable families (Planting), as these elements are best suited to represent landscape features such as soil surfaces and trees.

The new project parameters must be assigned to these two categories, since it is precisely between Floors and Planting that the exchange of imported GIS information will take place.

To guarantee a seamless connection during the data transfer process, the names of the parameters were set to coincide exactly with the field names of the GIS attribute table. Since each GIS-derived feature can carry a specific value, the parameters were defined as instance parameters, allowing values to differ for every single element within the model. Although many of the indices are originally expressed as numerical values, the parameters were generally stored as *Text* type, a choice that facilitates their reading and manipulation within Dynamo.

For clarity and consistency, all parameters created for GIS-BIM interoperability were grouped under the category *Identity Data*, thereby ensuring their immediate recognition and interpretation inside the Revit environment. Figure 3.10 illustrates the creation of a Project Parameter within the Revit environment, together with the configuration of its main characteristics.

Figure 3.10 - Example of creation of Project Parameter inside the Revit Model ready for the importation of GIS data



These parameters are fundamental not only for transferring GIS attributes to BIM elements but also for setting up view filters, since only project parameters can be used as rule definitions within filter configurations. The list of Project Parameter and their characteristics is listed in Table 3.6.

Table 3.6 - Mapping of GIS Parameters into BIM Project Parameters

GIS Attribute (Field Name)	Revit Project Parameter	Data Type (Instance)	Group Parameter in Revit	Description / Role in BIM Model
ID	GIS_ID	Text (instance)	Identity Data	Unique identifier for linking GIS features with BIM elements
NDVI_clas	GIS_NDVI_clas	Text (instance)	Identity Data	Vegetation vigour class assigned to floor/planting elements
EVI_clas	GIS_EVI_clas	Text (instance)	Identity Data	Canopy density and vegetation monitoring class
SAVI_clas	GIS_SAVI_clas	Text (instance)	Identity Data	Vegetation class adjusted for soil reflectance
NDMI_clas	GIS_NDMI_clas	Text (instance)	Identity Data	Vegetation water content / drought stress class
NDWI_clas	GIS_NDWI_clas	Text (instance)	Identity Data	Water presence class in fluvial/industrial areas
MSI_clas	GIS_MSI_clas	Text (instance)	Identity Data	Moisture stress class (drought and stress detection)
BSI_clas	GIS_BSI_clas	Text (instance)	Identity Data	Bare/industrial soil condition class
SOC_clas	GIS_SOC_clas	Text (instance)	Identity Data	Soil organic carbon fertility class
UHI_clas	GIS_UHI_clas	Text (instance)	Identity Data	Urban Heat Island stress class

As already clarified in the methodological framework outlined in the previous section 1.5, the parameters included at this stage derive from a selection based on data availability and accessibility. Therefore, they do not represent the full spectrum of information that could be required in a comprehensive landscape project. Additional parameters can be incorporated as the workflow evolves, either to expand the environmental datasets or to introduce new project-relevant attributes, without altering the structure of the method. The objective is not to provide a fixed or exhaustive parameter set, but to establish a scalable framework through which further data can be progressively integrated. In future implementations, the same categories of information will be maintained to ensure consistency across projects, while allowing the model to accommodate higher levels of detail as new datasets become available. This approach reinforces the role of the workflow as a flexible solution aimed at overcoming current limitations in GIS-BIM interoperability rather than defining a closed data configuration.

3.4.2.2 GIS data into BIM: Revit Floors by Geometry and Information

Since the data and information in this workflow are directly related to the landscape, the chosen BIM elements must be able to reproduce surfaces such as soil and water. Within Revit, the *Floor* system family was identified as the most appropriate element for hosting GIS-derived data, as it can represent extensive horizontal surfaces while supporting both geometric definition and parameter attribution, within the already created Project Parameter related to GIS. The objective is therefore to transfer GIS data into the BIM environment through Floors that simultaneously inherit the shape (geometry) and the information (parameters) of the shapefile. The outcome is a Revit model enriched with GIS-based environmental information, where each Floor element conveys both spatial geometry and ecological significance.

Before initiating the transfer, the shapefile must be exported using the same projected Coordinate Reference System (CRS) adopted in the BIM model to ensure spatial consistency and prevent misalignment during import.

To achieve the integration, the workflow relies on Dynamo in combination with the *DynamoGIS* package. Starting from a shapefile, two parallel workflows and processes are established:

- Geometry transfer - GIS shapefiles containing polygonal geometries are imported into Revit through the *DynamoGIS* package. Using computational design scripts, the polygons are converted into floor boundaries, which are then extruded into Revit Floors.
- Data attribute transfer - in parallel, the environmental information associated with the GIS polygons (e.g., NDVI class, NDMI class, etc.) is prepared in QGIS by creating dedicated attribute fields (code floor). These are then transferred via Dynamo into Revit parameters, ensuring that each BIM object retains the environmental attributes originally derived from GIS.

This dual process is illustrated in Figure 3.11, where geometry and attributes follow parallel computational paths and ultimately converge within the BIM environment. Geometry is generated from shapefiles to create Revit floors, while corresponding attributes are assigned as parameters, resulting in BIM elements enriched with EO-GIS data for project design scenarios.

The resulting BIM model does not merely store environmental attributes, but enables them to be queried and filtered, supporting scenario comparison, constraint identification and rule-based design reasoning.

Figure 3.11 - Workflow for integrating GIS data into the Revit environment using Dynamo, geometry and data processes

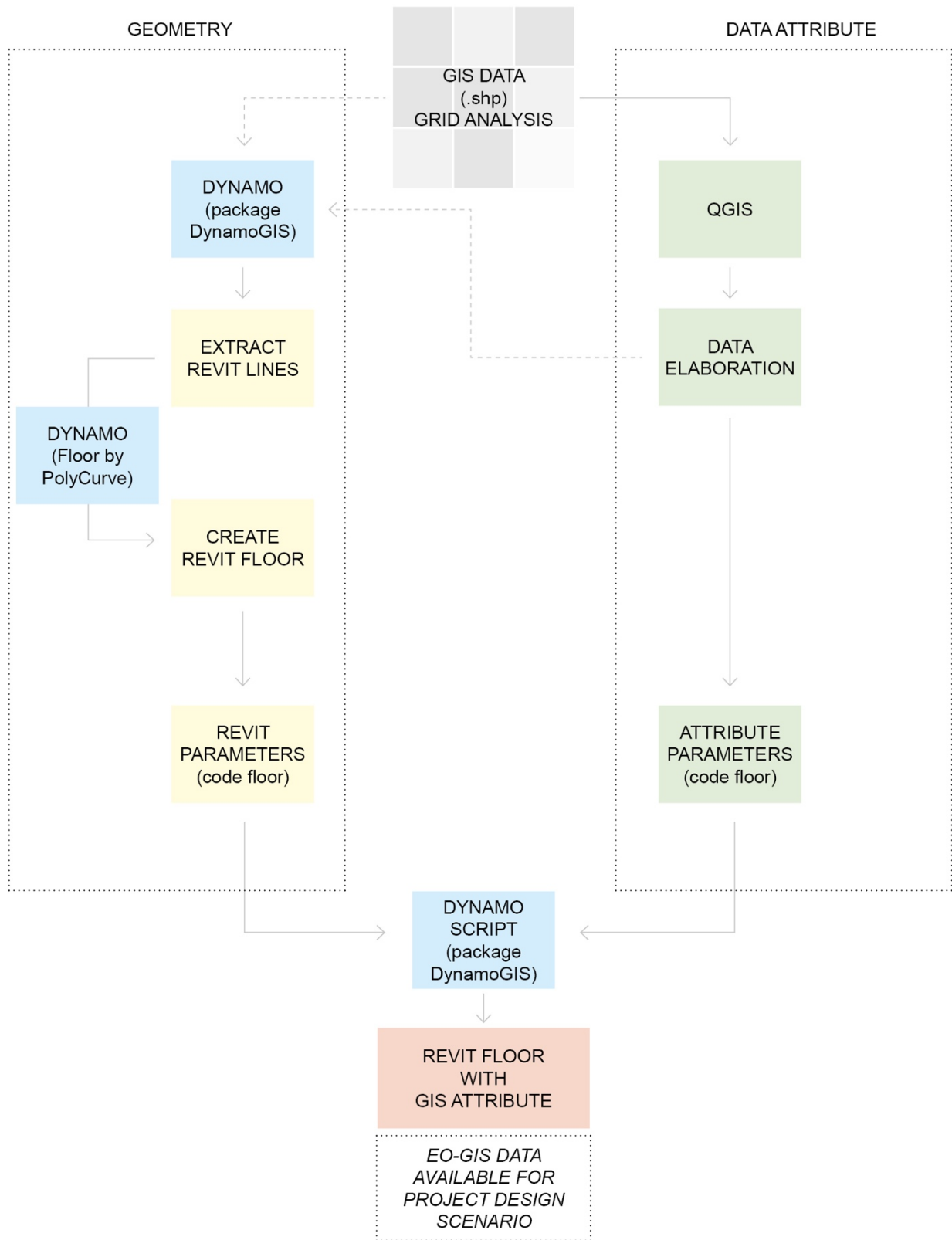
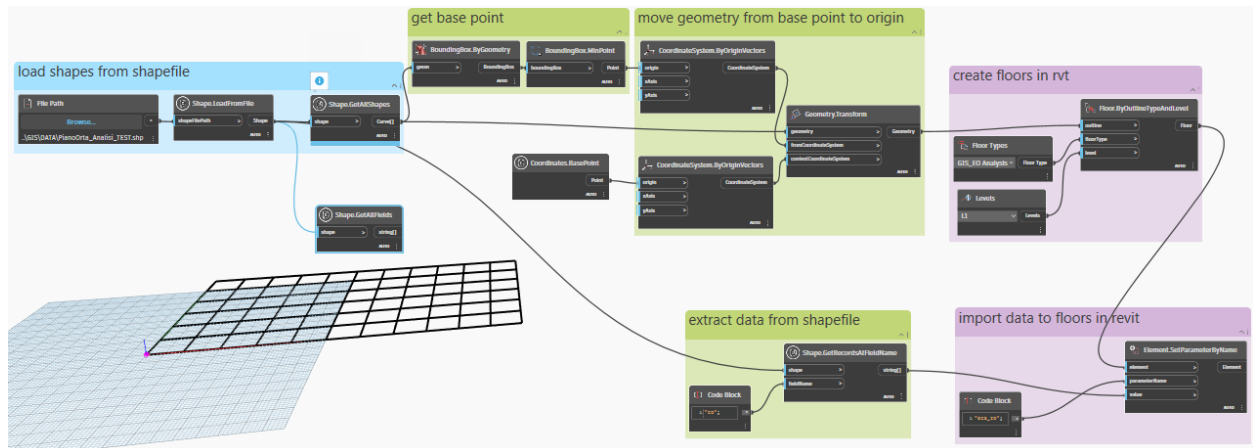


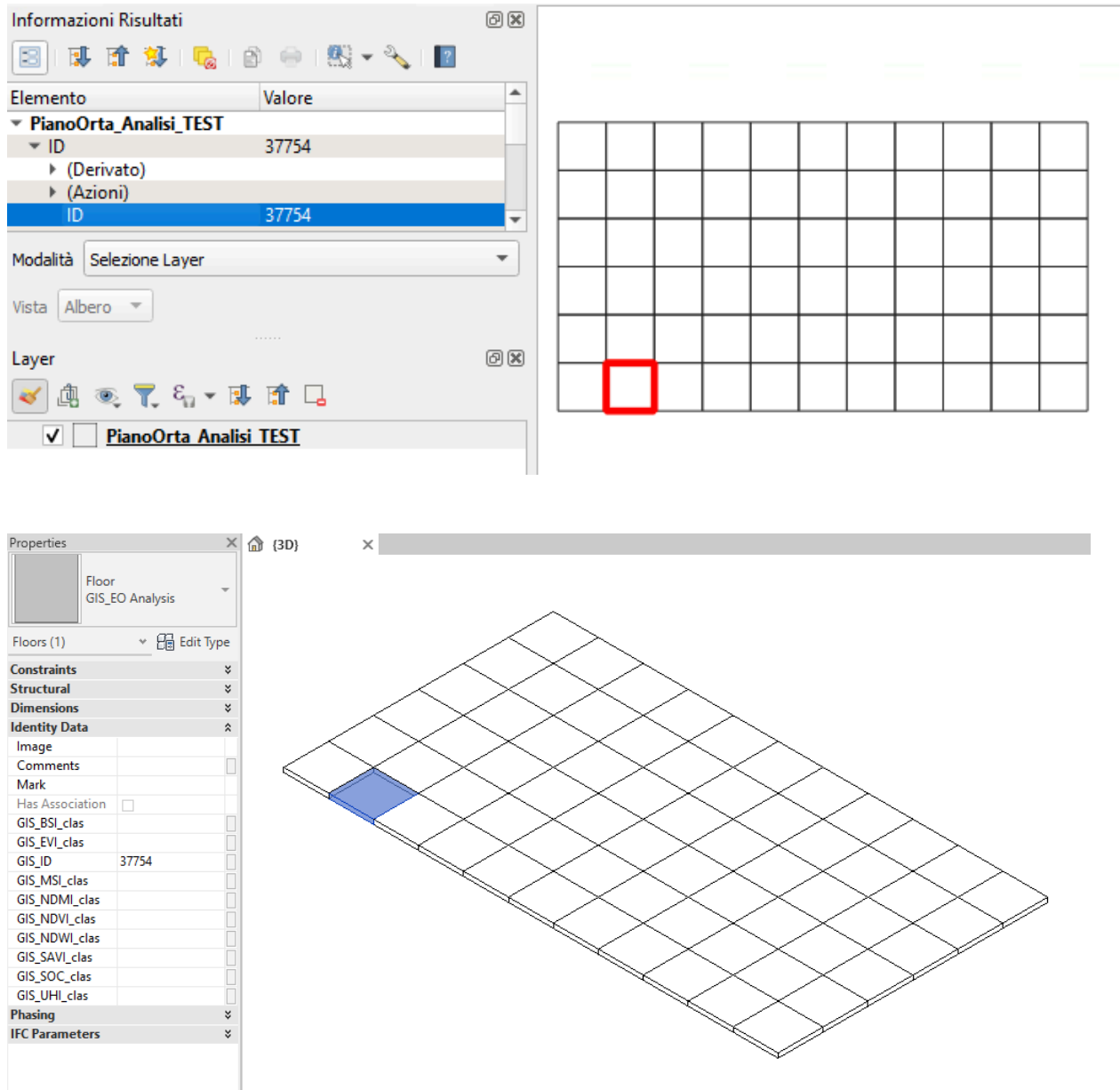
Figure 3.12 - Dynamo workflow for the creation of Revit floors with geometry and information



The workflow requires a sequence of specific Dynamo nodes, as shown in Figure 3.12. The shapefile is selected via the “File Path” node and loaded using “Shape.LoadFromFile”, which extracts both geometries and data. Geometries are retrieved with the “Shape.GetAllShapes” node, which allows the identification of polygonal outlines and their alignment with the Revit project base point. These outlines are then converted into Floors through the node “Floor.ByOutlineTypeAndLevel”, where the floor type and level are specified. In parallel, attribute data are extracted using the “Shape.GetRecordAtFieldName” node, by specifying the column of interest. To verify correspondence between GIS and BIM, this extraction is firstly applied to the values of the ID of each single element, transferred in the parameter field “GIS_ID” within the Revit model. The result is a BIM model in which Revit Floors replicate both the geometry and the attributes of the source shapefile, thereby transforming spatial datasets into design-ready elements.

To validate the proposed methodology, a preliminary test was conducted on a subset of elements extracted from the larger reference grid. Among all the project parameters created, the test focused on two key aspects: the generation of floor geometries derived from the polygon boundaries contained in the shapefile and the transfer of the unique identifier parameter (GIS_ID) associated with each element. This allowed verification that the parallel workflows of geometry and attribute assignment were correctly aligned. As illustrated in the Figure 3.13, the GIS features were successfully transferred into the Revit model, with a perfect correspondence between the geometry of the imported floor and the identification code of the selected element.

Figure 3.13 - Correspondence between the geometry and attribute of the selected polygon in QGIS and the corresponding Revit Floor; the figure highlights the matching ID value, demonstrating the correct transfer of information between the two environments



Such integration allows BIM to move beyond its conventional architectural and construction-oriented scope, becoming a landscape design tool informed by territorial and environmental evidence.

Nevertheless, some challenges remain: attribute simplification during transfer, potential coordinate misalignments and the absence of dynamic updating mechanisms still limit full interoperability between GIS and BIM. Despite these constraints, the proposed workflow demonstrates that it is possible to establish a design-oriented GIS-to-BIM interoperability: one in which environmental knowledge is not only visualised but structurally embedded into the BIM model, thereby informing landscape analysis and design decisions.

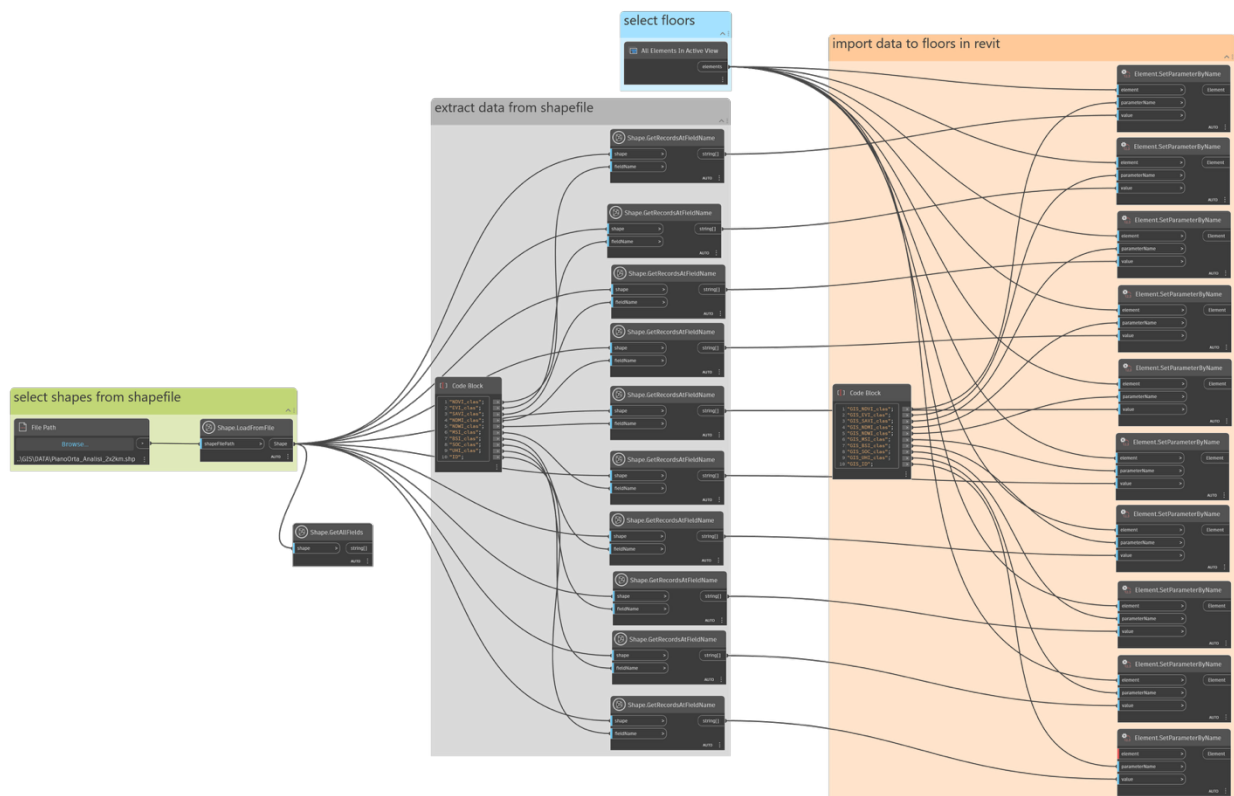
3.4.2.3 Update of Information inside Revit Elements

Up to this point, geometry and data have travelled in parallel within the workflow: when Floors were created in Revit, each element simultaneously received its corresponding GIS-derived information.

However, this linear process does not reflect the dynamics of real-world landscape projects, where information may evolve over time, require updates or need to be integrated with new datasets. For this reason, it is necessary to explore how newly generated GIS attributes (e.g., additional columns in the attribute table) can be transferred to Floors that already exist in the BIM environment. The objective is to update only the informational component of existing Floors, without altering their geometry or deleting them, which represents a crucial requirement.

The final step of the workflow is therefore the transfer of updated GIS data into Revit Floors that have already been created. This operation is performed through Dynamo and focuses exclusively on the importation of values into the project parameters previously defined for GIS-BIM interoperability (see previous Table 3.6). At this stage, the workflow concerns only data, not geometry: there is no need to extract shapes again or regenerate Floors. Instead, by modifying the initial Dynamo script, the geometric generation nodes are replaced with a selection node, which allows the user to directly select all active Floor elements in the Revit view, represented in Figure 3.14.

Figure 3.14 - Dynamo workflow showing how specific attributes derived from GIS analyses are extracted from the shapefile and transferred to the selected Revit Floors within the dedicated project parameters



To avoid overwriting existing validated information, the workflow maps only newly added attribute fields, ensuring controlled parameter updates and preventing data loss. This establishes a controlled update mechanism ensuring that previously assigned parameters remain unchanged and that only new information is appended.

To avoid overwriting previously validated information, the workflow maps only newly added attribute fields, ensuring controlled parameter updates and preventing data loss. This establishes a reliable update mechanism in which existing values remain unchanged and only new information is appended.

As illustrated in the Dynamo script, a Floor that initially contained only the “GIS_ID” parameter can be progressively enriched with multiple attributes corresponding to the classification of environmental indices. These values are transferred using the “Element.SetParameterByName” node, which assigns each dataset to the appropriate project parameter. The geometry of the Floor is therefore preserved, while its informational content expands, providing the designer with an increasingly detailed dataset. Once all GIS-derived attributes have been imported, the values can also be visualised through dedicated filters within the “Visibility/Graphic Overrides” panel, ensuring coherence between analytical classification and graphical representation. The procedure can be repeated whenever updated GIS layers become available, allowing the informational component of the model to evolve without regenerating its geometry. As shown in Figure 3.15, the correspondence between the QGIS shapefile and the Revit Floor element confirms that all attributes have been successfully transferred to the selected reference object.

The analyses presented in this chapter demonstrate how Earth Observation and GIS-derived information can be systematically translated into the BIM environment to support evidence-informed landscape design. Through the progressive integration of spectral indices, spatial classifications and parameter-based data structures, the workflow enables environmental conditions to be embedded directly within BIM elements, moving beyond a purely geometric representation of the landscape. The resulting model is not a static digital reproduction of the site, but a data-rich and adaptive system in which design choices remain traceable to their analytical foundations. The ability to update existing BIM elements with newly generated GIS attributes further confirms the iterative nature of the workflow, aligning with the dynamic processes of the landscape and with contemporary information-management principles.

While the approach does not yet establish a live connection between platforms, it provides a reproducible and scalable foundation for future developments, including automation, bi-directional data exchange and scenario-based modelling. Overall, this chapter confirms that integrating EO-GIS data into BIM is not merely a technical operation, but a methodological shift that repositions the BIM model as an active analytical tool within the landscape design process. The following chapter will examine how these data can be operationalised within the BIM environment to support design decision-making and project-level applications. Finally, Figure 3.16 schematically summarises the workflow adopted to transfer both geometry and data from shapefiles into Revit Floors, starting from validated GIS datasets and concluding with BIM objects capable of hosting environmental information.

Figure 3.15 - Correspondence between the QGIS shapefile and the Revit Floor elements, showing how all information has been successfully transferred to the selected reference element, in the example the "EVI_clas" values are represented

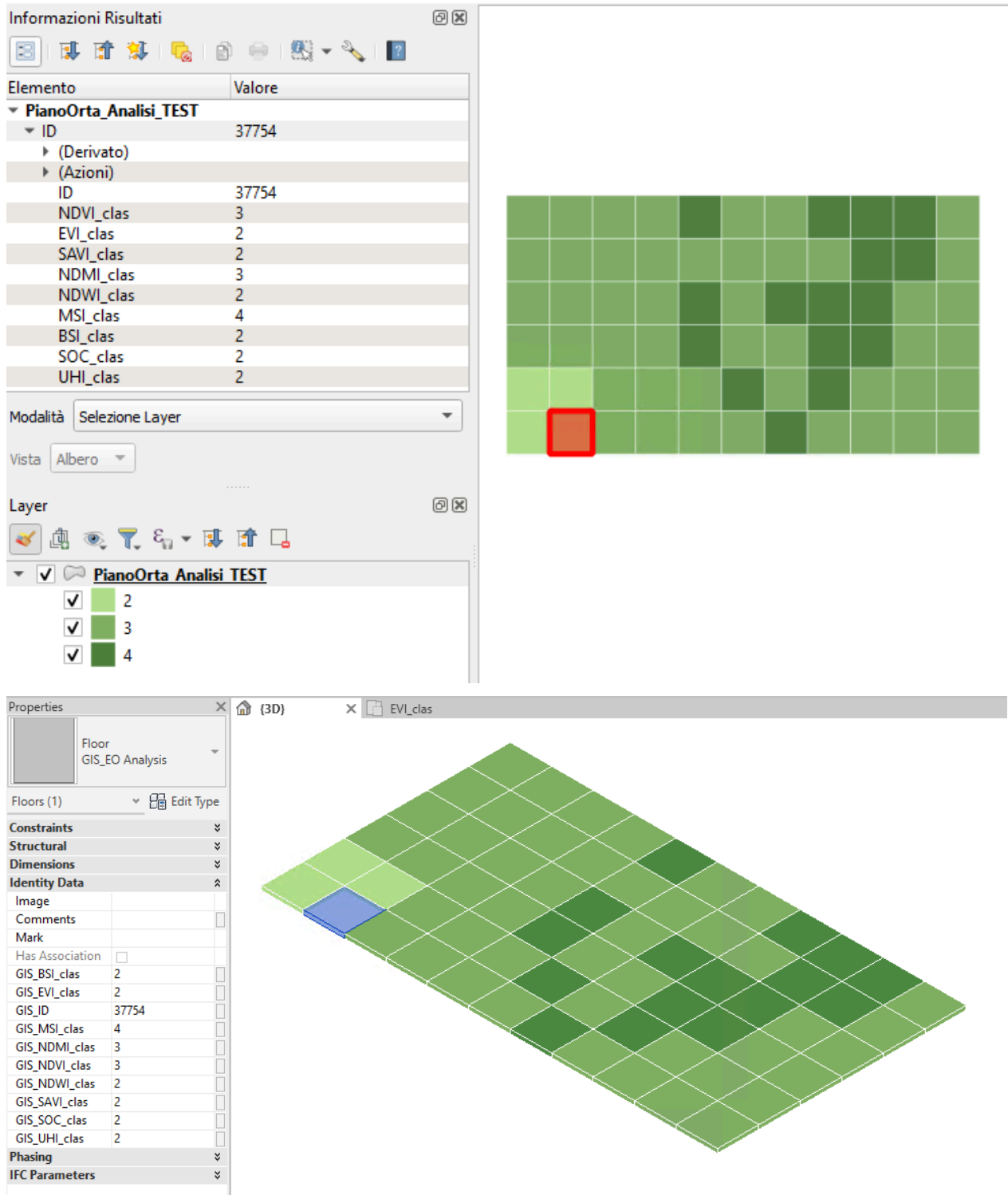
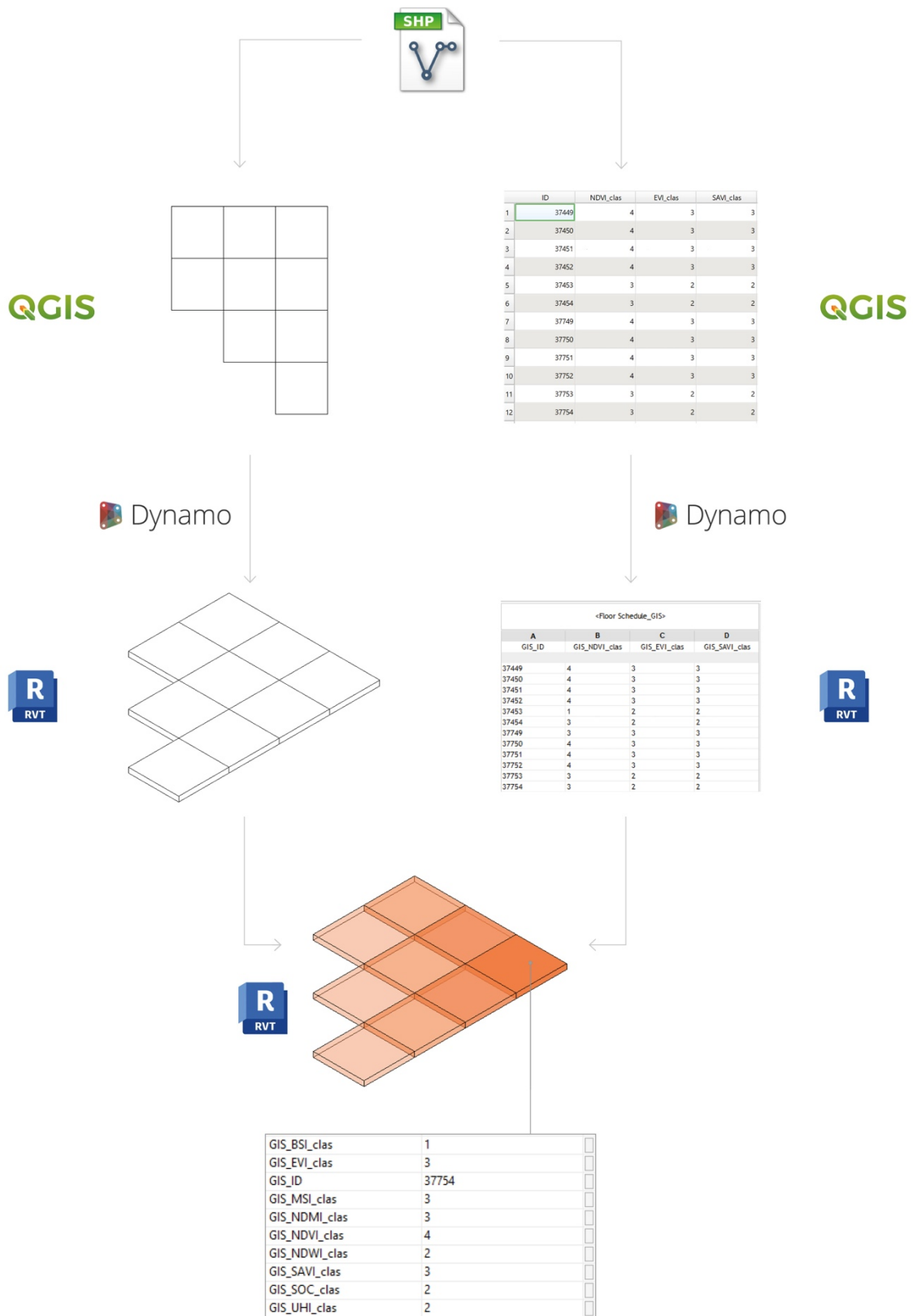


Figure 3.16 - Overview of the GIS-to-BIM data transfer workflow: GIS grid geometries and their associated attribute tables are prepared in QGIS, imported into Revit via Dynamo and assigned as parameters to Floor elements, resulting a BIM objects retain both the spatial subdivision and the environmental classifications



3.5 Environmental Data into BIM: New Potentials for Landscape Architect

The integration of GIS-derived datasets into the BIM environment does not simply enrich the model with additional attributes; it redefines the role of BIM from a static repository of project data into a decision-making and design-support environment. In this perspective, BIM becomes a dynamic and creative platform where territorial and environmental knowledge is translated into parameters that directly inform landscape analysis and design.

The methodological workflow developed in the previous sections demonstrates how environmental attributes derived from EO and GIS (vegetation indices, soil conditions, hydrological information) can be associated with BIM system families and project elements. This shift allows the landscape architect to operate with a model that is not only geometrically accurate, but also ecologically meaningful.

Traditionally, BIM has been conceived as a tool for the construction sector, where its primary function is to structure architectural and engineering data into parametric objects. Within the landscape discipline, however, this paradigm expands: BIM can become an interface that enables environmental data drive design decisions. The association of GIS attributes with BIM elements allows for parametric simulations that link ecological conditions to project requirements. For example, areas characterised by Class 1 NDMI values (indicating very dry areas) can guide the allocation of drought-resistant tree species, while zones with Class 1 BSI values (indicating bare or degraded soil) can be prioritised for reforestation or soil restoration measures.

The linkage between environmental indices and BIM elements opens new avenues for landscape practice. Rather than serving as static representational models, the BIM environment can host data-driven simulations that include:

- Vegetation strategies: tree species typologies and planting densities adapted to vigour indices (NDVI, EVI, SAVI) and soil moisture conditions (NDMI, MSI);
- Hydrological design: NDWI together with NDMI informing the allocation of buffer zones, wetlands or water management features;
- Soil restoration: where critical classes of SOC and BSI indices indicate low soil fertility or bare/industrial soils, these areas are prioritised for ecological interventions;
- Urban resilience: UHI indices guiding the implementation of green infrastructure.

The data imported from GIS into Revit are primarily hosted within Floors, which act as the main containers of environmental attributes. However, their influence extends beyond the Floors themselves: the parameters stored in these elements can be dynamically connected to other BIM families, such as vegetation (Planting) or project zones, through Dynamo-based workflows.

This relational capacity is central to the methodology, as it transforms the Floors from simple geometric objects into bridges between territorial information and design elements.

For instance, the parameter “GIS_NDVI_clas” assigned to Floors can be transferred to Planting families to regulate tree density or typology, establishing a direct relationship between vegetation vigour and planting strategies. Similarly, parameters such as “GIS_NDMI_clas” or “GIS_MSI_clas” can inform irrigation planning and drought mitigation measures. Parameters like “GIS_UHI_clas” can instead guide the distribution of shade-providing trees or water features in areas subject to microclimatic stress. Topographic information (e.g., slope or DEM-derived attributes) can also be linked to Topography families, informing grading strategies, drainage patterns and earthwork optimisation. In this way, BIM ceases to be a neutral modelling environment and becomes a responsive design platform where environmental indicators shape project outcomes.

The design choices remain nevertheless dependent on the project objectives and on the specific requirements set by the client. GIS-derived parameters therefore act as evidence-based drivers, but they must be interpreted within the broader design framework, ensuring that quantitative and qualitative indices support the creative and strategic dimension of landscape architecture.

Table 3.7 provides a synthesis of these correspondences, showing how environmental indices transferred from GIS to Floors can inform both territorial interpretation and strategies in the BIM model.

Table 3.7 - GIS attributes in BIM Floors and their role in design implication

GIS-BIM Index (Floor parameter)	Interpretation	BIM Design Implication	Project Output
NDVI / EVI / SAVI	Vegetation vigour, canopy density	Identify areas suitable with high/low vegetation vigour	Inform zoning for conservation or replanting for ecological restoration
NDMI / MSI	Moisture content, drought stress	Detect of drought or humid zones;	Guide irrigation planning and drought-resistant strategies
NDWI	Water presence and distribution	Mapping of water presence and resources	Guide location of riparian buffers, wetlands, or infiltration zones
BSI	Bare or degraded soil	Identify brownfields, industrial areas and degraded zones	Propose soil remediation or sealing reduction; prioritisation of reforestation or phytoremediation
SOC	Soil fertility baseline	Evaluate soil fertility assessment	Inform selection of vegetation types according to soil quality, integrate soil improvement strategies
UHI	Microclimatic stress	Map microclimatic and thermal stress	Inform strategies for urban greening, shade creation, cooling vegetation or cooling water features

In this research, the parameters are not only used to identify strategic areas suitable for intervention, but also to inform specific project components. This includes both surface-based elements and Revit System families (e.g., Floors, Topography) and landscape design elements such as Revit loadable families (e.g., Planting objects, furniture, water features). In doing so, the workflow demonstrates how environmental attributes can be embedded across different types of BIM elements, allowing data to influence design decisions at multiple scales and across disciplinary boundaries within a single model.

The integration of GIS-derived parameters into BIM does not imply that the software dictates planting design choices. Rather, it provides a structured decision-support framework where environmental evidence guides, but does not replace, the expertise of the landscape architect. The final design outcome always depends on the project objectives, site-specific conditions and client requirements. What BIM adds is the possibility to associate parameters stored in Floors with Planting families or with Topography grading zones, enabling the simulation of alternative strategies directly within Revit. Through Dynamo scripts, these relationships can be tested, compared and visualised, transforming abstract indices into tangible design options and opening the way to scenario-based exploration.

Table 3.8 illustrates how key GIS parameters can be translated into planting or topography strategies, showing their potential implications and example actions within the BIM environment. This synthesis offers an initial overview of how environmental data can inform design elements, while the subsequent chapters provide a more detailed and operational discussion.

Table 3.8 - Translation of GIS-derived Floor parameters into Planting and Topography strategies within BIM

GIS-BIM Parameter (from Floors)	Planting Implication in Revit	Topography Implication in Revit	Design Action / Simulation
Low class NDMI / MSI (very dry, moisture stressed zones)	Select drought-tolerant species; regulate density	Adjust grading to minimise irrigation demand; design efficient slopes for water retention	Introduce drought-tolerant trees or shrubs; reduce planting density in water-stressed zones; integrate terracing or micro-water basins
High class NDWI (water presence)	Use hydrophilic species; support wetland/riparian planting	Lower terrain or create depressions for wetland formation; design drainage corridors	Plant willows, alders, or buffer strips along waterways; integrate bioswales or retention ponds
Low class BSI / SOC (bare, degraded soils, low fertility)	Pioneer / soil-regenerating species; improve fertility	Regrade surfaces to reduce erosion; stabilise slopes with soil-retaining structures	Introduce nitrogen-fixing trees, shrubs for phytoremediation, implement erosion control and soil restoration
Low class NDVI / EVI (sparse or low-vigour vegetation)	Plan reforestation / densification	Modify grading to support new planting pits; improve microtopography for soil aeration	Add canopy-forming species, increase tree groups for ecological restoration; adjust topography for planting success
Low class UHI (heat-stress zones)	Increase shade and evapotranspiration	Reconfigure terrain to allow airflow corridors; integrate water surfaces in topographic depressions	Plant large-crown, wide-canopy trees; create green corridors to mitigate heat islands; combine shading with cooling topographic features

Such a workflow ensures that design choices are grounded in quantifiable data while remaining flexible and open to interpretation by the landscape architect.

To further demonstrate the operational relevance of GIS-to-BIM interoperability, three practical examples are presented. These workflows, developed through Dynamo scripts, illustrate how environmental data stored in BIM parameters can directly inform design strategies. The first example focuses on the identification of strategic project areas for specific intervention based on data. The second explores the transfer of GIS-derived soil and vegetation attributes to Planting families. The third examines the integration of environmental parameters to support grading strategies, showing how terrain modelling can be informed by data-driven conditions.

To make this conceptual link operational, three Dynamo-based workflows were developed as demonstrators:

- Workflow 1 - Identification of Strategic Areas: environmental parameters stored in BIM are analysed to highlight zones that require priority attention, supporting decisions on where ecological or design interventions should be concentrated.
- Workflow 2 - Association with Planting Families: classified data are transferred from surfaces to planting elements, enabling the simulation of species selection, planting density and distribution strategies directly within the BIM environment, simulating how the informed-model can support design decision-making in a data-driven way.
- Workflow 3 - Topography-informed grading: terrain-related attributes are connected to topographic elements in BIM by identifying areas where earthworks should be minimised, drainage corridors reinforced, or micro-topographic adjustments introduced. The workflow demonstrates how environmental evidence can guide terrain modelling, erosion control and water-sensitive design strategies directly within BIM.

Together, these simulations exemplify how the approach can be applied both as a tool of verification, testing the coherence of existing projects with site-specific conditions and as a design-driven framework for generating new, data-informed solutions.

The following sections illustrate these three workflows, demonstrating how environmental evidence can be translated into project-oriented simulations to support both verification of existing design choices and the generation of new informed alternatives.

3.5.1 Identification of Strategic Areas

The workflow developed in the previous sections demonstrated how environmental data derived from EO and GIS can be discretised and stored within Floors in the BIM environment. At this stage, the focus shifts from data storage to interpretation and project-oriented use. The parameters contained in each floor unit (e.g., NDVI, MSI, BSI, UHI, etc.) are no longer considered as isolated numerical values, but as classified indices (see previous Table 3.4) that act as indicators guiding design decisions.

The discretised Floors within the BIM environment already contain a significant amount of environmental information inherited from GIS. These attributes are not to be understood as isolated numerical values, but as indicators that acquire meaning when interpreted in relation to design objectives. Vegetation vigour, soil moisture stress, degradation of surface soils and microclimatic risk become not simply analytical datasets but decision-support layers. Their combined reading allows the identification of areas where interventions are most strategic, embedding environmental evidence into planning priorities (Forman, 1995; Nassauer & Opdam, 2008).

Environmental indices, once transferred into BIM, acquire a new role: they operate as indicators that reveal vulnerabilities or opportunities within the landscape. Rather than being interpreted as isolated datasets, their combination outlines patterns that guide the prioritisation of interventions. From their combined interpretation emerge five strategic principles that underpin the identification of intervention areas: drought mitigation planting, soil remediation, shading planting, cooling intervention and ground cover stabilisation. Each design principle reflects a correspondence between measured conditions and design responses, ensuring that interventions are not arbitrary but rooted in quantifiable ecological evidence.

The first principle is Drought Planting, which applies to areas where sparse canopy cover coincides with moisture stress. The rationale is that replanting with drought-tolerant species, combined with protective ground measures, strengthens the resilience of vegetation under water-limited conditions. Studies on ecological restoration emphasise that matching species traits to site-specific water availability is essential to reduce plant loss and ensure long-term stability (Chaves et al., 2003; Valladares et al., 2014).

The second principle is Soil Remediation, relevant to surfaces where bare soils overlap with low organic carbon content. Here, the objective is to restore soil functionality through decompaction, organic amendments and phytoremediation. Research in soil science highlights that restoring soil quality is a prerequisite for sustainable vegetation establishment and ecosystem service provision (Bünemann et al., 2018; Reicosky, 2003).

A third principle is Shading Planting strategies, which concern microclimatic hotspots characterised by limited vegetation cover. The ecological rationale is that increasing canopy density maximises shade and evapotranspiration, thereby reducing local heat stress. Urban climate research consistently shows that

strategic tree planting mitigates urban heat islands and improves human comfort (Bowler et al., 2010; Emmanuel & Krüger, 2012).

The fourth principle is Cooling Intervention enhancement, which applies to zones where drought and thermal stress overlap. In such conditions, vegetation alone is insufficient: combined measures are required, including efficient irrigation systems and the use of permeable or reflective surfaces. Integrating planting with engineered cooling strategies has been identified as a critical pathway for climate adaptation in cities (Krüger et al., 2013; Zölch et al., 2016).

Finally, the principle of Ground Cover Planting concerns areas with sparse vegetation and degraded soils. The introduction of fast-growing cover species provides immediate soil stabilisation, soil protection, reduces erosion and creates a vegetative layer that supports subsequent interventions. Soil conservation research demonstrates the effectiveness of rapid ground cover in stabilising fragile areas and enhancing ecological succession (Morgan, 2005; Zuazo & Pleguezuelo, 2009).

This interpretative framework, summarised in Table 3.9, defines the correspondence between environmental conditions and project typologies, ensuring that landscape interventions are not arbitrary but explicitly grounded in data-driven diagnosis. For example, critical classes of vegetation indices (NDVI/EVI = Class 1-2) highlight areas with limited canopy cover and when combined with moisture stress (MSI = Class 1-2), these zones become priority areas for drought-resistant planting. Similarly, high Bare Soil Index (BSI class 1-2) together with low Soil Organic Carbon (SOC class 1-2) identifies surfaces where soil remediation measures are essential before any new vegetation strategy is applied. In the same way, UHI indices in critical classes (Class 1) overlapping with weak vegetation cover (NDVI/EVI = Class 1-2) identify microclimatic hotspots that require shading interventions.

Table 3.9 - Parameter combinations and intervention typologies

Parameter condition (classes)	Interpretation	Intervention typology tag
NDVI/EVI = class 1-2 and MSI = class 1-2	Low vegetation vigour + high drought stress	Drought Planting (replanting with drought-resistance species)
BSI = Class 1-2 and SOC = Class 1-2	Exposed or degraded soils + low fertility	Soil Remediation (decompaction, soil phytoremediation)
UHI = Class 1 and NDVI/EVI = class 1-2	Microclimatic hotspot + limited canopy cover	Shading Planting (trees with high canopy density, evapotranspiration)
MSI = Class 1-2 and UHI = Class 1-2	Drought stress + thermal stress	Cooling Intervention (dense-canopy trees, shade on impervious surfaces, irrigation efficiency)
NDVI/EVI = Class 1-2 and BSI = Class 1	Sparse vegetation + bare soil	Ground Cover Planting (fast-cover species to stabilise soil and reduce erosion)

The classification rules summarised in Table 3.9 remain theoretical unless they are embedded in the BIM environment as an operational tool. To achieve this, a Dynamo script was developed to automate the translation of environmental indices into typological tags directly within Revit. In this way, the BIM model evolves from a passive container of environmental data into an active diagnostic platform where strategic areas are immediately identifiable. The process does not predetermine design solutions but offers the landscape architect a structured map of priorities, ensuring that ecological vulnerabilities and opportunities are made visible at an early stage of the design workflow.

Through Dynamo scripts (Figure 3.17), these rules are codified and automatically applied to all discretised units, such as Revit Floors. The script queries the parameters stored in each Floor, evaluates the conditions defined by the designer and writes a single tag into the parameter “GIS_Intervention_Typology”, ensuring that each unit is assigned to one specific intervention category.

Figure 3.17 - Dynamo Workflow for assigning Typology Tag into Revit Floors

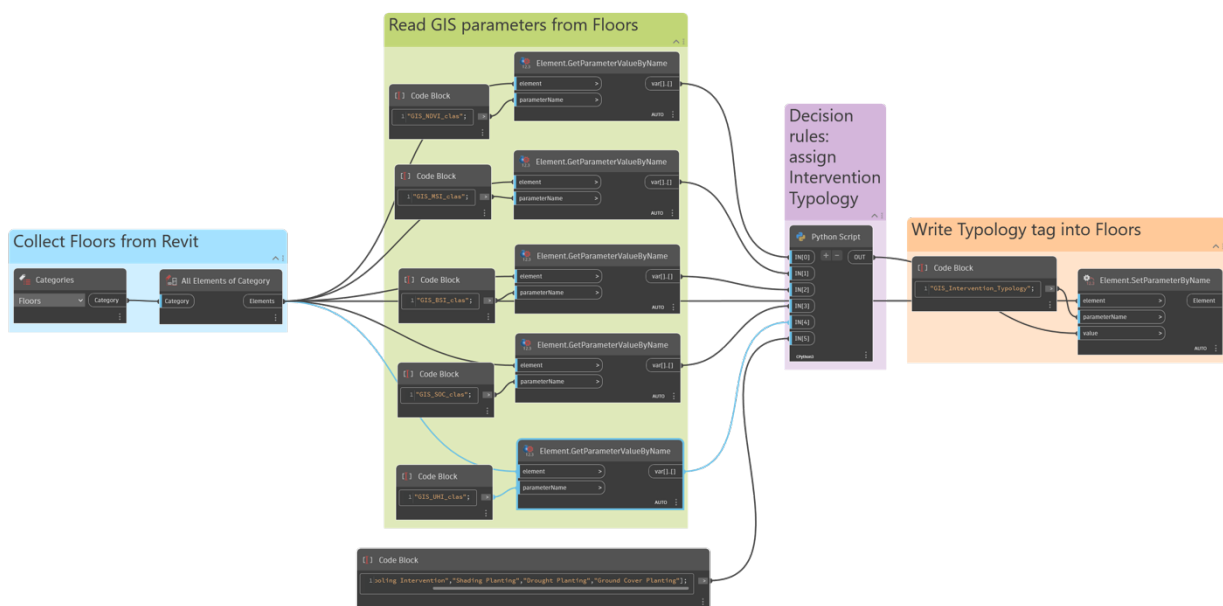


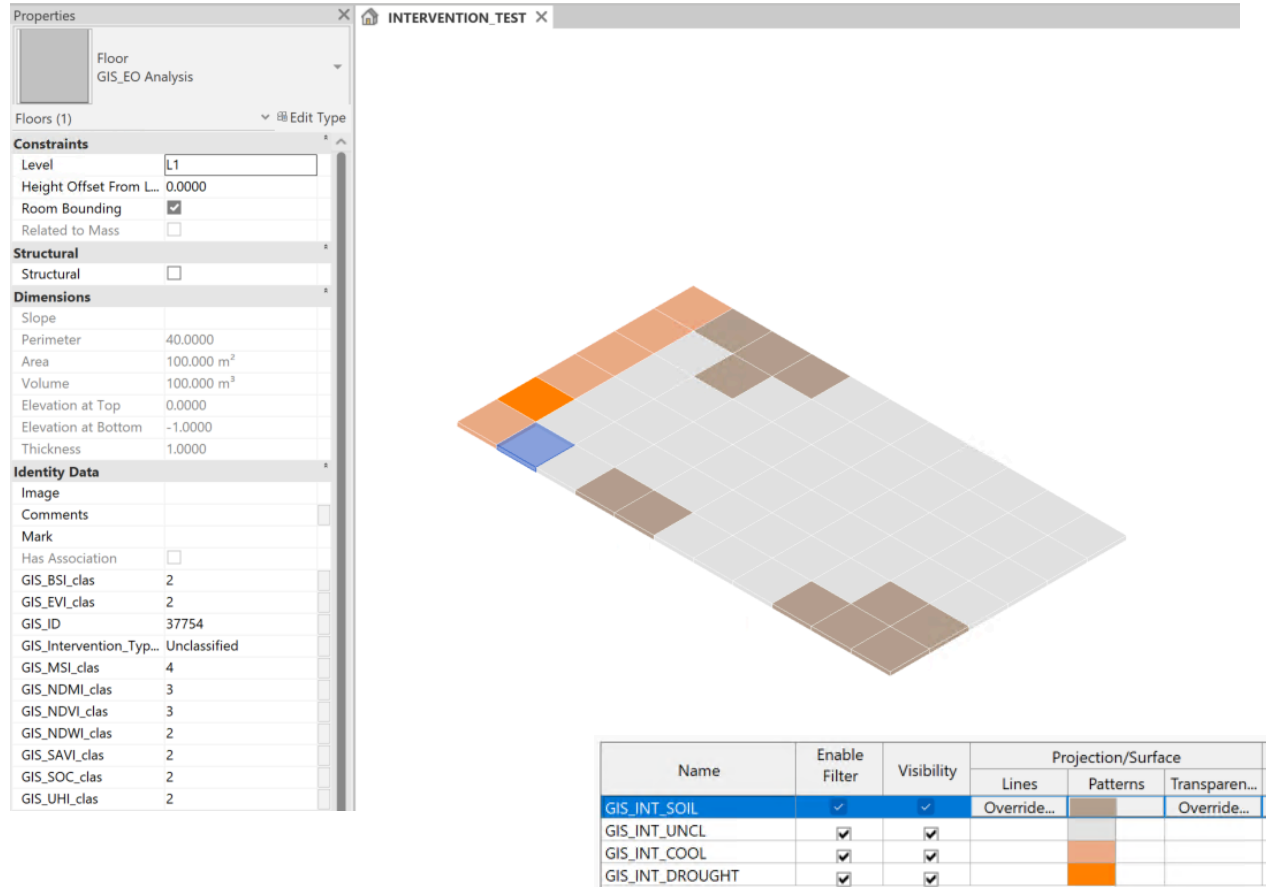
Table 3.10 and Figure 3.18 show the results of the interpolation of the data, where each Floor is colour-coded according to its assigned typology. The visualisation makes critical zones immediately recognisable, while the tabular output ensures that the underlying logic remains transparent and verifiable. This dual representation (graphic and tabular) enhances both the interpretability of the model and its usability as a decision-support tool for subsequent design phases. However, due to the limited number of cells used in this preliminary simulation, not all intervention typologies can be visually represented at this stage. In the subsequent multiscale applications developed on real territories, the full range of interventions will become visible and spatially explicit, allowing a more comprehensive interpretation of the model outcomes.

Table 3.10 - Example of schedule with intervention typology

GIS_NDVI/ EVI_clas	GIS_MSI_clas	GIS_BSI_clas	GIS_UHI_clas	GIS_SOC_clas	Typology Tag
1-2	1-2	-	-	-	Drought Planting
-	-	1-2	-	1-2	Soil Remediation
1-2	-	-	1	-	Shading Planting
-	1-2	-	1-2	-	Cooling Intervention
1-2	-	1	-	-	Ground Cover Stabilisation
-	-	-	-	-	Unclassified*

* *Unclassified value: Some units may remain without a typology tag when none of the rule conditions are met or when input data are missing. These cases are retained in the schedule to ensure transparency and allow the designer to manually evaluate whether further data refinement or a customised interpretation is required.*

Figure 3.18 - Results of the applied Typologies Tag inside the Revit floors and relative filters applied



Thanks to this workflow, strategic areas are not only automatically identified and labelled, but also translated into project-relevant categories that can inform different levels of decision-making. On the one hand, the resulting typologies provide a reproducible and transparent basis for further digital analyses, simulations, or scenario testing. On the other hand, they act as a concrete design indication for the landscape architect, highlighting where specific interventions such as replanting, remediation, or cooling strategies may be prioritised. In this way, the workflow functions both as a methodological foundation for advanced modelling and as an operative guide for project-oriented interpretation.

In doing so, the identification of strategic areas becomes not an isolated analytical output, but the starting point of a coherent data-driven process in which environmental evidence is progressively transformed into design action. This step therefore marks the transition from data interpretation to design operation, establishing the basis upon which the following simulations and scale-based applications are developed.

3.5.2 Association of Data with Planting Design

The workflow developed in Section 0 demonstrated how environmental data derived from GIS could be discretised within the BIM environment to identify strategic surfaces and interventions. Based on this foundation, the present section shifts the focus from Floors to Planting families. The aim is to explore how vegetation elements can become responsive objects, interacting with the site-specific conditions already embedded in the model. This allows vegetation elements within Revit to inherit site-specific characteristics, effectively simulating compatibility between soil conditions and tree species. For example, areas with low moisture indices can be populated with drought-resistant species, while fertile zones may host trees with higher ecological requirements. This relational workflow highlights the potential of BIM not only as a repository of vegetation objects but as a responsive design tool capable of aligning planting strategies with environmental data.

To this end, Planting families were enriched with three shared environmental parameters:

- Water Demand (Low, Medium, High);
- Drought Resistance (Low, Medium, High);
- Canopy Cover (Small, Medium, Large).

These parameters, combined with environmental data inherited from GIS (e.g., moisture indices, bare soil, urban heat stress) establish a framework for testing the compatibility of vegetation with site conditions and for generating planting scenarios.

The selection of reference species for each typology was supported by the i-Tree database¹⁵, a suite of peer-reviewed tools developed by the USDA Forest Service for quantifying the structure, composition and ecosystem services of urban forests (Nowak, 2020; Nowak et al., 2008). i-Tree provides comprehensive datasets on tree species performance, including growth rates, canopy development and environmental benefits, making it a valuable source for linking planting choices with evidence-based ecological data.

Based on these references, six typologies were defined (Table 3.11), mixing different combinations of water demand, drought resistance and canopy cover and complemented by example species commonly recorded in i-Tree surveys. Figure 3.19Figure 3.18 illustrates the resulting tree typologies generated from the combined parameters and dimensional rules.

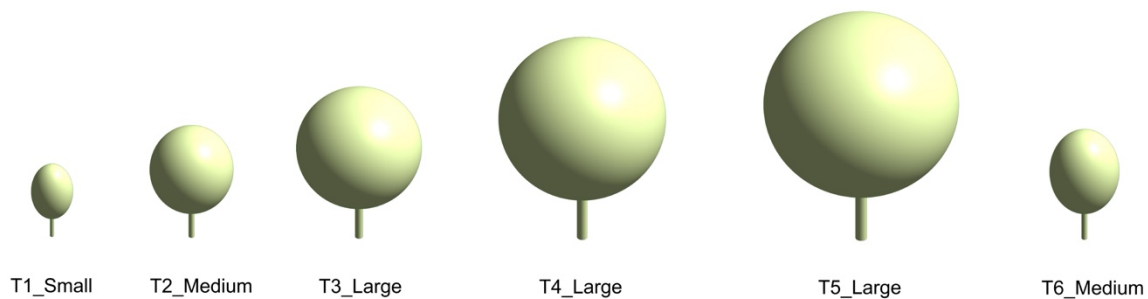
In this way, the association between environmental parameters and planting typologies establishes a reproducible decision-making framework, ensuring that species selection is not arbitrary but grounded in measurable ecological criteria and adaptable to future project contexts.

¹⁵ Available at the following website link: <https://www.itreetools.org/>

Table 3.11 - Planting typologies combining environmental characteristics and i-Tree reference species

Typology	Characteristic	Water Demand	Drought Resistance	Canopy Cover	Example Species (i-Tree based)
T1_Small	Drought-resilient pioneer	Low	High	Small	<i>Robinia pseudoacacia</i> , <i>Celtis australis</i> , <i>Tamarix gallica</i>
T2_Medium	Medium urban tree (adaptive)	Medium	Medium	Medium	<i>Acer campestre</i> , <i>Carpinus betulus</i> , <i>Prunus avium</i>
T3_Large	Shade provider (resilient)	Medium	High	Large	<i>Quercus pubescens</i> , <i>Fraxinus ornus</i> , <i>Ulmus minor</i>
T4_Large	Xeric shade tree	Low	High	Large	<i>Quercus ilex</i> , <i>Pinus pinea</i> , <i>Olea europaea</i>
T5_Large	Water-demanding canopy	High	Low	Large	<i>Platanus × acerifolia</i> , <i>Populus alba</i> , <i>Salix alba</i>
T6_Medium	Ornamental/fast cover	High	Medium	Medium	<i>Cercis siliquastrum</i> , <i>Malus domestica</i> , <i>Magnolia grandiflora</i>

Figure 3.19 - Tree Typologies identified through i-Tree data and dimensions



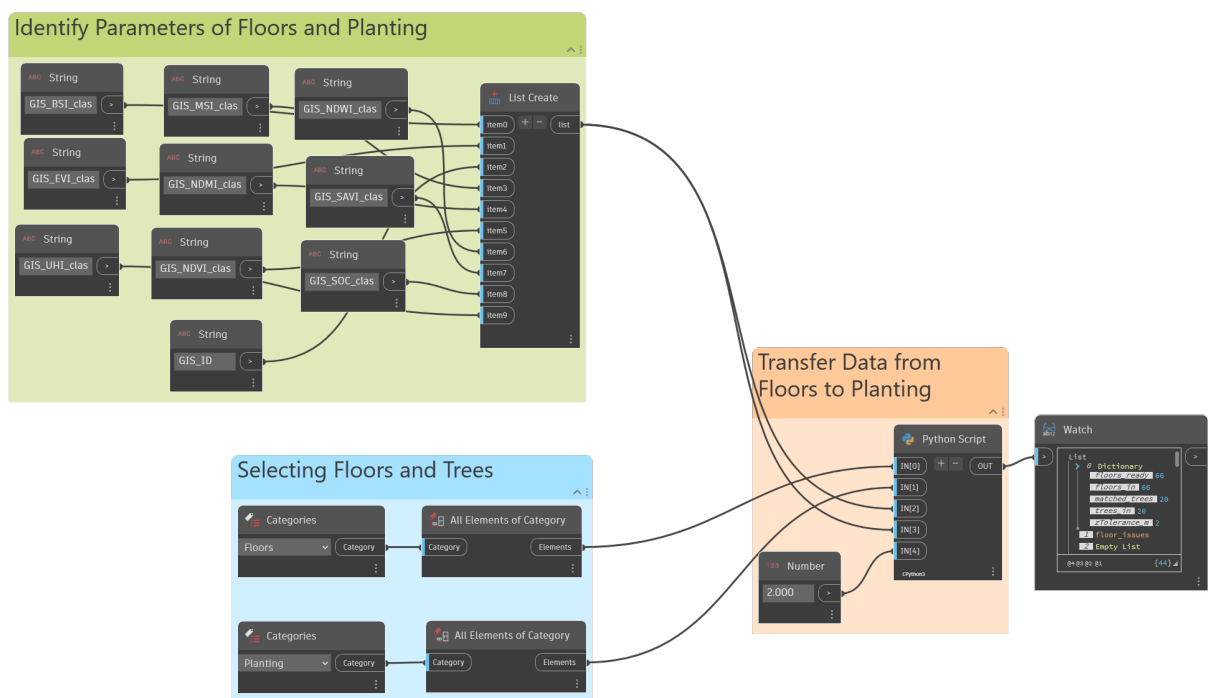
The workflows developed in this section explore two complementary approaches. The first section 3.5.2.1 (Compatibility and verification) focuses on testing the coherence between environmental conditions stored in BIM and the ecological requirements of vegetation elements, ensuring that design choices are environmentally sound. Section 3.5.2.2 (Data as a driver for planting selection) moves a step further, using environmental data as prescriptive inputs to generate planting scenarios in terms of species typology and quantity. Together, these methods illustrate how BIM can support both verification and proactive design strategies in landscape architecture.

3.5.2.1 Compatibility and Verification

The first workflow addresses the verification of compatibility between site conditions and the ecological requirements of vegetation elements. Using the shared key “GIS_ID”, GIS-derived parameters stored in Floors (e.g., “GIS_NDMI_clas”, “GIS_MSI_clas”, “GIS_UHI_clas”, etc.) are automatically transferred from Floors to Planting instances, where they are compared with the family parameters introduced earlier (Water Demand, Drought Resistance, Canopy Cover).

The Dynamo script (Figure 3.20) is executed in automatic mode, ensuring that any modification in either the environmental data of the Floors or the attributes of the Planting families is immediately reflected in the compatibility check. This interactivity transforms the BIM model into a responsive environment, where each planting decision can be verified in real time against the underlying environmental data.

Figure 3.20 - Dynamo workflow for real-time Data Transfer for the Compatibility check



The logic of verification is expressed through a three-tier classification:

- Compatible (green): the environmental conditions match the ecological requirements of the species;
- Warning (yellow): partial compatibility, where the species may adapt but could require additional management measures;
- Incompatible (red): the environmental conditions do not support the species, making planting unsustainable without major interventions.

In the analysed portion of the model, a set of planting elements belonging to different typologies was placed across multiple Floors. These species were not positioned according to a design intention, but distributed under a randomised test scenario, serving exclusively to validate the workflow. This setup allows the workflow to be tested independently from project-driven decisions, ensuring that the compatibility check evaluates the logic of data transfer and parameter matching rather than the outcome of a specific planting design. In the illustrative example shown in Figure 3.21, different planting typologies were distributed across the analysed Floors, each represented by a distinct colour and symbol. Their placement is not intended as a design proposal but as a controlled testing configuration, allowing the compatibility workflow to be demonstrated under varied environmental conditions. This visual representation makes it possible to observe how individual planting instances respond to the underlying GIS-derived parameters, providing a clear and immediate understanding of the verification process.

In order to have a first Compatibility evaluation, Table 3.12 shows different combination of values and results. NDMI high values indicate wetter conditions, favouring high water-demand species. MSI high values correspond to higher drought stress, requiring drought-resistant species. UHI high values indicate microclimatic hotspots, where large-canopy trees are most effective. The classification into Compatible, Warning and Incompatible provides the designer with immediate feedback on the coherence between planting strategies and site conditions.

Figure 3.21 - Test configuration of planting elements across Floors for compatibility validation

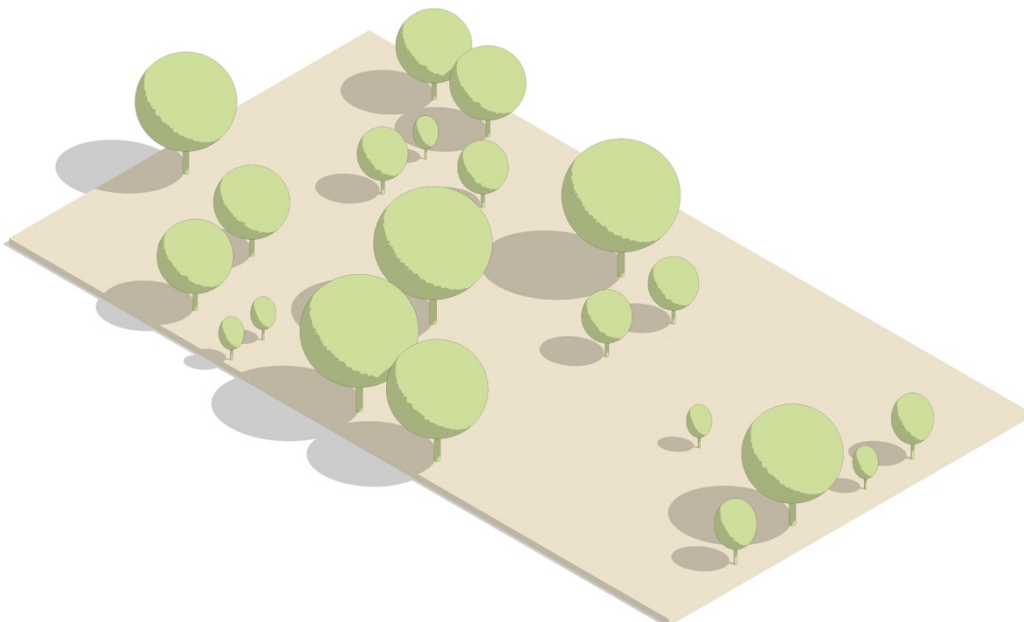
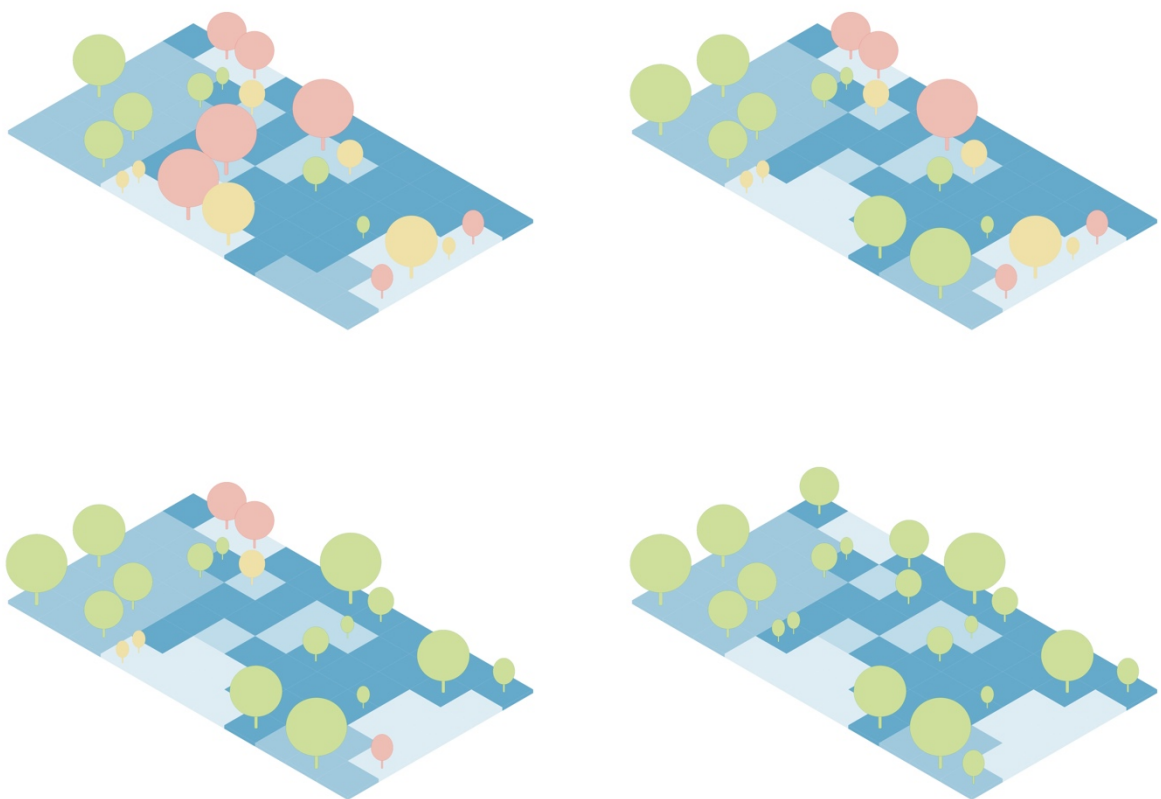


Table 3.12 - Compatibility rules between Planting parameters and GIS-derived environmental classes within Revit floors

Planting parameter	Floor parameter	Class condition	Compatibility
Water Demand (WD)	Normalized Difference Moisture Index GIS_NDMI_clas	WD= Low NDMI = 3-4 (wet to very wet)	Compatible
		WD= Low NDMI = 2 (moderately dry)	Compatible
		WD= Low NDMI = 1 (very dry)	Warning
		WD= Medium NDMI = 3-4 (wet to very wet)	Compatible
		WD= Medium NDMI = 2 (moderately dry)	Warning
		WD= Medium NDMI = 1 (dry)	Incompatible
		WD= High NDMI = 3-4 (wet to very wet)	Compatible
		WD= High NDMI = 2 (moderately dry)	Incompatible
		WD= High NDMI = 1 (dry)	Incompatible
		Drought Resistance (DR)	Moisture Stress Index GIS_MSI_clas
DR= High MSI = 2 (high drought stress)	Warning		
DR= High MSI = 1 (very high drought stress)	Warning		
DR= Medium MSI = 3-4 (low-medium drought stress)	Compatible		
DR= Medium MSI = 2 (high drought stress)	Warning		
DR= Medium MSI = 1 (very high drought stress)	Incompatible		
DR= Low MSI = 3-4 (low-medium drought stress)	Compatible		
DR= Low MSI = 2 (high drought stress)	Incompatible		
DR= Low MSI = 1 (very high drought stress)	Incompatible		
Canopy Cover (CC)	Urban Heat Island GIS_UHI_clas		
		CC= Large UHI = 2 (medium heat stress)	Warning
		CC= Large UHI = 1 (high heat stress)	Warning
		CC= Medium UHI = 3-4 (low-very low heat stress)	Compatible
		CC= Medium UHI = 2 (medium heat stress)	Warning
		CC= Medium UHI = 1 (medium heat stress)	Incompatible
		CC= Small UHI = 3-4 (low-very low heat stress)	Warning
		CC= Small UHI = 2 (medium heat stress)	Incompatible
		CC= Small UHI=1 (high heat stress)	Incompatible

In Revit, compatibility can be directly visualised through colour filters (Figure 3.22). Tree instances are automatically colour-coded (green, yellow, red) based on their compatibility status, providing the designer with an immediate and intuitive overview of where interventions are feasible, risky, or unsustainable. This workflow thus reinforces BIM as a verification tool, ensuring that planting strategies remain coherent with local environmental conditions. A demonstration video of the Dynamo-Revit workflow is available at the following [Link](#). For convenience, for the printed copy reading, a QR code is also provided below.

Figure 3.22 - Revit model with Planting families colour-coded by compatibility status as shown in the filters legend (green, yellow, red); the four steps show how minimal design modifications can align with soil data to achieve full compatibility



Name	Enable Filter	Visibility	Projection/Surf	
			Lines	Patterns
PLANT_WD-NDMI_Low_3-4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_Low_2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_Low_1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_Med_3-4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_Med_2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_Med_1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_High_3-4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_High_2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
PLANT_WD-NDMI_High_1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
GIS_NDMI_clas 1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
GIS_NDMI_clas 2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
GIS_NDMI_clas 3	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
GIS_NDMI_clas 4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		

QR code for demonstration video of the Dynamo-Revit workflow for the Planting compatibility workflow



3.5.2.2 Data as a Driver for Planting Selection

The second approach moves beyond simple compatibility checks and employs environmental data as a generative driver for the planting strategy. The central idea is that the attributes inherited from GIS (e.g., soil moisture, fertility, microclimatic stress) can directly determine the type, location and number of vegetation elements within the BIM environment. In this way, the BIM model evolves from being a static repository of vegetation objects to becoming a tool for simulating different design scenarios based on ecological performance.

While compatibility verification ensures that design choices are aligned with site conditions, the second workflow adopts a more proactive approach: using environmental data as a driver for planting selection. In this case, the attributes contained in the Floors are not only tested against vegetation requirements, but actively guide the definition of species typology and planting density.

In this workflow, each discretised Floor acts as a host surface from which one or more planting instances are generated. The generation process is governed by a set of rules linking the environmental parameters stored in each Floor with the typology of tree to be placed. The mapping follows three main criteria:

- Ecological Suitability - the environmental conditions (e.g., NDMI, BSI, UHI) are interpreted in relation to the ecological requirements of the available typologies (e.g., drought resistance, canopy cover). Only species consistent with the site conditions are considered.
- Design Objectives - once compatibility is established, different project goals can be pursued. For instance, a “low maintenance irrigation” scenario favours trees with low water demand, whereas a “cooling” scenario maximises canopy cover.
- Density of Planting - the number of instances generated within each Floor is proportional to the dimension of the typology (e.g., small canopy trees are placed in higher density than large canopy trees).

The generative workflow developed in this section is based on the assumption that environmental parameters inherited from GIS can drive not only the classification of surfaces but also the creation of vegetation elements within BIM. In this approach, environmental evidence is translated into planting scenarios through four complementary design principles.

The first concerns Low-maintenance irrigation, whereby planting is located in areas that already present relatively favourable conditions in terms of soil moisture and reduced drought stress. Even in these zones, the strategy prioritises species with low water demand, ensuring long-term resilience and minimising the need for artificial irrigation.

A second principle focuses on Soil fertility enhancement, targeting degraded or bare surfaces with low organic content and assigning medium-sized adaptive trees capable of stabilising the soil, improving its structure and supporting progressive ecological recovery.

A third principle responds to Cooling and shading needs in urban hotspots identified through high UHI values and limited vegetation cover; in these areas, large-canopy species are introduced to maximise evapotranspiration and shading, directly mitigating microclimatic stress in line with climate-adaptation objectives.

Finally, in riparian or humid zones species tolerant of saturated soils are selected to reinforce ecological corridors, enhance biodiversity and prevent the inappropriate placement of vegetation in sensitive areas. The intervention strengthens ecological corridors, enhances biodiversity and prevents unsuitable species from being placed in sensitive riparian areas.

Together, these principles ensure that planting is not randomly distributed but strategically aligned with both ecological processes and design objectives. Table 3.13 summarises the operative rules adopted in this workflow.

Table 3.13 - Rules for generative planting selection in BIM

Design Principle	Environmental condition (Floor parameters, classes 1-4)	Selected Typology (examples)	Planting density rule	Design implication
Low-maintenance irrigation	NDMI = 3-4 (moderate-high soil moisture) OR MSI = 3-4 (low-moderate drought stress)	T1_Small (<i>Robinia pseudoacacia</i> , <i>Celtis australis</i>), T4_Large (<i>Quercus ilex</i> , <i>Olea europaea</i>)	2 trees for small canopy; 1 tree for large canopy per 100 m ²	Resilient planting with low irrigation demand, even in currently humid zones
Soil fertility enhancement	SOC = 1-2 (very low-low fertility) OR BSI = 1-2 (high- very high bare soil)	T2_Medium (<i>Acer campestre</i> , <i>Carpinus betulus</i>), T6_Medium (<i>Cercis siliquastrum</i> , <i>Magnolia grandiflora</i>)	1-2 trees per Floor depending on area	Improves soil fertility and stabilises degraded surfaces
Cooling and shading	UHI = 1-2 (high-very high microclimatic stress) OR NDVI/EVI = 1-2 (very low-low canopy vigour)	T3_Large (<i>Quercus pubescens</i> , <i>Fraxinus ornus</i>), T5_Large (<i>Platanus × acerifolia</i> , <i>Salix alba</i>)	1 large-canopy tree per 100 m ²	Reduces urban heat stress through evapotranspiration and shading
Riparian or humid zones	NDWI = 3-4 (moderate-high water presence) AND NDMI = 3-4 (humid soils)	T5_Large (<i>Populus alba</i> , <i>Salix alba</i>)	1 tree per Floor	Enhances riparian buffers, biodiversity and water regulation

The Dynamo workflow developed to operationalise these principles is articulated in two phases. In the first phase (Figure 3.23), the script writes into each discretised Floor the results of the logical rules, assigning three project parameters: GEN-PLANT_Typology (the planting typology derived from environmental conditions), GEN-PLANT_Number (the number of trees to be placed in each unit, calculated according to canopy cover and density rules) and GEN-PLANT_Species (the list of reference species associated with

the typology, retrieved from the i-Tree database). These parameters become part of the BIM database and can be queried, scheduled or filtered as any other attribute, as shown in Figure 3.24.

Figure 3.23 - Dynamo workflow (Phase 1) for identifying planting strategies and assigning typologies and data to the Generative Planting parameters within the Revit Floor units

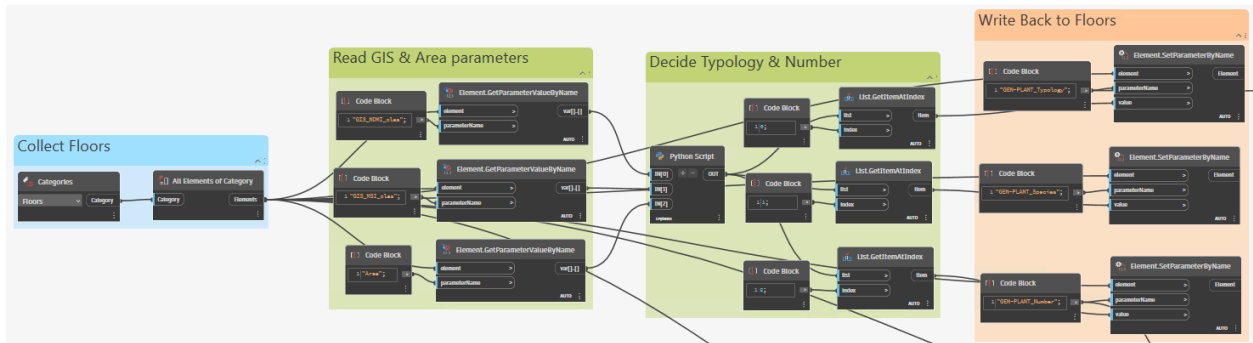


Figure 3.24 - Results of the applied planting-strategy tags within the Revit Floors, including the corresponding visual filters

Floor
GIS_EO Analysis

Floors (1) Edit Type

Constraints

Structural

Dimensions

Identity Data

Image

Comments

Mark

Has Association

GEN-PLANT_Number 1

GEN-PLANT_Species Quercus ilex; Olea europaea

GEN-PLANT_Typology T4_Large

GIS_BSI_clas 4

GIS_EVI_clas 3

GIS_ID 39854

GIS_Intervention_Typ... Soil Remediation

GIS_MSI_clas 2

GIS_NDMI_clas 3

GIS_NDVI_clas 3

GIS_NDWI_clas 2

GIS_SAVI_clas 3

GIS_SOC_clas 1

GIS_UHI_clas 2

Phasing

IFC Parameters

Name	Enable Filter	Visibility	Projection/Surface		
			Lines	Patterns	Transpare...
GEN-PLANT_Typology T1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Override...		Override...
GEN-PLANT_Typology T4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>			
GEN-PLANT_Unclassified	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>			

In the second phase (Figure 3.25), the script uses these same parameters to automatically instantiate the corresponding Planting families. Each Floor is therefore not only semantically classified, but also populated with the correct typology, number and associated species, placed directly at the centre points of the discretisation. This makes the process reproducible and transparent: the logic used for planting selection is embedded in the parameters of the model, while its spatial outcome is visible in real time.

Figure 3.25 - Dynamo workflow (Phase 2) that locates the corresponding planting typology and number of elements on the identified Floor units

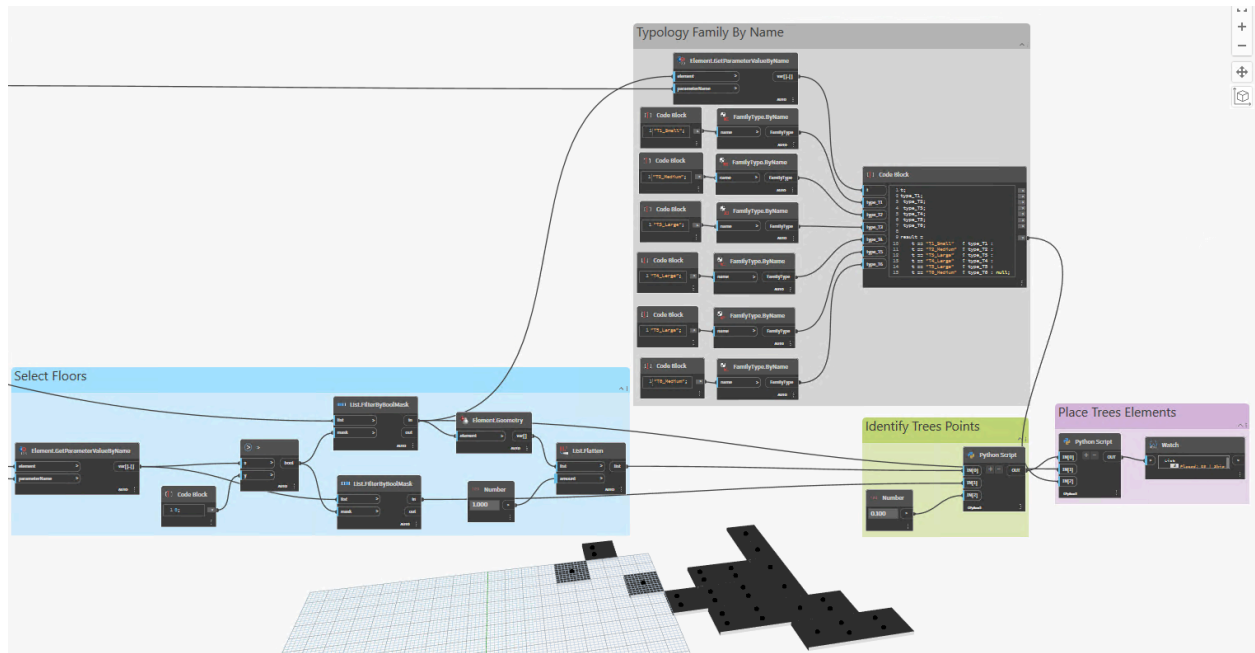
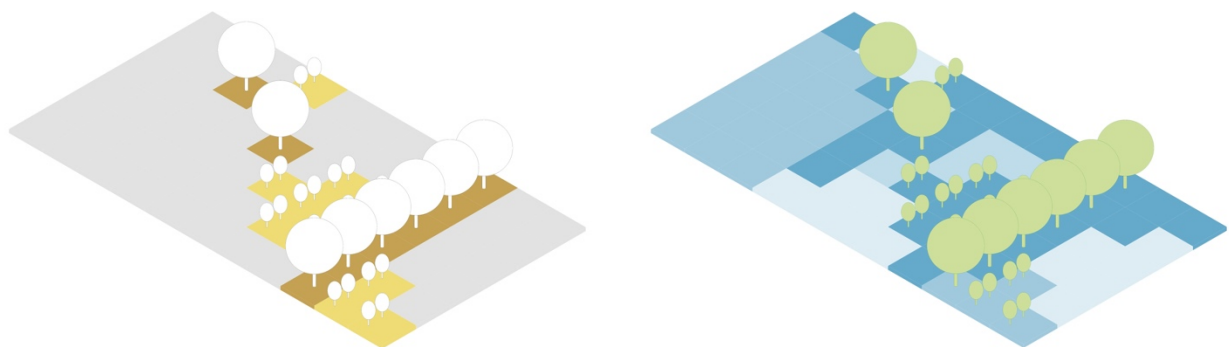


Figure 3.26 - Tree instances generated through the Dynamo script, corresponding to the number and typologies identified in Phase 1 and assigned to the respective Floor elements; on the left, Trees and Planting interventions, on the right full compatibility of the elements and NDMI data



Through this workflow, planting scenarios can be interactively tested and compared. As represented in Figure 3.26, a “low-maintenance irrigation” strategy, for instance, will immediately result in a planting scheme dominated by drought-resistant species, whereas a “cooling” strategy will generate large-canopy trees concentrated in microclimatic hotspots. This allows the designer to evaluate different strategies directly in BIM, using environmental data as prescriptive inputs rather than post-design evaluations.

The result is a model in which vegetation is not randomly distributed but follows explicit ecological and design criteria. This approach opens the way to scenario-based planning, where multiple planting strategies can be simulated, compared and eventually combined, providing the landscape architect with a data-driven design support system embedded in the BIM environment.

3.5.3 Topography-informed Grading

The third generative scenario focuses on terrain modelling, introducing the concept of topography-informed grading. Unlike the previous tests, which primarily addressed data compatibility and planting design, this step aimed to demonstrate how GIS-derived environmental parameters can guide localized morphological adaptations of the terrain itself. The rationale is that landscape design extends beyond vegetation placement, integrating soil grading and microtopographic adjustments as complementary strategies that support hydrological performance, ecological processes and microclimatic regulation (European Commission, 2014; Lal, 2015).

To translate environmental data into actionable design, the workflow identifies a set of guiding principles that operate as a bridge between abstract indices and concrete interventions. Rather than treating indices such as NDMI, SOC or UHI as ends in themselves, they are interpreted as diagnostic layers that reveal vulnerabilities or opportunities in the landscape. From these diagnostics emerge four guiding principles that underpin the micro-grading strategy: drought soil mitigation, soil fertility enhancement, cooling and shading and riparian reinforcement. Each principle synthesises a specific ecological rationale with targeted grading actions, ensuring that terrain modifications are not arbitrary but aligned with measurable environmental processes.

The first principle is Drought Soil Mitigation, where micro-depression zones (swales) are introduced in areas with low water availability. The rationale is that small concavities increase infiltration, reduce runoff and create localised reservoirs of soil moisture, thereby supporting vegetation establishment under stress conditions. These measures are widely applied in agricultural and restoration contexts to mitigate drought and erosion (Shaxson & Barber, 2003).

The second principle is Soil Fertility Enhancement, achieved by raising subtle berms in degraded or erosion-prone soils. Micro-reliefs act as protective barriers, stabilising the surface, accumulating organic matter and slowing water flow. Research in soil conservation highlights how small topographic adjustments can significantly improve soil quality and resilience, particularly in contexts of low organic carbon and bare surfaces (Nichols et al., 2023)

A third principle addresses Cooling and Shading in urban or peri-urban environments. Here, micro-bumps are designed to host tree planting pockets. By enabling the establishment of woody vegetation, these interventions provide shade, enhance evapotranspiration and mitigate local urban heat island (UHI) effects. Numerous studies confirm that even small increments in vegetation cover contribute to reducing heat stress and improving thermal comfort in cities (Bowler et al., 2010; Gill et al., 2007).

Finally, the principle of Riparian Reinforcement concerns the design of shallow, channelled swales in humid or riverine contexts. By directing micro-topographic adaptations along drainage lines, these interventions strengthen riparian buffers, regulate hydrological flows and expand habitats for biodiversity.

Such practices align with international guidelines for stream and river restoration, where morphology is used as a tool to enhance ecological functions (Palmer et al., 2014).

Across these principles, the environmental indices introduced earlier serve as diagnostic tools to identify priority zones and calibrate interventions. Their role is not prescriptive but interpretative, supporting a data-driven framework where grading offset values (small positive or negative grading adjustments) are justified by measurable environmental conditions. The resulting workflow ensures that terrain modelling in BIM (Toposolid elements within Revit software) is not arbitrary, but anchored in ecological reasoning and design intention.

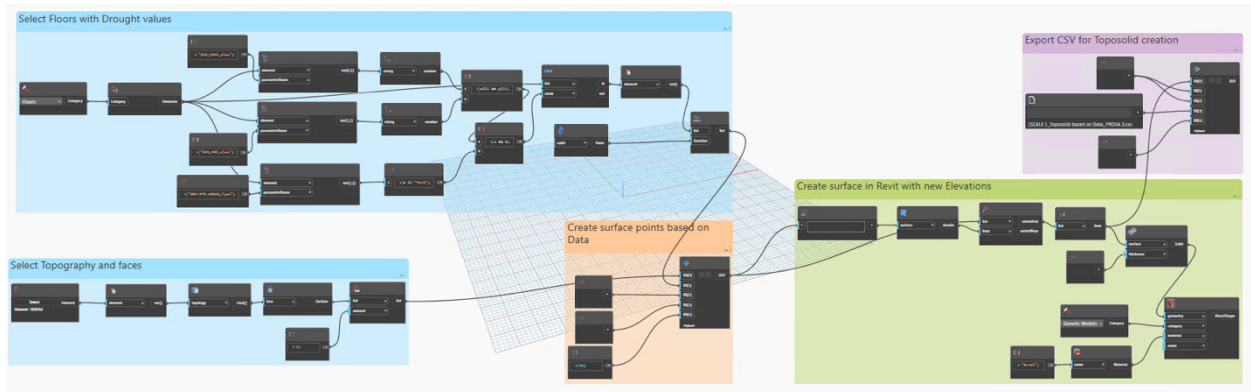
This interpretative framework, summarised in Table 3.14, defines a direct correspondence between environmental conditions and topographic rules, ensuring that earth movements are not generic but explicitly grounded in the data-driven diagnosis of the landscape. In this framework, grading offset values (small positive or negative adjustments) should be understood as preliminary thresholds rather than fixed prescriptions. They provide a first approximation based on measurable environmental conditions and can be modified as required during subsequent design iterations or technical coordination.

Table 3.14 - Correspondence between design principles, environmental conditions and grading interventions

Design principle	Environmental condition (Floor parameters)	Intervention type	Grading offset	Design implication
Drought soil mitigation	NDMI Class 1 (very dry)-2 (dry); MSI Class 1 (very high stress)-2 (high stress)	Swale (micro-depression)	- 0.25 to -0.40 m	Retains water and increases infiltration in dry or stressed soils
Soil fertility enhancement	SOC Class 1 (very low)-2 (low); BSI Class 1 (high bare soil)-2 (moderate bare soil)	Berm (micro-raise)	+0.20 to +0.30 m	Protects soil from erosion, promotes fertility and surface stability
Cooling and shading	UHI Class 1 (very high stress)-2 (high stress); NDVI/EVI/SAVI Class 1 (very low)-2 (low vegetation vigour)	Micro-bump (small raise)	+0.15 m	Creates pockets for tree planting, mitigates heat stress and improves evapotranspiration
Riparian reinforcement	NDWI Class 3 (moderate water presence)-4 (high water); NDMI Class 3 (moderate moisture)-4 (high moisture)	Channelled swale	-0.20 m	Enhances riparian buffer, biodiversity and water regulation

To test this approach, the Dynamo workflow was applied to a selected Toposolid within the Revit environment, focusing on the case of drought soil mitigation (Figure 3.27). The method consisted of four main phases: (1) extraction of Floor elements enriched with GIS attributes, (2) identification of environmental targets (dry or stressed soils), (3) sampling of the existing topography into a regular grid of points and (4) modification of elevation values through a Python script based on rules informed by the environmental indices. The modified point grid was then used to reconstruct a new surface within Revit, visualised as a DirectShape for comparison with the existing terrain.

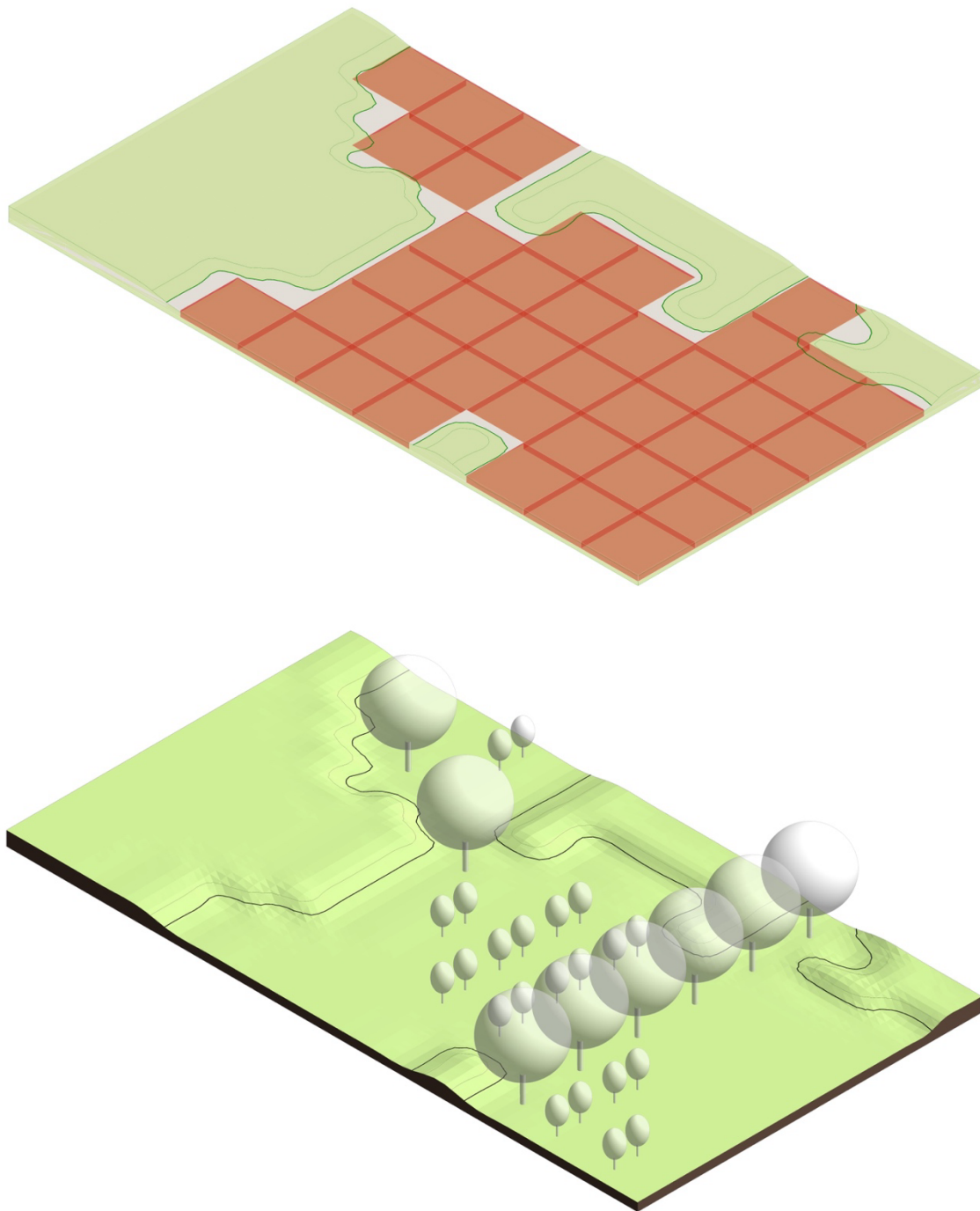
Figure 3.27 - Dynamo workflow for identifying the areas to be modified and generating the new toposolid based on GIS-derived data



The modified point grid was subsequently reconstructed into a new surface within Revit and visualised as a *DirectShape*, allowing direct comparison with the original terrain. This procedure demonstrates how environmental conditions diagnosed through GIS can be systematically translated into parametric grading interventions in BIM. In this case, the generation of swales in areas with limited water availability simulated a design strategy aimed at increasing infiltration and mitigating drought stress, in line with best practices in soil and water conservation.

Before presenting the visual outputs, it is useful to clarify the operation carried out in this step. Once the grading rules were applied to the selected Toposolid, the workflow generated a modified point grid and reconstructed a new surface reflecting the required micro-depressions. In this test, the drought-soil mitigation scenario was simulated not only on the Floors identified as moisture-stressed, but also extended to those hosting planting elements, widening the intervention area and ensuring that trees benefit from increased water availability. This allowed the results of the data-driven intervention to be compared spatially with the original environmental diagnosis, verifying whether the areas affected by drought stress effectively corresponded to the zones where swales were introduced. Figure 3.28 illustrates the visual outcome of this process. The upper image shows the areas identified as having low moisture availability, based on the combined reading of NDMI and MSI classes. These zones appear as continuous spatial clusters rather than isolated points, confirming the capacity of the workflow to detect patterns of environmental stress that may not be immediately evident from raw numerical values. The lower image displays the resulting micro-depressions generated through the grading rules, where the surface is locally lowered to enhance water retention and infiltration. By comparing the two visualisations, it becomes clear how the environmental diagnosis directly informs the topographic response, increasing the potential compatibility of future planting interventions within the most critical portions of the terrain.

Figure 3.28 - Micro-depressions generated through data-driven grading interventions: on the top, Floors classified with critical NDMI and MSI values; on the bottom, Resulting surface modifications produced by the Dynamo workflow, showing swale formations designed to increase infiltration and improve planting compatibility in previously stressed areas



The topography-informed grading experiment illustrates how micro-topographic interventions, such as swales, berms and micro-bumps, can be systematically derived from environmental conditions diagnosed through GIS indices. By operationalising design principles like drought mitigation, soil fertility enhancement, cooling and shading and riparian reinforcement, the Dynamo workflow demonstrated that terrain modelling within BIM can transcend geometric representation to become a data-driven design process. This approach ensures that earthworks are targeted, ecologically grounded and reproducible within digital environments, opening new perspectives for integrating hydrological and ecological intelligence into landscape design. In doing so, as the final experimental workflow developed in this chapter, this marks the transition from proof-of-concept to an operational framework, showing that topographic reasoning can be formalised, tested and iterated within a BIM environment.

The subsequent chapter applies the same logic to real territorial contexts and across multiple spatial scales, demonstrating how the approach can shift from controlled simulation to context-specific decision-making within real territories applications.

3.6 From Digital Workflow to Design Application

Although the workflow developed in this chapter demonstrates the feasibility of GIS-to-BIM integration for landscape projects, it is important to acknowledge that the current implementation represents an initial methodological framework. Some operations still require manual updates, particularly when new GIS datasets are produced, and certain simplifications are necessary to ensure interoperability between platforms. These aspects should not be understood as limitations of the methodology, but rather as natural characteristics of a prototype workflow that can be progressively refined and expanded in future developments.

Beyond these preliminary considerations, the processual path outlined in Chapter 3 highlights the complexity and richness of an integrated workflow for landscape architecture. Each step in the workflow adds a distinct layer of information and design potential, transforming raw environmental data into actionable knowledge. Beginning with Earth Observation analysis (3.1), spectral indices were derived to capture vegetation vigour, soil moisture, organic carbon, bare soil exposure and microclimatic stress. These indices provided a first diagnostic layer, revealing vulnerabilities and opportunities across the landscape. As clarified in the methodological outline presented in Chapter 1.5, the datasets used to test the workflow do not represent the full range of information typically required for a comprehensive landscape project. Rather, they constitute a targeted selection intended to demonstrate the functioning of the process. The workflow, however, is designed to accommodate additional environmental, ecological or planning datasets and can be progressively enriched with all the information necessary for specific project contexts.

Through GIS structuring and interpretation (3.2-3.3), these datasets were georeferenced, interpolated and reclassified into discrete classes, making them both comparable and spatially legible. The introduction of a regular multi-scale grid allowed the information to be organised into a modular system, enabling cross-comparison between indices and scales. GIS thus acted not only as a container of data but as an interpretative platform, where complex environmental conditions were reduced to clear categories that could inform design reasoning.

The subsequent step, transfer into BIM (3.4), addressed the challenge of interoperability, ensuring that geospatially rich but external datasets could become embedded parameters within Revit. By associating environmental attributes with BIM elements, the model acquired a dual identity: geometric representation and environmental intelligence.

Finally, in the generative workflows (3.5), these attributes were operationalised as rules for design. Strategic areas were identified through the cross-analysis of multiple indices. Planting layouts were assigned according to site-specific conditions of fertility, moisture or stress. Micro-topographic grading was tested as a means of supporting hydrological balance, soil stability and microclimatic regulation. What emerges is not a static digital model but a dynamic design framework, where data continuously drives the generation of form, function and ecological performance.

Taken together, these stages confirm that the proposed methodology is more than a proof of concept. It constitutes a ready-to-use workflow capable of guiding the landscape architect in moving from environmental diagnosis to spatial intervention. Its value lies in the ability to integrate multiple sources of information (remote sensing, geospatial layers, classification schemes and parametric rules) into a coherent and replicable process.

What this work ultimately establishes is an effective interoperability between GIS and BIM, which provides the landscape architect with a unified environment where environmental diagnostics, spatial analysis and design modelling can converge (Piras et al., 2024; Schaller et al., 2017). Thanks to this integration, the landscape model can align with the most recent technologies and methodologies while retaining all the instruments and analyses required for rigorous environmental design. This ensures that decision-making is not fragmented, but guided by data from the macro scale to the detail, enabling design that is responsive, evidence-based and ecologically informed (Cepa et al., 2024).

The following chapter 4 - Multiscale Approach Applied to Real Territories applies this workflow to real case studies, testing its effectiveness across different scales and conditions. These applications will demonstrate how the workflow can serve not only to verify and evaluate existing landscapes, but also to generate innovative, data-driven design solutions that respond to ecological and climatic challenges.



4 Multiscale Approach Applied to Real Territories

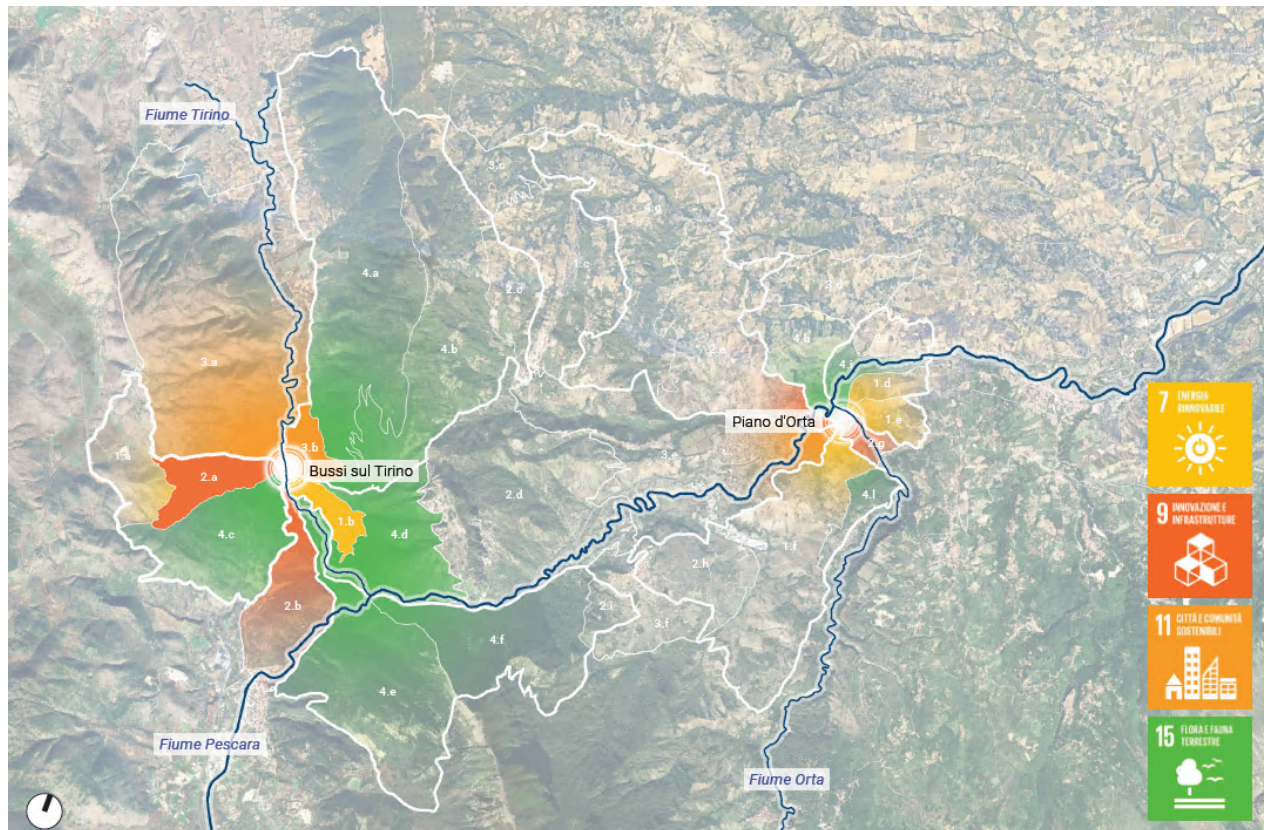
The methodological framework defined in the previous chapter is here tested within a real territorial context, in order to assess its operational applicability and scalability. The chosen case study concerns the area of Bussi sul Tirino and Piano d'Orta, located in the Abruzzo region (Italy), which forms part of the National Interest Sites (Siti di Interesse Nazionale - SIN) due to its historical industrial background and ongoing remediation programmes. This area, positioned along the Tirino River and the Pescara river valley, represents a highly complex system where industrial, ecological, infrastructural and social dynamics converge, making it an exemplary context for testing digital tools and data-driven methodologies in landscape architecture.

The case study area has been the subject of a multiscale regeneration strategy promoted by Edison SpA-Edison Regea s.r.l. in collaboration with LAND Italia Srl, a landscape architecture and planning firm with extensive experience in large-scale regeneration projects worldwide. The strategy combines environmental remediation, landscape restoration and spatial requalification, addressing both ecological and socio-economic challenges. Within this framework, two main intervention areas have been defined: Macroarea 1, located in the Municipality of Bussi sul Tirino within the lower Tirino valley and Macroarea 2, situated in Piano d'Orta (Municipality of Bolognano), as shown in Figure 4.1. The latter, characterised by the remains of the former Montecatini industrial settlement, constitutes a particularly emblematic site for testing digital interoperability within a degraded and environmentally fragile context.

Beyond its design dimension, this project represents a concrete expression of Edison's long-term commitment to the territories in which it operates. The regeneration strategy aims to translate the company's attention to sustainability into tangible actions, promoting processes of ecological transition and environmental restoration. In this sense, the initiative aligns with the principles and objectives of the United Nations 2030 Agenda for Sustainable Development¹⁶, particularly those related to affordable and clean energy (Sustainable Development Goal 7), industry innovation and infrastructure (SDG 9), sustainable cities and communities (SDG 11) and life on land (SDG 15). By coupling industrial remediation with landscape design, the project aspires to redefine the relationship between production, environment and community, offering an example of how private and public actors can collaborate towards shared sustainability goals.

¹⁶ The 17 Sustainable Development Goals (SDGs) part of the 2030 Agenda for Sustainable Development, available at <https://sdgs.un.org/goals>

Figure 4.1 - Redevelopment strategy of Macroareas 1 and 2 in Bussi sul Tirino and Piano d'Orta (Bolognano), in relation to the SDGs. Image courtesy of Edison SpA-Edison Regea s.r.l. and LAND Italia Srl.



The decision to focus on this context is based on its dual character, both territorial and design-oriented. At the territorial level, Bussi sul Tirino and Piano d’Orta are part of a larger ecological and infrastructural system extending along the Pescara valley, where environmental processes such as river dynamics, soil contamination and vegetation regeneration interact across scales. At the local and project level, the area hosts concrete interventions of landscape remediation and requalification that can be reinterpreted and reconstructed within a digital framework. This double nature allows the research to explore how a single methodological workflow can operate across scales, linking broad territorial processes with detailed design actions.

In this perspective, the chapter applies the workflow developed in Chapter 3, which moves progressively from Earth Observation (EO) data to Geographic Information Systems (GIS) and then to Building Information Modelling (BIM). This process establishes a continuous flow from environmental monitoring to spatial analysis and finally to design simulation, allowing information to evolve from large-scale interpretation to project-oriented modelling. The methodology is therefore tested at three different scales of investigation (micro, medium and macro) corresponding respectively to site-specific, urban or municipal and territorial levels of analysis.

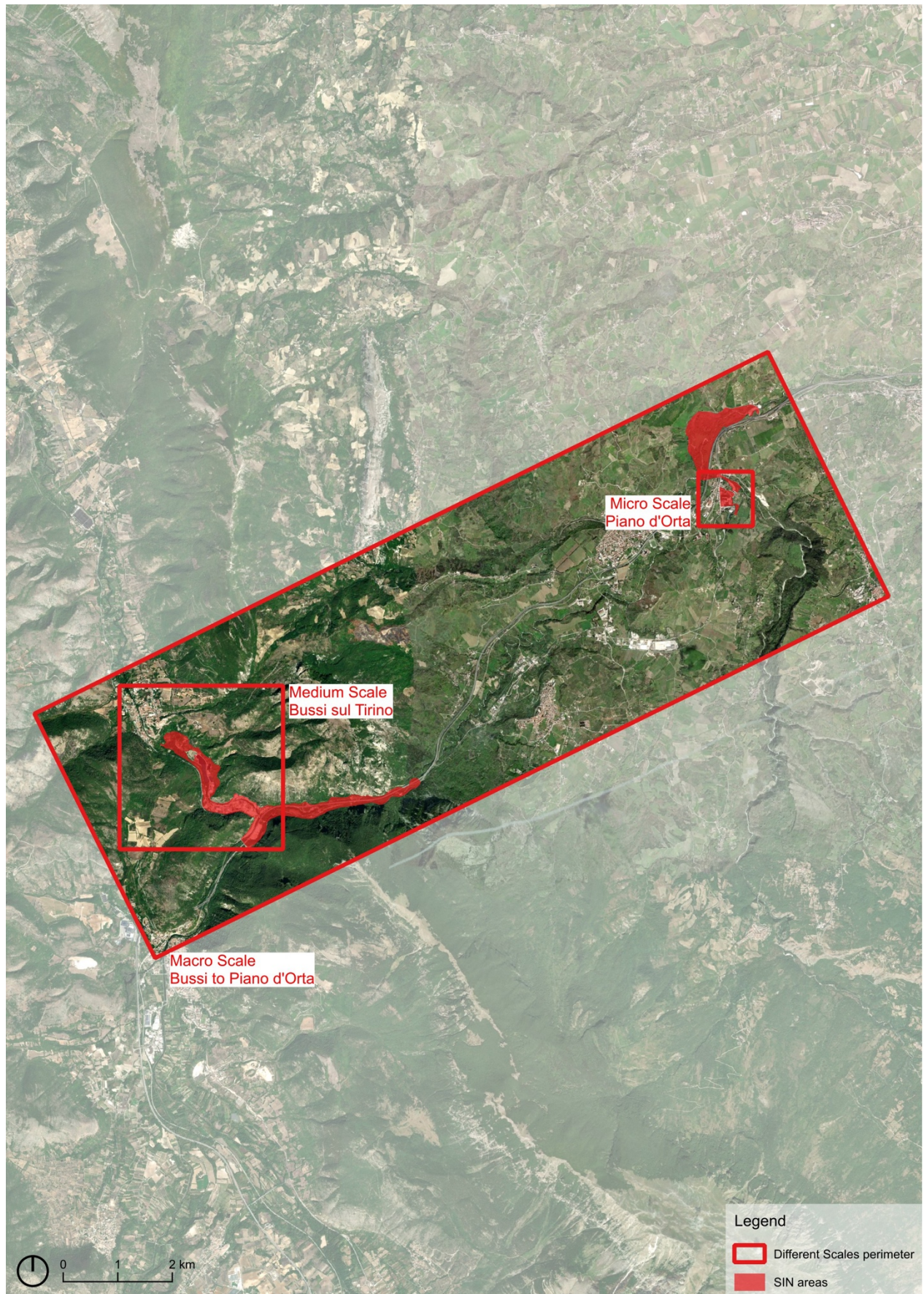
The chapter is therefore structured to demonstrate how the same data-driven methodology can support distinct design objectives at different levels:

- at the Micro scale, corresponding to the Piano d’Orta pilot site, the workflow enables detailed simulations of planting and grading strategies directly within the BIM environment;
- at the Medium scale, focusing on Bussi sul Tirino, the method supports the identification of areas for environmental recovery and regeneration based on combined indices;
- at the Macro scale, covering the river corridor between Bussi and Piano d’Orta, it provides a strategic overview of potential interventions and environmental dynamics at the territorial level.

Through this multiscale application, this chapter aims to demonstrate both the potential and limitations of GIS-BIM interoperability and BIM design actions when applied to real design contexts. The results not only allow the validation of the proposed workflow in practical scenarios but also contribute to a broader reflection on how digitalisation can enhance landscape design processes at multiple scales, ensuring consistency between territorial strategies and project implementation.

The chapter is organised into five main sections. Section 4.1 introduces the rationale behind the multiscale structure, explaining how different levels of spatial resolution modify the nature of the workflow’s outputs. It defines the three operational scales (Micro, Medium and Macro) and clarifies the relationship between data density, modelling complexity and design intent, supported by the comparative framework presented in Table 4.1. Section 4.2 presents the Micro scale, focusing on the Piano d’Orta site, where the full EO-GIS-BIM workflow is tested through design verification and the generation of new scenarios. This section is articulated into two parts: verification of the existing project without data (4.2.1) and the creation of data-driven alternatives (4.2.2), including strategic-areas mapping, planting simulation and topography-informed grading. Section 4.3 expands the workflow to the Medium scale, applying it to the wider Bussi sul Tirino area in order to identify environmental recovery zones through the integration of classified indices and territorial datasets. Section 4.4 further scales up the methodology to the river corridor at Macro level, using a coarser grid and emphasising large-scale ecological patterns and priority intervention areas derived from strategic environmental indicators. Finally, Section 4.5 reflects on the representational and communicative dimension of the workflow, discussing how digital tools support the visual synthesis of multiscale outputs and prepare the transition to the methodological reflections developed in Chapter 5. Together, these sections demonstrate how a consistent data-driven workflow can adapt to multiple spatial scales, producing differentiated yet coherent design insights, from detailed project scenarios to strategic territorial interpretations, while maintaining continuity between environmental evidence and spatial reasoning.

Figure 4.2 - Different Areas of Case studies: Micro, Medium and Macro scales.



4.1 From Micro to Macro: Different Scales for Different Outputs

The methodological workflow developed in Chapter 3 was conceived as a flexible system, adaptable to different levels of spatial detail and information density. Its scalability allows the same logic of data acquisition, processing and integration to be applied across diverse contexts, from detailed design sites to territorial analyses. This flexibility responds to one of the central challenges in contemporary landscape research: the capacity to operate across scales while maintaining coherence between data resolution, spatial representation and design intent (Forman, 1995; Turner & Gardner, 2015). However, as the scale of application changes, as well as the objectives, the available data and the type of outcomes that can be achieved.

The multiscale approach adopted in this thesis reflects the intrinsic nature of the landscape, which operates through interconnected processes extending from the local to the regional scale. As highlighted by Batty (2017) and Liu & Nijhuis (2021), spatial systems are inherently hierarchical and relational, where local morphologies are conditioned by broader territorial dynamics. Understanding this interdependence is crucial to ensuring that design interventions are not isolated actions, but rather parts of broader ecological and infrastructural systems. The digitalisation of the landscape, through the integration of Earth Observation (EO), GIS and BIM with the use of computational tools, provides an opportunity to represent and analyse these relations with precision and consistency. Digital interoperability, in this sense, allows the designer to navigate fluidly between levels of abstraction, from satellite-derived indicators to site-specific design elements, preserving the continuity between analysis and project.

In this framework, the workflow was tested at three distinct yet complementary scales, each corresponding to a specific level of design investigation, as represented in Figure 4.2: Micro scale, Medium scale and Macro scale.

At the Micro scale, represented by the Piano d'Orta pilot area, the focus is on the detailed reconstruction of the project and on the exploration of alternative scenarios generated through the direct integration of environmental data within BIM. This scale allows for a comprehensive application of all three workflows presented in Chapter 3, the identification of strategic areas, the association of data with planting design and topography-informed grading, thus enabling the validation of the entire methodological sequence. The Micro scale corresponds to a delimited area of approximately 1×1 km, with a specific design focus of approximately 6 ha within the former Montecatini industrial site. Here, Copernicus-based datasets are discretised through a 10×10 m grid, providing high-resolution indicators that can be directly transferred into BIM. This level of precision enables a one-to-one correspondence between spatial data and design components, allowing environmental parameters to influence planting, soil and terrain modelling choices directly.

At the Medium scale, focusing on Bussi sul Tirino and its surrounding areas, the workflow is adapted to support strategic design decisions related to environmental recovery. The analysis operates with a lower spatial resolution and a simplified set of parameters, privileging synthetic outputs that can guide regeneration strategies rather than detailed design solutions. The Medium scale covers an area of approximately 3×3 km, including the town of Bussi sul Tirino and its surroundings. In this case, environmental data are aggregated into a 30×30 m grid, suitable for identifying manageable intervention zones. At this intermediate level, the workflow functions as a design-support instrument, enabling comparisons between different environmental conditions and facilitating the identification of areas where data-driven regeneration strategies may be prioritised.

Finally, at the Macro scale, the methodology is applied along the territorial corridor connecting Bussi and Piano d'Orta, where it serves as a diagnostic and interpretative tool to identify potential intervention zones and to visualise the interactions between environmental processes and infrastructural systems. Here, the workflow functions primarily as a form of landscape intelligence (Steinitz, 2012), providing a structured framework for territorial interpretation and strategic planning. The Macro scale spans approximately 5×15 km along the Tirino and Pescara river valley, establishing a territorial connection between Bussi sul Tirino and Piano d'Orta. Environmental data are reclassified into a 100×100 m grid, which enables the identification of broad intervention areas while minimising local detail. This configuration allows the model to capture overarching patterns of degradation, vegetation dynamics and hydrological connectivity, linking local design actions to regional environmental systems.

Across these three levels, the same logic of interoperability is maintained: information derived from EO and GIS is progressively translated into the BIM environment, where it informs design-oriented representations and simulations. The outputs vary in form and purpose, from detailed parametric models to schematic territorial maps, but they are all generated through a consistent digital process. By testing the workflow across scales, the research not only demonstrates its technical adaptability, but also explores its epistemological implications: how digital tools can mediate between quantitative analysis and qualitative design, between environmental data and creative decision-making (Cantrell & Mekies, 2018; Zajickova & Achten, 2013). This multiscale experimentation aims not only to demonstrate the flexibility of the proposed workflow, but also to reflect the dynamic and systemic nature of the landscape itself, in which every local action is embedded within wider spatial and ecological relationships.

To ensure the consistency of the workflow across different scales, a structured framework was defined to relate the extent of the area, the data resolution and the expected design output. Each level of analysis corresponds to a distinct balance between information density and spatial abstraction, reflecting the relationship between environmental knowledge and design intent. The following Table 4.1 summarises the main features of the three operational scales highlighting how variations in data resolution influence the applicability of the workflow and the nature of the outputs.

Table 4.1 - Comparison of the three scales and their corresponding data structures and design outputs

Scale	Area and extent	Data resolution / grid size	Workflow applied	Design focus / objective	Type of output
Micro scale	Piano d'Orta pilot site (approx. 1 × 1 km; design area ≈ 6 ha)	10 × 10 m	Strategic areas, Planting design, Topography-informed grading	Verification of existing design and generation of alternative data-driven scenarios	Detailed BIM model (Floors, Planting, Topography) with parametrically linked environmental data
Medium scale	Bussi sul Tirino and surroundings (approx. 3 × 3 km)	30 × 30 m	Strategic areas, Planting design	Identification of regeneration zones and simulation of landscape recovery strategies	GIS-BIM integrated model for environmental planning and visual mapping
Macro scale	Territorial corridor along Tirino-Pescara valley (approx. 5 × 15 km)	100 × 100 m	Strategic areas	Definition of priority intervention areas and territorial connections	Large-scale schematic maps and interpretative territorial models

Note: The progressive variation in data resolution and model complexity reflects the relationship between scale and purpose: at the micro level, precision supports design detailing and direct parametrisation; at the medium level, synthesis allows for strategic decision-making; at the macro level, abstraction facilitates territorial reading and scenario definition.

The following three sections illustrate the application of the workflow at the micro, medium and macro scales, each corresponding to a different level of design investigation and data complexity. Together, they constitute a progressive sequence of experiments aimed at testing the interoperability between GIS and BIM across diverse spatial contexts. Through this multilevel application, the research evaluates not only the technical feasibility of GIS-BIM integration, but also its conceptual adaptability, how a consistent digital process can generate different types of knowledge and design outcomes depending on scale, resolution and purpose.

Figure 4.3 - Actual condition of the Micro scale area case study: Piano d'Orta in the Municipality of Bolognano



4.2 Micro Scale: Different Data-Driven Project Scenarios

The micro scale represents the most detailed level of the multiscale experimentation and serves as the main testing ground for the proposed methodology. At the core of this application lies the existing landscape project developed by LAND Italia in collaboration with Edison SpA-Edison Regea s.r.l., within the broader regeneration strategy of the National Interest Sites (SIN) of Bussi sul Tirino and Piano d’Orta. The project, located in the area of the former Montecatini industrial complex, covers approximately 6 hectares and focuses on the ecological and spatial requalification of a contaminated and degraded site, through the restoration of soil quality, vegetation systems and landscape continuity.

The existing design aims to reconcile ecological recovery with new energy production and public accessibility. A key requirement set by the client concerns the inclusion of an ecovoltaic¹⁷ park within the site, while retaining part of the existing industrial structures as testimonies of local heritage. Based on these keypoints, the proposal includes six main spatial components, as shown in Figure 4.4: (1) an equipped sports park located in the northern part of the site; (2) the historic access to the park, reconnecting the former industrial area to the settlement fabric; (3) a green boulevard, acting as a linear connector and visual axis; (4) a parking area integrated with vegetation to reduce impermeable surfaces; (5) the landscape integration of an ecovoltaic power plant, consisting of solar fields organised in orthogonal bands; (6) the “Sun Avenue”, a tree-lined promenade crossing the photovoltaic area and linking the park to the river corridor.

Figure 4.4 - Project of the Piano d’Orta area, part of the Masterplan. Image courtesy of Edison SpA-Edison Regea s.r.l. and LAND Italia Srl.



¹⁷ Ecovoltaic: an integrated approach to photovoltaic development that combines renewable energy generation with environmental conservation, biodiversity protection and the socio-economic sustainability of local territories

This project represents a concrete expression of Edison's commitment to sustainability and to the territories in which it operates, translating the company's environmental objectives into spatial design actions.

The proposed project alternatives of this thesis form the basis of the research application, which seeks to determine whether the proposed GIS-BIM approach can support design decisions that meet both environmental and programmatic requirements. The experiments presented in this chapter therefore aim to test the workflow's capacity to evaluate, compare and generate spatial configurations that respond to the client's expectations while maintaining ecological and landscape coherence.

Rather than just redefining the project, the research builds upon it, using it as a two-step experimental framework to test the applicability and potential of the proposed GIS-BIM approach.

In a first phase, the existing project is reconstructed within the BIM environment and connected to the geospatial structure previously described, allowing for a verification of its coherence with the environmental conditions derived from GIS and EO analysis. This step enables an evaluation of how effectively the current design responds to site-specific constraints such as soil quality, vegetation vigour, or microclimatic stress.

In a second phase, the same methodological framework is used as a generative design tool, developing new data-informed configurations based on both the client's objectives, as defined in the broader regeneration strategy promoted by Edison SpA-Edison Regea s.r.l. and the results of the environmental analysis. These alternative scenarios explore how integrating GIS parameters into the BIM model can guide the definition of planting layouts, terrain modelling and overall spatial organisation, fostering an adaptive design process grounded in environmental evidence.

Before reaching the design phase, it is essential to obtain all the necessary environmental parameters that will inform subsequent project development. This includes a comprehensive analysis of the intervention area, followed by the construction of a BIM model specifically dedicated to the simulation and evaluation of design scenarios. The analytical phase, therefore, precedes and supports the modelling one, ensuring that the digital representation of the site is not merely geometric but enriched with meaningful environmental information. The following paragraphs briefly outline this process, summarising the main operations previously described in detail in Chapter 3, from the acquisition of EO datasets to the reclassification of indices and their transfer into the BIM environment, before focusing on how these data are interpreted for project purposes.

At Micro scale, the workflow follows the complete sequence from Earth Observation (EO) to GIS and BIM, translating raw spectral information into project-oriented knowledge. To provide a more comprehensive spatial context for this experimentation, the analysis area was extended beyond the project boundaries to a 1×1 km frame. This broader perimeter captures the surrounding environmental dynamics, topographical gradients and infrastructural connections that influence the site, offering a more integrated understanding of local-territorial relationships.

The process begins with the acquisition of EO Images from Copernicus Browser, from which a set of environmental indices are extracted. Each indicator captures specific environmental conditions such as vegetation vigour, soil moisture, surface degradation, or microclimatic stress. In detail, the dataset included in the analysis are:

- Vegetation and Ecology - NDVI and EVI for quality and extension of vegetated areas;
- Water and Moisture - NDMI, NDWI and MSI for the water and moisture availability within the soil and the relative drought stress;
- Soil conditions - BSI and SOC for the identification of contaminated and barren sites;
- Disturbance conditions - UHI for highlighting the thermal stress areas.

Once processed, these raster datasets are normalised and reclassified into four standardised classes and discretised within a 10×10 m grid, providing the geometric framework for interoperability with BIM.

This grid-based approach transforms continuous spectral information into discrete, design-readable units. Each cell stores classified environmental attributes, functioning as a “knowledge unit” within the spatial model. Within the GIS environment, these layers are visualised and compared, generating a composite matrix of relationships among ecological, morphological and anthropogenic factors.

At the same time, to ensure that the digital model accurately represents the current conditions of the area, the land use dataset was integrated into the GIS model. These layers were obtained from the official Geoportale of Regione Abruzzo, using the Carta Tecnica Regionale¹⁸ (Regional Technical Cartographic - CTR) at a 1:10000 resolution. This additional level provides detailed information on existing land cover, road networks and settlement patterns. The combination of EO-derived indices with regional cartographic data enables a multi-dimensional understanding of the site, linking analytical precision with contextual awareness.

In the following pages, Figure 4.4, Figure 4.5, Figure 4.6 and Figure 4.7 illustrate how each environmental index has been analysed, processed and adapted to the 10×10 m grid, ensuring both an accurate spatial interpretation and a simplification of the original datasets. This operation guarantees that the EO-derived information remains legible, comparable and ready for subsequent transfer into the BIM environment.

¹⁸ Available at <http://opendata.regione.abruzzo.it/content/dbtr-regione-abruzzo-scala-110000-edizione-2007-formato-shp>

Figure 4.5 - Land Use map of the Micro scale, NDVI and EVI indices showing the EO-to-GIS process from Copernicus Browser imagery to grid adaptation (10×10 m) and classification into four standardised environmental classes for BIM integration.

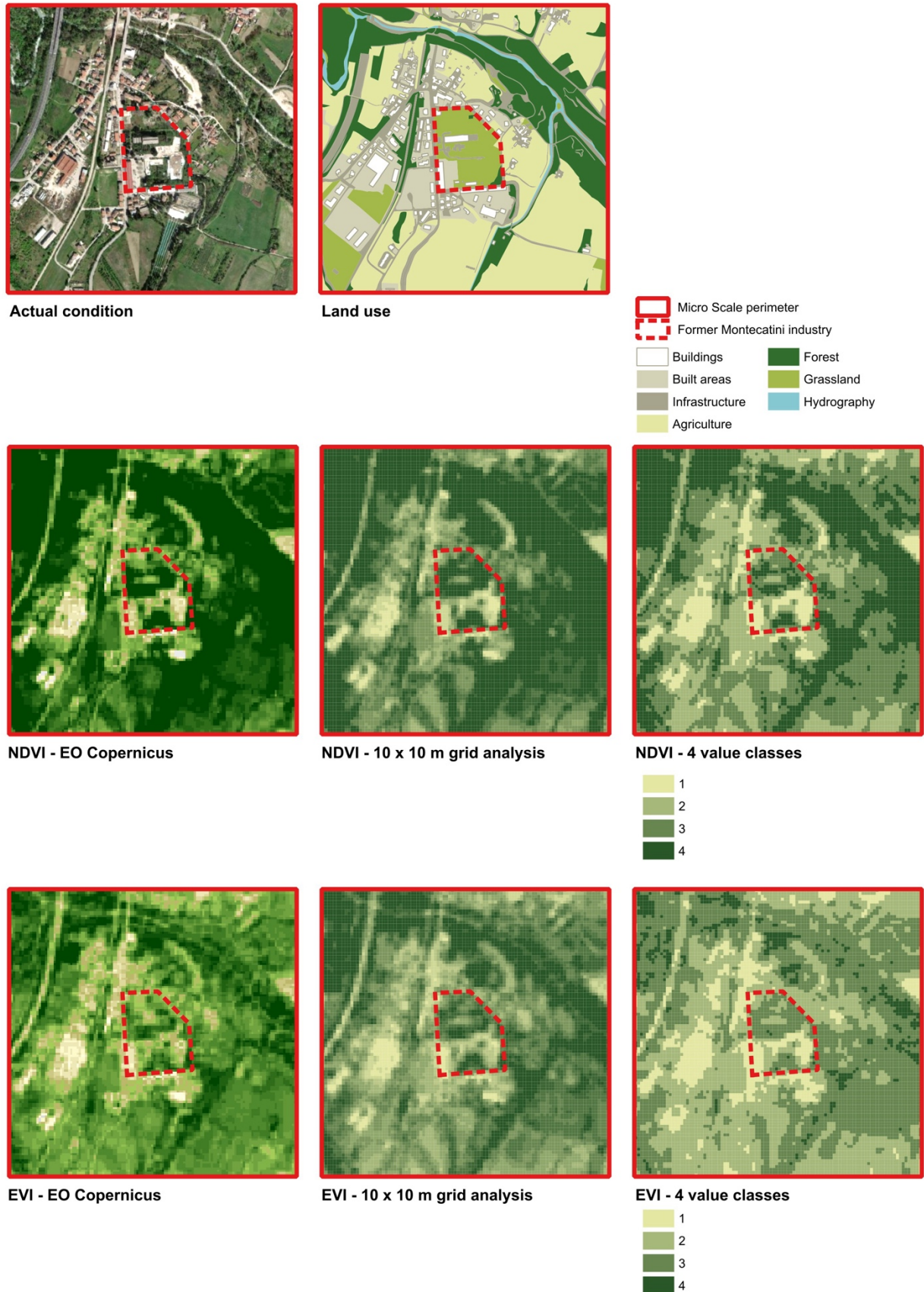


Figure 4.6 - NDWI, NDMI and MSI indices showing the EO-to-GIS process from Copernicus Browser imagery to Micro scale grid adaptation (10 × 10 m) and classification into four standardised environmental classes for BIM integration.

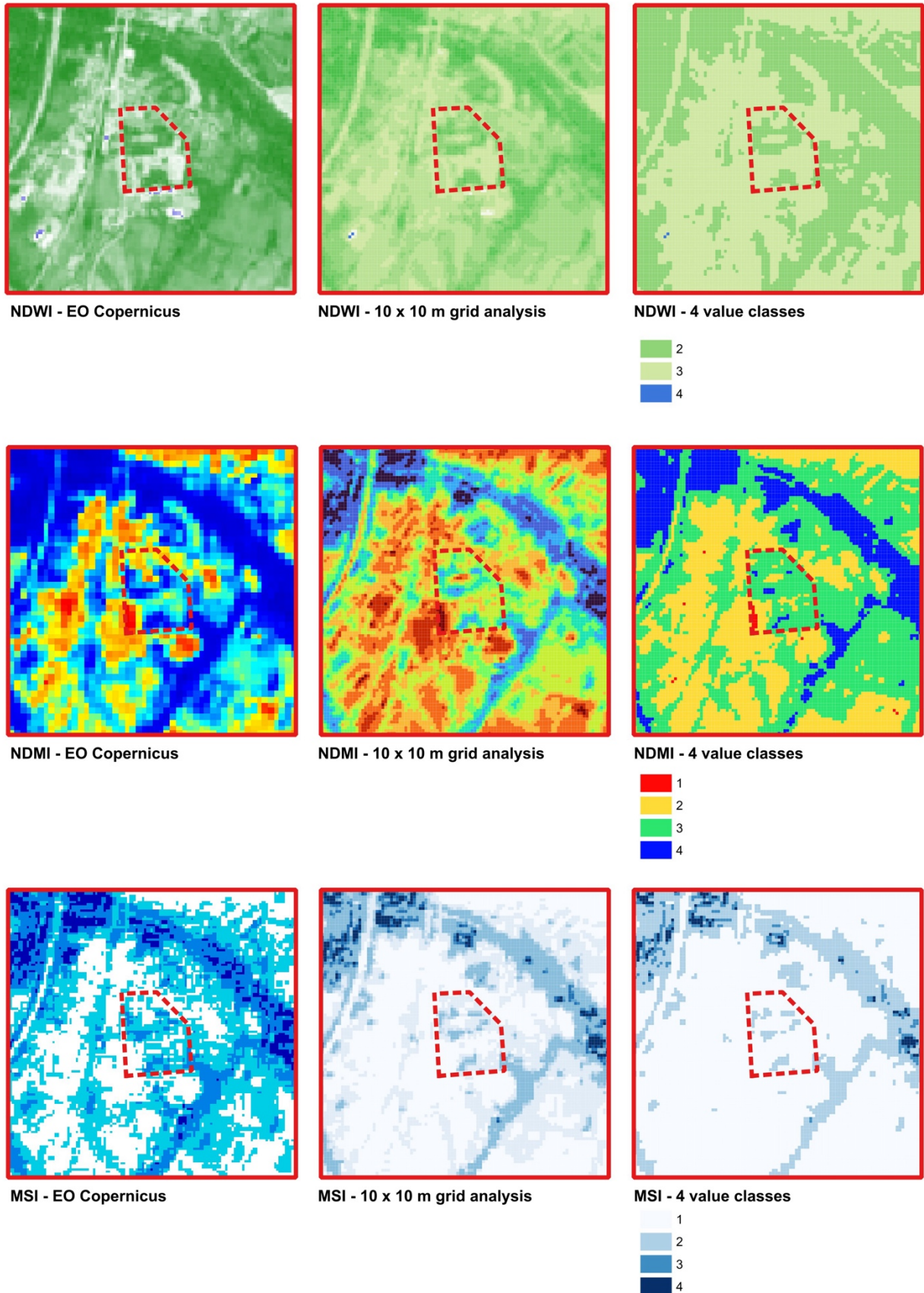
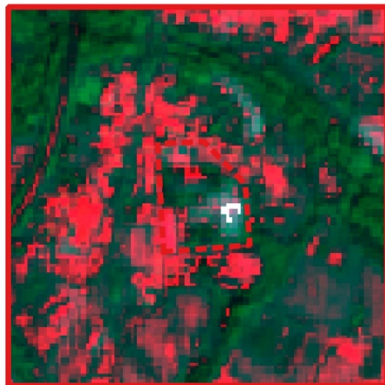
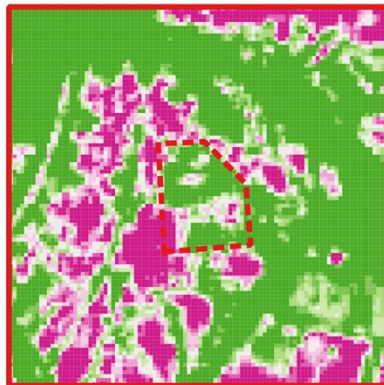


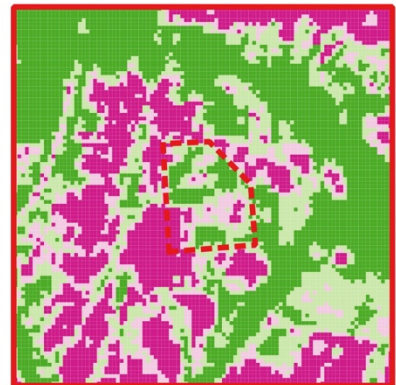
Figure 4.7 - BSI, SOC and UHI indices showing the EO-to-GIS process from Copernicus Browser imagery to Micro scale grid adaptation (10 × 10 m) and classification into four standardised environmental classes for BIM integration.



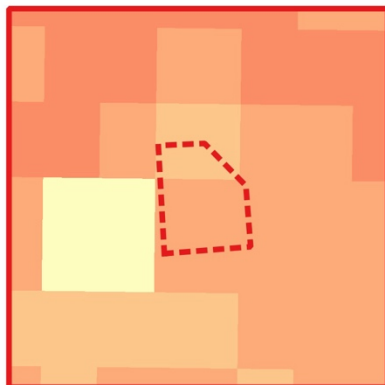
BSI - EO Copernicus



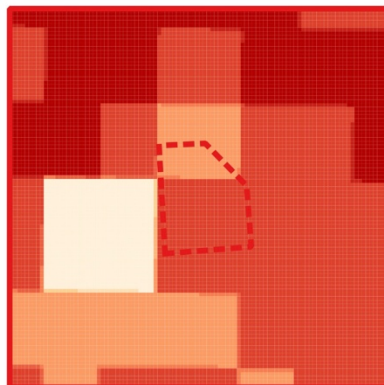
BSI - 10 x 10 m grid analysis



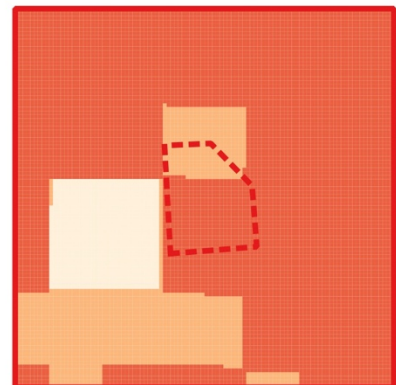
BSI - 4 value classes



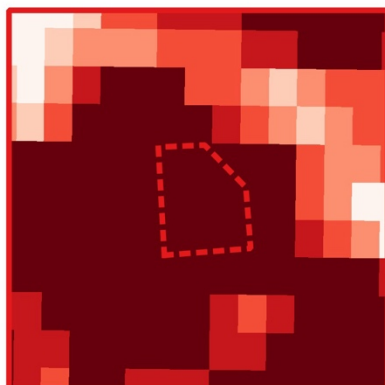
SOC - EO Copernicus



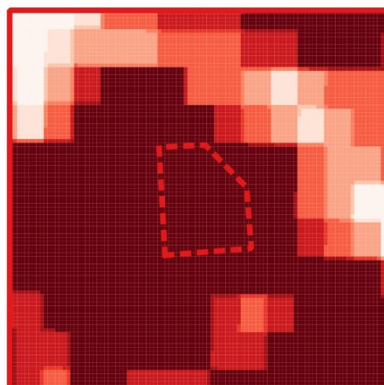
SOC - 10 x 10 m grid analysis



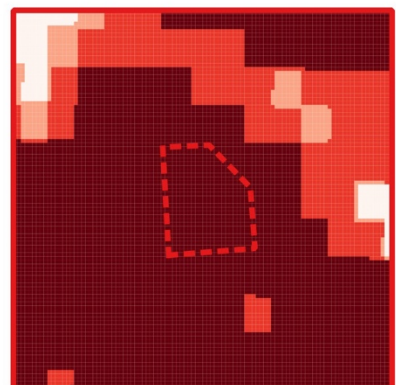
SOC - 4 value classes



UHI - EO Copernicus



UHI - 10 x 10 m grid analysis



UHI - 4 value classes



Before the data are imported into Revit, an intermediate phase is conducted in InfraWorks, which provides a comprehensive territorial reconstruction and a smoother transition from GIS to BIM. Using the Model Builder tool, a detailed 3D terrain model was generated, including roads, hydrography and the main morphological features of the area. This model functions as a digital base that allows the contextualisation of the 1×1 km study area within the broader valley system.

The integration of EO data within InfraWorks enables a first visual comparison between the raster information (e.g., vegetation indices and soil moisture maps) and the physical morphology of the territory. By overlaying the raster datasets onto the 3D surface, it becomes possible to observe how environmental conditions correspond to the terrain, slope exposure and land use distribution. However, it is important to note that InfraWorks operates as a visualisation and analysis platform rather than a parametric modelling tool: the EO-derived rasters imported into InfraWorks cannot directly interact with other model elements such as vegetation, infrastructures or designed objects. Their function remains informative and supportive, helping to interpret spatial patterns before entering the design-driven BIM environment.

The following Figure 4.8 and Figure 4.9 show the consistency of the InfraWorks model and its overlay with an example of selected EO raster analysis.

Figure 4.8 - InfraWorks model of the Micro Scale, generated through Model Builder, including the surrounding hydrographic and infrastructural systems

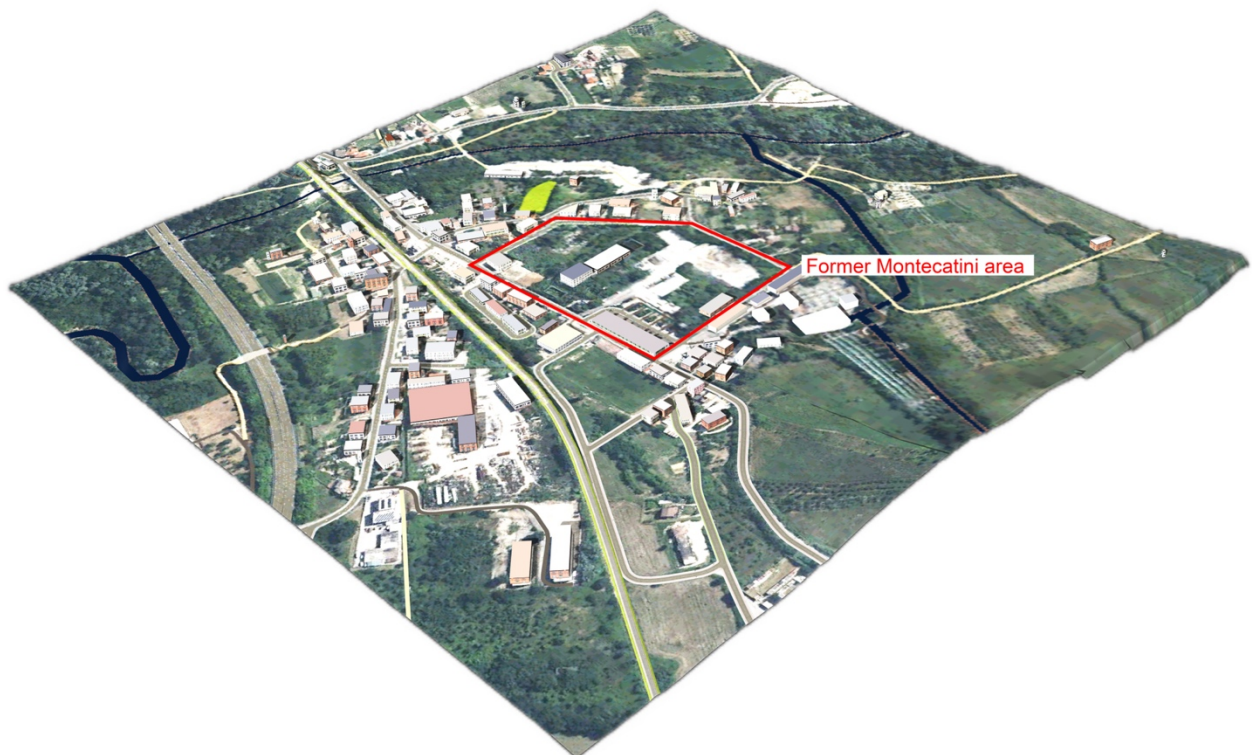
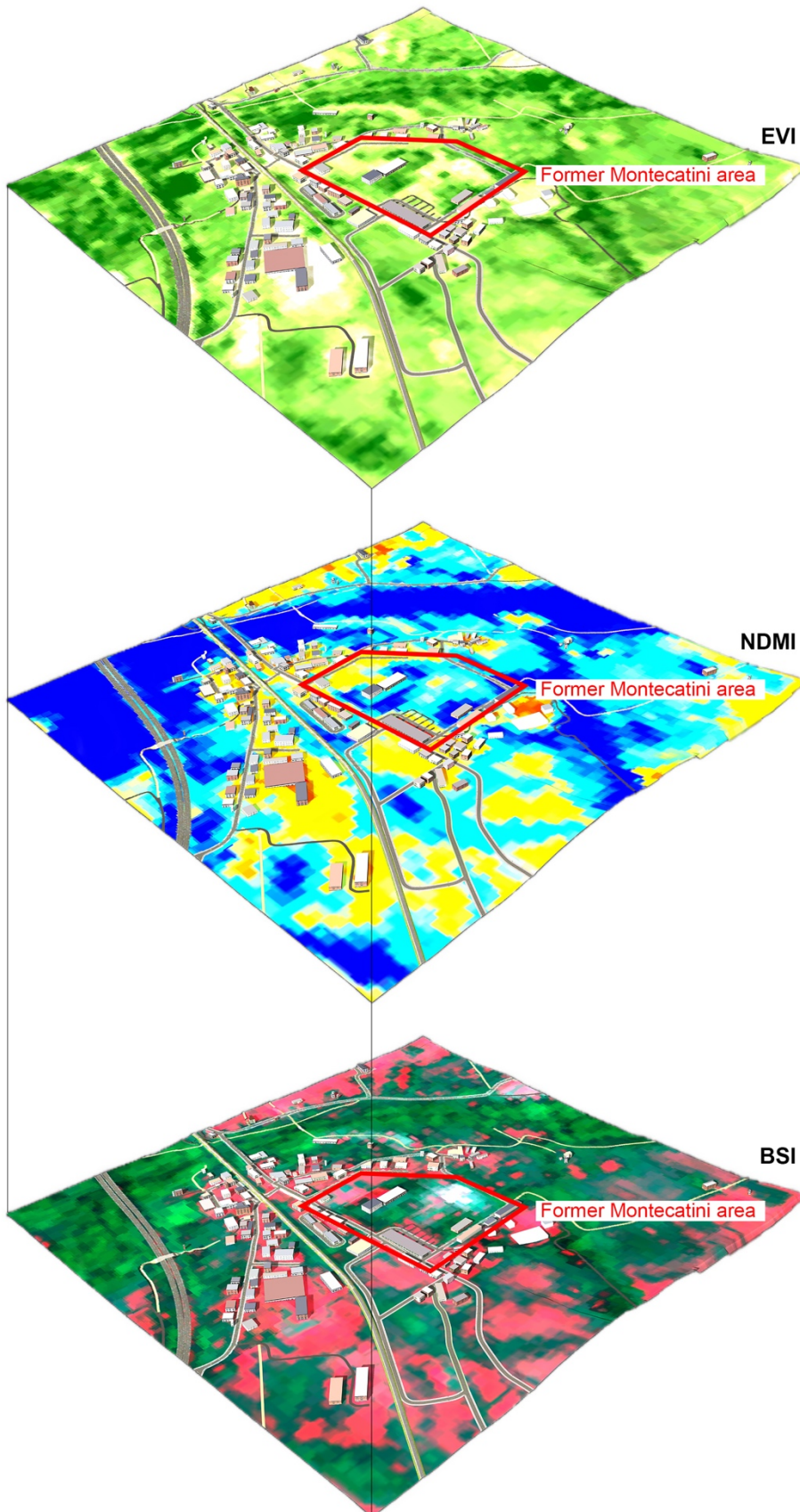


Figure 4.9 - InfraWorks model enriched with selected raster datasets (e.g., EVI, NDMI and BSI), highlighting how environmental gradients correspond to the terrain at the Micro scale



After verifying and aligning the InfraWorks model with the GIS base, it is exported to Revit, where the analytical grid is imported and used as a reference framework for linking environmental data to design entities. This passage marks the transition from an analytical environment to a design-oriented one, where data cease to be external references and become embedded within the modelling logic itself.

At this stage, each cell of the 10×10 m grid is converted into a Revit Floor element, serving as the basic unit for data integration and subsequent design operations. The classified attributes derived from GIS are transferred to these BIM elements through Dynamo-based scripts, which automate the reading, matching and writing of parameters within the Revit environment. The imported values include indices (e.g., GIS_NDVI_clas, GIS_MSI_clas, GIS_SOC_clas, etc.) corresponding to the thematic layers produced during the GIS phase. This automated process ensures the consistency and traceability of information, reducing the risk of data loss or misalignment during the transfer between platforms.

Beyond the technical integration, this phase also represents a conceptual shift: the environmental parameters no longer operate as external datasets to be interpreted separately, but as active properties of the BIM elements, directly queryable, filterable and visualisable within the model. Each Floor thus becomes a semantic object, capable of expressing not only its geometric attributes but also its environmental condition within the site.

Through this operation, the BIM model evolves from a purely geometric representation into a parametric and information-rich environment, where the relationships between terrain, vegetation and environmental performance can be explored through dynamic simulations. In this context, topography, planting families and system elements can be associated with environmental data, enabling the development of rule-based or conditional design scenarios. This integrated structure allows the designer to test multiple alternatives, verify consistency with ecological evidence and progressively refine the model based on measurable spatial conditions.

Ultimately, this interoperability step establishes the base for the subsequent analyses and design scenarios, transforming the BIM model into a dynamic interface between environmental information and design decision-making.

The following Figure 4.10 and Figure 4.11 show a series of axonometric visualisations produced in order to illustrate the integration of environmental data within the BIM environment. These representations clarify how the classified grid and corresponding parameters are structured in Revit and how analytical information progressively connects with design elements. The sequence highlights the transition from environmental analysis to project modelling, revealing the hierarchical composition of the digital landscape model.

Figure 4.10 - Revit environment after data import, where the classified grid and environmental parameters at the Micro scale are visible within the BIM environment, the indices EVI, NDMI and BSI are represented below

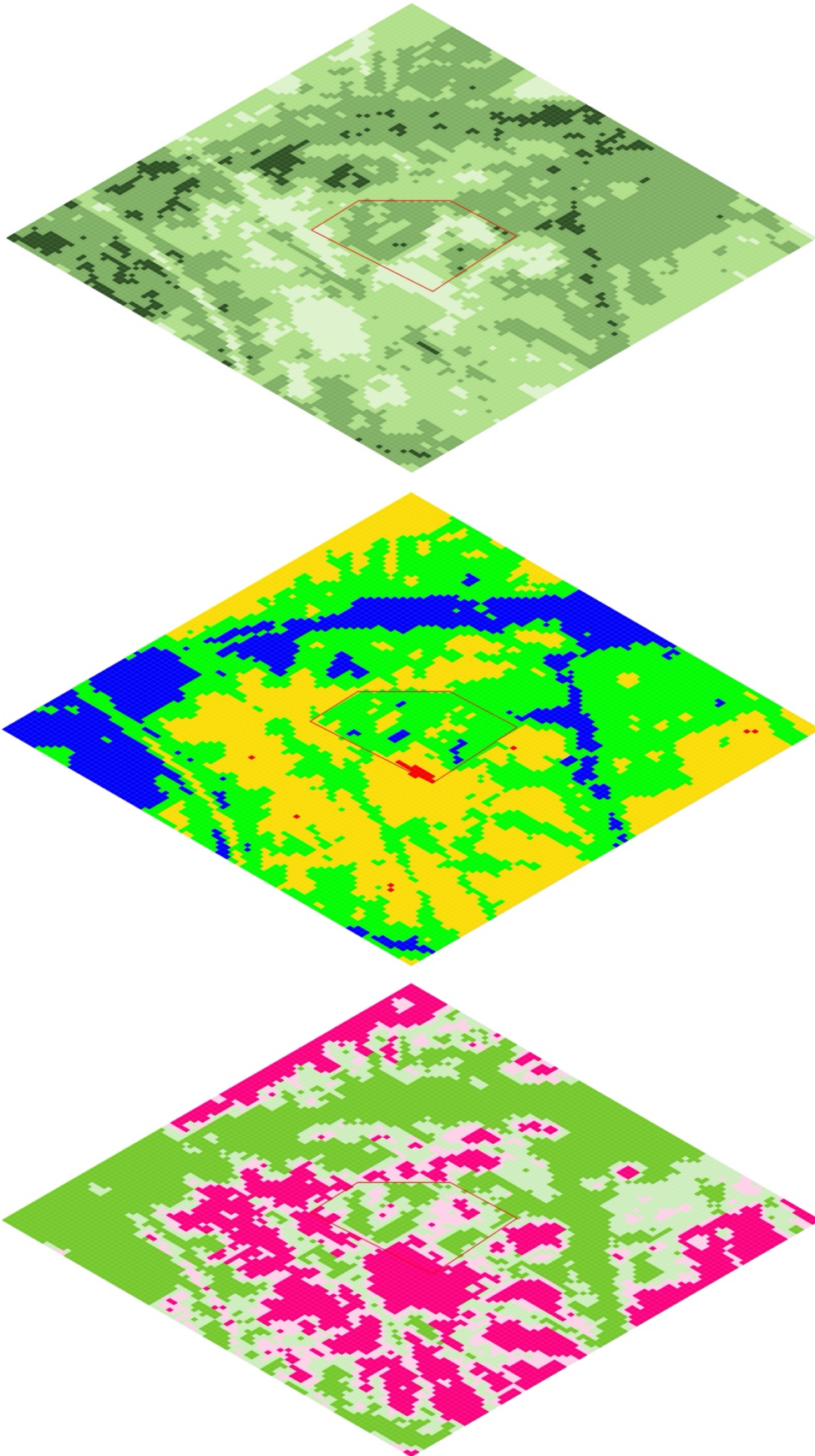


Figure 4.11 - Exploded axonometric view within Revit, showing the hierarchical composition of the Micro scale digital model: from the EO analysis layer (UHI represented) to land use, topography and project area



Through this sequence, the workflow demonstrates how the integration of InfraWorks between GIS and BIM supports a multi-layered understanding of the landscape, allowing environmental information to be spatially contextualised before being operationalised in the design model.

This structured transition from EO analysis to InfraWorks visualisation and finally to BIM parametrisation, establishes a coherent methodological chain that ensures continuity across different digital environments.

The digitalisation of landscape processes, through the integration of EO, GIS and BIM supported by computational tools and scripting environments, allows the project to mirror the complexity and dynamics of the environmental system it represents. As emphasised by Goodchild (2007), digital mapping and geospatial analysis acquire value not only through data acquisition but through their capacity to generate structured knowledge. In this sense, the digital workflow operates as both a technical and conceptual bridge, enabling landscape design to evolve from static representation to dynamic simulation.

The model thus becomes a decision-support environment, where environmental evidence derived from EO and GIS informs both the verification of existing design solutions and the generation of new alternative scenarios. The following two sections illustrate these complementary applications:

- Section 4.2.1 addresses the compatibility and verification of the existing project, reconstructed in BIM without prior data integration;
- Section 4.2.2 presents data-driven design scenarios, where environmental parameters directly influence planting and topographic configurations.

Through these applications, the research aims to assess how GIS-BIM interoperability can enhance the precision, interpretability and ecological responsiveness of landscape design processes at the site scale, supporting more integrated and adaptive approaches to transformation.

4.2.1 Not Data-Driven Design: Compatibility and Verification

Before proceeding with the verification of the existing project, the spatial extent of the model was refined to focus on the actual intervention area within the former Montecatini industrial site. While the previous analyses covered a 1×1 km frame to ensure a comprehensive understanding of territorial relations, this phase concentrates on the approximately 6 ha project area, where the BIM environment can be managed with higher precision and computational efficiency.

The surrounding areas remain included as contextual references, functioning as boundary conditions that ensure continuity in hydrological, morphological and ecological processes influencing the site. In particular, these peripheral zones are used to define slope gradients, drainage directions and vegetation patterns, ensuring that the design interpretation does not become an isolated operation but remains integrated within the larger territorial framework.

This methodological narrowing allows the focus to shift from data preparation to model evaluation, verifying the compatibility between the existing design solution (as developed by Edison SpA-Edison Regea s.r.l. and LAND Italia) and the environmental evidence previously derived from GIS analyses. In this phase, BIM is used primarily as a diagnostic tool: the objective is not yet to modify or generate new design proposals, but to test how the reconstructed model behaves when cross-checked with environmental parameters, identifying potential discrepancies or alignments between project assumptions and site conditions.

The reconstructed project, imported into Revit as it was originally conceived, serves as the baseline model for verification. The comparison between design features (e.g., planting areas, paths, ecovoltaic area) and environmental datasets (e.g., NDMI, MSI, UHI, etc.) enables the identification of potential mismatches between project assumptions and site-specific constraints. This operation provides insight into how well the design aligns with the real environmental dynamics captured through GIS, revealing both its strengths, such as the appropriate location of shaded areas, or low-impact surfaces and its limitations, for example where irrigation needs may exceed the site's available moisture or where vegetation placement does not correspond to optimal soil conditions.

Figure 4.12 presents the reconstructed BIM model of the current design, while Figure 4.13 shows the elements on which this part will focus on. The verification in this section will be in relation with the planting choice and location. The ecovoltaic power plant will be part of the new project scenario proposal in the next section.

Figure 4.12 - Revit model of the existing project, with planting boulevard and vegetated areas, around the ecovoltaic power plant

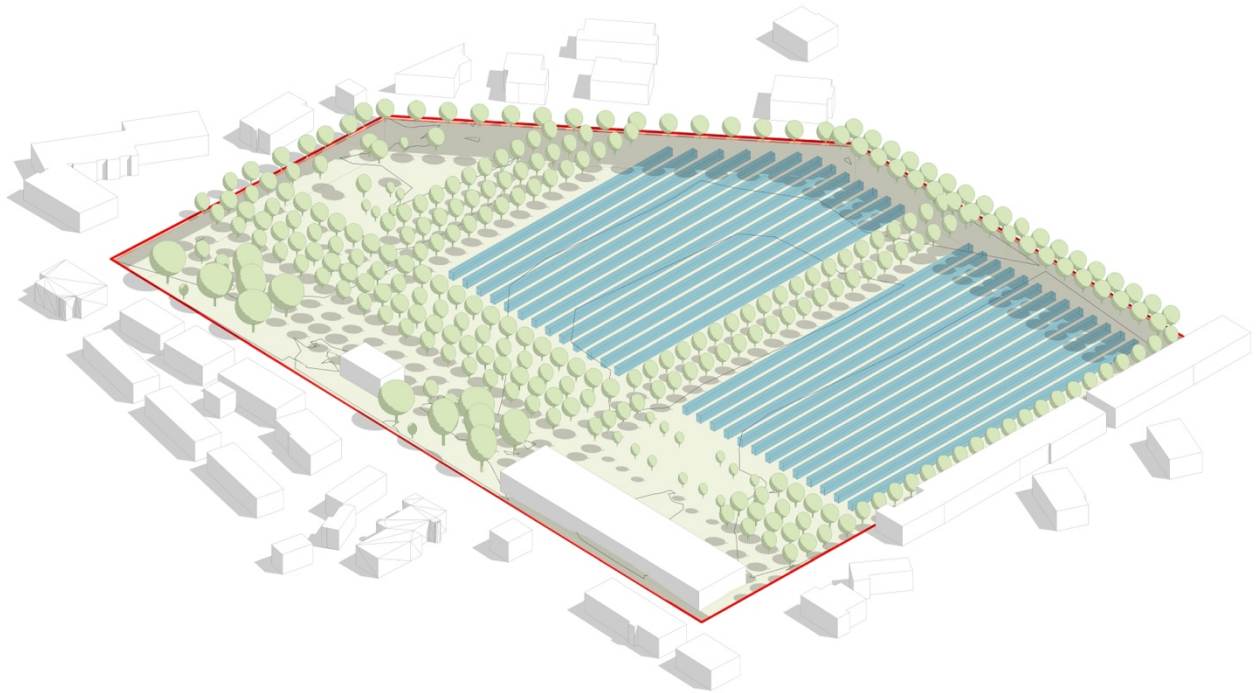
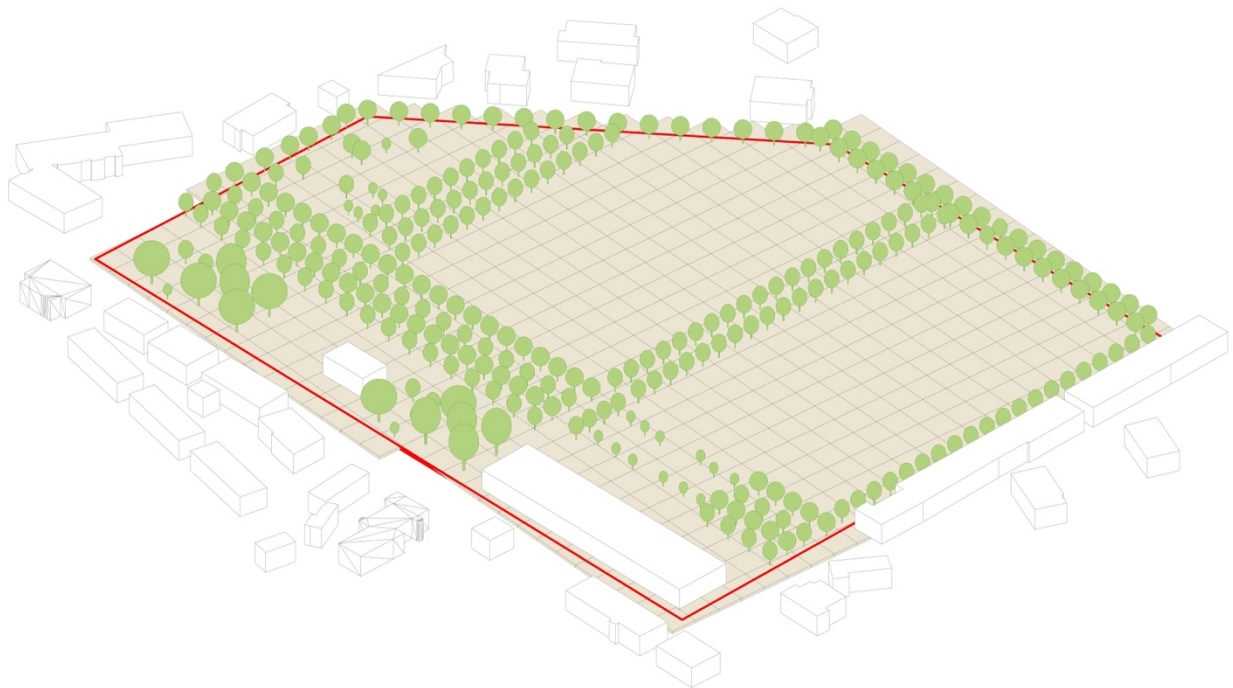


Figure 4.13 - Revit elements on which the verification process will be applied: Planting component overlapped on Floors GIS-informed floors



Within the reconstructed model, the existing vegetation layout was replicated to allow compatibility testing with environmental data, the typologies of trees are related to the one selected within Chapter 3.

Along the main north-south axis, rows of deciduous trees were placed to emphasise the linear structure of the design and provide shading along the pedestrian route, such as typology T6_Medium (*Cercis siliquastrum* and *Malus domestica*) and T2_Medium (*Acer campestre* and *Prunus avium*).

In the equipped sport park area, groups of large and medium-sized trees were distributed to define open spaces for public use and ecological continuity between the different parts of the site, in continuity with the previous area T3_Large (*Quercus pubescens*, *Fraxinus ornus* and *Ulmus minor*) and T2_Medium (*Carpinus betulus* and *Prunus avium*).

Towards the southern portion, in the “Viale del Sole” near the productive area and the photovoltaic field, the tree rows are composed by ornamental vegetation to enhance the view and the relationship between nature and energy, such as typology T6_Medium (*Cercis siliquastrum* and *Malus domestica*).

Finally, along the edges, a mix of trees is used, such as typology T2_Medium (*Acer campestre*, *Carpinus betulus* and *Prunus avium*).

This configuration reproduces the general structure of the existing project and serves as a reference for the subsequent data-driven scenarios developed in Section 4.2.2, where the spatial distribution of vegetation will be refined according to the site’s measured environmental conditions.

Three main verification layers were defined to evaluate project-environment compatibility:

- Water Demand Compatibility, based on NDMI and MSI values, highlighting areas where existing vegetation may require more water than the site can sustainably provide.
- Drought Resistance Compatibility, focusing on zones where the species palette should correspond to lower moisture availability or higher exposure.
- Canopy Cover Compatibility, analysed in relation to UHI and NDVI, to evaluate whether tree distribution effectively contributes to microclimatic regulation.

The following paragraphs describe comparative analyses and illustrate the degree of alignment between design components and environmental indicators. These maps provide a first quantitative measure of project-environment coherence.

Water Demand Compatibility

The first level of verification focuses on the relationship between the project’s vegetated areas and the site’s hydrological conditions. Using NDMI (Normalized Difference Moisture Index) the analysis identifies zones affected by limited soil moisture.

These indicators provide a synthetic representation of the site’s water balance, highlighting where existing planting layouts may conflict with the natural hydrological behaviour of the terrain.

Figure 4.14 illustrates the comparison between the current project and the environmental data. The coloured grid represents moisture variability across the site, discretised into four classes, while the circles correspond to the existing planting scheme.

Overall, the site does not show particularly high levels of drought, except for the zones previously occupied by industrial buildings and productive areas.

However, the current planting layout proves to be partially incompatible with the soil’s intrinsic water availability: the selected typologies and species are not fully aligned with the site’s hydrological conditions. As a result, the composition appears homogeneous across sectors that present different levels of soil moisture. This condition will therefore require a reconsideration of planting types and densities, with the aim of defining a configuration that is more consistent with the local water balance and capable of optimising irrigation demand. Table 4.2 illustrates the compatibility analysis between planting data and GIS-informed floors, providing a clearer understanding of the model.

Table 4.2 - Water Demand Compatibility rules between Planting and NDMI classes within Revit floors

Planting parameter	Floor parameter	Class condition	Compatibility
Water Demand (WD)	Normalized Difference Moisture Index GIS_NDMI_clas	WD= Low NDMI = 3-4 (wet to very wet)	Compatible
		WD= Low NDMI = 2 (moderately dry)	Compatible
		WD= Low NDMI = 1 (very dry)	Warning
		WD= Medium NDMI = 3-4 (wet to very wet)	Compatible
		WD= Medium NDMI = 2 (moderately dry)	Warning
		WD= Medium NDMI = 1 (dry)	Incompatible
		WD= High NDMI = 3-4 (wet to very wet)	Compatible
		WD= High NDMI = 2 (moderately dry)	Incompatible
		WD= High NDMI = 1 (dry)	Incompatible

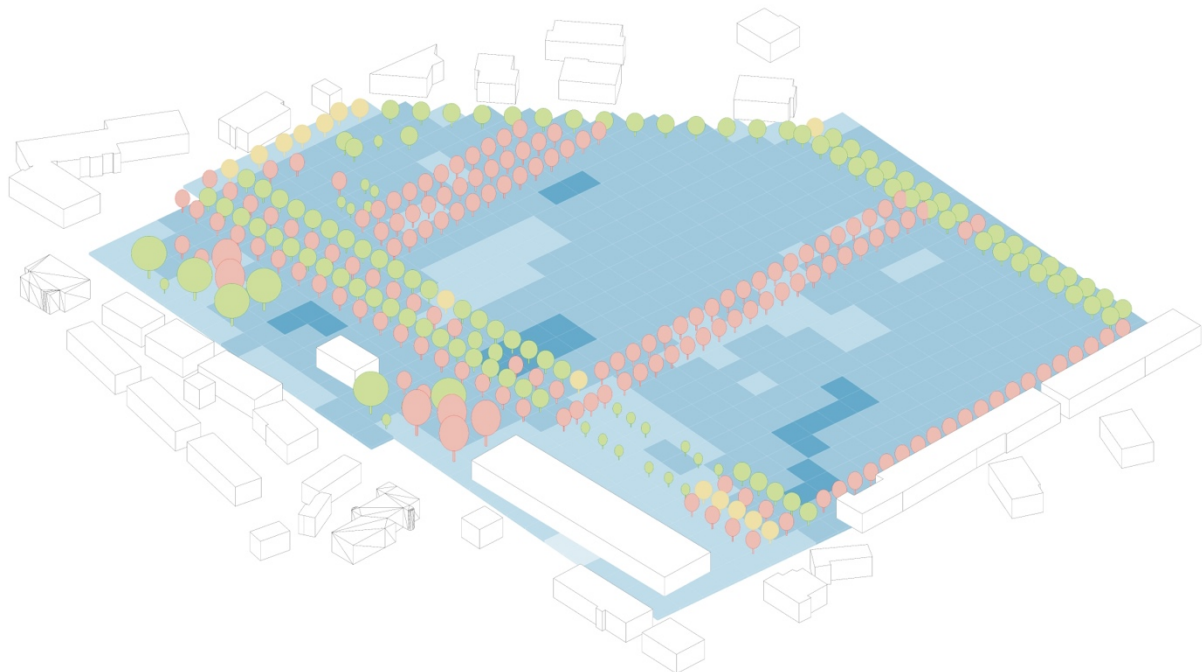
Overall, the Water Demand Compatibility test highlights a partial mismatch between the project's vegetative structure and the site's hydrological characteristics.

While the design establishes a coherent formal rhythm, it does not fully reflect the spatial distribution of available water resources. The analysis therefore suggests the need for a more adaptive planting configuration, where vegetation typologies and densities respond directly to moisture availability, reducing irrigation requirements and enhancing ecological resilience.

This assessment demonstrates that, in the absence of GIS-informed data, the original design relied primarily on formal and functional considerations, without fully integrating site-specific hydrological variability.

The verification provides valuable insight into how future revisions could balance water-demanding species with areas of higher soil moisture, improving both the efficiency and the ecological coherence of the landscape intervention.

Figure 4.14 - Water demand compatibility between existing vegetation layout and NDMI/MSI analysis



Drought Resistance Compatibility

The second verification focuses on the resilience of the existing planting layout in relation to the site’s drought stress conditions, analysed through the MSI (Moisture Stress Index).

This index provides a measure of the level of water stress affecting vegetation, with higher values indicating more critical conditions and lower values corresponding to well-watered or stable environments.

The BIM model, cross-checked with the classified moisture data, as shown in Figure 4.15, highlights several planting zones positioned in areas of moderate to severe stress. The area under analysis is characterized by 2 levels of MSI: 1 corresponding to very high drought stress; 2 corresponding to high drought stressed. As mentioned before, these values result from a broader classification analysis, indicating that this area is severely affected by drought conditions within its context.

Consequently, the results must be interpreted by considering the planting values in relation to their drought resistance levels (low, medium, high). These can only be compared to low or very low MSI values, from which an incompatibility between planting and soil can be inferred, or at least potential warnings for future incompatibilities and related issues. Table 4.3 resents a detailed compatibility assessment between the planting data and the GIS-informed floors, allowing for a more comprehensive interpretation of how vegetation performance aligns with site-specific environmental parameters. This correlation provides valuable insights into the degree of adaptation of existing species to current drought stress levels and highlights the potential need for adaptive planting strategies.

Table 4.3 - Drought Resistance Compatibility rules between Planting and MSI classes within Revit floors

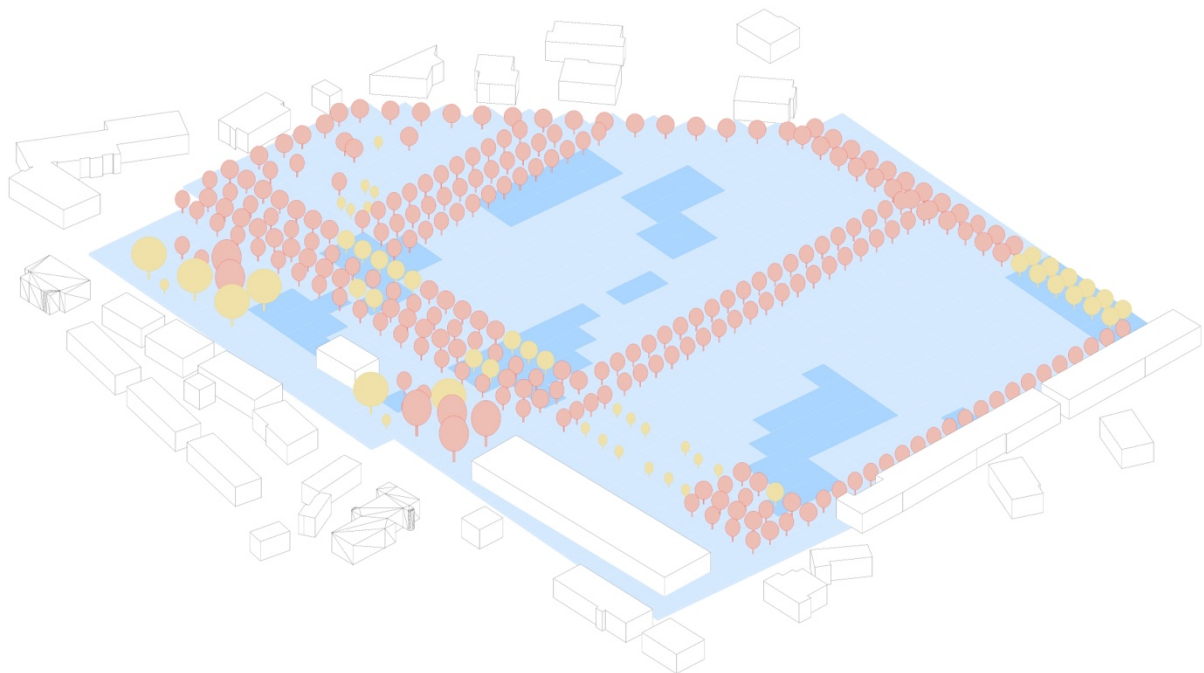
Planting parameter	Floor parameter	Class condition	Compatibility
Drought Resistance (DR)	Moisture Stress Index GIS_MSI_clas	DR= High MSI = 3-4 (low-medium drought stress)	Compatible
		DR= High MSI = 2 (high drought stress)	Warning
		DR= High MSI = 1 (very high drought stress)	Warning
		DR= Medium MSI = 3-4 (low-medium drought stress)	Compatible
		DR= Medium MSI = 2 (high drought stress)	Warning
		DR= Medium MSI = 1 (very high drought stress)	Incompatible
		DR= Low MSI = 3-4 (low-medium drought stress)	Compatible
		DR= Low MSI = 2 (high drought stress)	Incompatible
		DR= Low MSI = 1 (very high drought stress)	Incompatible

Overall, the Drought Resistance Compatibility assessment reveals a significant degree of incompatibility between the current planting configuration and the site's moisture stress conditions. While the existing design defines an organized and coherent spatial layout, it does not fully correspond to the areas identified as highly or very highly drought stressed. As a result, several planting zones appear exposed to environmental conditions that exceed their adaptive capacity, leading to potential long-term instability and maintenance challenges.

The analysis therefore highlights the importance of re-evaluating the planting palette in relation to the MSI values, promoting the selection of species with higher drought tolerance in the most stressed areas, while preserving the current structure where environmental conditions remain stable. Integrating such adaptive criteria would reduce the vulnerability of the vegetation system, enhancing its overall resilience and ecological performance.

This verification demonstrates how the incorporation of GIS-informed environmental data into the BIM workflow can substantially improve decision-making during the design and management phases. By aligning planting strategies with spatially explicit drought indicators, future revisions can foster a more sustainable and context-responsive landscape capable of withstanding increasing climatic stressors.

Figure 4.15 - Drought resistance compatibility map highlighting stress-prone planting zones in relation to MSI data



Canopy Cover compatibility

The third verification focuses on the relationship between the existing canopy cover and the site’s exposure to Urban Heat Island (UHI) effects. The analysis, conducted through the GIS-informed UHI classification, reveals that the entire study area falls within Class 1, corresponding to zones of very high heat stress. This condition indicates a continuous heat accumulation pattern, largely influenced by limited shading elements, extensive impermeable surfaces and low evapotranspiration potential. The area belongs to a broader territorial analysis composed of four UHI classes, confirming that this sector is among the most critically affected by thermal stress and, in combination with the previously discussed MSI results, requires both water and heat remediation measures.

The cross-check between canopy data and the UHI map (Figure 4.16) shows that the current vegetation structure provides partial mitigation of local thermal loads. In the central area of the park-parking interface and along the related rows, the tree typologies that were previously disadvantageous in terms of water demand now prove highly compatible, thanks to their broad canopy extension. Conversely, along the edges of the ecovoltaic park, the trees present a warning condition, a deliberate and strategic design choice, justified by the need to avoid excessive shading over the photovoltaic panels. Table 4.4 presents the compatibility analysis between planting data and GIS-informed UHI classes, providing a clearer understanding of the relationship between canopy extent and thermal performance across the model.

Table 4.4 - Canopy Cover Compatibility rules between Planting and UHI classes within Revit floors

Planting parameter	Floor parameter	Class condition	Compatibility
Canopy Cover (CC)	Urban Heat Island GIS_UHI_clas	CC= Large UHI = 3-4 (low-very low heat stress)	Compatible
		CC= Large UHI = 2 (medium heat stress)	Warning
		CC= Large UHI = 1 (high heat stress)	Warning
		CC= Medium UHI = 3-4 (low-very low heat stress)	Compatible
		CC= Medium UHI = 2 (medium heat stress)	Warning
		CC= Medium UHI = 1 (medium heat stress)	Incompatible
		CC= Small UHI = 3-4 (low-very low heat stress)	Warning
		CC= Small UHI = 2 (medium heat stress)	Incompatible
		CC= Small UHI=1 (high heat stress)	Incompatible

By visualising these relationships within the BIM environment, it becomes evident that microclimatic mitigation is not yet a fully integrated design parameter, but rather a secondary outcome of the spatial composition. Incorporating UHI-based information into subsequent design stages could therefore guide the strategic placement of high-canopy trees and green corridors, improving both ecological functionality and thermal comfort.

Overall, the Canopy Cover Compatibility test highlights a critical mismatch between the existing vegetative density and the site's thermal exposure. While the design may respond to spatial or formal logic, it does not adequately reflect the environmental need for extensive canopy shading in high UHI zones. The analysis therefore suggests the adoption of a strategic reconfiguration of the planting design, prioritizing species with wide and dense canopies and increasing tree density in the most exposed sectors.

This verification ultimately demonstrates how integrating climatic and GIS-derived thermal data within BIM-based modelling can support informed decision-making, enabling designers to anticipate environmental vulnerabilities. Through this integrated approach, future interventions can enhance thermal comfort, lower surface temperatures and foster a more resilient and adaptive urban landscape.

Figure 4.16 - Canopy cover compatibility between NDVI-derived vegetation density and UHI distribution, the entire area presents value 1 (very high heat stress)

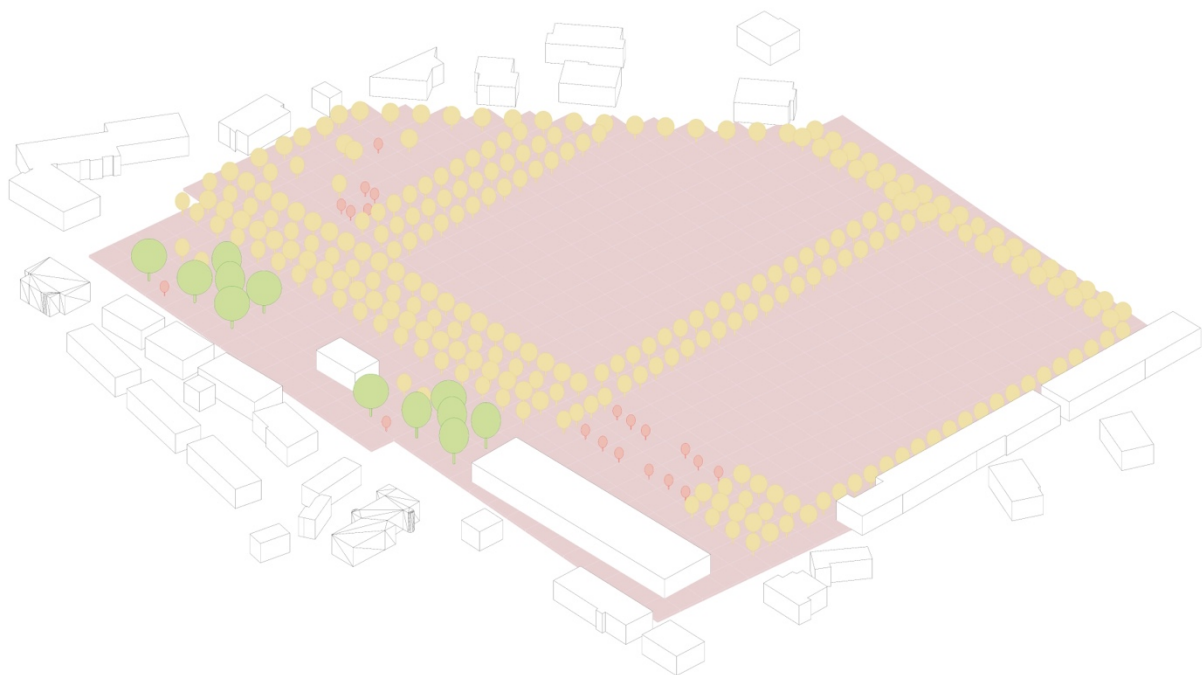
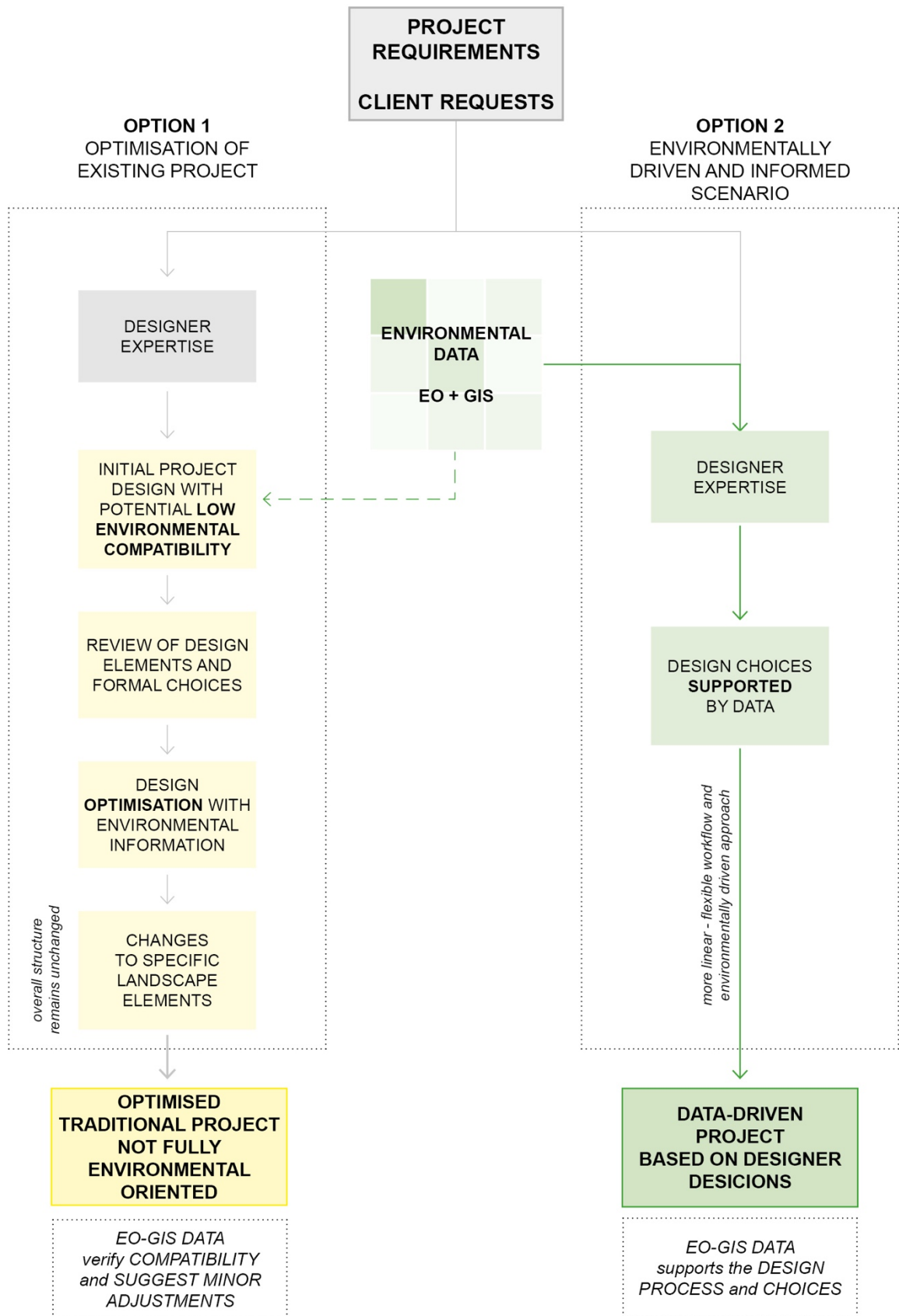


Figure 4.17 - Two possible directions and alternative design pathways integrating environmental data within the GIS-BIM workflow: (1) optimising the initial proposal by applying data-driven refinements while maintaining the original structure; (2) developing a new environmental scenario in which EO-GIS insights and design decisions evolve in parallel



The series of compatibility assessments, concerning water demand, drought resistance and canopy cover, collectively demonstrate how environmental performance parameters can be effectively integrated into BIM-GIS workflows to evaluate the resilience of planting strategies. Each verification highlights specific forms of misalignment between the existing vegetative structure and the site's environmental conditions, emphasizing the importance of data-driven adjustments to improve ecological stability. The analyses confirm that while the current design maintains spatial coherence and functional logic, it does not fully correspond to the site's hydrological and thermal constraints.

Overall, the findings suggest that the resilience of the landscape system depends on a more dynamic interaction between vegetation typology, soil moisture availability and thermal exposure. By embedding GIS-informed environmental indicators into the BIM environment, the design process becomes more performance-oriented, enabling planting configurations to respond more precisely to measurable site conditions.

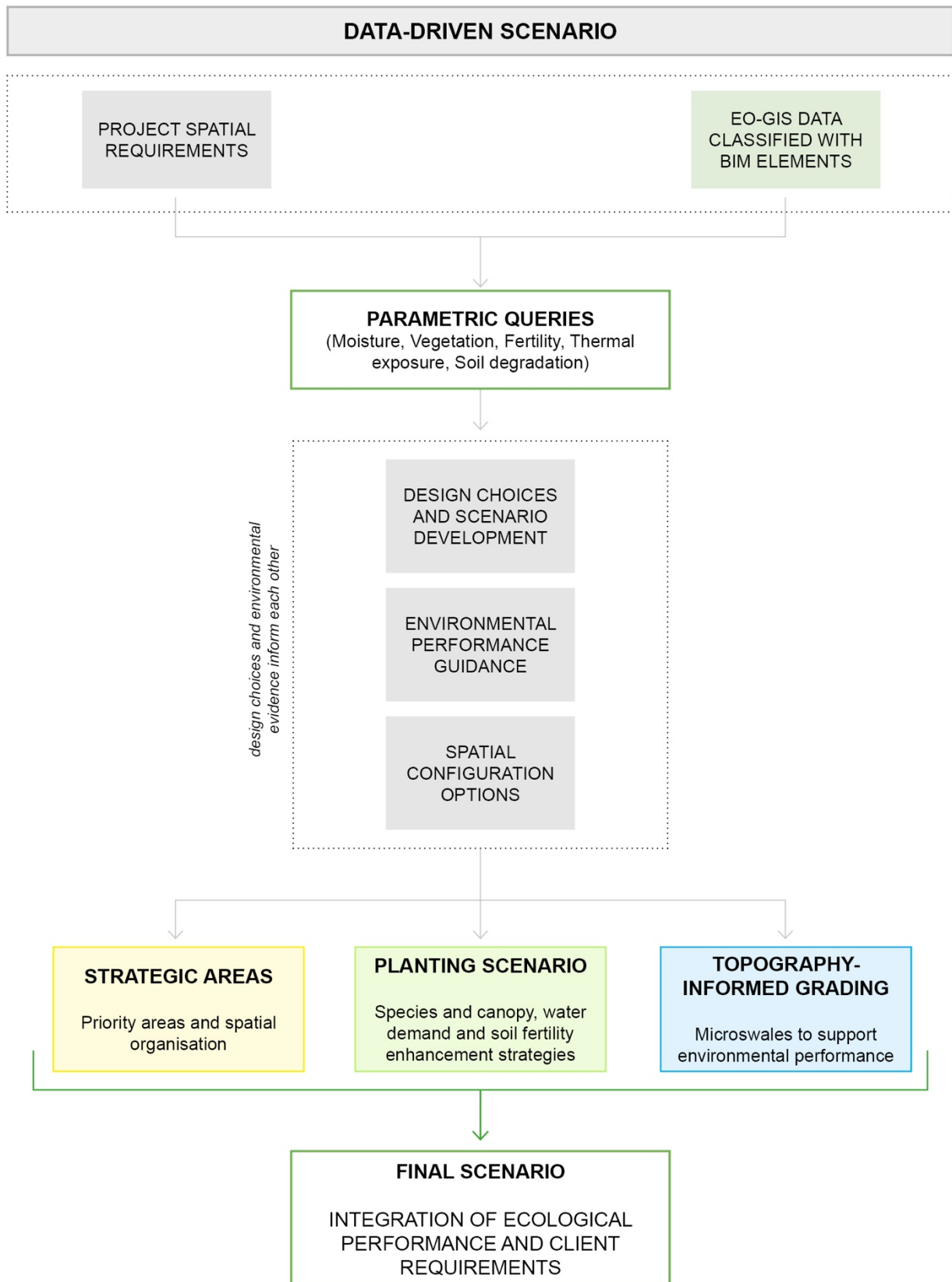
At this stage, with the compatibility checks and environmental verifications completed, two possible directions emerge for advancing the design process, as illustrated in Figure 4.17.

The first involves optimising the existing proposal, initially developed without environmental inputs, by adjusting its components so that they better align with the hydrological, thermal and ecological conditions identified. This would refine the current design without altering its overall structure.

The second option, however, offers a broader and more generative perspective: developing a new scenario in which the project is re-elaborated through a combined synergy between environmental evidence, design reasoning and client requirements. In this approach, the role of data is not prescriptive. Rather than dictating the configuration of the project or determining a single optimal solution, the environmental indicators operate as an additional layer of knowledge that accompanies the evolution of the design. Their contribution is interpretative and supportive: they help reveal spatial tensions, confirm appropriate choices or suggest areas where adjustments could enhance performance, yet they always remain in dialogue with the programme, the spatial vision and the strategic intentions expressed by the client.

This means that the new scenario represents a data-driven design pathway, where environmental evidence, functional requirements and aesthetic or conceptual ambitions evolve in parallel. Every adjustment proposed by the environmental model is therefore weighed against project priorities, user needs, feasibility aspects and the overarching identity that the landscape is expected to embody. The result is not a deterministic response to data, but a more conscious, evidence-supported progression of design decisions. This thesis adopts the second approach. It provides a clearer demonstration of how interoperable workflows enable data to enrich, rather than override, design processes, supporting decision-making while preserving the creative, contextual and client-driven nature of landscape architecture. The next section 0 presents this revised scenario, illustrating how the integration of EO, GIS and BIM parameters can accompany the transformation of the project in a balanced and iterative manner.

Figure 4.18 - Workflow of the Data-Driven design scenario: integration of environmental parameters and spatial requirements generates three data-supported design domains that converge into a final environmentally scenario



4.2.2 Data-Driven Design and Output: New Scenarios

The second approach explores how the integration of environmental parameters within the BIM environment can actively inform design choices, generating data-driven and data-informed scenarios that extend beyond the verification stage described in Section 4.2.1. While the previous workflow demonstrated the diagnostic potential of compatibility, this section focuses on its generative capacity, testing how geospatial evidence can be translated into concrete design transformations. As recent research highlights (Gnädinger, 2023; Ivankovic-Waters et al., 2024), digital interoperability enables landscape models to evolve from static repositories of data to dynamic systems capable of guiding design through measurable environmental information.

In this phase, the focus shifts from verification to design. The BIM model developed in the previous section already contains all environmental attributes derived from GIS analyses, structured according to the classified grid. These datasets are now used not as background information but as active design variables, capable of influencing spatial configuration and informing project decisions.

Each parameter embedded in the model, such as vegetation vigour, soil moisture, fertility, surface degradation and heat exposure, provides a specific layer of environmental evidence. When analysed together, these values create a complex matrix of relationships that allows the designer to identify priorities, constraints and potential synergies between ecological processes and spatial structures. The objective is no longer to assess compatibility but to explore how the existing environmental conditions can generate new design logics.

Through computational tools and parametric rules, the model evolves into a responsive system. Environmental attributes are queried, compared and combined to test how different configurations can perform under specific ecological and programmatic conditions. For instance, zones with low soil moisture and high surface temperature may suggest drought-tolerant planting schemes, while areas with degraded soil values may become candidates for phytoremediation or reforestation strategies. In this sense, the data guide the formation of design scenarios rather than simply describing the site.

This process is illustrated in Figure 4.18, which shows how project requirements and EO-GIS environmental data converge to inform design decision-making. The workflow transitions from input datasets to parametric queries, supporting the development of a coherent scenario that balances ecological evidence with spatial, functional and client-driven needs.

The same methodological sequence defined in Chapter 3 (linking Earth Observation, GIS classification and BIM parametrisation) is now applied to generate alternative spatial layouts for the former Montecatini industrial site in Piano d'Orta. According to Edison's updated requirements, the new scenario explores a configuration to locate a public park and green areas, to preserve industrial buildings concentrated in the

central zone and to think the location of a photovoltaic field. These design elements and requests offer the opportunity to test how data-driven interpretation can align ecological performance with functional and programmatic needs.

However, in this phase the workflow operates with a dual objective: (1) to test how GIS-based data integration can support the redesign of specific project components and (2) to assess how the resulting configurations align with both environmental performance and client requirements.

Indeed, following Edison's strategic indications, the new project scenario is required to explore an alternative layout configuration. These modifications were used as a design driver to test the flexibility of the workflow and to assess whether data-informed decision-making could ensure both environmental coherence and programmatic feasibility.

The following sections illustrate this process, structured according to three main design workflows, each addressing a specific design domain:

- Strategic Areas, identifying priority zones for intervention through multi-criteria environmental analysis;
- Planting Scenario, translating environmental data into planting strategies that respond to moisture, fertility and microclimatic parameters;
- Topography-Informed Grading, using terrain modelling to reinforce ecological and hydrological performance.

Through these experiments, the workflow demonstrates that the integration of environmental information within BIM can move the design process from static representation to dynamic simulation, enabling the testing of multiple configurations based on measurable site parameters.

This data-informed approach enhances the ability of landscape architects to negotiate between ecological constraints and design intent, ensuring that each spatial decision is grounded in environmental evidence while remaining responsive to functional and aesthetic goals.

4.2.2.1 Strategic Areas Scenario

The first design workflow focuses on the identification of strategic areas, where environmental conditions indicate specific priorities or constraints for intervention. Building upon the GIS-to-BIM parameters imported in the previous phase, the classified datasets are now queried within the BIM environment to produce a semantic mapping of the site. Each cell of the grid already contains the reclassified environmental attributes, NDVI, EVI, NDMI, MSI, BSI, UHI and SOC, which are automatically analysed and combined according to predefined rules developed in Chapter 3 (see previous Table 3.9).

Through the Dynamo-based script, the system reads the combination of parameters stored in each Floor element and assigns a corresponding “Intervention Typology” label. The script evaluates the co-occurrence of vegetation, moisture, soil and heat conditions to derive five typological responses: Drought Planting, Soil Remediation, Shading Planting, Cooling Intervention and Ground Cover Stabilisation. This process converts abstract environmental data into explicit design information, producing a project-oriented map in which each spatial unit is classified according to its ecological condition and potential response strategy. The result is a semantic surface, where the digital model becomes both an analytical and generative tool: analytical, because it reveals environmental patterns otherwise invisible; generative, because it provides the basis for spatial decisions grounded in data.

Each typology corresponds to a specific ecological rationale: Drought Planting applies to dry and sparsely vegetated areas, Soil Remediation targets degraded soils with low organic content, Shading Planting mitigates thermal hotspots through canopy increase, Cooling Intervention integrates vegetative and engineered solutions in heat-stressed and moisture-deficient zones, while Ground Cover Stabilisation addresses erosion-prone surfaces by improving soil protection (Bowler et al., 2010; Krüger et al., 2013; Zölch et al., 2016).

At the micro scale of intervention, where the grid corresponds to the spatial resolution of 10×10 m of the design model, the classification logic must operate with greater sensitivity to local variations. Small differences in vegetation vigour or soil moisture can substantially modify the environmental performance of a limited portion of the site. Therefore, the Python script has been refined to distinguish subtle conditions and generate more site-specific responses.

In this context, the distinction between Shading Planting and Cooling Intervention becomes particularly meaningful. When vegetation is scarce ($NDVI < 2$), the logic interprets the condition as one of limited canopy cover and prioritises the reintroduction of trees or shading structures. These areas are classified as Shading Planting, where the objective is to improve microclimatic comfort through evapotranspiration and direct solar filtering.

Conversely, where vegetation cover is already moderate ($NDVI > 3$) but moisture stress remains high ($NDMI = 1$), the script assigns the typology Cooling Intervention.

In these cases, vegetation alone is not sufficient to mitigate heat and the strategy must integrate engineered cooling components such as permeable pavements, high-albedo materials or small-scale water devices (Santamouris, 2013).

This adjustment of script sensitivity allows the workflow to detect micro-environmental gradients that would otherwise be flattened at coarser scales.

Since the entire site presents homogeneous thermal stress conditions (UHI = 1), temperature is no longer the main discriminant: the model instead differentiates interventions through the balance between vegetative density, soil moisture and local substrate conditions.

Such detailed classification is essential at the micro scale, where design actions, whether planting, material selection or surface treatment, directly translate into measurable microclimatic effects.

Moreover, since the entire site lies within a Sito di Interesse Nazionale (SIN), the presence of legacy soil pollution constitutes an underlying environmental constraint rather than a discrete design parameter. Pollution conditions the ecological and technical feasibility of each intervention typology, influencing rooting depth, soil disturbance and water management strategies. Soil Remediation corresponds to zones where contaminant accumulation overlaps with soil degradation, requiring mechanical or biological restoration. Drought and Shading Planting operate mainly on capped or remediated surfaces, where shallow-rooted and pollutant-tolerant species can be introduced without compromising the protective layers. Cooling Intervention areas can incorporate constructed wetlands or phytoremediation plantings, enhancing both thermal mitigation and pollutant absorption. Finally, Ground Cover Stabilisation ensures dust control and erosion prevention, limiting the dispersion of contaminated fine particles during and after remediation works. Table 4.5 summarises the parameter logic and the resulting intervention typologies at the micro scale and serves as colour legend for the figure that follows.

Table 4.5 - Environmental parameters and intervention logic applied at Micro scale

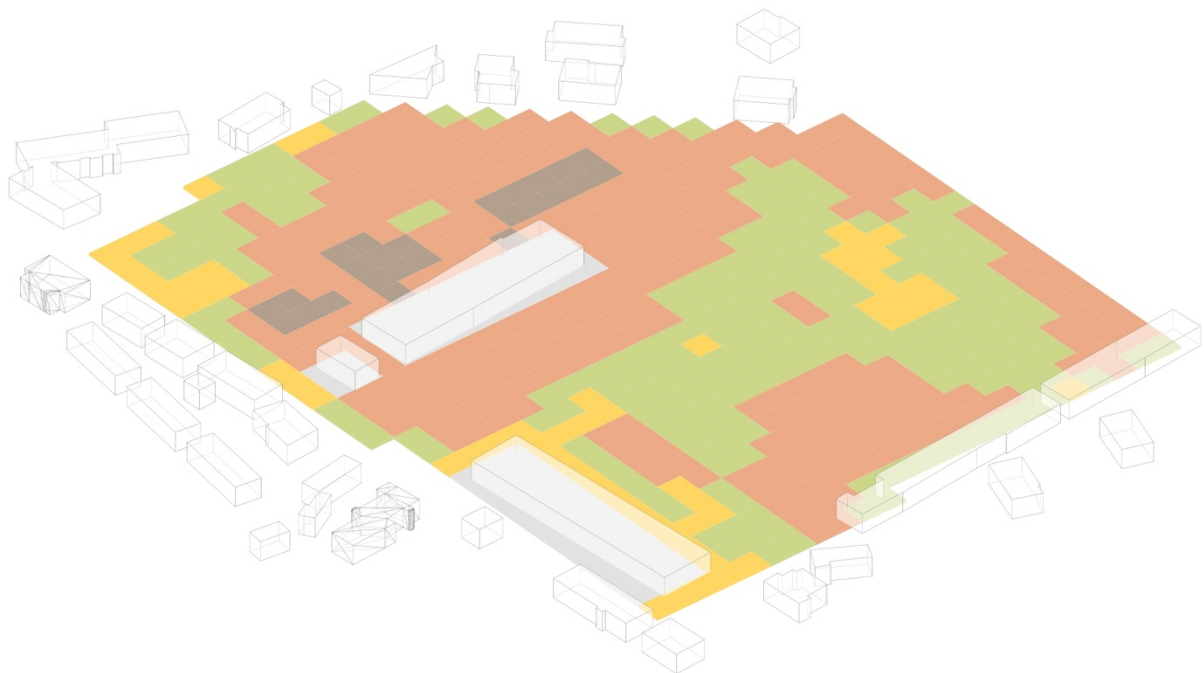
Typology	Key environmental conditions (GIS-based)	Ecological rationale (Micro scale)	Design strategy within SIN context
Soil Remediation	BSI = 1 (bare soil); SOC ≤ 2	Contaminated and compacted soils	Mechanical and biological remediation (decompaction, organic amendments, phytoremediation species)
Shading Planting	NDVI ≤ 2; UHI = 1 (hotspot)	Heat stress with sparse canopy	Increase tree canopy where soil capping allows; use pollutant-tolerant and low-root species
Cooling Intervention	NDVI ≥ 3; NDMI/MSI = 1 (dry); UHI = 1	Thermal + moisture stress combined	Combine vegetative and material cooling (permeable, reflective or water surfaces) integrated with runoff filtration or phytoremediation
Ground Cover Stabilisation	NDVI ≤ 2; BSI = 1	Erosion and dust risk on remediated soils	Introduce fast-growing ground cover vegetation to stabilise contaminated surfaces and prevent particulate dispersion
Unclassified	<i>No corresponding data or areas where the application of interventions is not possible (e.g. the location of buildings)</i>		

Figure 4.19 shows the result of this automatic classification within the Revit environment, where each coloured unit represents a specific intervention typology derived from the combination of environmental parameters.

The distribution reveals a clear spatial differentiation of environmental conditions across the site. The central portion is largely dominated by Shading Planting (green), indicating zones where low vegetation vigour coincides with uniform thermal stress. These areas represent the primary target for canopy increase and natural shading, forming the ecological core of the project. Around this central belt, orange patches of Cooling Intervention appear in peripheral sectors exposed to higher radiation and moisture stress, where hybrid vegetation-material strategies can improve comfort and resilience. Brown areas, concentrated around the former industrial core, correspond to Soil Remediation zones, where low organic carbon and compaction indicate the need for restoration of soil fertility and structure. Yellow units, mainly distributed along the southern and eastern edges, identify Ground Cover Stabilisation zones, essential for preventing erosion and surface dust dispersion. Finally, a limited number of grey cells remain Unclassified, marking areas with incomplete datasets or overlapping areas where existing buildings are present.

At this stage, the workflow does not impose design forms but defines the logic of intervention that will guide subsequent spatial configurations. By translating environmental diagnostics into actionable typologies, the model provides a bridge between ecological evidence and design strategy. This data-driven stratification offers a new way of reading the site, not as a homogeneous surface, but as a mosaic of differentiated ecological potentials.

Figure 4.19 - Classification of intervention typologies through a Dynamo script within Revit model, applied to Micro scale area



In accordance with the Edison SpA-Edison Regea s.r.l. programme and design requirements, the environmental classification produced through the GIS-BIM workflow is not conceived to generate a formal zoning plan, but to verify and optimise the compatibility between intended function and the site's ecological conditions. This approach reflects the principles of data-informed design and evidence-based landscape planning, in which design decisions are derived from the correlation between environmental diagnostics and programmatic requirements (Brown & Corry, 2020; Chokhachian et al., 2022).

The resulting dataset acts as an operational knowledge base, allowing for the spatial allocation of functions (public park, photovoltaic field, remediation areas and buildings with cultural value and services) based on measurable environmental indicators.

Based on the outcomes of the environmental classification and the client's priorities, the site and the model enable the maximisation of project performance by aligning each function with the most suitable ecological context.

The micro-scale configuration is articulated along three main north-south bands (Figure 4.20), ensuring a gradual transition between remediation, public use and energy production, consistent with adaptive principles for contaminated landscapes (De Gregorio et al., 2020).

Northern sector - Remediation and soil improvement park

The northern portion, dominated by Soil Remediation and Cooling Intervention typologies, presents compacted and moisture-stressed soils. Interventions focus on soil restoration and phytoremediation, combining decompaction, organic amendments and the use of pioneer species. Parallel planting of shading vegetation mitigates surface temperature and enhances comfort, establishing an ecological threshold for the park. This dual strategy aligns with best practices in ecological remediation, integrating vegetative restoration with microclimatic regulation (Bünemann et al., 2018).

Central belt - Reuse of existing buildings for cultural and informative purposes

The existing industrial volumes are repurposed as a cultural and environmental hub supporting the park and the remediation process. Functions include exhibition spaces on the history of the site, classrooms and laboratories for environmental education and a monitoring centre connected to the SIN remediation network. This belt operates as the social core that mediates between restoration, public use and energy production.

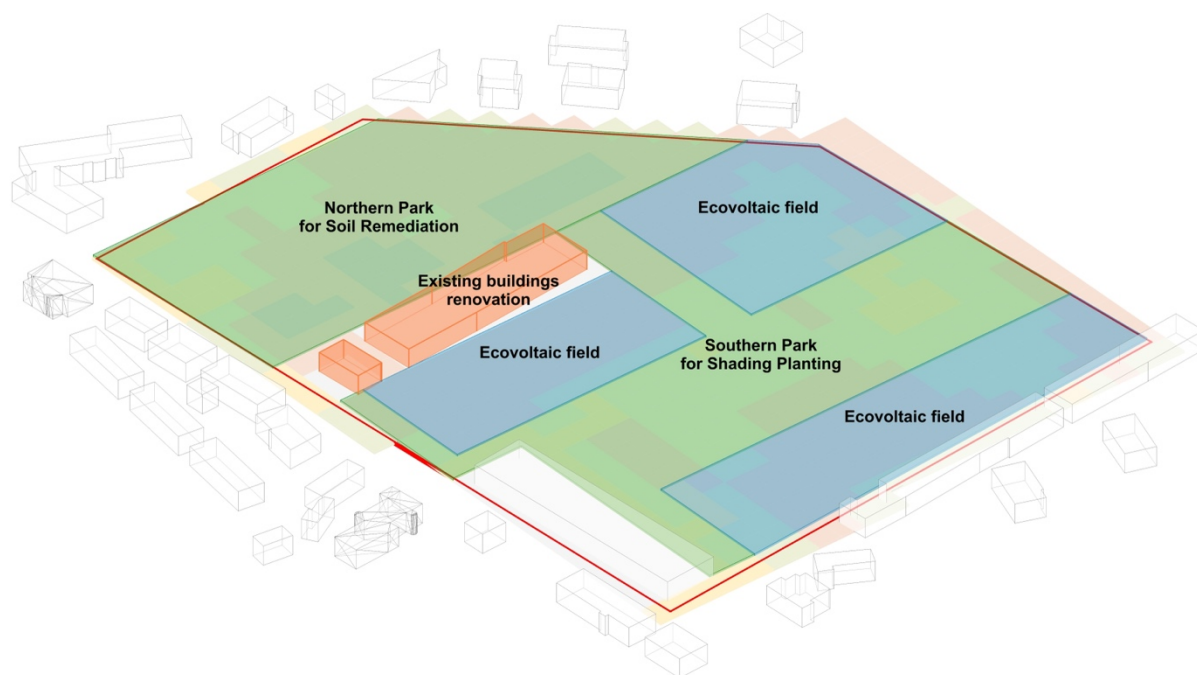
Southern sector - Alternating photovoltaic and public park layers

In the southern portion of the site, where Cooling Intervention, Shading Planting and Ground Cover Stabilisation occur in alternation, the project adopts a layered morphology that merges production and recreation. The first ecovoltaic strip, located south of the built complex, hosts elevated solar panels over permeable and vegetated ground, ensuring both energy generation and ecological continuity.

The central park, acting as the main public open space, overlays remediated soils and integrates shading vegetation to enhance microclimatic comfort and social accessibility, including areas for ground cover stabilisation. The southern photovoltaic strip extends the productive logic with ecovoltaic solutions that combine low-growing vegetation with renewable energy infrastructure.

This alternation between productive and ecological systems translates the analytical results into a spatially adaptive structure, consistent with the emerging models of energy landscapes that combine resilience, biodiversity and productivity (Stremke & Koh, 2010). This configuration is particularly suited to the SIN context, where soil capping and limited permeability constrain deep-root interventions but allow for extensive surface stabilisation and ecological buffering (ISPRA, 2022)

Figure 4.20 - Synthesis diagram of the proposed spatial organisation (north remediation park; central reuse belt; southern photovoltaic and public park)



At the Micro scale, the distinction between intervention typologies no longer defines rigid functional zones but rather an operational sequence of actions and environmental processes. Each typology contributes to a different layer (vegetative, pedological, material, or infrastructural) collectively ensuring the site's adaptive capacity. The resulting configuration is therefore a stratified landscape system, where remediation, shading and energy production coexist in proximity rather than segregation. This reflects a shift from form-based planning towards a performance-oriented landscape (Giroto & Imhof, 2016), in which spatial design becomes a medium for reconciling environmental recovery, energy transition and public use.

This integration demonstrates how the GIS-BIM classification framework extends beyond environmental diagnostics to support risk-aware design decisions, aligning the spatial reasoning of the landscape project with the technical and regulatory framework of contaminated-site management. As highlighted by Gnädinger & Roth (2021), the integration of GIS and BIM in landscape planning enables the creation of “knowledge models” that support decision-making through the correlation of environmental layers, ensuring that spatial design becomes both evidence-based and adaptive.

The next sections will explore in greater depth the design of the vegetated areas of the parks, focusing on planting design and topographic information as fundamental components of the data-driven workflow.

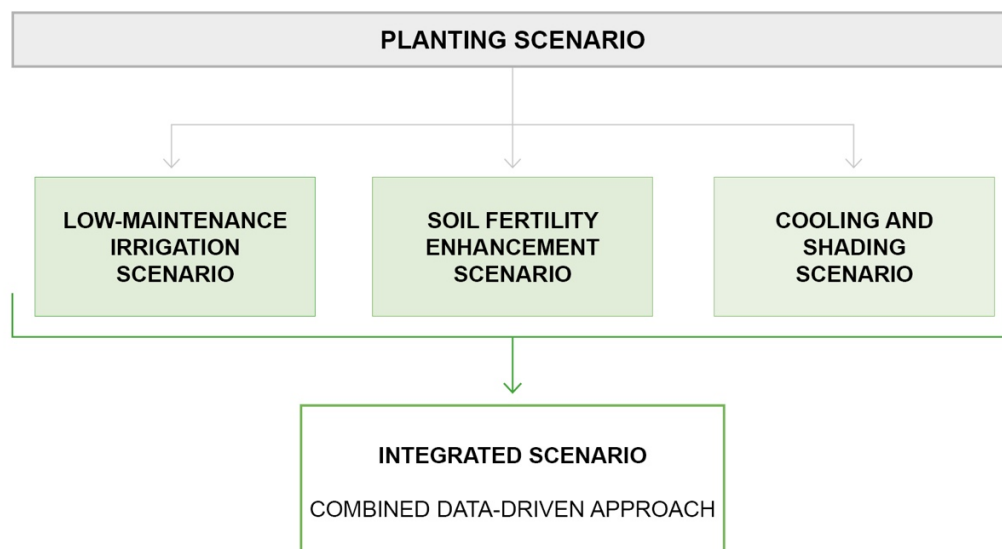
4.2.2.2 Planting Scenario

Following the identification of strategic areas, the workflow proceeds with the generation of planting scenarios within the zones designated as park or ecological buffer. This phase marks the transition from environmental diagnosis to design synthesis, where data are not only interpreted but operationalised to shape the vegetative structure of the site. In this stage, the digital model becomes a design medium rather than a diagnostic tool, transforming the quantitative values of the environmental layers into spatial patterns, species distribution and canopy composition.

The BIM model developed in the previous section already contains the environmental parameters derived from GIS classification, such as vegetation vigour (NDVI, EVI), soil moisture (NDMI, MSI), soil quality (SOC, BSI) and heat exposure (UHI). These attributes are now directly linked to Planting Families through a Dynamo-based workflow that allows the model to simulate different vegetative configurations according to environmental conditions. Each cell of the 10 × 10 m grid thus becomes a programmable design unit, capable of hosting adaptive planting strategies that respond to its specific micro-conditions.

To test how environmental evidence can inform design decisions, three data-driven planting scenarios were developed, each based on a specific ecological principle and corresponding environmental parameters, as illustrated in the previous Chapter 3.5.2.2. The scenarios are conceived as simulations rather than fixed solutions, exploring how vegetation type, density and spatial organisation can vary according to measurable environmental conditions. This approach enables the designer to compare alternative outcomes, assessing the ecological, spatial and visual implications of each strategy before implementation. Following the testing of the three individual strategies, the workflow also explores their integration into a single adaptive planting configuration that combines water efficiency, soil regeneration and microclimate mitigation.

Figure 4.21 - Three data-driven planting scenarios (low-maintenance irrigation, soil fertility enhancement and cooling-shading) and their integration into a combined scenario for the final planting design strategy



Low-Maintenance Irrigation Scenario

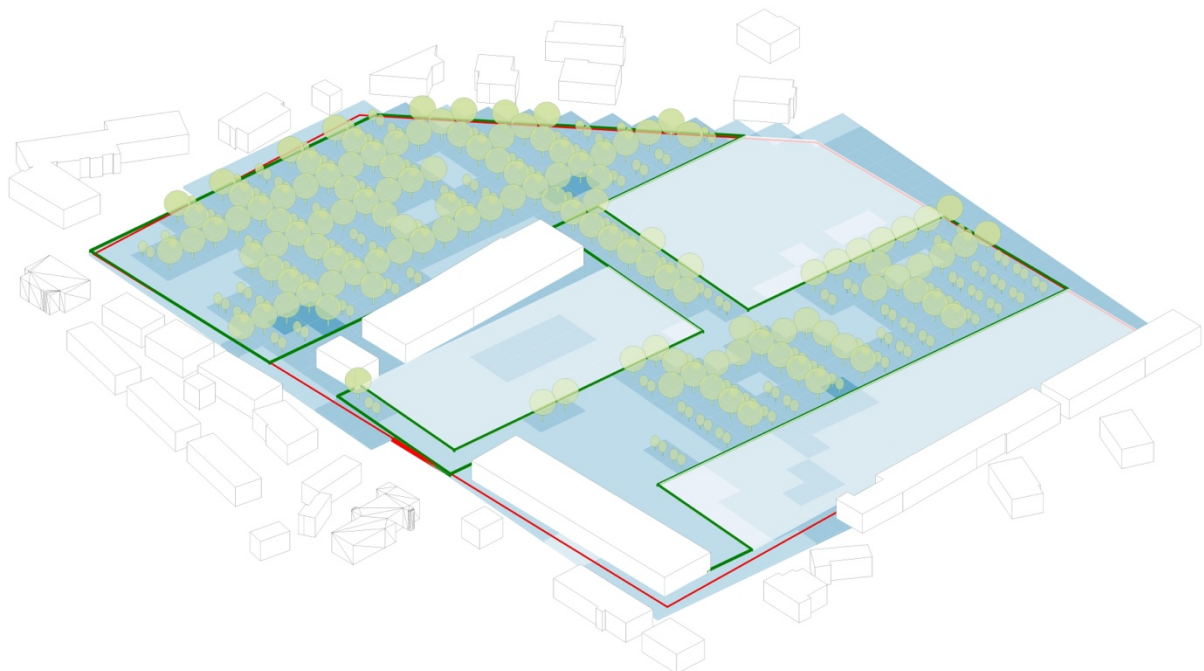
This scenario aims to reduce water consumption and ensure vegetation resilience under fluctuating hydrological conditions. It focuses on areas with moderate to high soil moisture (NDMI = 3-4) or low drought stress (MSI = 3-4), where planting can rely primarily on natural water availability.

Within the BIM model, these areas automatically activate the Low-Maintenance Irrigation rule, assigning “T1_Small” and “T4_Large” planting typologies (e.g., *Robinia pseudoacacia*, *Celtis australis*, *Quercus ilex*, *Olea europaea*) at a density of two small or one large canopy tree per 100 m².

The resulting configuration promotes a self-sustaining system that minimises irrigation requirements and maintenance costs, aligning with water-saving strategies promoted in sustainable landscape design (Cortesi et al., 2020).

Figure 4.22 illustrates the distribution of these species within the site, showing how the planting density follows the natural gradients of moisture, creating zones of higher canopy density in the northern and central belts. At the design scale, this scenario defines the backbone of the park’s ecological structure, identifying areas where water efficiency can coexist with aesthetic and functional qualities such as shading and seasonal variation.

Figure 4.22 - Data-driven planting simulations for Low-Maintenance Irrigation scenario at Micro scale



Soil Fertility Enhancement Scenario

The second scenario addresses areas where soil degradation and low organic content constrain vegetation performance. It targets cells with low fertility values (SOC = 1-2) or high bare soil index (BSI = 1-2), automatically assigning the Soil Fertility Enhancement rule.

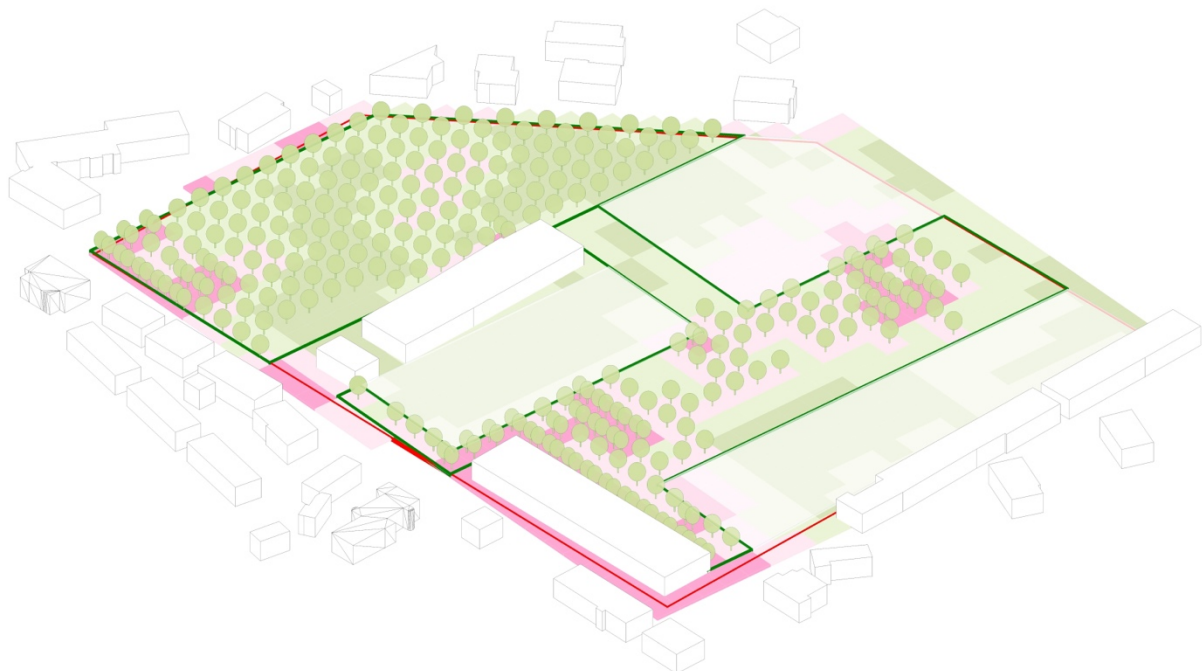
The model generates T2_Medium and T6_Medium typologies (e.g., *Acer campestre*, *Carpinus betulus*, *Cercis siliquastrum*, *Magnolia grandiflora*), with a density of one or two trees per grid cell depending on the surface area.

These species are selected for their capacity to stabilise soils, accumulate organic matter and initiate ecological regeneration processes through litter production and root systems.

The simulation produces a patchy structure that concentrates interventions around the former industrial core and the southern perimeter, reflecting the priority zones for soil improvement, as shown in Figure 4.23.

This approach supports long-term ecological recovery within contaminated or compacted soils, complementing remediation processes already underway in the SIN framework (Shen et al., 2023; Yang et al., 2023). From a design perspective, the outcome defines a more textured and layered vegetation palette, where soil-improving species also create visual buffers between public areas and technical zones, turning remediation sites into ecological interfaces rather than exclusion areas.

Figure 4.23 - Data-driven planting simulations for Soil Fertility Enhancement scenario at Micro scale



Cooling and Shading Scenario

The third scenario responds to microclimatic stress, using vegetation to mitigate heat accumulation and enhance thermal comfort. It applies to areas with high microclimatic stress ($UHI = 1-2$) and low canopy vigour ($NDVI/EVI = 1-2$), assigning the Cooling and Shading rule.

Large-canopy typologies (T3_Large and T5_Large) such as *Quercus pubescens*, *Fraxinus ornus*, *Platanus × acerifolia* and *Salix alba* are distributed at a density of one tree per 100 m².

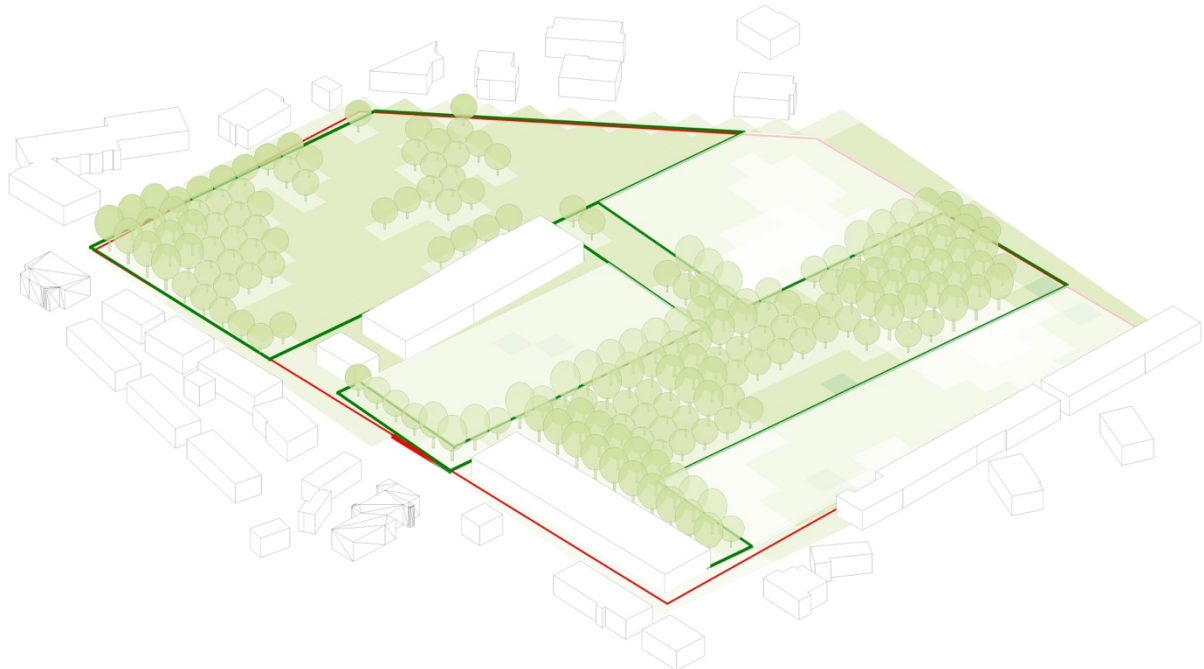
These species are known for their high evapotranspiration rates and wide crowns, which provide shade and regulate air temperature through leaf transpiration and surface cooling (Yin et al., 2024).

The simulation represented in Figure 4.24 highlights how the densest shading areas coincide with the central park and the pedestrian corridors, improving both environmental performance and user comfort.

At the spatial level, this translates into a clear hierarchy of green spaces: shaded corridors for movement, open clearings for gathering and denser canopy zones for climate regulation.

The result is not a uniform tree cover but a microclimatic network where the density, species and canopy size are optimised according to local stress gradients.

Figure 4.24 - Data-driven planting simulations for Cooling and Shading scenario at Micro scale



Integrated Scenario: Combined Data-Driven Approach

After testing each principle separately, the workflow integrates all three rules into a unified simulation, combining the logics of water efficiency, soil fertility and cooling performance. The Integrated Scenario acts as the synthesis of the previous analyses, where the information derived from environmental classification is combined into a single decision-making framework.

Through the Dynamo-based workflow, each cell of the BIM model becomes a design unit capable of responding autonomously to the prevailing site conditions. The model therefore evolves from a descriptive archive of environmental data into an operational design simulator, where ecological evidence directly influences spatial form, vegetation type and planting density.

This phase of the workflow embodies the principle of adaptive design, in which the project adapts its configuration to measured environmental gradients rather than imposing a predetermined spatial order.

The integrated rules are structured hierarchically to reflect ecological and spatial priorities, translating complex environmental correlations into clear design responses (Cantrell & Mekies, 2018; Meerow & Newell, 2017). Each rule corresponds to a specific function within the park: ecological restoration, hydrological efficiency, microclimatic regulation and spatial openness.

The first step identifies areas that should remain free from tree planting, because they present already suitable vegetation vigour and stable soil conditions. Cells characterised by high vegetation vigour (EVI = 3-4) and moderate soil stability (BSI = 3-4) are designated as zones where rest and gathering areas can be located within the new park. These open clearings perform a dual role: ecologically, they maintain areas of high light penetration and soil permeability; spatially, they provide flexible surfaces for recreation, visibility and circulation.

This approach reflects the balance between openness and vegetative density that defines contemporary park design (Gobster et al., 2007).

After the identification of the rest areas, the script proceeds with the selection of cells where soil fertility is low (SOC = 1-2) or bare soil dominates (BSI = 1-2) activating the Soil Fertility Enhancement rule.

Here, medium and fast-growing typologies (T2_Medium and T6_Medium), including *Acer campestre*, *Carpinus betulus* and *Cercis siliquastrum*, are placed at higher densities to promote soil recovery, organic accumulation and long-term ecological stability.

This approach aligns with nature-based remediation strategies, where vegetation acts as a key agent in restoring soil functionality (Bünemann et al., 2018).

Sequentially, in areas with favourable water balance (NDMI = 3-4) or low drought stress (MSI = 3-4), the Low-Maintenance Irrigation rule is applied.

Depending on canopy vigour, the system assigns T1_Small typologies for sparse vegetation zones and T4_Large for more established ones, both with a “Low” Water Demand parameter, promoting water efficiency and self-sustainability.

The resulting configuration mirrors a dynamic gradient of moisture, where planting density follows the natural hydrological structure of the site’s terrain (Raymond et al., 2017).

Finally, the Cooling and Shading rule targets areas of high microclimatic stress (UHI = 1-2) combined with low vegetation vigour (EVI = 1-2).

In these zones, large-canopy trees are introduced to increase evapotranspiration and reduce surface heat. Two typologies are used depending on stress intensity: T5_Large species such as *Platanus × acerifolia* and *Salix alba* for critical heat islands and T4_Large species, like *Quercus ilex*, for moderately stressed contexts. This differentiation reflects evidence from microclimatic studies showing that canopy cover and evapotranspirative flux can reduce air temperature in dense urban environments (Armson et al., 2012; Rahman et al., 2020).

Table 4.6 - Summary of the integrated rule-based planting logic applied to the Micro scale area

Rule / Design Function	Environmental Condition (GIS-BIM Parameters)	Assigned Typology	Example Species	Planting Density (per 100 m ²)	Design Objective
NoTree Areas	EVI = 3-4 AND BSI = 3-4	Rest Areas	-	0	Preserve spatial openness, maintain visual and functional permeability; provide resting and recreational clearings.
Soil Fertility Enhancement	SOC = 1-2 OR BSI = 1-2	T2_Medium / T6_Medium	<i>Acer campestre</i> , <i>Carpinus betulus</i> , <i>Cercis siliquastrum</i>	2 trees / cell	Regenerate degraded soils, improve fertility, stabilise slopes through root and litter action.
Low-Maintenance Irrigation	NDMI = 3-4 OR MSI = 3-4	T1_Small (EVI ≤ 2) / T4_Large (EVI ≥ 3)	<i>Robinia pseudoacacia</i> , <i>Celtis australis</i> , <i>Quercus ilex</i> , <i>Olea europaea</i>	1-2 trees / cell	Promote self-sustaining vegetation under low irrigation; enhance resilience to water stress.
Cooling and Shading	UHI = 1-2 AND EVI = 1-2	T4_Large / T5_Large	<i>Quercus ilex</i> , <i>Pinus pinea</i> , <i>Platanus × acerifolia</i> , <i>Salix alba</i>	1 tree / cell	Reduce surface temperature through shading and evapotranspiration; increase human comfort and microclimatic balance.

Note: the table represents the summary of the integrated rule-based planting logic applied to park areas. Each cell of the BIM model activates a specific typology according to the prevailing environmental conditions. The resulting configuration alternates shaded zones, remediation clusters and open clearings, producing an adaptive and multifunctional park structure.

When combined, these rules (summarized above in Table 4.6) produce a heterogeneous but ecologically coherent structure: shaded corridors alternate with open clearings and remediation clusters, composing a mosaic that adapts to both environmental logic and programmatic needs.

The Integrated Scenario therefore acts as a digital synthesis of the park's ecological metabolism, where each design choice is informed by measurable evidence yet remains open to interpretation and refinement by the designer (Nijhuis & Bobbink, 2012).

Rather than fixing a definitive configuration, the model establishes a framework for adaptive management, supporting future needs based on environmental monitoring, climatic variation or maintenance feedback.

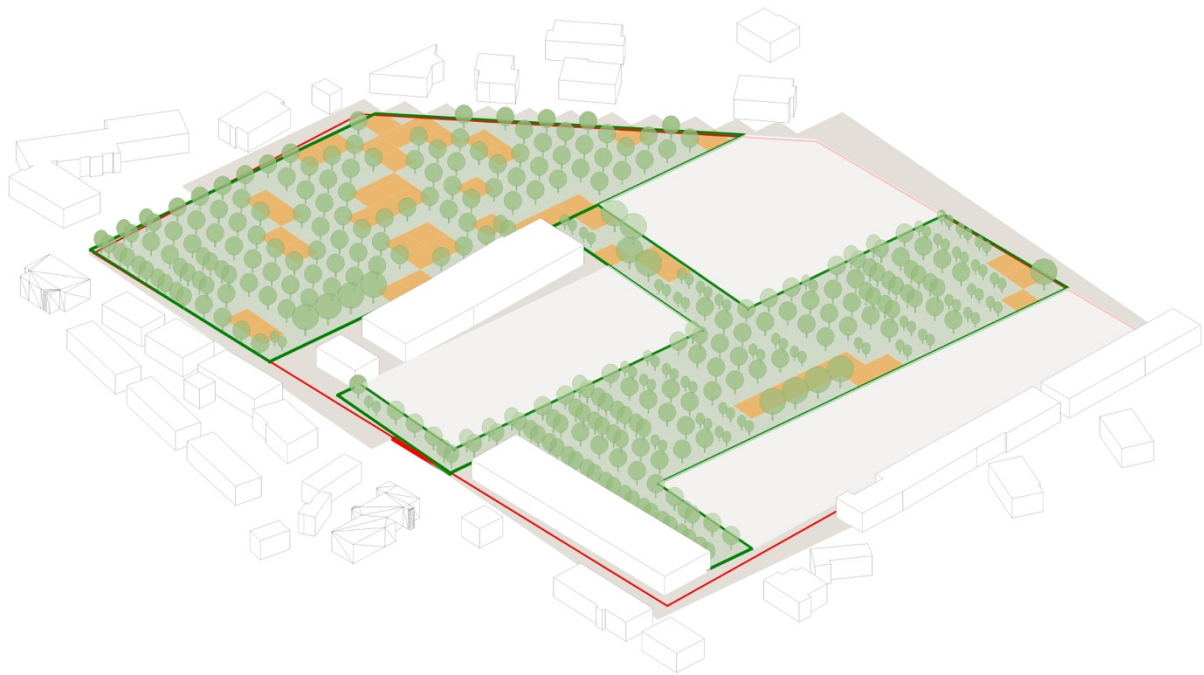
This approach embodies the concept of the evidence-based landscape, in which environmental knowledge, digital modelling and design creativity converge to produce resilient and context-specific landscapes (Nassauer & Opdam, 2008; Steiner, 2014).

The resulting configuration (Figure 4.25) shows a layered vegetative system that adapts to environmental gradients while maintaining functional coherence with the project's programme. Different planting typologies and canopy sizes are distributed across the site according to the rules previously defined. In the figure, rest and open areas are highlighted in orange, indicating the zones intentionally left free from tree planting to preserve spatial openness and ensure visual continuity within the park.

Expanding the vision of the singular project, this layout defines a multiscale green infrastructure: at the macro scale, the park acts as a cooling corridor; at the meso scale, it reconnects the industrial and natural areas; lastly, at the micro scale, it expresses ecological variability through differentiated planting units (Hansen & Pauleit, 2014).

This synthesis reflects the principles of adaptive and evidence-based design, in which ecological processes and project requirements are continuously aligned through interoperable digital models (Cantrell & Mekies, 2018; Nijhuis, 2015) Ultimately, the model demonstrates how digital workflows can guide planting design not only as a technical process but as a dynamic design language that translate data into spatial form, ecological meaning and experiential quality.

Figure 4.25 - Integrated data-driven planting scenario within the BIM environment that combines the planting principles (Low-Maintenance Irrigation, Soil Fertility Enhancement and Cooling and Shading) and spatial layouts necessities



After defining the vegetative structure through data-driven planting strategies, the next phase addresses the terrain itself. The following section explores how topography can be shaped through topography-informed grading, aligning soil movements and surface modelling with ecological and hydrological principles.

4.2.2.3 Topography-informed Grading Scenario

After defining the vegetative structure through the integrated planting simulation, the workflow proceeds to the modelling of terrain morphology. Topography plays a crucial role in shaping hydrological behaviour, soil stability and the overall ecological performance of the site and, therefore, represents the final layer of the data-driven design sequence.

The Topography-Informed Grading Scenario represents the final phase of the data-driven design workflow and it focuses on how terrain modification can enhance ecological processes, such as drainage, water retention, erosion control and habitat connectivity, while maintaining technical feasibility and design intent. The GIS datasets stocked within the floors are not used as static background information but as drivers for the adaptive reshaping of the topography, ensuring that soil movements respond to real geomorphological and hydrological conditions (Palmer et al., 2014).

At the Micro scale, rather than a general reshaping of the terrain, this simulation focuses on micro-topographic adjustments aimed at improving the hydrological resilience of the park's planting zones. The workflow builds upon the terrain model generated in InfraWorks and refined within Revit through Toposolid tool. The process begins with the identification of areas affected by low soil moisture and high drought stress, corresponding to cells where $NDMI \leq 2$ and $MSI \leq 2$. These areas, previously classified as "Park" within the BIM environment, are selected through a dedicated Dynamo script that filters the spatial units according to their environmental parameters. The objective is to model localised depressions and collection basins capable of capturing and storing surface runoff during rainfall events, ensuring a more stable water supply for vegetation during dry periods.

Within this scenario, the BIM model functions as a hydrological simulation platform, allowing the designer to visualise and test the interaction between planting layout, soil morphology and hydrological flow.

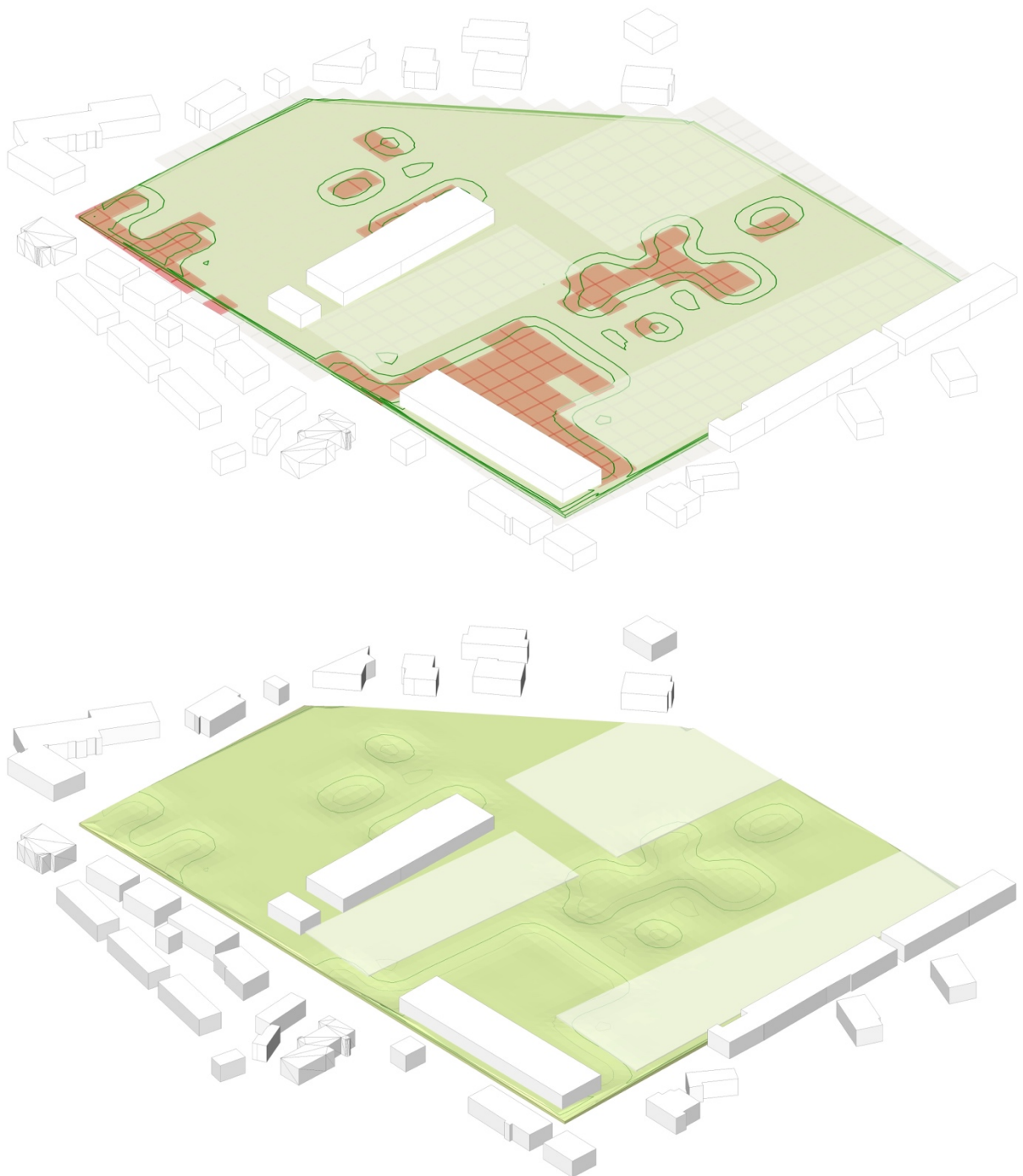
Using Toposolid modifiers, small-scale grading operations (typically within ± 1 m) are introduced to create a sequence of shallow basins and swales following the natural slope of the terrain (Ekka et al., 2021). These elements form a network of infiltration zones that temporarily retain water, allowing it to percolate into the soil and support nearby planting units (Frei & Fleckenstein, 2014). The workflow thus translates the environmental evidence derived from remote sensing and GIS analysis into a hydrologically adaptive landscape design. By coupling the spatial distribution of drought areas with topographic modification, the system improves water availability where it is most needed, reducing irrigation demand and promoting vegetation self-sufficiency.

This strategy reflects the principles of nature-based solutions for water-sensitive design, where grading and vegetation act synergistically to restore the local hydrological cycle (Cansian et al., 2025).

The resulting configuration (Figure 4.26) shows how the dry areas identified through NDMI and MSI data (highlighted in red) are reshaped into micro-catchment structures integrated with the vegetated park zones.

These low-impact earthworks support the park's long-term ecological function by balancing water retention, soil permeability and vegetation health, turning topography into a performative ecological device rather than a static form.

Figure 4.26 - Topography-informed grading simulation: above, identification of drought-sensitive areas ($NDMI$ and $MSI \leq 2$) and slope analysis within the park boundaries used as input for grading operations; below, render view of the resulting micro-topographic configuration, showing local depressions and swales designed to enhance water retention and support vegetation in dry periods



The Topography-Informed Grading Scenario completes the data-driven design sequence by translating analytical evidence into a performative morphological strategy.

While previous simulations focused on the adaptive configuration of vegetation, this stage demonstrates how terrain manipulation can actively contribute to ecological balance and water management within the park system.

The introduction of micro-depressions and shallow grading patterns allows the landscape to react to drought-sensitive areas identified through NDMI and MSI indicators, creating a hydrological infrastructure that supports vegetation in periods of scarcity.

Through this workflow, topography becomes an operational layer, not a static background, but a dynamic medium capable of regulating water flows, influencing soil behaviour and reinforcing the ecological structure defined by planting design.

The combination of digital modelling and environmental data ensures that every topographic intervention corresponds to measurable conditions, transforming site morphology into a controllable and optimisable variable within the BIM environment. This scenario also confirms the value of integrating hydrological intelligence into the design process, anticipating the effects of climate variability and supporting long-term maintenance strategies.

The resulting model acts as both a predictive and adaptive tool, allowing designers to test multiple configurations of grading and planting while maintaining coherence with environmental parameters and client requirements (Sun et al., 2024).

In synthesis, the Topography-Informed Grading Scenario consolidates the transition from descriptive to generative digital models, where geometry, vegetation and terrain collectively perform as a single ecological system.

It establishes the methodological foundation for the Final Integrated Scenario described in the following section, where all data-driven rules (vegetation, soil and topography) are combined into one coherent and operational landscape framework.

4.2.2.4 Final Project Scenario

The Final Integrated Scenario represents the synthesis of the three previous data-driven simulations, merging the logics of environmental classification, adaptive planting and topography-informed grading into a single coherent design framework (Karan et al., 2016).

At this stage, the BIM model integrates all datasets and rules developed throughout the EO-GIS-BIM workflow, providing a complete digital representation of the park's ecological and spatial structure.

Here, environmental intelligence, design intent and spatial modelling converge into one operative environment, where each component, vegetation, soil, topography and infrastructure, performs as part of a single interconnected system (Piras et al., 2024).

The integrated model combines information layers derived from Earth Observation indices (NDVI, NDMI, MSI, BSI, SOC, UHI), planting simulations (based on typologies, density and water demand) and micro-grading operations (linked to drought and infiltration conditions). This multilayer structure transforms the model from a static digital archive into a living representation of landscape dynamics, capable of simulating ecological responses to changing environmental inputs. Through this approach, the workflow demonstrates how interoperable models can reproduce, at a design scale, the continuous exchange between terrain, vegetation and hydrological processes that characterises real landscapes (Schaller et al., 2017).

The resulting configuration (Figure 4.27) shows the complete Revit environment populated with all data-driven elements. Each Floor cell retains its environmental parameters, while vegetation families and Toposolid geometries are directly connected through the rules previously defined. The visual output illustrates how the combination of semantic data and geometric representation creates a multilayered model that is both analytical and performative (Ahern, 2013).

To illustrate the internal logic of this digital construction, Figure 4.28 presents an exploded axonometric view in which the model is vertically decomposed into its main layers:

- the GIS-derived grid and environmental parameters at the base;
- the topography-informed surfaces and grading operations;
- the vegetation system linked to the planting rules;
- the infrastructural and architectural components of the park.

This vertical reading of the model reveals how environmental evidence informs each design layer, ensuring that every geometric element corresponds to a defined ecological or functional rationale.

The integration of the three workflows results in a park system that is both ecologically adaptive and spatially coherent.

In the northern portion, remediation and phytostabilisation strategies prevail, transforming compacted soils into productive ecological buffers.

The central belt hosts the public park and cultural facilities, where large-canopy species enhance comfort and accessibility while ensuring a visual connection with the preserved industrial heritage.

Towards the southern edge, the reduced photovoltaic field merges with vegetated surfaces through an ecovoltaic approach, creating a hybrid zone that reconciles energy production with ecological continuity.

This distribution aligns with the client's requirements, while optimising environmental performance according to measurable site conditions.

Figure 4.27 - BIM model of the Final Scenario project integrating all the created elements starting from GIS environmental data, vegetation typologies and topography-informed grading

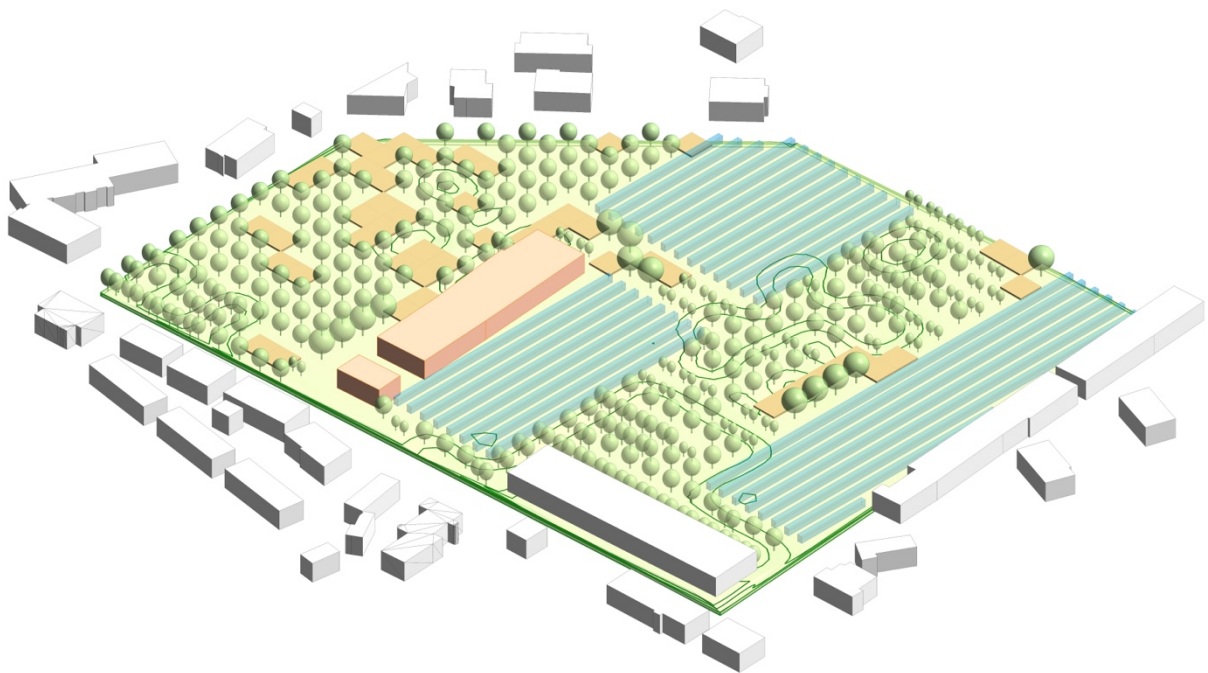
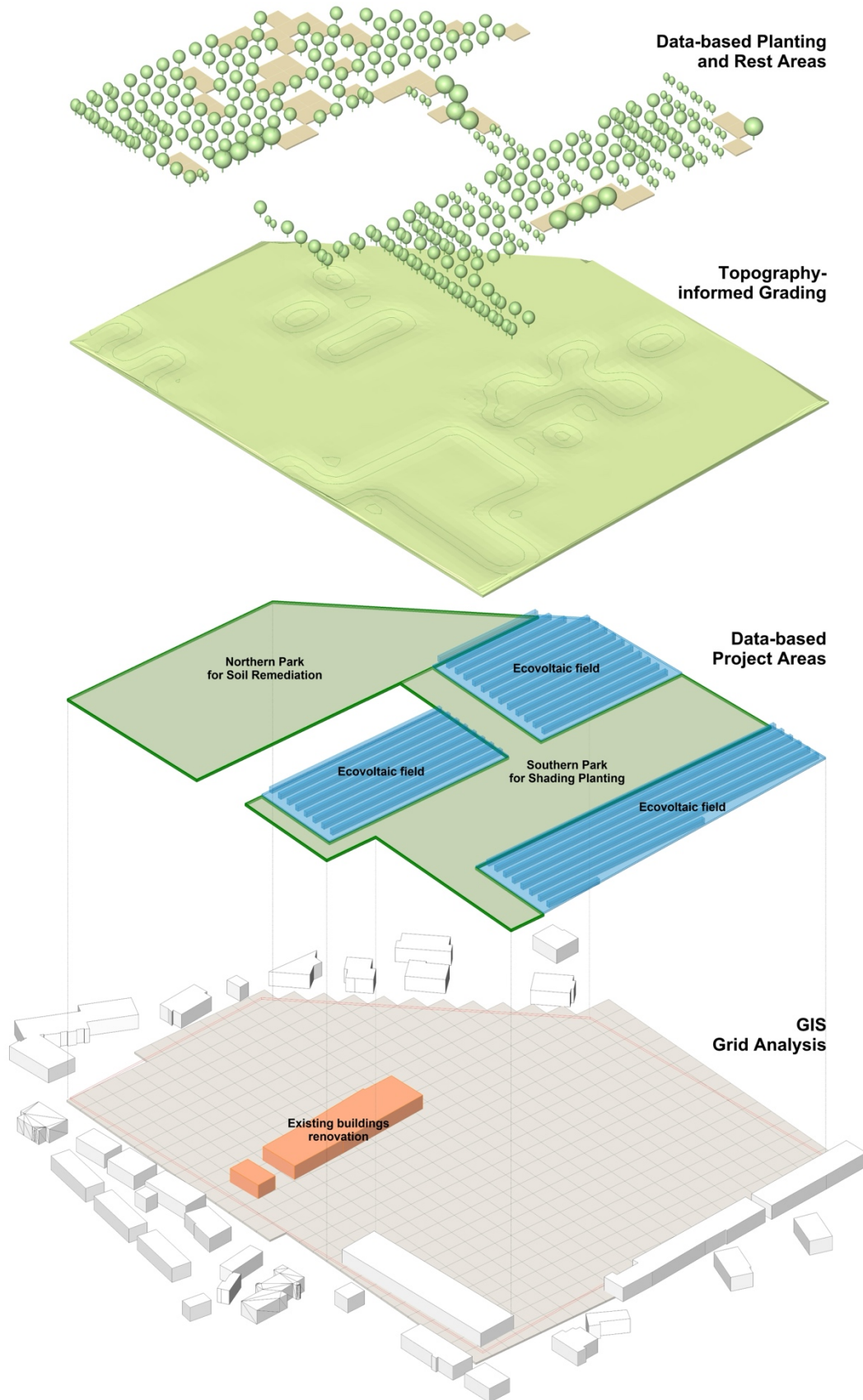


Figure 4.28 - Exploded axonometric view showing the integration of GIS data within the BIM model and all the created generative levels data-based: Planting, Topography and Project areas



The final render (Figure 4.29) visualises the combined environmental and spatial performance of the proposal. The model demonstrates how vegetative density, micro-topography and material selection interact to generate microclimatic diversity, shade patterns and water-sensitive surfaces.

The result is not a fixed design but an adaptive framework, capable of evolving through monitoring and maintenance, in line with the principles of resilient and evidence-based landscape design (Ahern et al., 2014).

Figure 4.29 - Rendered view of the Final Integrated Scenario, showing the interaction between vegetation, terrain and built structures



To evaluate the effectiveness of the data-informed workflow, a comparative assessment was carried out between the original project configuration and the new scenario generated through GIS-BIM integration. The comparison focuses on key parameters related to vegetation quantity, environmental compatibility and overall ecological coherence. The analysis reveals how the integration of environmental data significantly influences the distribution and selection of vegetation within the park.

To visualise the transition from a conventional to a data-informed design approach, the following Figure 4.30 present a direct comparison between the original project layout and the generative scenario developed through the GIS-BIM workflow.

The plan on the left illustrates the design configuration initially conceived for the redevelopment of the former Montecatini site, based primarily on spatial composition and programmatic logic.

The plan on the right shows the new configuration generated from the integration of environmental datasets within the BIM environment, where vegetation, open spaces and energy infrastructures are spatially

reorganised according to site-specific conditions and compatibility parameters derived from EO and GIS analyses.

At an equivalent photovoltaic surface area of approximately 2 hectares, the table shows the comparison between the two scenarios, providing the basis for the subsequent quantitative evaluation of performance indicators summarised in Table 4.7.

Figure 4.30 - Comparison between the two project configurations: on the left, the original project layout; on the right, the data-driven generative scenario produced through the GIS-BIM workflow

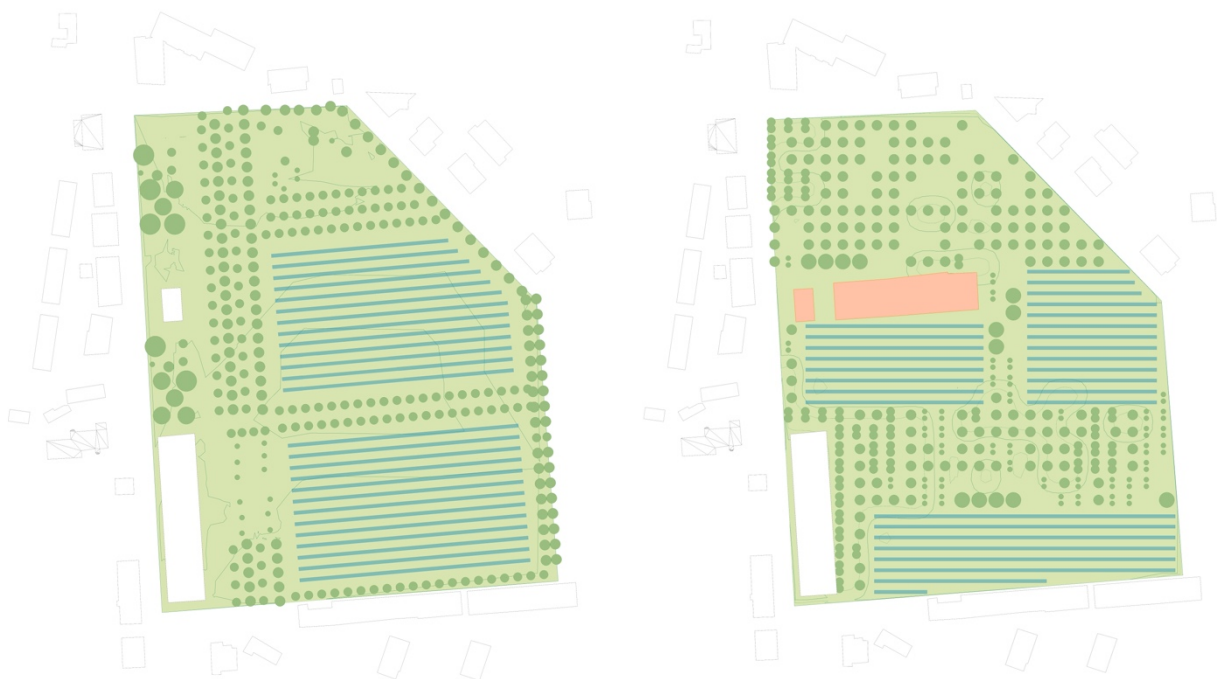


Table 4.7 - Comparative performance indicators between original project and data-driven scenario

Parameter	Original Project	Data-Driven Scenario	Variation / Interpretation
Total number of trees	298	345	+16% canopy density
Ecological compatibility (%)	43%	80%	Better alignment with EO-derived soil and moisture data
Average planting density (trees/ha)	49	58	More uniform distribution
Water retention basins (n.)	0	5	Integration of topography-informed grading
Shaded area (m ²)	6,850	8,350	Higher comfort and reduced UHI
Irrigation demand (qualitative)	Medium-high	Low	Improved resource efficiency

The data show a clear improvement in both ecological performance and functional adaptability. While the original project relied primarily on client’s requests and formal principles, the new scenario redistributes vegetation according to measurable environmental gradients. The increase in the number of compatible trees indicates a more efficient use of resources: species are placed in areas with suitable soil moisture and fertility, reducing irrigation requirements and maintenance effort. The elimination of non-compatible trees highlights the capacity of the GIS-BIM model to function as a diagnostic and corrective tool, supporting decision-making during the early design phases.

From a methodological perspective, this comparison confirms the added value of environmental interoperability. The data-driven approach transforms the design model into a responsive system capable of balancing ecological evidence and spatial intent (Gnädinger & Roth, 2021).

In quantitative terms, the new configuration achieves higher vegetation compatibility and coverage, while in qualitative terms it enhances the site’s ecological coherence and adaptive potential. When environmental parameters actively inform the design workflow, the project evolves from static representation toward a more predictive and evidence-based system, capable of guiding sustainable spatial decisions.

The integration of environmental information does not replace the role of the designer. Rather, it strengthens design authorship by providing actionable evidence that can be critically interpreted in relation to experiential knowledge, spatial intentions and client requirements. This reciprocity ensures that data-supported solutions remain coherent with both ecological conditions and project ambitions (Figure 4.31).

By merging EO, GIS and BIM within a single operational model, the landscape project becomes a dynamic system of relations open to iteration, responsive to environmental variability and grounded in measurable evidence. This synthesis at the micro scale provides the methodological foundation for the following chapter, where the workflow is extended and tested across larger territorial contexts.

Figure 4.31 - Synthesis of the data-driven workflow: the diagram illustrates the reciprocal exchange between designer choices and environmental data, leading to a final scenario that integrates ecological performance with client requirements

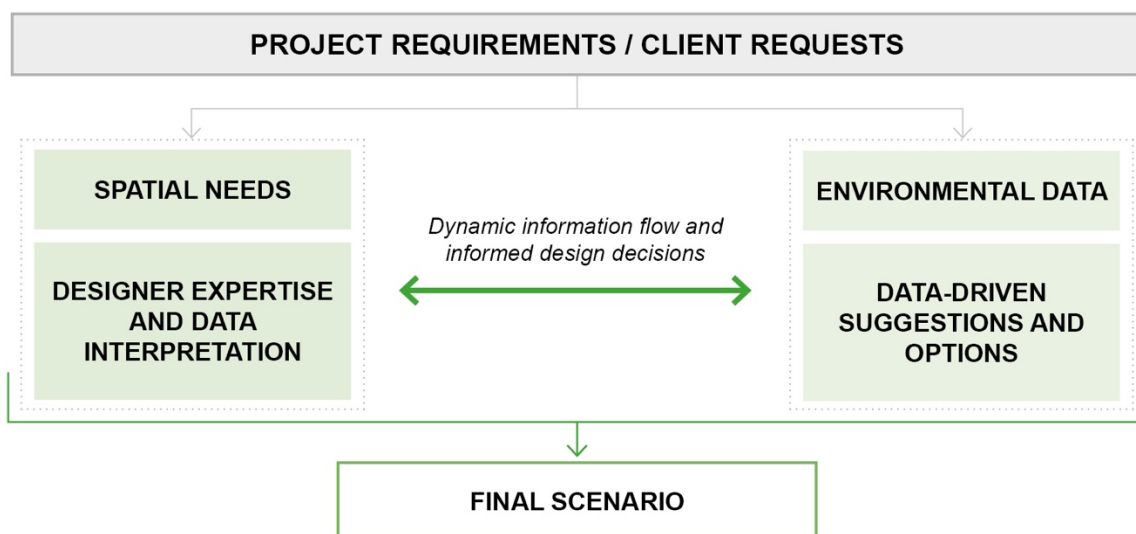


Figure 4.32 - Actual condition of the Medium scale area case study: Bussi sul Tirino and the industrial zone



4.3 Medium Scale: Environmental Recovery Based on Data

At the Medium scale, the workflow is applied to the Municipality of Bussi sul Tirino and its surrounding territory, one of the most emblematic and complex cases of industrial transformation in central Italy.

The study area, covering approximately 3×3 km, includes the historical and ongoing industrial activities, the landfill sites 2A and 2B and the Edison thermoelectric power plant, together with the Tirino River corridor, a fragile ecological structure flowing southward to merge with the Pescara River. The area is enclosed by two major infrastructural axes, the A25 motorway and the F.S. Bussi sul Tirino railway, that mark the boundary between the industrial core and the surrounding natural landscape composed of forests, riparian vegetation and agricultural mosaics.

This portion of the valley represents a critical point of convergence between industrial legacy, environmental remediation and landscape regeneration, where environmental recovery, industrial memory and ecological regeneration must coexist. It is within this condition of tension, between remediation and transformation, that the Medium scale model finds its significance, it becomes a testing ground for data-driven landscape recovery, translating environmental evidence into strategic design actions (Karan et al., 2016).

The methodological focus at this scale shifts from design detailing to strategic environmental and territorial analysis. The objective is not to reproduce the form of the project, but to understand and map the processes that define its ecological potential. To this end, a comprehensive GIS database was created, integrating both Earth Observation data and local environmental information.

The core of this dataset is constituted by the Copernicus Sentinel-2 and Google Earth Engine multispectral imagery, from which the main vegetation and soil indices were extracted: NDVI and EVI (vegetation vigour), NDMI and MSI (moisture balance and drought stress), BSI and SOC (soil conditions) and UHI (urban heat island intensity). The NDWI dataset, which indicates the presence of water, was excluded at the Medium scale because it was not suitable for the level of spatial detail considered in the analysis.

Each raster dataset was processed in QGIS and adapted to a 30×30 m analytical grid, ensuring consistency between the GIS classification and the later BIM integration. This resolution proved effective for representing large-scale environmental gradients while maintaining a manageable number of data points for interoperability (Gabriele et al., 2022).

All indices were then normalised and classified into four environmental classes, following the same logic applied at the Micro scale but recalibrated for broader territorial variability (Figure 4.33, Figure 4.34 and Figure 4.35). The resulting dataset provides a quantitative description of the environmental state of the area, functioning as the analytical foundation for the following design steps.

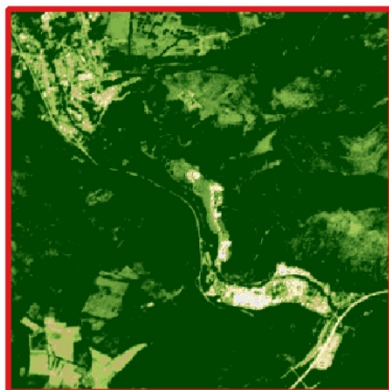
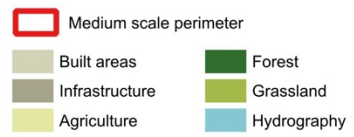
Figure 4.33 - Land Use map of the Medium scale, NDVI and EVI indices showing the EO-to-GIS process from Copernicus Browser imagery to grid adaptation (30 × 30 m) and classification into four standardised environmental classes for BIM integration.



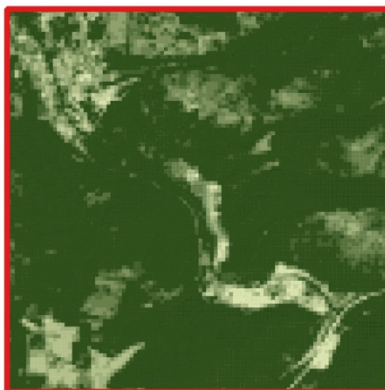
Actual condition



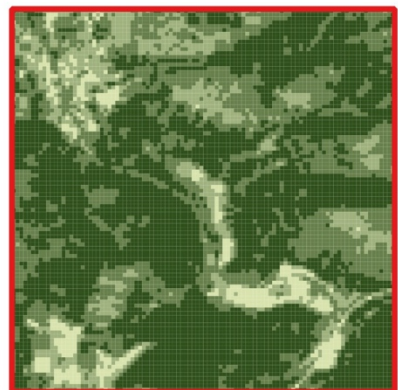
Land use



NDVI - EO Copernicus



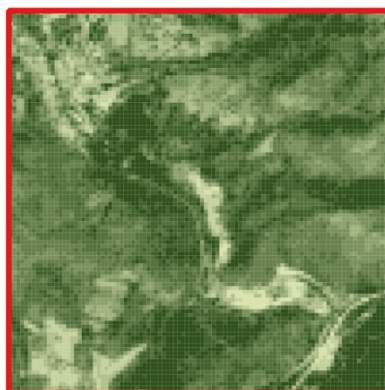
NDVI - 30 x 30 m grid analysis



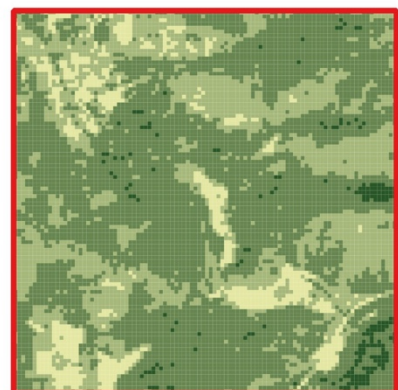
NDVI - 4 value classes



EVI - EO Copernicus



EVI - 30 x 30 m grid analysis



EVI - 4 value classes

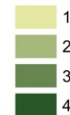


Figure 4.34 - NDWI, NDMI and MSI indices showing the EO-to-GIS process from Copernicus Browser imagery to Medium scale grid adaptation (30×30 m) and classification into four standardised environmental classes for BIM integration.

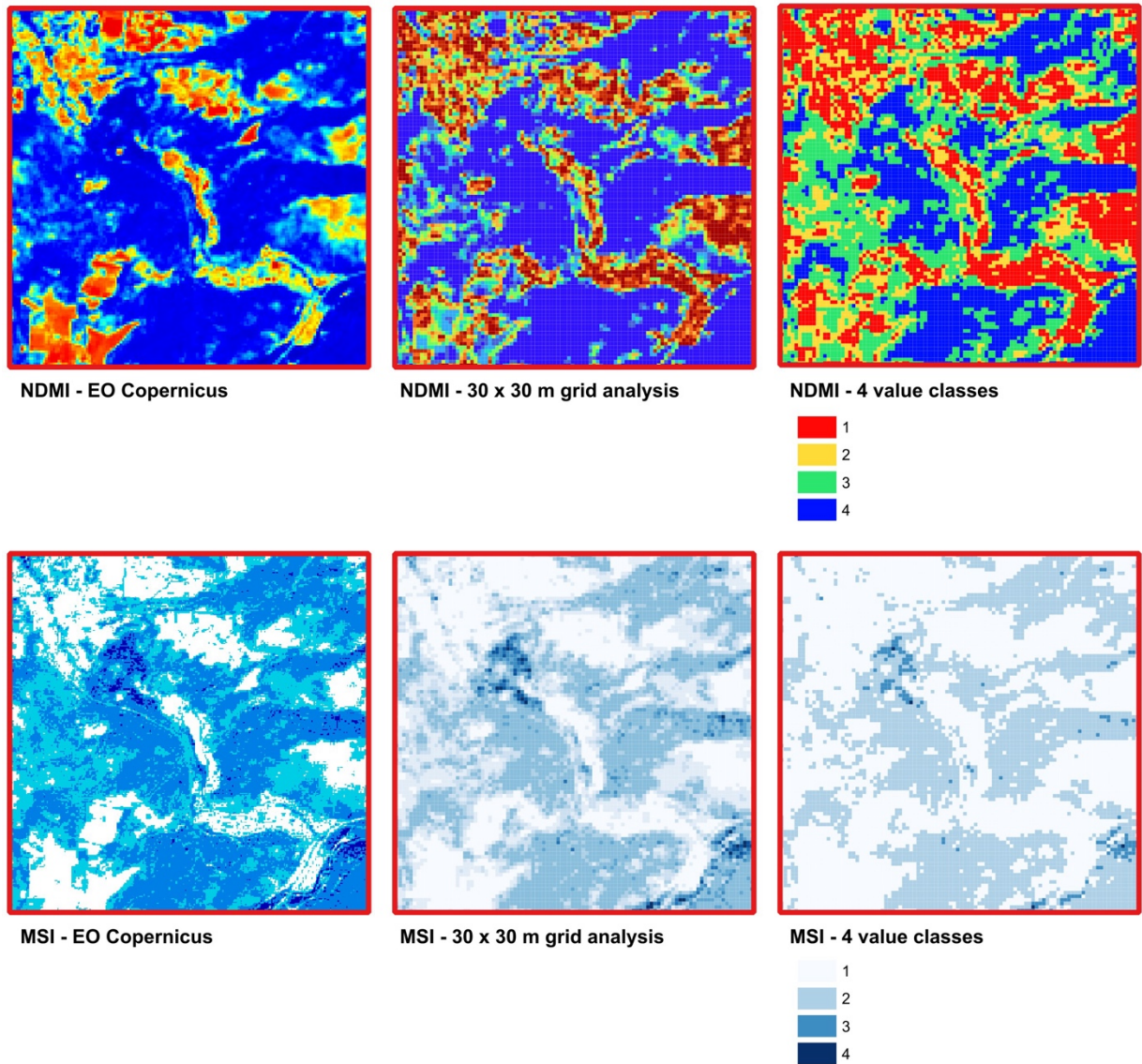
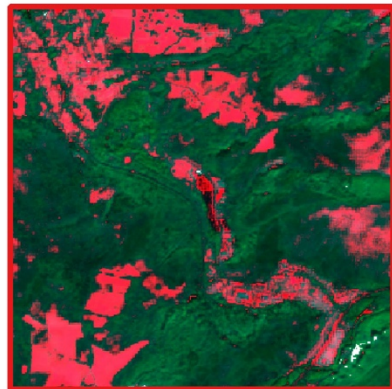
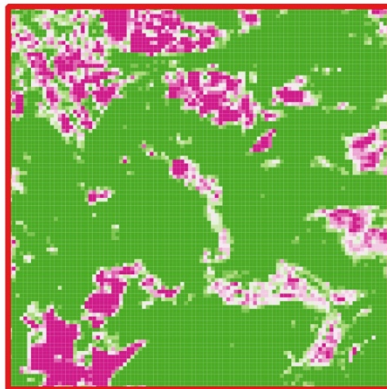


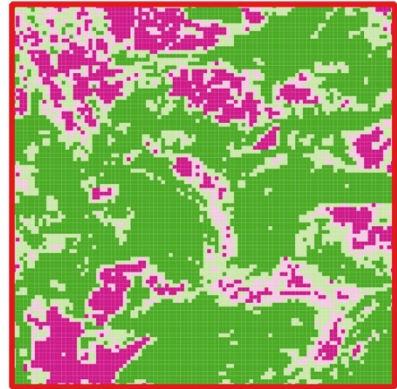
Figure 4.35 - BSI, SOC and UHI indices showing the EO-to-GIS process from Copernicus Browser imagery to Medium scale grid adaptation (30 × 30 m) and classification into four standardised environmental classes for BIM integration.



BSI - EO Copernicus



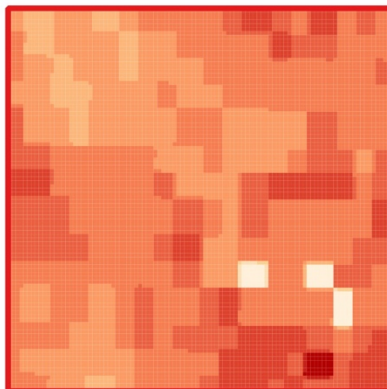
BSI - 30 x 30 m grid analysis



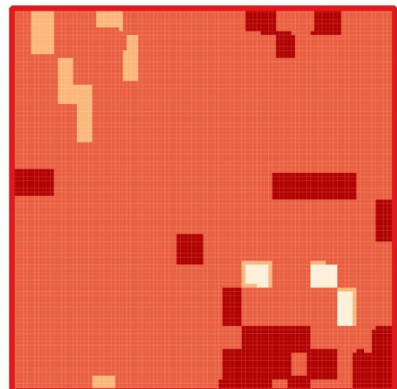
BSI - 4 value classes



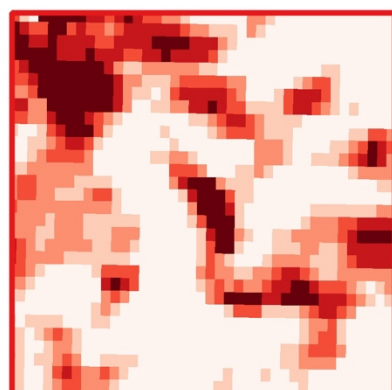
SOC - EO Copernicus



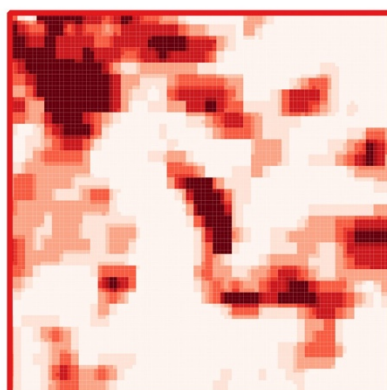
SOC - 30 x 30 m grid analysis



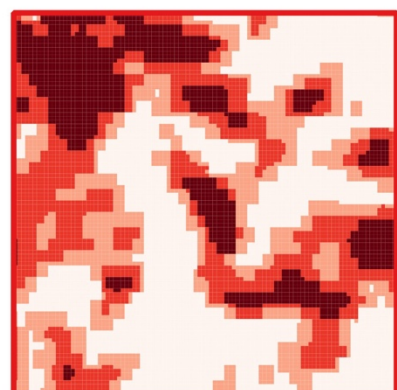
SOC - 4 value classes



UHI - EO Copernicus



UHI - 30 x 30 m grid analysis



UHI - 4 value classes



To improve the perceptual and interpretative understanding of this data, the classified rasters were imported into Autodesk InfraWorks, as shown in Figure 4.36 and Figure 4.37. This digital environment proved particularly effective at the Medium scale, as it allowed an immersive, three-dimensional visualisation of the territory.

Through its integration of elevation models, river networks, vegetation cover and infrastructure, the software enables the user to perceive how environmental gradients correspond to geomorphological and land-use structures.

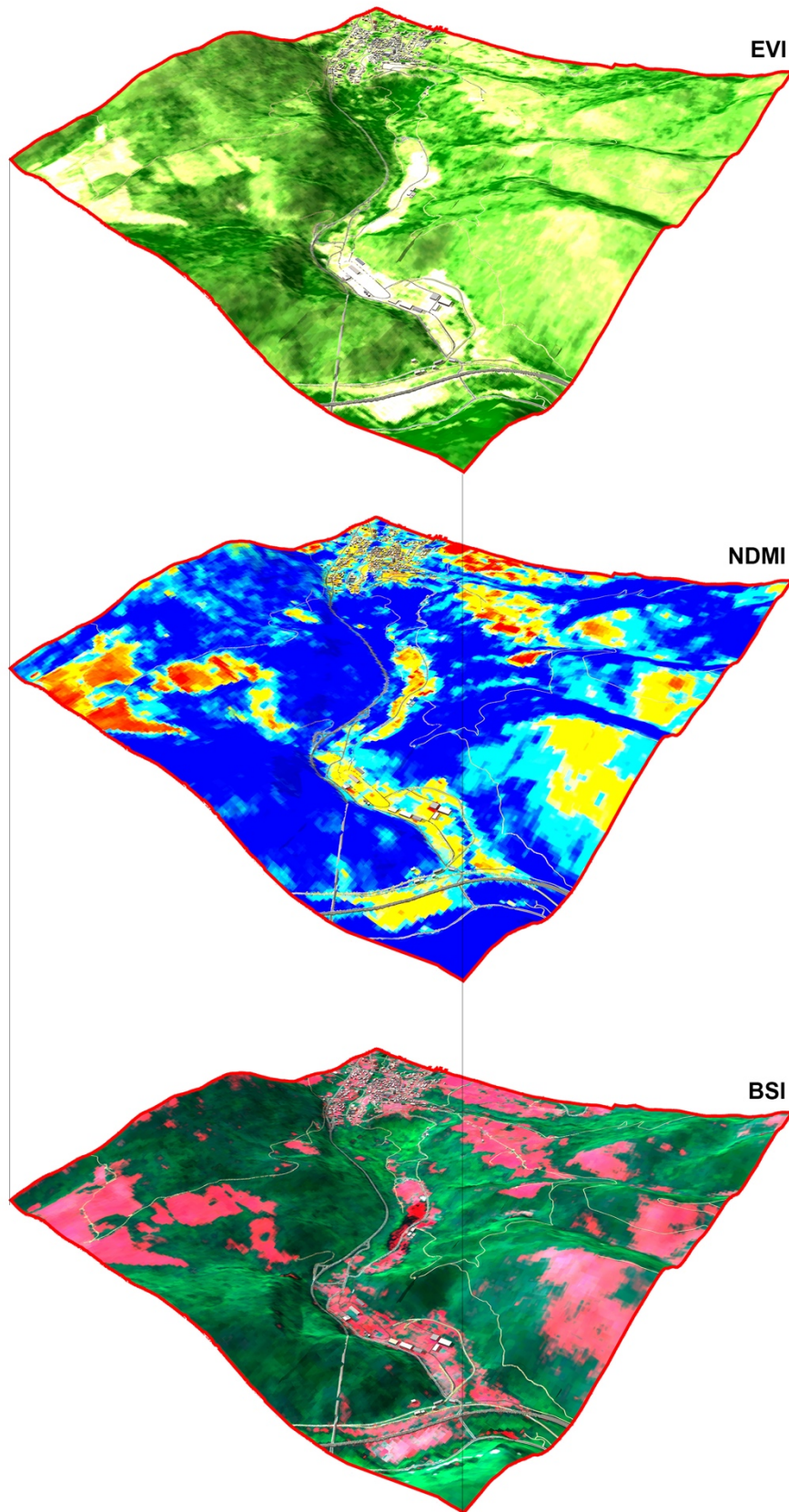
In contrast to the Micro-scale application, where InfraWorks mainly served as a representational tool, here it assumes a diagnostic function, helping to identify relationships between hydrology, vegetation and topography that would be less evident in planimetric representations.

The visualisation of environmental datasets within a spatially realistic 3D context also facilitates the communication of complex ecological patterns to stakeholders and decision-makers, bridging the gap between technical analysis and landscape interpretation.

Figure 4.36 - InfraWorks model of the Medium Scale, generated through Model Builder, including the surrounding hydrographic and infrastructural systems



Figure 4.37 - InfraWorks model enriched with selected raster datasets (e.g., EVI, NDMI and BSI), highlighting how environmental gradients correspond to the terrain at the Medium scale



Compared to the Micro-scale case study, where the BIM model served as a detailed testing ground for integrating environmental data with planting and grading design, the medium-scale application operates at a broader level of abstraction. At the Medium scale, the focus shifts from the fine-grained control of design elements to the strategic understanding of landscape systems, using BIM not only as a modelling platform but as a decision-support environment for territorial-scale ecological planning. This shift of scale implies a change in purpose: while the Micro-scale workflow demonstrated the feasibility of linking GIS and BIM for precise, data-driven design, the medium-scale model explores how the same methodology can be used to read, interpret and guide landscape transformation over larger extents.

The transition from GIS to BIM therefore acquires a renewed significance. Rather than simply transferring data, it represents a translation from environmental evidence into spatial reasoning, a way of making complex territorial phenomena legible and operational within a three-dimensional framework.

The Revit model becomes not a detailed representation of individual design elements, but a digital prototype of the landscape, capable of aggregating environmental, morphological and typological information within a single parametric system. At this scale, the interoperability workflow acts as a conceptual bridge: it connects the analytical precision of GIS with the synthetic capacity of BIM to visualise relationships, hierarchies and design potentials.

The environmental parameters previously elaborated in GIS were imported into Revit through the same Dynamo-based workflow tested at Micro scale, but now adapted to the coarser 30×30 m analytical grid. Each grid cell was converted into a Floor element carrying the corresponding parameter values as instance attributes. In addition to these environmental datasets, the grid also integrates the information derived from the Land Use classification, providing a categorical layer that distinguishes between forests, grasslands, agricultural areas and built-up zones. This addition introduces a territorial dimension to the BIM model, enabling it to relate ecological parameters to land-use functions and to identify the potential for transformation or conservation in different sectors of the valley, as shown in Figure 4.38 and Figure 4.39. The Land Use field, at this scale, becomes particularly relevant in the following phase, where it is used, together with environmental indicators, to define and filter the Strategic Areas for ecological intervention.

In this way, the model preserves a consistent structure between the two scales, yet modifies its function: while at micro scale each cell represented a potential design unit, here it becomes an analytical unit within a territorial matrix, allowing designers to interpret patterns rather than to refine geometric details.

Figure 4.38 - Revit environment after data import, where the classified grid and environmental parameters at the Micro scale are visible within the BIM environment, the indices EVI, NDMI and BSI are represented below

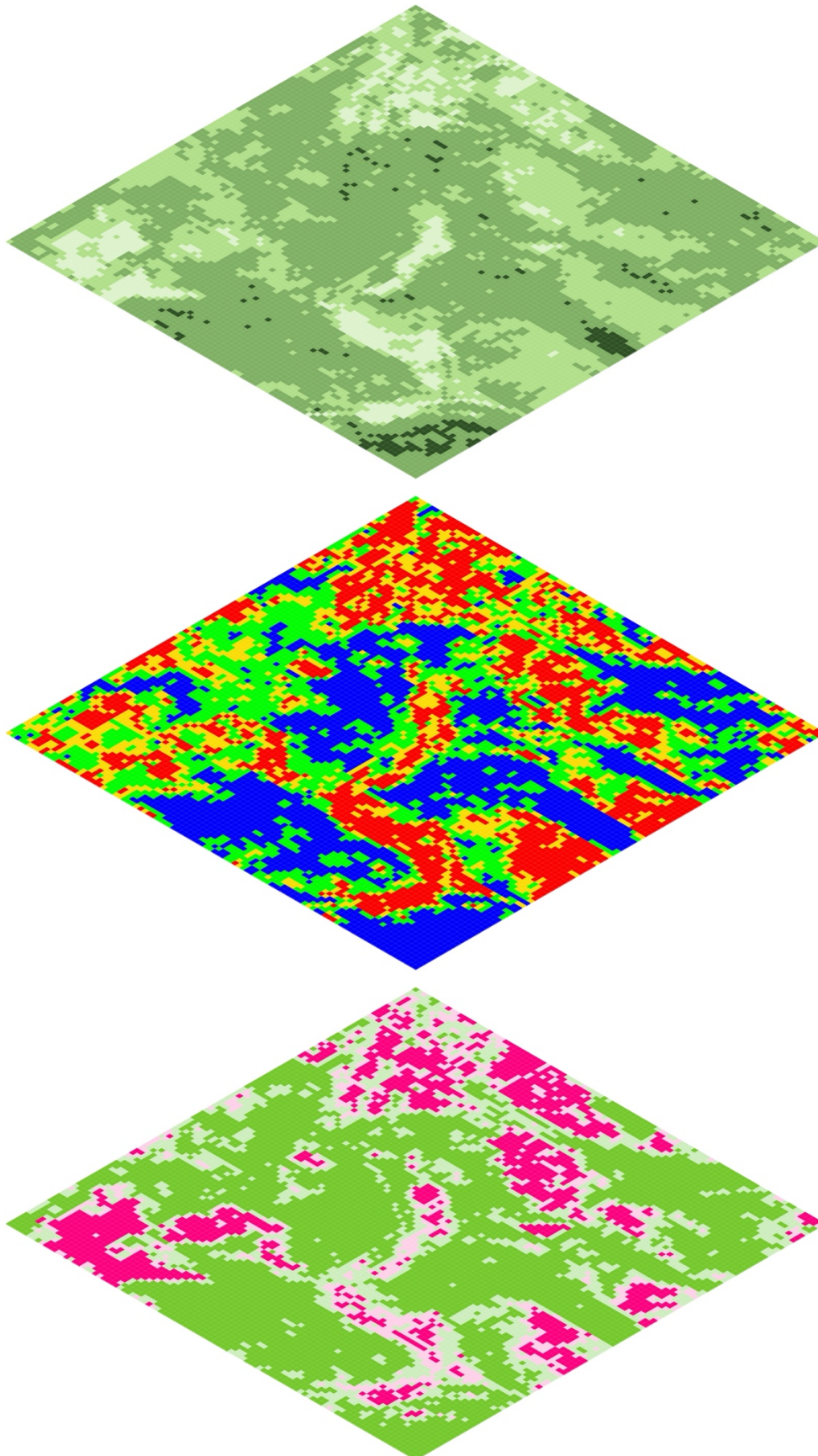
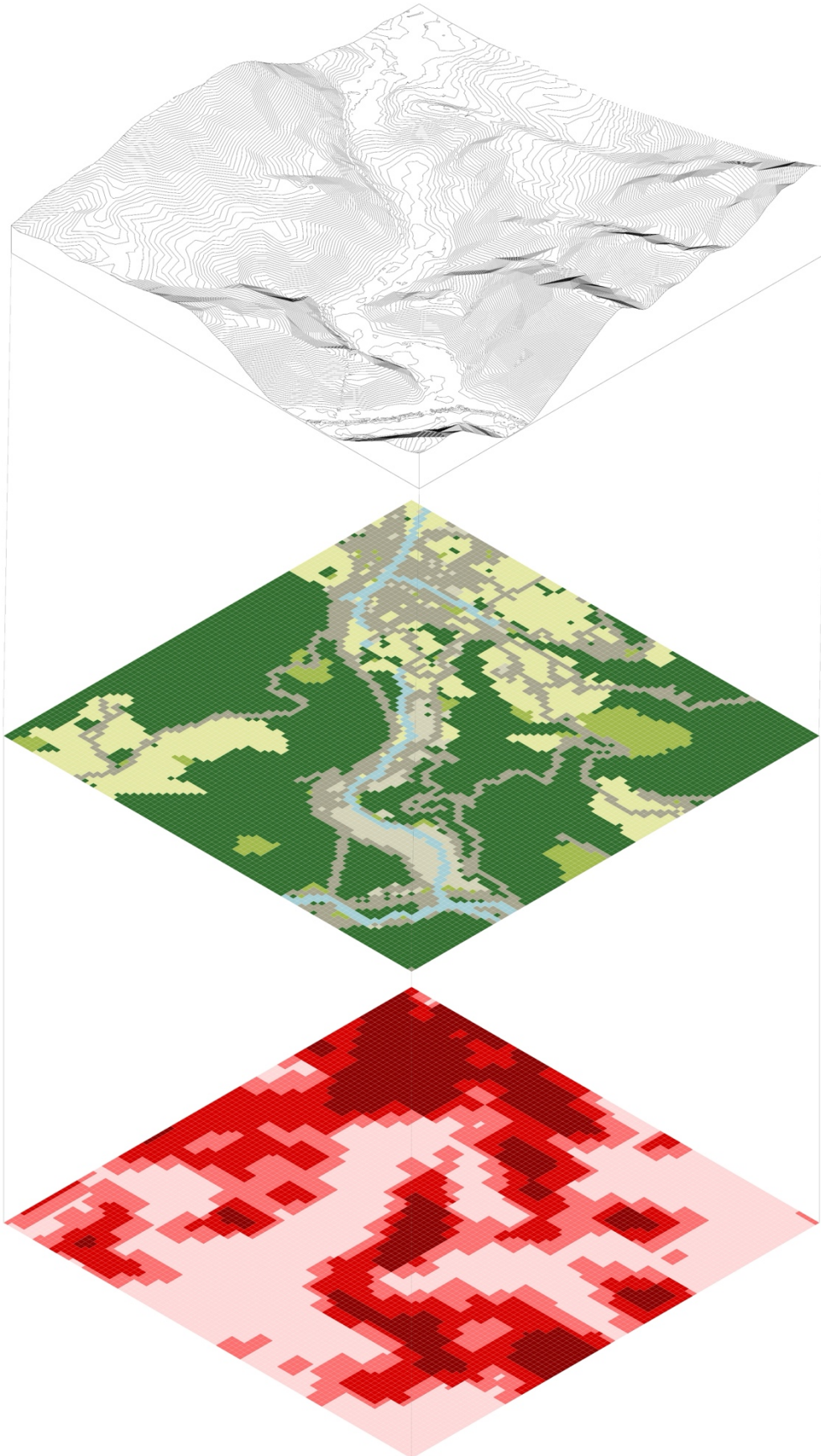


Figure 4.39 - Exploded axonometric view within Revit, showing the hierarchical composition of the Medium scale digital model: from the EO analysis layer (UHI represented) to land use, topography and project area



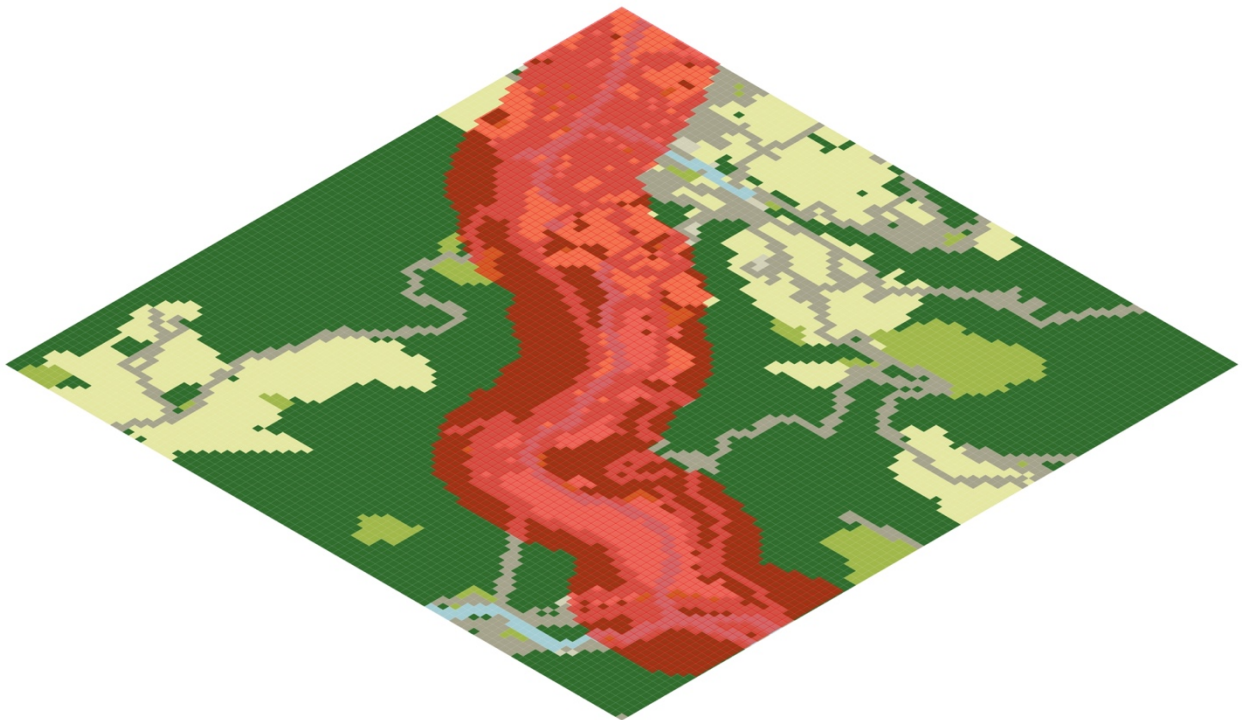
This scale adaptation changes not only the resolution but also the purpose of the model. At Micro scale, the environmental data directly controlled the configuration of planting families or grading operations. At Medium scale, the same data acquire a diagnostic role, guiding the identification of where ecological recovery is most needed and where it can have the greatest systemic impact.

The BIM environment thus shifts from a space of detailed design simulation to one of spatial reasoning, where environmental evidence is used to frame strategic priorities.

A central step in this translation is the definition of a 300 m intervention buffer along the Tirino River which is the main ecological corridor of the valley and a key component of the Bussi sul Tirino SIN (Sito di Interesse Nazionale). The introduction of this buffer responds to both ecological and regulatory motivations. Ecologically, the river corridor represents the most sensitive and dynamic system in the study area: its hydrological processes (water flow, sediment transport, soil moisture variation) govern much of the surrounding landscape's ecological behaviour. From a planning standpoint, national guidelines for SIN areas prioritise interventions aimed at restoring hydrological continuity, riparian vegetation and ecological connectivity along river systems (ISPRA, 2022).

The 300 m distance was therefore defined as a functional radius that captures the main fluvial terraces, floodplains and degraded agricultural margins likely to benefit from restoration measures, as illustrated in Figure 4.40.

Figure 4.40 - Identification of the buffer area of 300 meters around the Tirino river overlaying the Land Use layer



Within the Revit environment, this buffer becomes an operative boundary: not merely a static polygon but a parametric condition controlling subsequent actions in the model. By linking the buffer to each Floor element through a specific field parameter (`GIS_Buffer_Intervention = Inside`), the workflow automatically filters all following operations, such as planting allocation or soil modelling, so that they apply only to eligible cells. This logic ensures that every design action remains contextually grounded, acting where it is ecologically relevant and excluding zones where interventions would be redundant or incompatible (e.g., active industrial plants or forested areas).

Building on this operational framework, the next phase focuses on the identification of Strategic Areas for intervention within the defined buffer.

This step translates the analytical potential of the GIS-BIM integration into a spatial hierarchy of ecological priorities, identifying where restoration, reforestation or soil improvement actions should be concentrated. At this scale, the methodology evolves from simple data transfer to interpretative reasoning: the model does not only reproduce environmental evidence, but starts to interpret it, recognising spatial patterns that suggest potential for regeneration.

To achieve this, the workflow integrates the Land Use classification into the 30×30 m analytical grid previously imported into Revit. This additional parameter expands the interpretative capacity of the model, allowing each cell to be characterised not only by its environmental indices (EVI, NDMI, BSI, SOC, UHI), but also by its functional context, whether it corresponds to grassland, agricultural land, built-up fabric or natural forest. This connection between ecological conditions and land-use functions is fundamental at the medium scale, where the objective is to understand how territorial processes and ecological dynamics interact along the Tirino River corridor.

The model enables the interpretation of the landscape not only as a collection of environmental conditions but as a living structure shaped by human and natural processes. This allows the analysis to focus on those portions of territory where a change in land use can actively contribute to the ecological recovery of the river corridor.

Agricultural and grassland areas are therefore identified as priority targets for intervention, since they offer both spatial availability and ecological permeability, as well as certain built-up or degraded zones are included when they show potential for conversion or soft transformation into ecological buffers or green corridors. In addition, forested and natural zones, already performing stabilising functions, are deliberately excluded from the next phases, ensuring that the project concentrates its efforts where it is most needed.

This multi-criteria interpretation is operationalised within the Dynamo environment, where the parameters imported from GIS (such as GIS_Buffer_Intervention and GIS_LandUse) interact dynamically with the BIM model.

Through this interoperability, the model automatically isolates cells that correspond to the desired combinations of buffer inclusion and land-use typology, effectively building a map of strategic areas.

In the Revit environment, these cells are visually highlighted, providing an immediate representation of the ecological and spatial logic guiding the next steps of the project.

This process transforms the model into a decision-making tool rather than a static dataset. By translating GIS data into a parametric framework, the designer can not only visualise where the landscape is most fragile or transformable but also begin to understand why certain areas carry higher potential for regeneration. Thus, the selection of strategic areas becomes both an analytical and a design act, one that mediates between data interpretation and project vision and that prepares the ground for the subsequent planting and topographic simulations. The combination of aforementioned parameters enables the identification of intervention typologies, ranging from soil remediation to cooling and shading, as summarised in Table 4.8.

Table 4.8 - Environmental Parameters and Intervention Logic for the identification of Strategic Areas at Medium Scale

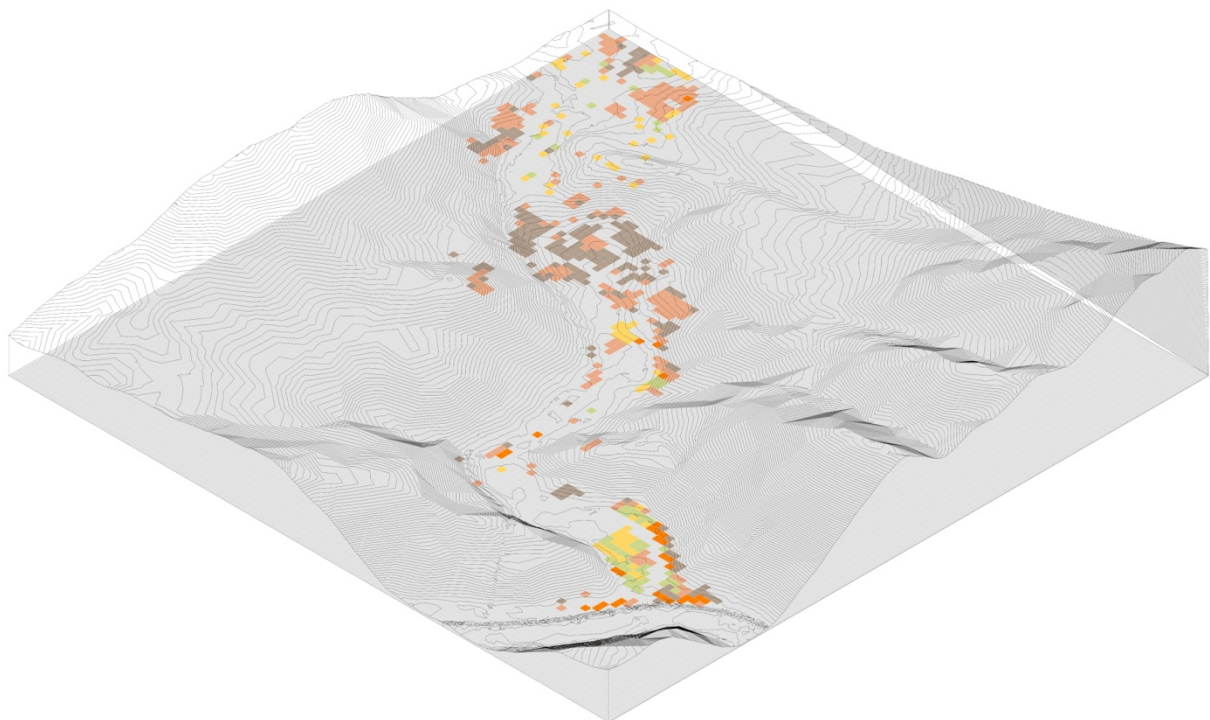
Typology	Key Environmental Conditions (GIS-based)	Ecological Rationale (Medium scale)	Design Strategy within SIN Context
Buffer Definition	GIS_Buffer_Intervention = Inside (within 300 m from Tirino River)	Ensures all interventions contribute directly to the ecological restoration of the river corridor.	Limits design operations to ecologically relevant zones connected to the hydrological system
Soil Remediation	BSI = 1 (bare soil); SOC ≤ 2 (low organic content)	Contaminated or compacted soils with reduced biological activity.	Apply mechanical and biological remediation (decompaction, organic amendments, phytostabilising species)
Shading Planting	NDVI ≤ 2; UHI = 1 (hotspot)	Heat stress with sparse canopy	Increase tree canopy where soil capping allows; use pollutant-tolerant and low-root species
Cooling & Shading	UHI = 1-2 (heat stress); EVI ≤ 2 (sparse canopy)	Mitigate microclimatic peaks along infrastructure or built margins.	Introduce large-canopy species to reduce surface temperature and improve comfort levels
Ground Cover Stabilisation	BSI ≤ 2 and EVI ≤ 2	Control erosion and particulate dispersion on remediated soils.	Use fast-growing herbaceous or shrub layers to stabilise contaminated surfaces
Drought Planting	NDVI/EVI = class 1-2 and MSI = class 1-2	Dry and nutrient-poor soils with low vegetation vigour and limited moisture availability.	Introduce drought-resistant species to stabilise dry substrates and promote ecological succession
Unclassified / Excluded	<i>Areas with active industrial use or ongoing remediation. Non-applicable or already managed zones. Excluded from ecological modelling and planting simulations.</i>		

The results of this multi-parameter selection are visualised within the Revit environment, where the strategic areas emerge as an operational layer within the BIM model.

Each coloured cell represents a potential intervention typology, directly linked to the environmental and functional conditions summarised in the table above. Figure 4.41 illustrates this configuration, showing how the combination of environmental evidence, land-use classification and buffer logic produces a spatially coherent map of ecological opportunities. The resulting configuration highlights zones of potential ecological transformation, such as degraded soils, cooling corridors and unstable grounds, while excluding active industrial and forested areas. This layer establishes the operational foundation for subsequent planting and grading simulations, ensuring that all design actions remain spatially and ecologically coherent with the river restoration framework.

This visualisation not only supports the subsequent planting simulations but also serves as a decision-making interface, where the designer can verify how each environmental process interacts with the project's spatial structure.

Figure 4.41 - Strategic Areas for Ecological Intervention within the Medium scale BIM Model



Following the identification of the strategic areas, the workflow proceeds with the generation of the Planting Scenario, translating the analytical evidence into a spatial and vegetative configuration within the BIM environment.

While at the Micro scale the objective was to test the detailed interoperability between environmental data and model components, at the Medium scale the approach shifts toward a broader understanding of ecological patterns and their relationship to territorial structures.

Here, the planting model operates as a spatial synthesis tool, able to visualise the overall ecological logic of the intervention rather than the precision of single planting units.

The data-driven planting process builds upon the same set of environmental parameters, but it is now filtered through the Strategic Areas identified in the previous step. Only those cells marked with GIS_Intervention_Typology are considered for planting, ensuring that interventions occur exclusively within the areas where ecological restoration is both meaningful and feasible. This condition replaces the “Park” type filter used in the Micro-scale model, adapting the logic to a more extensive and heterogeneous landscape.

Each 30×30 m cell of the classified grid acts as a design module in which vegetation typologies are assigned according to the integrated rule hierarchy. Large-canopy species (T3_Large, T4_Large, T5_Large) are prioritised in zones affected by microclimatic stress (UHI = 1-2; EVI = 1-2), while adaptive medium typologies (T2_Medium, T6_Medium) are allocated to areas with low soil fertility or bare surfaces (SOC = 1-2; BSI = 1-2). Conversely, cells characterised by favourable vegetation and soil conditions (EVI \geq 3; BSI \geq 3) are left intentionally free to preserve visual permeability and create open clearings for future recreational or ecological continuity spaces.

At this scale, the density logic also changes: each 30×30 m cell (900 m²) hosts between 9 and 18 trees, depending on typology and environmental condition, maintaining a balance between representational readability and ecological realism. Smaller or fast-covering species reach higher densities (18 elements per cell) to accelerate soil recovery and ecological colonisation, while medium and large-canopy trees are distributed at lower densities, averaging 9 per cell, to ensure adequate spacing and canopy development. The result is a vegetative mosaic that reflects both the analytical depth of the data and the interpretative role of design. By linking digital rules to measurable site conditions, the model becomes a dynamic representation of ecological reasoning, an instrument to visualise, test and communicate how restoration actions can emerge from the interaction between data and design intent.

Figure 4.42 shows the planting configuration generated from the GIS_Intervention_Typology selection within the 300 m buffer of the Tirino River.

The upper view presents the rule-based placement of trees in wireframe mode over the intervention areas, while the lower render visualises the resulting composition and canopy coverage.

The model demonstrates how environmental data can guide the spatial structure of planting at a territorial scale, producing a pattern that integrates restoration, shading and visual continuity across the reclaimed landscape.

Figure 4.42 - Data-Driven Planting Scenario within the Medium scale BIM environment based on strategic areas location



The Medium scale application demonstrates how the workflow evolves from a localised and design-oriented logic to a territorial and analytical one. While at the Micro scale the BIM model operated as a testing ground for data interoperability and detailed representation, at the Medium scale it becomes an instrument of spatial synthesis, capable of revealing large-scale ecological patterns and supporting strategic planning decisions.

The integration of environmental parameters, land-use information and proximity to the river system allowed the model to act as a diagnostic map for ecological regeneration.

Through the combined use of GIS classification, InfraWorks visualisation and BIM parametrisation, the workflow translates environmental data into spatially explicit design layers, from Strategic Area Identification to Data-Driven Planting Simulation.

Each operation, from the generation of the 30×30 m grid to the rule-based allocation of vegetation, contributes to the definition of a coherent and measurable landscape framework.

Compared to the Micro scale case, the design intent here is not limited to verifying the precision of the workflow but rather to testing its scalability and adaptability.

The model is used to visualise relationships between contamination, hydrology, land use and potential restoration corridors, producing a dynamic structure that balances ecological reasoning and territorial representation. In this sense, the BIM environment transcends its conventional representational role, functioning instead as an analytical and decision-support platform, becoming a platform for evidence-based landscape planning that bridges analytical modelling and strategic decision-making.

The results underline the potential of digital interoperability in supporting complex ecological restoration frameworks, such as the recovery of the Tirino River and its surrounding SIN areas. The capacity to visualise, simulate and quantify vegetative responses across an extended territory reinforces the use of data as both a design driver and a monitoring instrument. Ultimately, the medium scale establishes the methodological and conceptual link between detailed design and territorial planning: it connects the precision of local modelling with the interpretative depth of landscape systems.

To quantify the ecological and spatial implications of the medium-scale scenario, a set of synthetic indicators was extracted directly from the BIM model through parameter scheduling.

These values, listed in Table 4.9, summarise the total extent of intervention, the estimated number of trees per typology and their corresponding ecological function. Although approximate, the results provide a measurable translation of design logic into environmental performance, illustrating how the workflow can be used as a monitoring and decision-support tool for restoration planning.

Table 4.9 - Quantitative Summary of the Medium scale Environmental Recovery and Planting Scenario

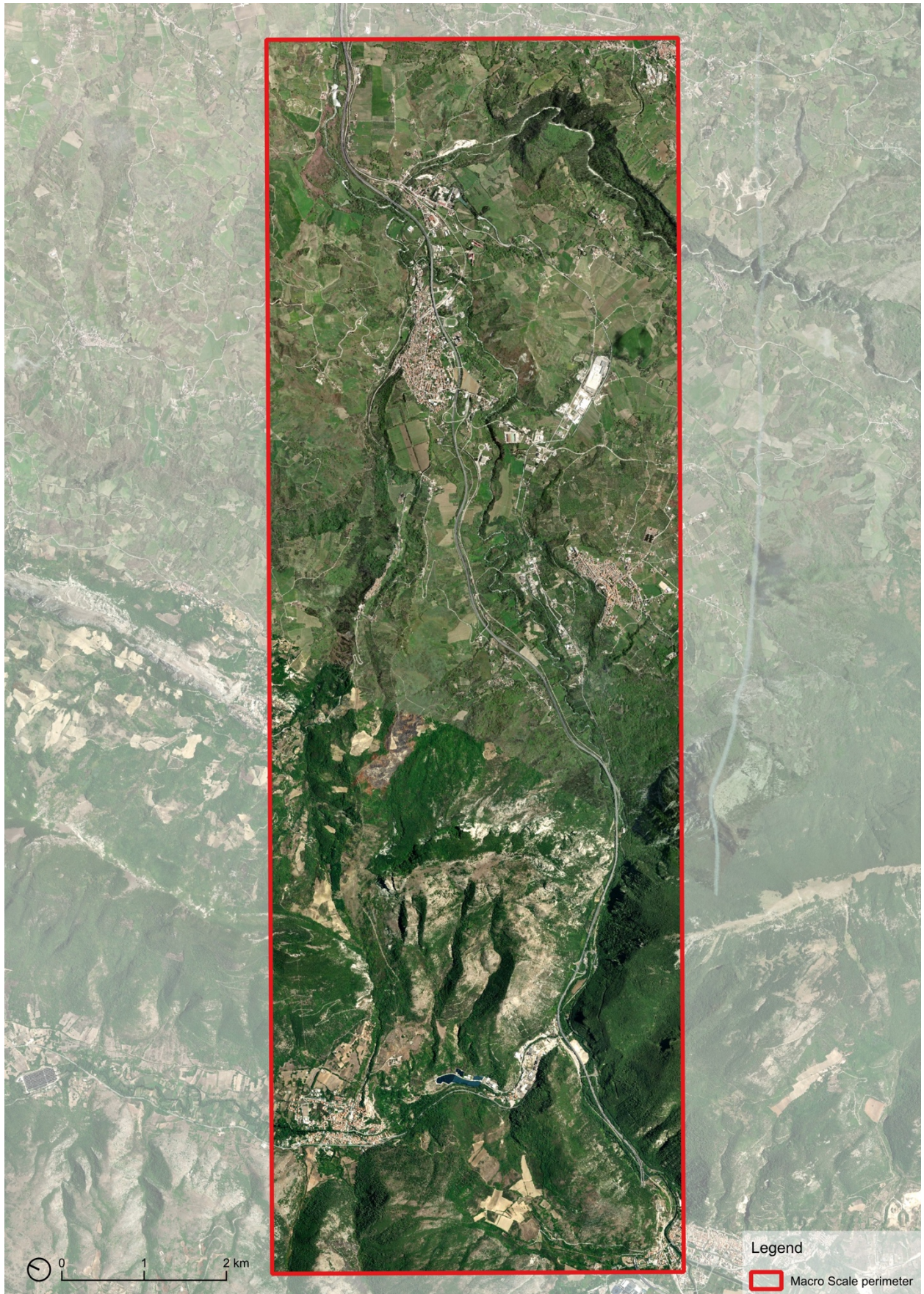
Typology	Intervention	Main Ecological Function
Soil Remediation	176,400 m ²	Soil regeneration and contamination mitigation
Shading Planting	52,200 m ²	Microclimatic regulation and canopy restoration
Cooling & Shading	195,300 m ²	Urban cooling and thermal comfort enhancement
Ground Cover Stabilisation	60,300 m ²	Surface stabilisation and erosion control
Drought Planting	27,900 m ²	Drought adaptation and gradual vegetation recovery
Tree Planting	5,481 (number)	Adaptive planting for soil recovery, cooling and shading

The Medium scale demonstrates how data-driven workflows can support strategic environmental recovery by linking ecological diagnosis and spatial decision-making. The model does not simply represent environmental conditions, it translates them into operable design structures, enabling the identification of where restoration efforts are most effective and feasible. Through the combined reading of vegetation vigour, soil quality and hydrological conditions, the workflow produces a framework that balances ecological priorities, spatial feasibility and territorial continuity.

This level of analysis confirms the value of working between local precision and territorial abstraction. While the Micro scale explored the detailed configuration of planting within a defined park, the Medium scale shifts the focus to patterns, connections and gradients. The resulting scenario articulates an ecological strategy that is both targeted and scalable, identifying where shading, soil remediation, water-efficient vegetation and open clearings can collectively support the long-term recovery of the Tirino River landscape. The workflow therefore operates as a synthesis tool, enabling multiple environmental, technical and spatial variables to be compared within a single interoperable model.

Building on these outcomes, the next section extends the workflow to the Macro (territorial) scale, where the integration between GIS, EO and BIM tools will focus on the modelling of environmental corridors and ecosystem networks. At that scale the objective is not the definition of individual planting configurations, but the construction of an environmental infrastructure, capable of guiding regeneration across a broader hydrographic system. This transition marks a shift from site-scale ecological adaptation to landscape-scale ecological governance, in which the digital model becomes a tool not only for design simulation but for territorial planning, scenario comparison and long-term stewardship.

Figure 4.43 - Actual condition of the Macro scale area case study: from Bussi sul Tirino to Piano d'Orta



4.4 Macro Scale: Potential Interventions on the Territory

At the macro scale, the workflow expands its scope beyond the project site to encompass the broader Tirino-Pescara valley, a territorial corridor approximately 5×15 km that connects the municipality of Bussi sul Tirino and the area of Piano d'Orta (Municipality of Bolognano).

This portion of the Abruzzo region represents one of the most emblematic and complex environmental systems in central Italy where industrial heritage, hydrological networks and natural landscapes intersect within a delicate equilibrium.

The area includes the major remediation sites of national interest (SIN Bussi-Piano d'Orta), specifically Macroarea 1 and 2, the Tirino and Pescara rivers and the infrastructural spine of the A25 motorway and the F.S. railway. Here, the challenge is not limited to localised design intervention but extends to the territorial scale, requiring an understanding of spatial patterns, environmental gradients and systemic connections.

At this scale, the GIS-BIM workflow evolves from a design-oriented methodology into an interpretative and decision-support tool. Rather than focusing on single cells or site-specific planting rules, the macro model operates as an analytical framework for identifying potential intervention areas, zones where ecological recovery, landscape continuity and infrastructural transformation can be jointly addressed.

The integration of Earth Observation data with land use, topography and hydrological networks enables a comprehensive reading of the territory, guiding spatial strategies towards restoration and connectivity rather than mere mitigation.

The Macro scale thus functions as a synthesis level within the multiscale methodology developed in this research. If the Micro scale explored how environmental evidence can drive design actions and the Medium scale focused on the definition of strategic areas for site-specific interventions, the Macro level reinterprets the same data logic across an extended landscape. It reveals how processes of regeneration and resilience can be coordinated along an entire river corridor, transforming the valley from a fragmented industrial landscape into a continuous ecological infrastructure (F. Steiner, 2018).

The methodological approach at the Macro scale relies on the same interoperability principles established in previous scales but adapted to a broader territorial extent and a coarser spatial resolution. A 100×100 m grid was adopted to generalise the environmental information and ensure a balance between spatial accuracy and computational efficiency. Each grid cell integrates multiple data sources, harmonised through GIS preprocessing and subsequently imported into the BIM environment for spatial analysis and visualisation.

Satellite-derived indices (NDVI, EVI, NDMI, MSI, BSI, SOC and UHI) were computed using Copernicus and Google Earth Engine Sentinel-2 imagery and processed in QGIS to obtain normalised environmental classes (1-4). These indices describe vegetation vigour, soil moisture conditions, surface stability and microclimatic stress, forming a multidimensional environmental dataset that underpins the subsequent classification and interpretation phases. The use of satellite-based EO data is particularly well-suited at the Macro scale, where the objective is to observe patterns, gradients and territorial logics, rather than fine-grain local variability. At resolutions of 10-30 m, Sentinel-2 imagery provides sufficient detail to distinguish ecological transitions (riparian, agricultural and forest areas) while maintaining a synoptic, landscape-scale perspective. This scale of observation is recognised as optimal for regional landscape monitoring, river corridor assessment and restoration planning (Nagendra et al., 2013; Turner, 1990; Turner & Gardner, 2015). Moreover, satellite indices are not only descriptive but process-oriented, they reveal patterns of biomass and canopy density, register hydrological gradients and drought stress and it is possible to indicate soil exposure and organic content in relation to surface temperature gradients trace anthropogenic heat accumulation along infrastructural networks. By processing these datasets within a structured classification system, the workflow translates continuous raster surfaces into discrete decision units (grid cells) that can be later manipulated within the BIM environment.

They were then resampled and aggregated according to the macro grid resolution, ensuring consistent alignment with other territorial layers such as land use, hydrographic systems and infrastructural networks (Geoportale of Regione Abruzzo, Regional Technical Cartographic - CTR).

In this phase, as in the Medium scale, land use information was explicitly embedded into the grid structure, introducing a categorical field that distinguishes between built-up, industrial, agricultural and natural areas. This addition represents a methodological advancement as it allows the workflow to interpret environmental data in relation to anthropic context. This methodological step advances the workflow by enabling the model to interpret environmental indices relationally: the same vegetation density value has different implications in a forest, an abandoned industrial yard or a cultivated field. As demonstrated in recent literature, the interaction between EO environmental indicators and land use categories enhances the robustness of territorial assessment and restoration prioritisation (D'Acunto et al., 2024; Estoque & Murayama, 2013).

The EO-to-GIS phase follows the established process of raster classification and grid adaptation (Figure 4.44, Figure 4.45, Figure 4.46). However, at the Macro scale the interpretative shift is conceptual, instead of producing localised diagnostics, the model works to identify patterns and gradients, reconstruct ecological corridors and reveal structural relationships between the river system, land transformation processes and soil conditions. The emphasis moves from the precision of single-site intervention to the coherence of territorial regeneration strategies.

Figure 4.44 - Land Use map of the Macro scale and UHI indices showing the EO-to-GIS process from Copernicus Browser imagery to grid adaptation (100×100 m) and classification into four standardised environmental classes for BIM integration

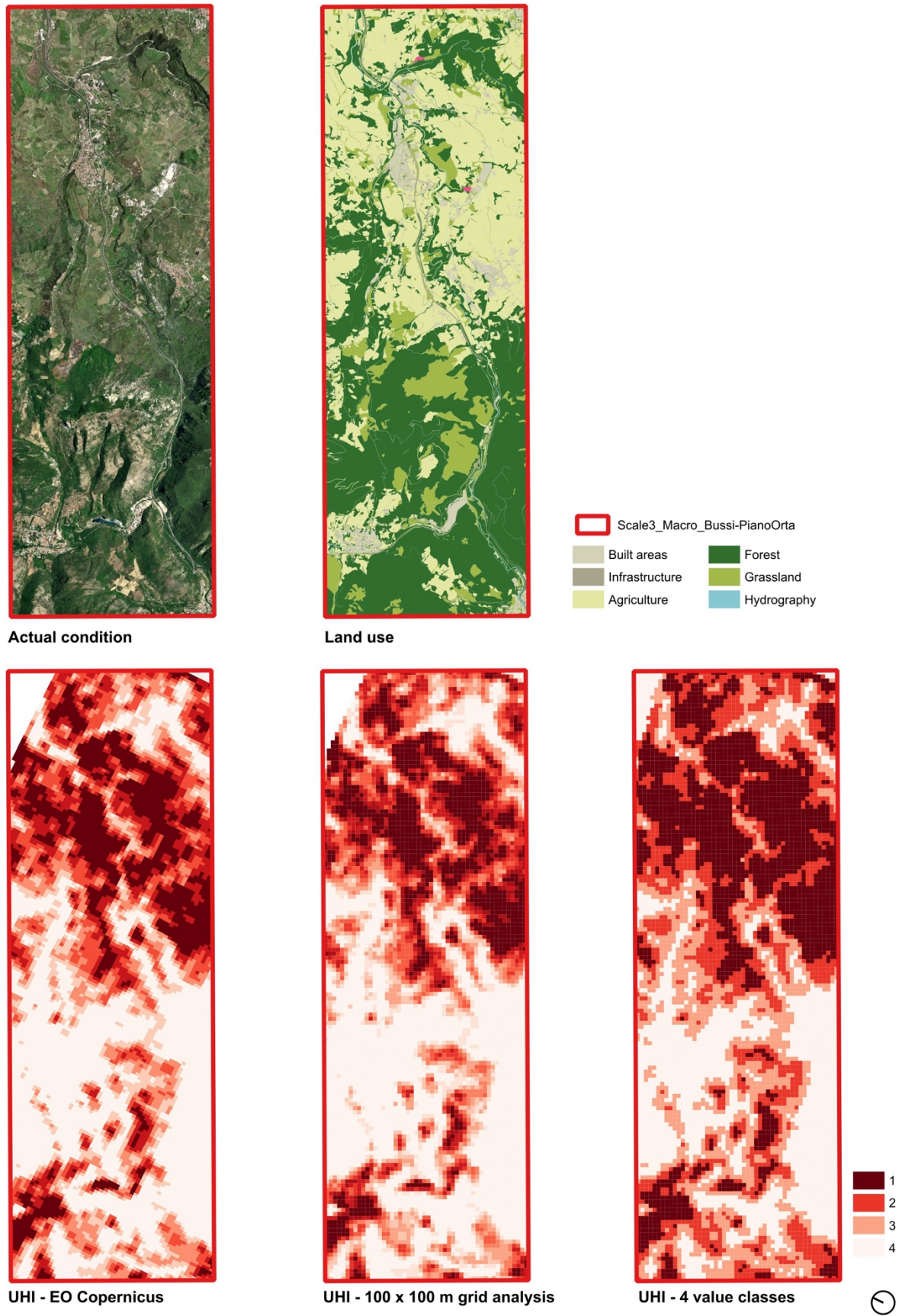


Figure 4.45 - NDVI and EVI indices showing the EO-to-GIS process from Copernicus Browser imagery to Macro scale grid adaptation (100 × 100 m) and classification into four standardised environmental classes for BIM integration

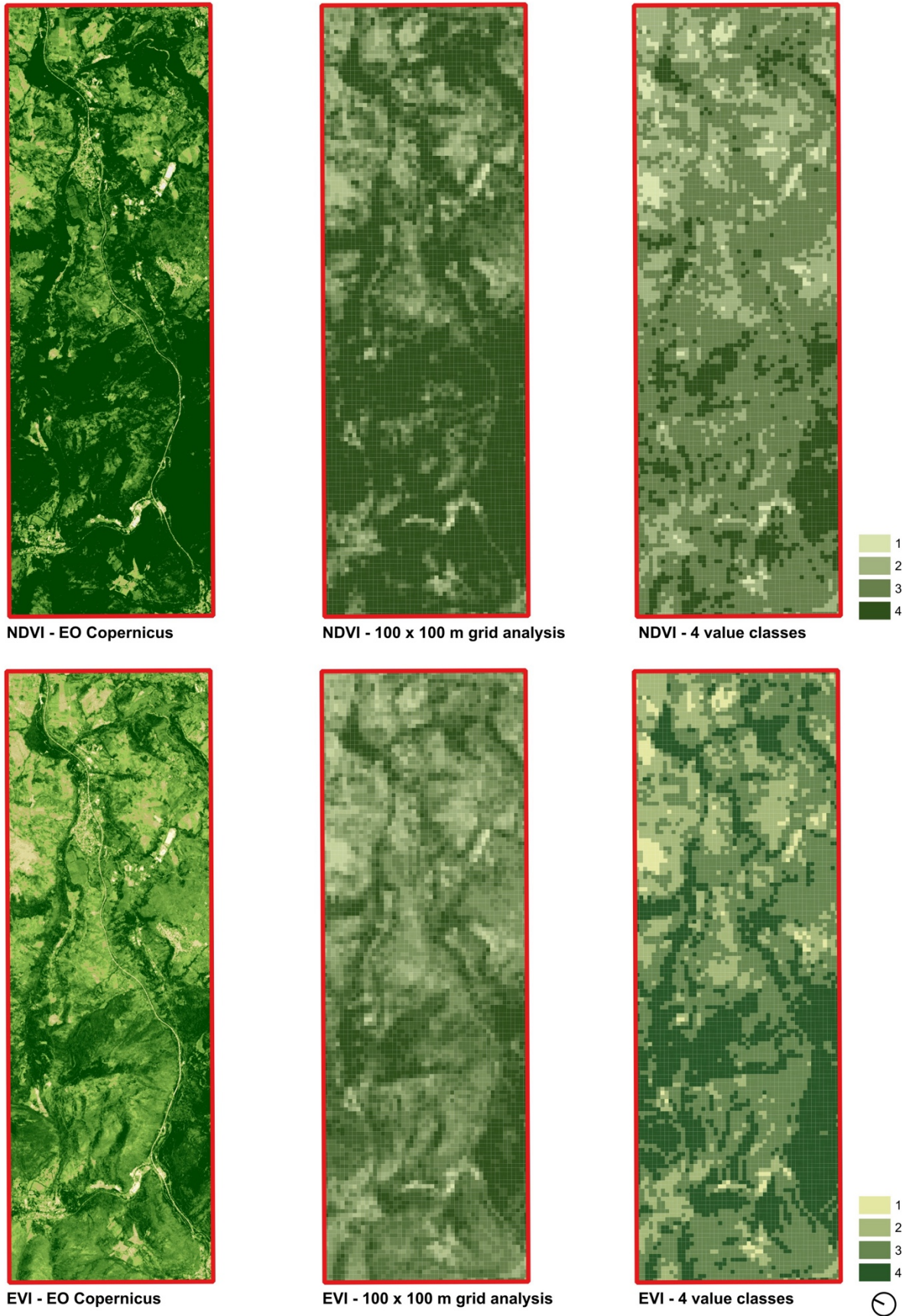


Figure 4.46 - NDMI and MSI indices showing the EO-to-GIS process from Copernicus Browser imagery to Macro scale grid adaptation (100×100 m) and classification into four standardised environmental classes for BIM integration

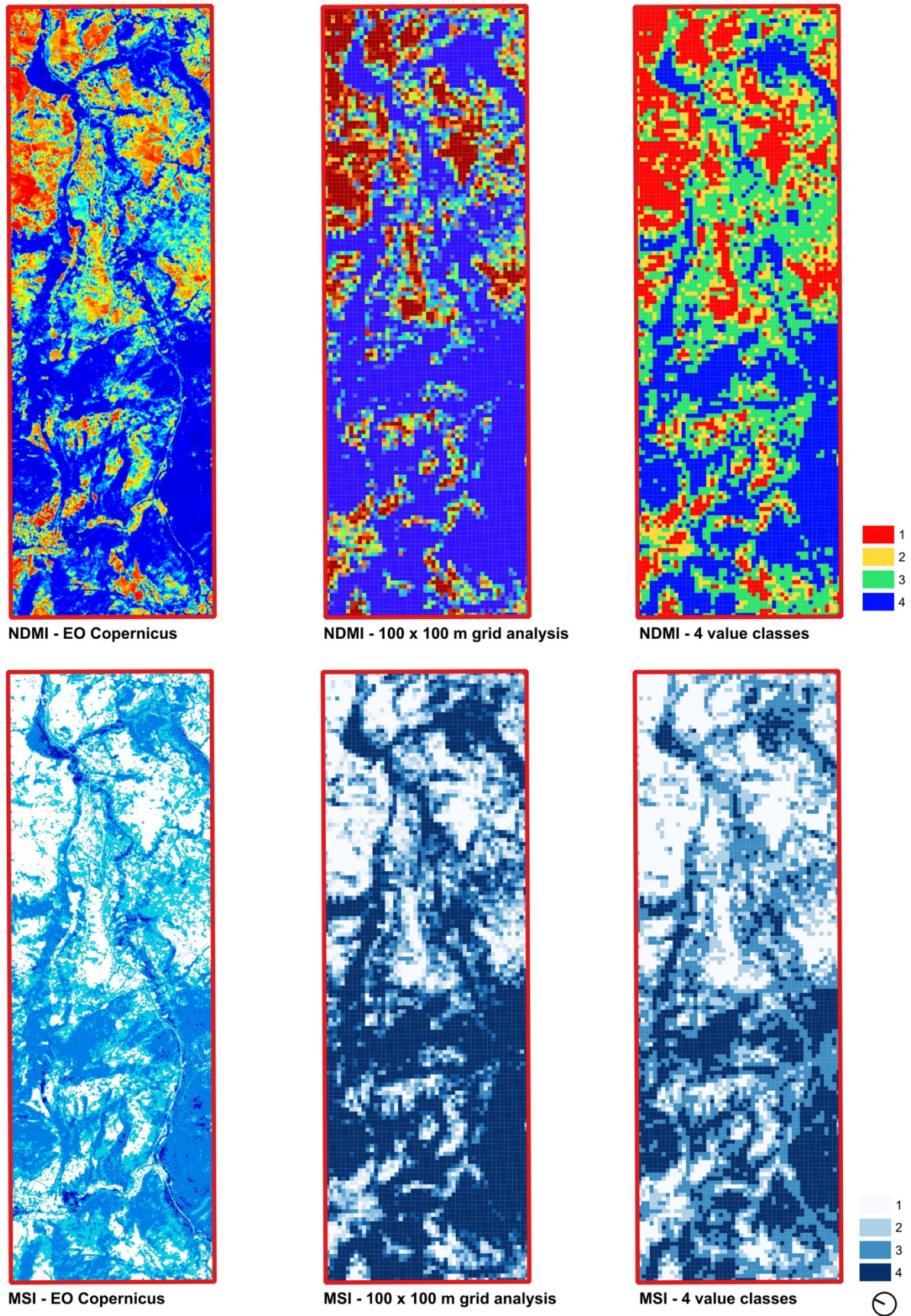
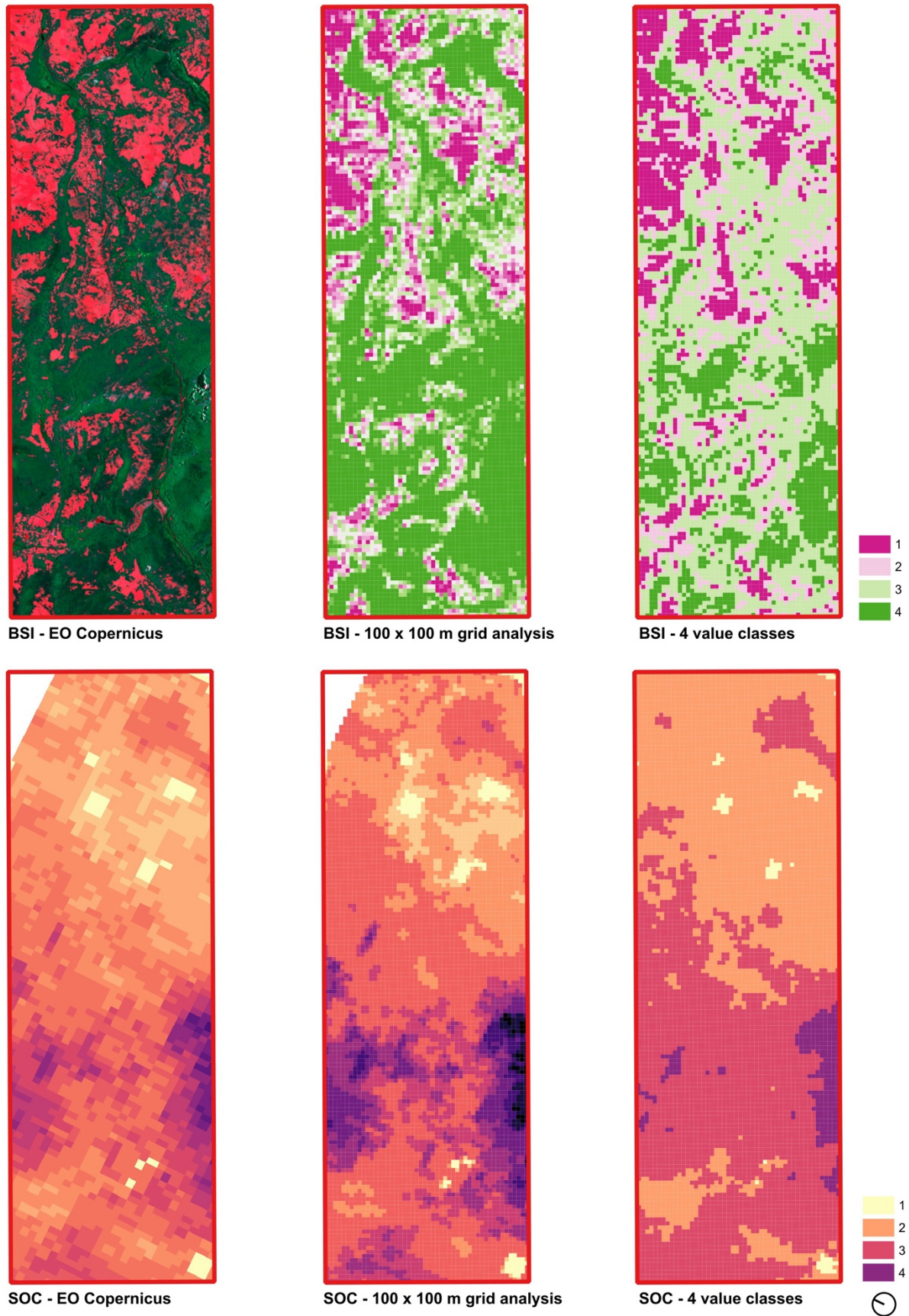


Figure 4.47 - BSI and SOC indices showing the EO-to-GIS process from Copernicus Browser imagery to Macro scale grid adaptation (100 × 100 m) and classification into four standardised environmental classes for BIM integration



InfraWorks serves as a key intermediary platform for territorial visualisation, enabling the translation of GIS data and raster classifications into a continuous three-dimensional environmental model. The terrain model, generated through Model Builder, incorporates hydrographic networks, infrastructural corridors, built environments and elevation morphology as shown in Figure 4.48. Within this environment, satellite-derived indices such as EVI, NDMI and BSI are imported as surface overlays, allowing environmental gradients to be read directly in relation to the shaping forces of the landscape (Figure 4.49).

This 3D representation enables a synoptic reading of environmental conditions across the valley, highlighting how the distribution of vegetation and moisture corresponds to topographic forms and hydrological structures. This visual integration is particularly valuable at the Macro scale, where the objective is not to examine single intervention sites, but to understand how ecological processes unfold across the valley system.

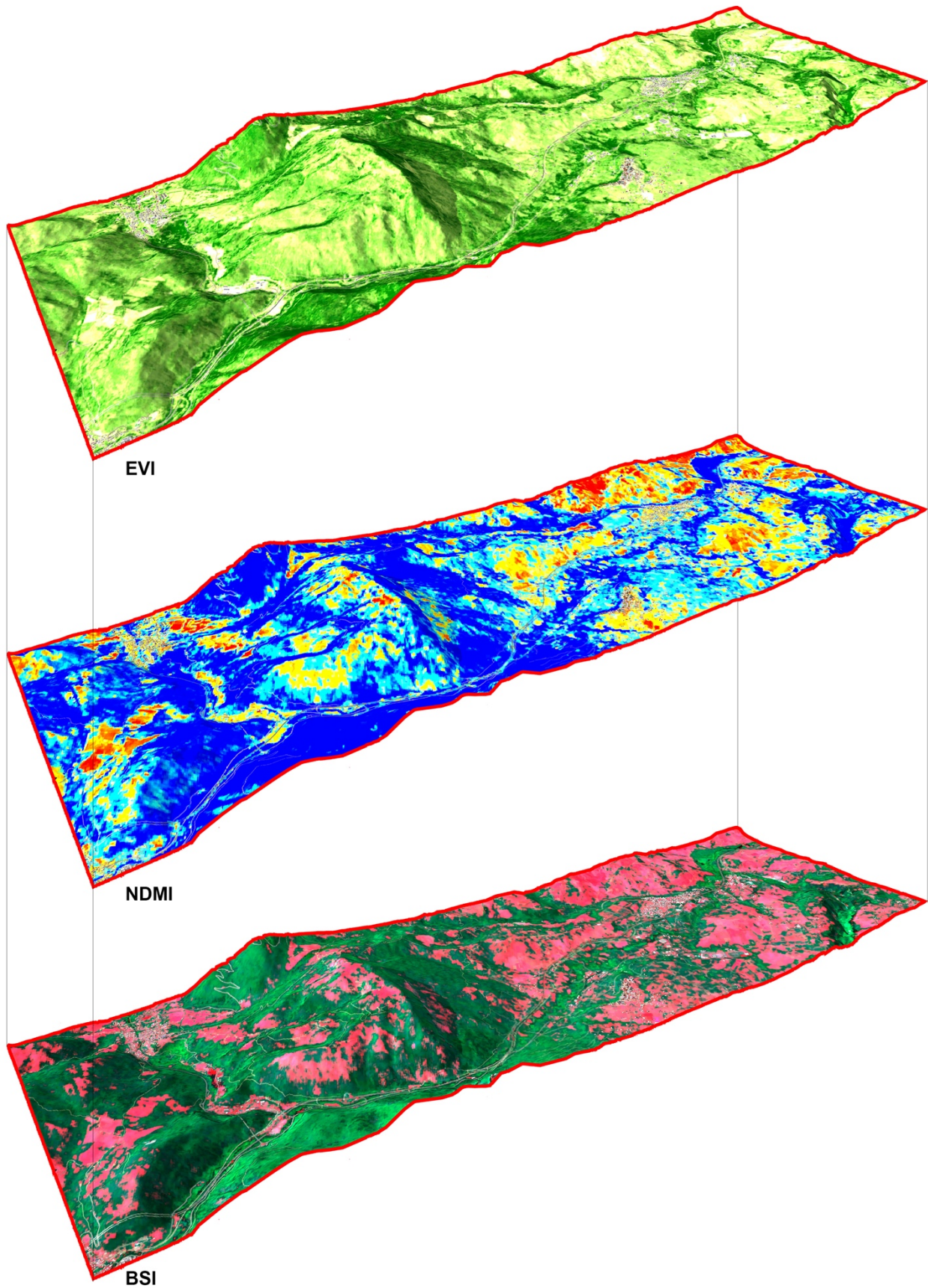
InfraWorks therefore provides a spatial framework in which terrain, hydrology and ecological performance can be perceived as interdependent layers, reinforcing a systemic understanding of the landscape (Rai et al., 2022; Si et al., 2025). This synoptic reading supports what landscape theorists describe as “territorial cognition”, a design capacity grounded in recognising patterns and flows across large-scale systems, rather than focusing exclusively on discrete sites (Corner, 1999; Waldheim, 2016).

This model thus acts as a bridge between remote sensing analytics and spatial reasoning, ensuring that environmental data informs territorial logic, rather than remaining a purely descriptive layer. This ability to move from data to spatial interpretation is fundamental in restoration-oriented planning, where the landscape is understood as an evolving system rather than a fixed form (Ahern, 2011; Prominski, 2018).

Figure 4.48 - InfraWorks model of the Macro scale, generated through Model Builder, showing the complex topography of the context, including the surrounding hydrographic and infrastructural systems



Figure 4.49 - InfraWorks model enriched with selected raster datasets (e.g., EVI, NDMI and BSI), highlighting how environmental gradients correspond to the terrain at the Macro scale



Once processed, all raster-derived and categorical datasets were imported into Revit through Dynamo scripts. Here, the 100×100 m cells are transformed into parametric Floor elements, each carrying embedded environmental attributes such as vegetation index, soil moisture and land use class, as shown in Figure 4.50. The grid becomes more than a cartographic reference, it operates as a parametric territorial model, where each cell is a discrete unit of decision-making containing its own environmental state.

The integration of land use into the GIS-BIM model enables the differentiation between restoration, transformation and conservation areas, establishing a direct link between ecological condition and functional land characterisation. The combination of vegetation indices (EVI, NDVI), soil condition (BSI, SOC), hydrological stress (NDMI, MSI) and thermal exposure (UHI), read alongside land use, allows the model to differentiate between: areas of ecological continuity (e.g., riparian corridors, forest slopes), areas of ecological fragmentation (e.g., industrial edges, infrastructures), areas of potential reconnection (e.g., agricultural mosaics and grasslands), areas where intervention is structurally constrained (e.g., active industrial perimeters).

This allows the BIM environment to act as an interpretative model rather than a mere geometric reconstruction, where environmental evidence becomes an operative layer for spatial reasoning.

The exploded axonometric view represented in Figure 4.51 reveals the vertical structure of this digital landscape layered condition. The topography forms the structural ground of the valley system, land use patterns highlight zones of anthropogenic transformation, while UHI values expose latent microclimatic stress aligned with infrastructural corridors.

This composition not only visualises the hierarchy of environmental factors but also demonstrates how the integration of GIS and BIM supports the translation of data into spatial strategy. By stacking these layers within a 3D model, the workflow allows relationships to become visually and spatially legible, something that 2D GIS alone does not fully provide.

In this sense, the BIM environment functions as a territorial reasoning interface, where spatial interpretation, environmental evidence and planning decisions intersect.

The model does not prescribe solutions at this stage; instead, it frames the landscape as a system of interconnected conditions, preparing the ground for the identification of strategic areas and corridors of ecological intervention.

Figure 4.50 - Revit environment after data import, where the classified grid and environmental parameters at the Micro scale are visible within the BIM environment, the indices EVI, NDMI and BSI are represented below

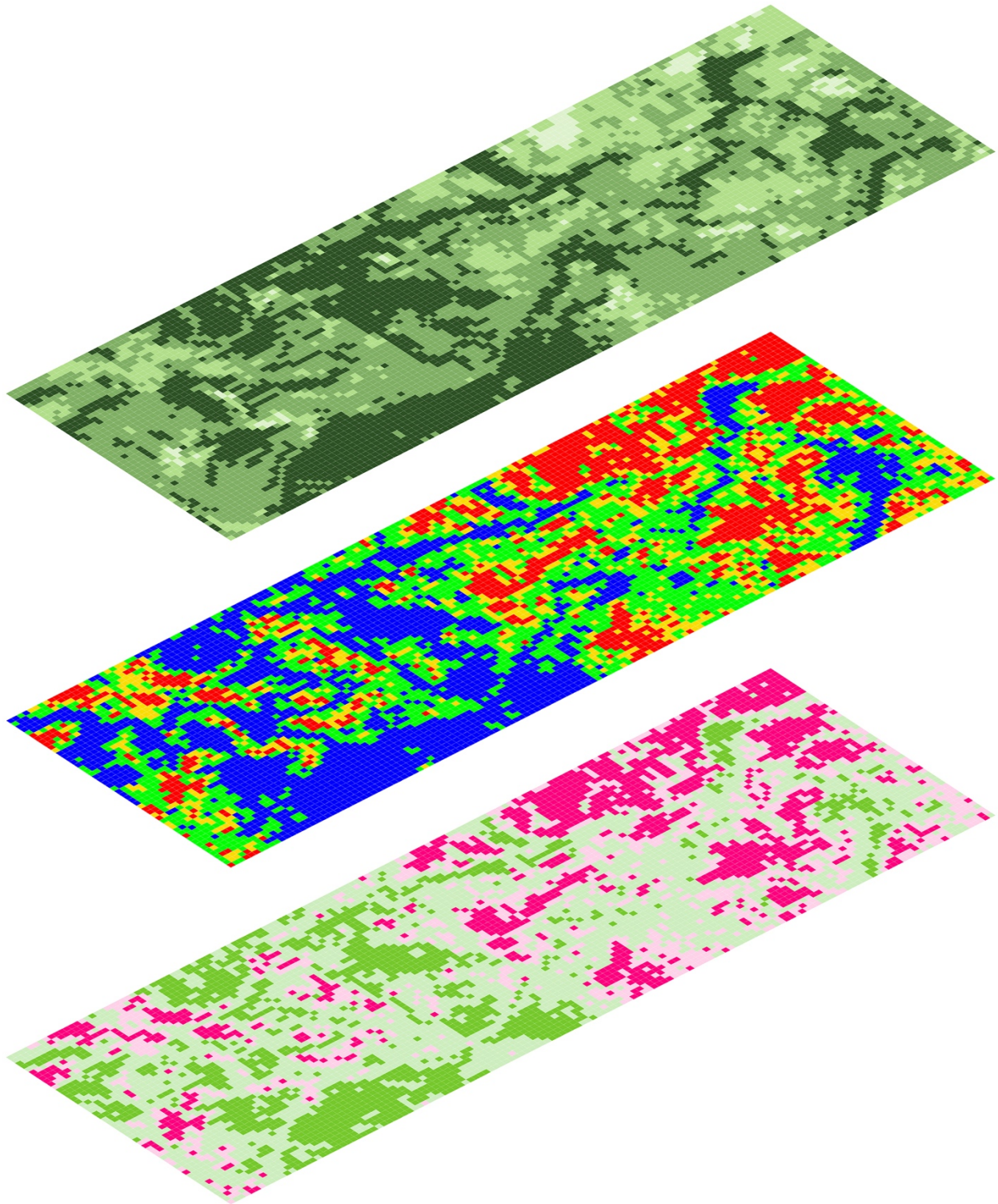
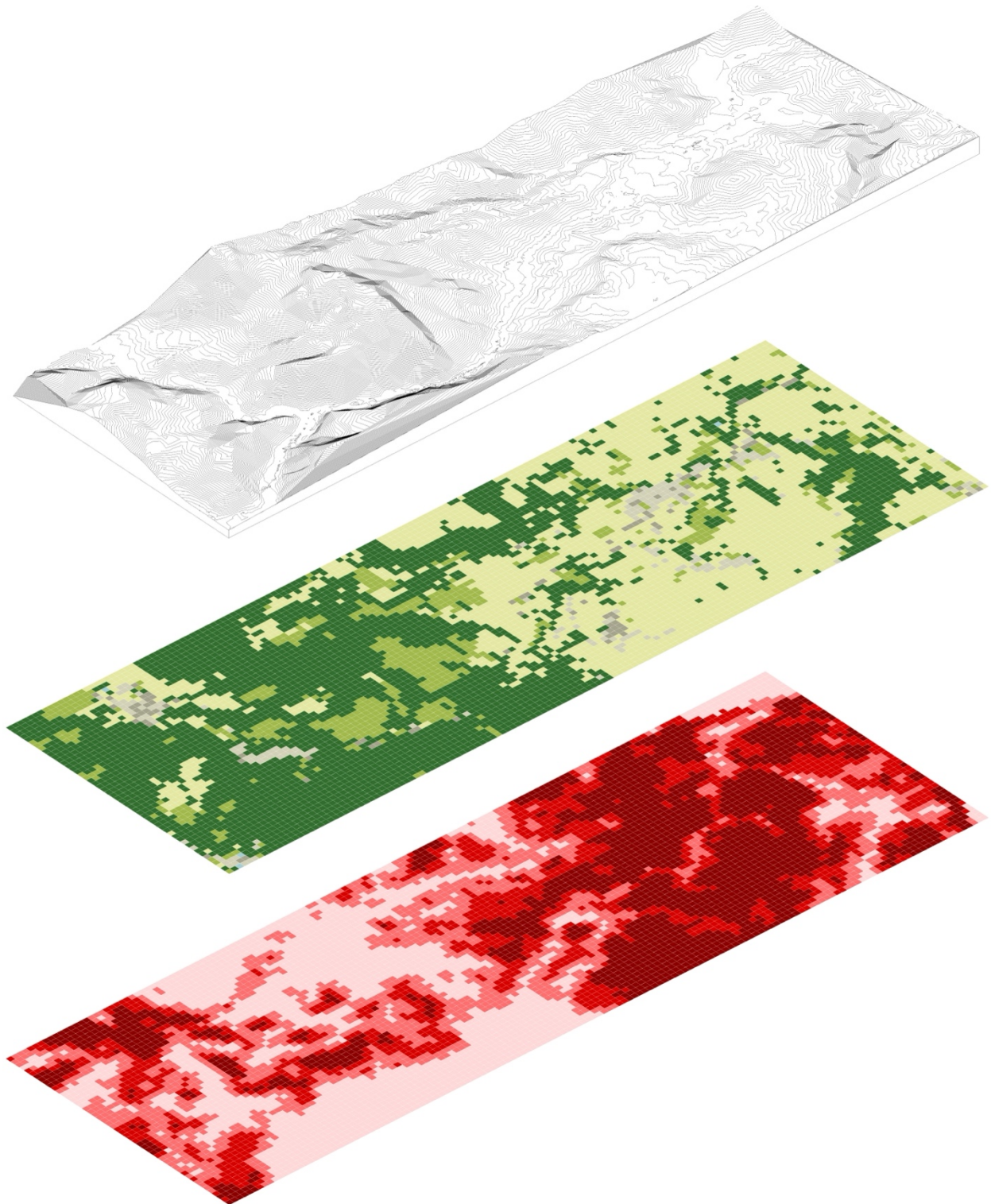


Figure 4.51 - Exploded axonometric view within Revit, showing the hierarchical composition of the Macro scale digital model: from the EO analysis layer (UHI represented) to land use, topography and project area

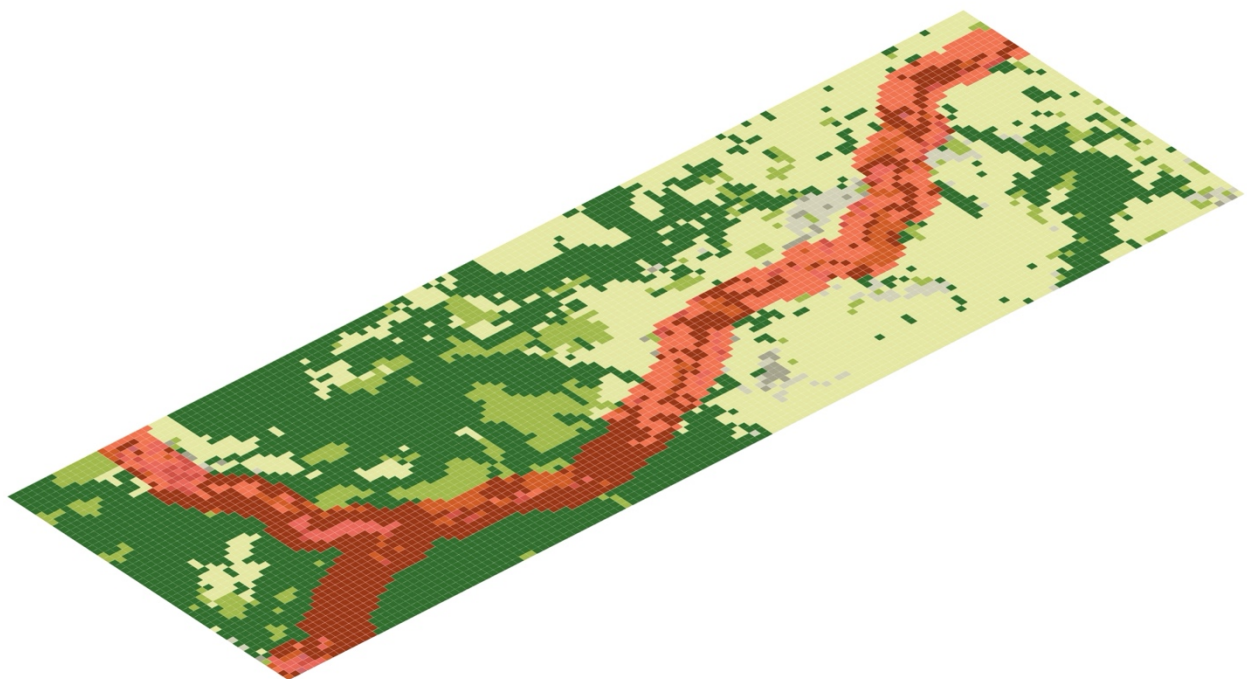


At the Macro scale, the identification of Strategic Areas does not focus on isolated intervention zones but rather at outlining territorial structures of ecological continuity. Following the same rationale introduced at the Medium scale, a 300 meter buffer around the Tirino and Pescara rivers was generated to delineate the spatial field where restoration and ecological enhancement would have the greatest systemic impact. However, unlike the Medium scale where the buffer operated at the Municipality level, at the Macro scale it functions as a territorial corridor, reinforcing the continuity between riparian ecosystems and adjacent productive or abandoned lands.

This buffer is not applied as a strict geometric boundary but as a hydro-ecological filter, ensuring that interventions align with the river's ability to act as a structural backbone of regional ecological recovery (Thorp et al., 2006; Vannote et al., 1980). In practice, only the cells within the buffer and belonging to suitable land-use categories (e.g., agricultural, grassland, abandoned built-fragments) are considered eligible for transformation, whereas areas under active industrial operation or ongoing remediation remain excluded. The buffer functions as a spatial constraint ensuring that restoration strategies contribute directly to the ecological recovery of the river corridor and its hydrological system. It establishes the territorial framework within which subsequent environmental evaluation and intervention prioritisation occur.

Figure 4.52 shows how this identified buffer area anchors the entire regeneration strategy to the hydrological system, recognising the river as the foundational ecological backbone of the valley.

Figure 4.52 - Identification of the buffer area of 300 meters around the Tirino and the Pescara rivers and overlaying the Land Use layer



At the Macro scale, the same intervention typologies used at the Micro and Medium scales are retained, but their meaning shifts from the definition of local planting strategies to the structuring of territorial ecological logics. Once the buffer is established, the environmental parameters (vegetation vigour, moisture balance, soil stability, microclimatic stress and land use) are evaluated together to identify where ecological functions should be reinforced or reconnected. This produces a set of Strategic Areas that take the form of linear riparian corridors, slope restoration bands, agro-ecological transition zones and infrastructural greenways, as represented in Figure 4.53. These areas articulate the valley as an interconnected system, moving from a fragmented landscape to a continuous ecological infrastructure capable of supporting biodiversity flows, improving microclimatic performance and enabling progressive recovery of soils and water systems.

Table 4.10 below summarises how each intervention typology is re-interpreted at the Macro scale, maintaining the same analytical parameters but reframing their ecological and territorial implications.

Table 4.10 - Environmental Parameters and Intervention Logic for the identification of Strategic Areas at Macro Scale

Typology	Key Environmental Conditions (GIS-based)	Ecological Rationale (Macro Scale)	Design Strategy at Territorial Scale
Buffer Definition	GIS Buffer Intervention = Inside (within 300 m of Tirino-Pescara rivers)	The river corridor is the primary ecological backbone of the valley.	Use the buffer as the territorial spine for defining connectivity, prioritising restoration along linear riparian networks.
Soil Remediation	BSI = 1 (bare soil); SOC \leq 2 (low organic content)	Conditions that indicate large degraded surfaces where contamination and soil exhaustion have landscape-level impacts.	Implement landscape-scale soil recovery: reforestation belts, phytoremediation mosaics, grazing rotation management and slope stabilisation strategies.
Shading Planting	NDVI \leq 2 and UHI = 1 (heat islands)	Heat accumulation forms continuous thermal corridors, often along infrastructures and industrial margins.	Create cooling green corridors along roads, railways and settlement edges to break heat islands and reconnect fragmented patches.
Cooling & Shading	UHI = 1-2 and EVI \leq 2	Areas where sparse vegetation and high heat stress overlap signal territorial microclimatic discontinuities.	Strengthen valley-scale ventilation pathways with continuous large-canopy planting to support cold-air drainage flows along slopes and riverbeds.
Ground Cover Stabilisation	BSI \leq 2 and EVI \leq 2	Erosion risk relates to hydrological dynamics and slope morphology, not only contaminated soils.	Apply slope re-vegetation, hydroseeding and pioneer-grassland reinforcement to stabilise landslide-prone or erodible terrains.
Drought Planting	NDVI/EVI = 1-2 and MSI = 1-2	Indicates structurally stressed ecological zones (dry ridgelines, abandoned fields, gravel terraces).	Introduce xerophytic ecological transition zones to prevent desertification and support gradual regeneration toward shrubland/woodland.
Unclassified / Excluded	<i>Active industrial sites or areas under ongoing remediation, which can not support ecological operations at this stage. Excluded from design and maintain monitoring and regulatory observance.</i>		

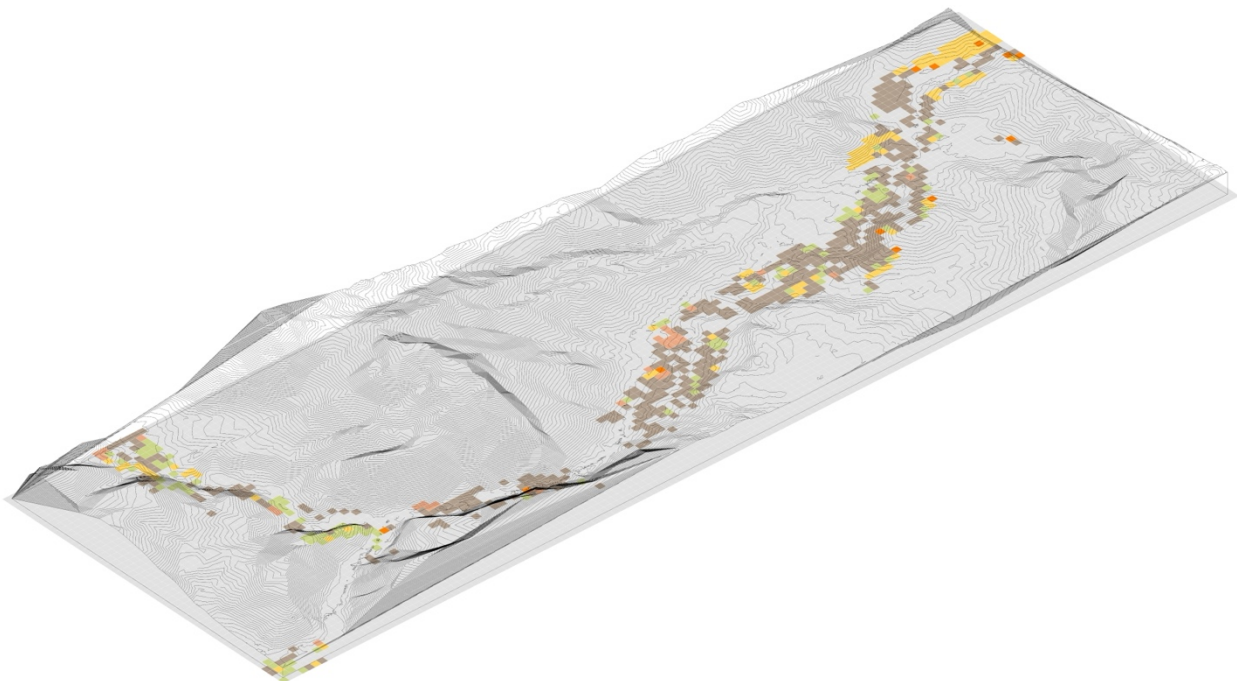
Through this integrated reading, the model delineates a series of Strategic Areas, which emerge not as isolated intervention sites but as continuous spatial systems.

Along the Tirino and Pescara rivers, the riparian corridors form the primary backbone of ecological continuity. The vegetation recovery plays a crucial role in filtering surface water, stabilising riverbanks and supporting longitudinal habitat connectivity. Moving outward from these linear ecosystems, a second system of intervention unfolds along the valley slopes. These areas, characterised by geomorphological fragility, require strategies that prioritise soil stabilisation and organic regeneration.

Between the cultivated fields of the valley floor and the forested or semi-natural patches of the foothills, these areas represent highly dynamic interfaces, where planting interventions can diversify land mosaics, increase ecological permeability and support low-intensity productive practices compatible with landscape regeneration. Finally, the infrastructural corridors constitute linear systems of fragmentation but also of opportunity. Here, vegetative buffers help reduce heat accumulation and noise propagation while mitigating visual and ecological discontinuities caused by transport infrastructures.

These areas reorganise the valley into a continuous ecological infrastructure, re-establishing relationships between soils, water systems, vegetation and land uses. The transition is from a landscape historically fragmented by industrial production and infrastructural barriers to one understood as a living territorial metabolism, capable of regenerating ecological processes over time.

Figure 4.53 - Strategic Areas for Ecological Intervention within the Macro scale BIM Model



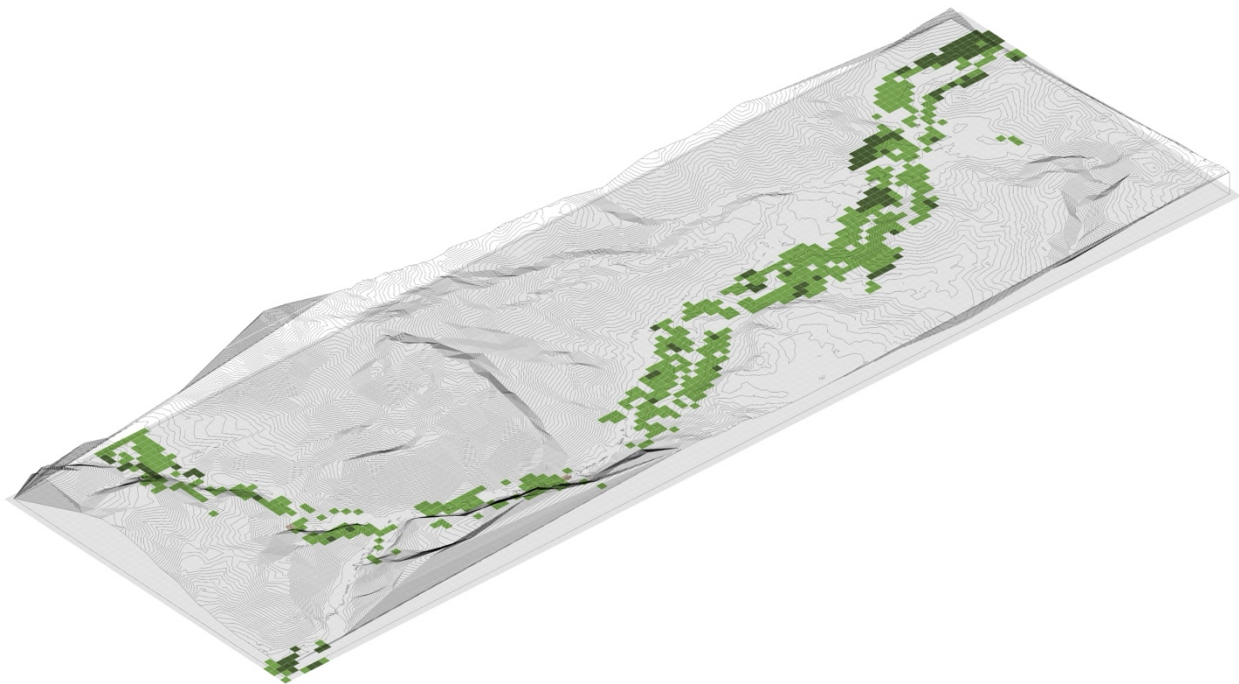
At the Macro scale, the objective of the planting model shifts once more. While at the Micro scale the workflow operated through detailed element placement and at the Medium scale it synthesised ecological patterns across a park system, at the Macro scale the model functions primarily as a strategic framework. The focus is not on representing individual trees, but on identifying where and what kind of vegetative structure should be promoted to restore ecological continuity along the valley.

The planting logic builds directly upon the Strategic Areas identified in the previous phase. Only those grid cells that fall within the 300 m hydrological buffer and that meet the ecological intervention criteria (GIS_Intervention_Typology) are considered for planting. In this way, the model ensures that vegetation is introduced exclusively in areas where it can meaningfully contribute to river ecological restoration.

Given the 100×100 m resolution, each selected grid cell represents a territorial planting zone. The workflow does not generate single tree instances, instead, it assigns the potential vegetation typology (e.g., T1_Small, T2_Medium, T3_Large, etc.) and the density ranges expressed in trees per cell (e.g., 100 or 200 based on the typology dimension). Instead of producing a fixed landscape configuration, the model provides a spatial strategy, describing how different vegetative structures can be assembled to strengthen ecological connectivity across the valley system. In this way, the planting model at the Macro scale becomes a territorial design instrument, enabling planners and institutions to negotiate priorities, compare scenarios and progressively refine the restoration agenda.

Figure 4.54 illustrates the patchwork of vegetative zones. It shows through different shades of greens the planting density, dark green 200 trees per cell and light green 100 trees per cell.

Figure 4.54 - Data-Driven Planting Scenario within the Macro scale BIM environment based on strategic areas location, the model shows only the different areas and density of planting but not the single elements due to the scale of analysis and project



The Macro scale workflow synthesises the analytical and design operations developed in the previous scales, extending them to a territorial dimension. At this stage, the model no longer focuses on the configuration of individual interventions or planting patterns, but on the identification of priority areas where ecological restoration can generate systemic impact. Through the classification of environmental indices and the integration of land use and hydrological buffer constraints, the workflow isolates a set of Strategic Areas along the valley, where vegetation recovery contributes to river corridor regeneration, slope stabilisation and the reconnection of fragmented ecological patches.

Within these areas, the rule-based planting model translates environmental conditions into vegetation typologies and indicative densities, ensuring that the design operates at a scale where single-tree placement is neither necessary nor effective. Instead, vegetation is organised into structural bands, corridors and patches, each associated with a specific ecological function. This output constitutes a territorial framework of intervention, which remains open to refinement in subsequent planning phases or through progressive implementation strategies.

Table 4.11 below summarises the main intervention categories that emerge from the Macro scale scenario, defining their extent and ecological purpose.

Table 4.11 - Quantitative Summary of the Macro scale Environmental Recovery and Planting Scenario

Typology	Intervention	Main Ecological Function
Soil Remediation	480 ha	Supports soil regeneration through organic accumulation, phytostabilisation and substrate decompaction in degraded or contaminated zones
Shading Planting	111 ha	Enhances microclimatic buffering and reinforces canopy continuity along infrastructure and settlement edges
Cooling & Shading	29 ha	Reduces surface temperature and heat accumulation along exposed valley floors and built margins through large-canopy evapotranspiration
Ground Cover Stabilisation	108 ha	Limits erosion, runoff and particulate dispersion by establishing fast-cover herbaceous and shrub layers on unstable slopes and remediated soils
Drought Planting	12 ha	Promotes vegetation recovery in dry and nutrient-poor substrates, supporting gradual ecological succession in low-moisture zones
Tree Planting	87, 200 (number)	Represents the strategic allocation of vegetation across the intervention areas, varying in density and typology according to environmental conditions

Note: Values express the total spatial extent of each intervention category across the Macro scale restoration corridor (Tirino-Pescara valley). The planting quantity refers to typology- and condition-based density assignments rather than detailed element placement, consistent with the territorial resolution (100 × 100 m grid).

The results of the Macro scale workflow highlight how environmental data, when spatialised and interpreted through interoperable models, can become a strategic foundation for landscape planning. Rather than prescribing a fixed design, the model reveals where ecological investment yields the greatest territorial benefit, enabling prioritisation and phased implementation. In this sense, the Macro scale acts as a bridge between environmental knowledge and decision-making, providing a structured basis for governance, funding allocation and long-term monitoring.

Moreover, the approach demonstrates that the regeneration of post-industrial landscapes is not limited to site-specific remediation, but can operate as a territorial project, where ecological continuity, landscape identity and infrastructural adaptation are treated as interconnected processes. The patterns emerging from the model suggest a valley that shifts from fragmented and mono-functional to layered, permeable and ecologically active. This scale confirms therefore the strategic role of GIS-BIM interoperability in contemporary landscape planning:

- GIS supports the recognition of territorial gradients and vulnerabilities;
- BIM ensures coherence, traceability and design adaptability across scales;
- Environmental data act as a shared language between disciplines.

The Macro scale does not close the design process, but opens the possibility for progressive refinement, participatory negotiation and territorial policy integration. It frames the landscape not as a static configuration, but as a dynamic system, capable of evolving through informed, adaptive and place-specific interventions.

4.5 Creative Layout Through Digital Tools

The multiscale workflow developed in this chapter demonstrates how digital tools transform environmental evidence into spatial design intelligence. Rather than substituting the role of the landscape designer, EO-GIS-BIM interoperability supports a form of assisted interpretation, where landscape decisions emerge from the interaction between data, context and design choices. In this sense, the model operates not only as a repository of environmental data but as a creative, generative and interpretative interface, where parameter-driven conditions guide and refine the emergence of project form.

At the Micro scale, the workflow was used to reconstruct and test fine-grained spatial configurations such as planting units and topographic micro-grading. Here, interoperability serves to verify the precision of data-model correspondence, evaluating how environmental indices can be translated into planting typologies and soil modelling operations within an urban park environment.

At the Medium scale, it supported the definition of ecological restoration strategies within the SIN framework, revealing where remediation and planting could most effectively reinforce the river corridor. The focus shifts toward pattern recognition and prioritisation, identifying strategic restoration zones where environmental gradients intersect with land use and programmatic conditions.

At the Macro scale, it enabled the recognition of territorial patterns and ecological continuities, contributing to the construction of a large-scale environmental green infrastructure. In this final step, the process reaches the territorial dimension, framing ecological connectivity and long-term restoration objectives across the rivers valley.

Across these scales, the methodological shift becomes evident when compared to traditional landscape planning. While conventional approaches typically rely on expert interpretation, cartographic synthesis and post scenario evaluation, the data-driven workflow enables forward iterative reasoning, where spatial decisions emerge directly from quantified site conditions. This does not imply determinism. Rather, it situates design agency within a structured field of ecological constraints, allowing designers to explore multiple configurations and alternatives that remain contextually and ecologically coherent (Liu & Nijhuis, 2020).

This approach aligns with recent shifts in landscape practice, where data is not treated as a representational layer but as an operational driver of design (Cantrell & Holzman, 2015; Cantrell & Mekies, 2018; Nijhuis et al., 2015). Earth Observation data, remote sensing indices and environmental modelling provide dynamic and continuously updateable readings of the territory, allowing designers to respond to real conditions rather than abstract planning assumptions (Geneletti et al., 2020; Heymans et al., 2019).

At the same time, the BIM environment provides a coherent spatial and parametric framework, enabling iterative scenario testing and interdisciplinary coordination, a condition increasingly necessary for complex environmental projects (Schaller et al., 2017).

However, the workflow does not imply a deterministic or fully automated design outcome. The translation from data to spatial form remains intentional and interpretative, guided by the designer's ability to recognise ecological relationships, cultural meaning and spatial expression (Corner, 2011). In this framework, digital tools act as creative mediators: they expand the designer's field of perception and possibilities, reveal patterns otherwise invisible and allow design intention to emerge as an informed and adaptive process. What changes is not the artistic nature of landscape design, but the knowledge framework upon which design decisions are made.

While the workflow provides a structured ecological and quantitative basis for decision-making, the project remains fundamentally a cultural and spatial act. Landscape is not only an environmental system but also a medium of meaning, memory and sensory experience. The designer's role is therefore to interpret, articulate and give form to these layers of significance, ensuring that the final outcome maintains experiential and narrative depth (Prominski, 2005).

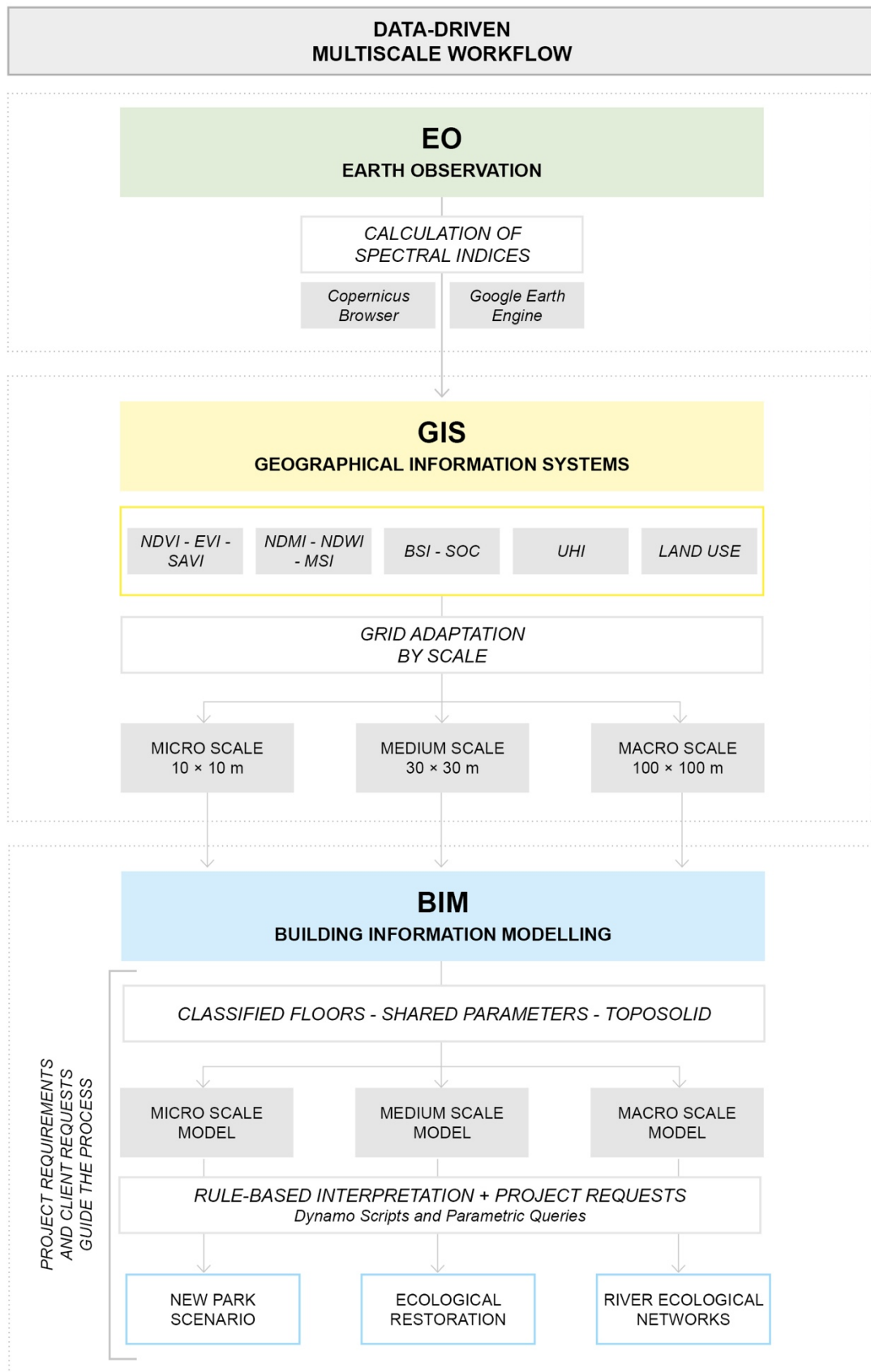
What this workflow ultimately enables is the emergence of a project scenario directly inside the BIM environment. This provides a shared spatial language for architects, landscape designers, ecologists and engineers, supporting coordinated decision-making and iterative refinement.

This comparison highlights that the workflow does not simply automate existing design operations, it reconfigures the cognitive structure of the design process, enabling:

- Early-stage scenario testing before formal design development;
- Progressive refinement from territorial strategy to local planting logic;
- Cross-disciplinary compatibility with ecological engineering, hydrology and remediation planning.

To make this methodological sequence explicit, the workflow is represented as a multiscale data pipeline that links environmental evidence to spatial modelling and design reasoning. The diagram in the next page (Figure 4.55) summarises how Earth Observation data is processed through GIS classification and parameterised within the BIM environment, before being translated into rule-based intervention scenarios. What emerges is not a linear process, but a structured feedback system in which data, interpretation and design continuously interact across scales.

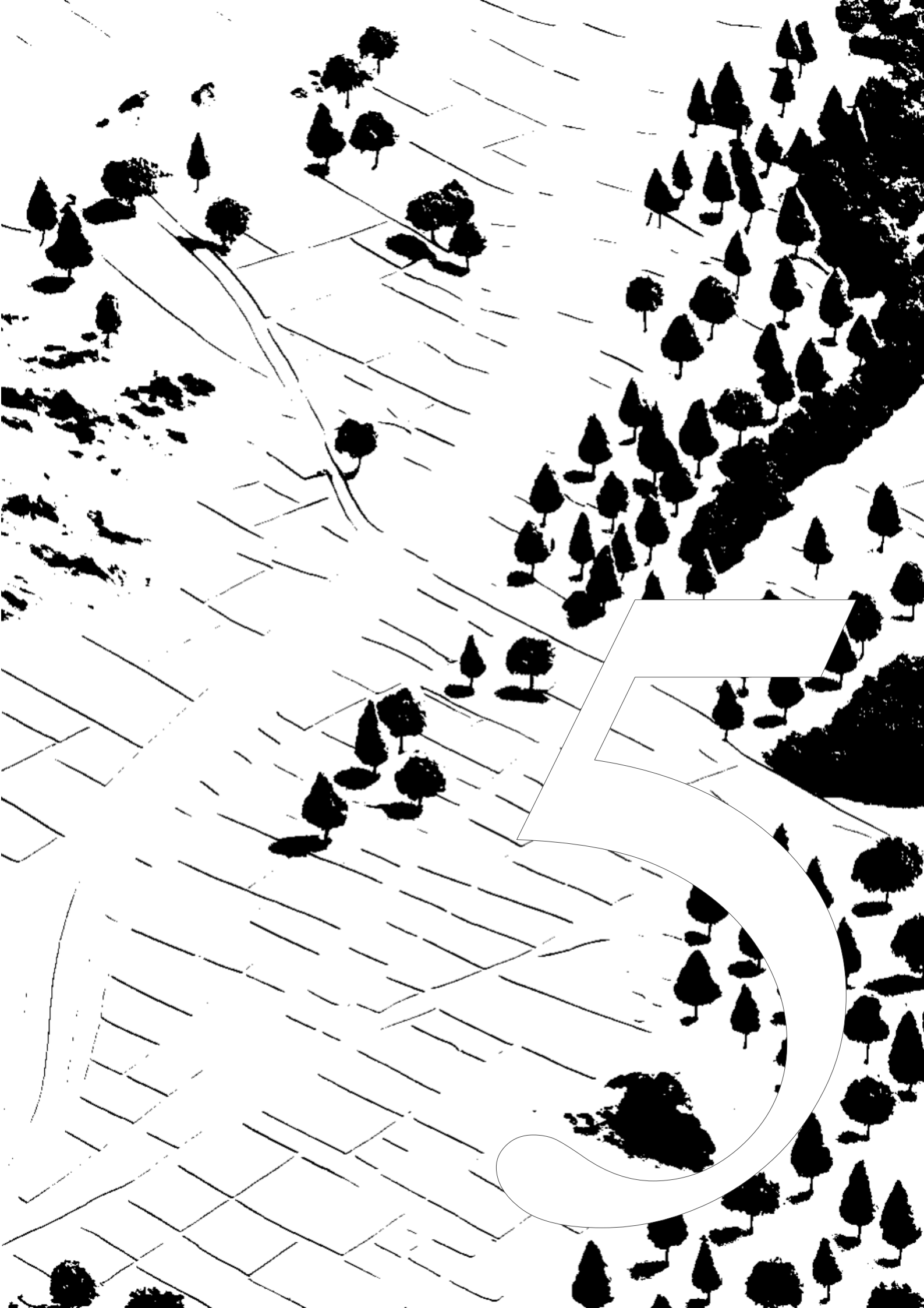
Figure 4.55 - Data-driven multiscale workflow: environmental indices derived from EO analyses are processed in GIS and translated into BIM through scale-specific data integration, enabling the generation of design scenarios that align ecological performance with project requirements across micro, medium and macro scales



The diagram summarises the functioning of the workflow as a continuous and adaptive process rather than a linear sequence of operations. Earth Observation data provide the initial environmental reading, GIS reorganises these datasets into interpretable spatial structures and the BIM environment enables their translation into design scenarios. This progression does not prescribe a single design outcome but sets up a framework of conditions through which project forms can emerge.

What changes is the mode of reasoning: instead of moving from a predefined design idea to its representation, the workflow allows the project to evolve from environmental evidence. The designer operates within a structured field of parameters, adjusting thresholds, testing alternatives and evaluating spatial consequences in real time. In this way, the model becomes a shared interface for ecological interpretation and interdisciplinary coordination, enabling design choices to remain both site-specific and conceptually grounded.

The workflow outlined in this chapter therefore provides not a definitive design proposal, but a scalable, evidence-based framework within which project scenarios can be generated, tested and compared directly within the BIM environment. This framework allows designers to move from analysis to proposition while retaining traceability to environmental data. Chapter 5 will expand on the implications of this approach, discussing its methodological contributions, limitations and potential developments toward a fully adaptive model of landscape governance and design.



5 Discussion and Conclusion

This chapter discusses the implications of the multi-scalar EO-GIS-BIM workflow developed throughout this research, evaluating its methodological contributions, operational performance and broader significance for landscape architecture. While the previous chapters described the technical construction of the workflow and its application across three spatial scales, the focus here shifts from implementation to interpretation. The aim is not to summarise again the results, but to show how they reposition landscape design as a data-informed practice capable of integrating evidence into decision-making and operating coherently across variable project conditions. Environmental data have become a driving component of landscape design, informing and guiding decisions across scales and redefining how landscape knowledge is transformed into project propositions. In this transition, digital environments restructure the production of evidence and its integration into spatial reasoning, enabling the landscape to operate as a dynamic information system.

The chapter is organised into four parts. Section 5.1 discusses the main contributions and impacts of the workflow, reflecting on how the integration of EO, GIS and BIM can support an adaptive, evidence-informed approach to landscape design embedded in BIM environment. It reflects also on the conditions for transferability and reproducibility of the workflow in professional and research contexts.

Section 5.2 addresses the limitations encountered during development and testing, including issues of data availability, scale translation, workflow complexity and interoperability.

Section 5.3 outlines potential future developments, with particular attention to software bridging, the role of artificial intelligence as a design support system and the evolving regulatory landscape in Italy.

Finally, Section 5.4 provides a concluding synthesis, highlighting the contribution of the research to contemporary landscape design theory and practice.

Taken together, these sections position the proposed workflow not as a prescriptive solution, but as a framework for reasoning through design: a set of methods that allows environmental data, spatial structure and design intention to be negotiated iteratively and coherently across scales.

5.1 Contributions and Impacts: Landscape as an Information Layer in BIM

The workflow developed in this research demonstrates how Earth Observation (EO), Geographic Information Systems (GIS) and Building Information Modelling (BIM) can be structured as an integrated and iterative design environment for landscape architecture. Rather than treating environmental data as external information to be consulted before, or sometimes after, design decisions have been made, the workflow embeds data classification, spatial interpretation and modelling directly within the design process. This shift aligns with the growing recognition that contemporary landscape practice must operate within complex socio-ecological systems, where form, process and performance are fundamentally interdependent (Forman, 2014; F. R. Steiner, 2018).

A central contribution of the workflow is its explicitly multi-scalar articulation as a disciplinary design logic. At the micro scale (10 × 10 m), the workflow supports fine-grained decisions related to planting composition and micro-topography. At the medium scale (30 × 30 m), it identifies strategic areas for ecological restoration or soil recovery, enabling design interventions to be spatially prioritised. At the macro scale (100 × 100 m), it frames territorial ecological connectivity and relational landscape structure. The movement across scales is not simply cartographic: it reveals how environmental gradients and ecological patterns become legible and actionable at different resolutions, confirming that landscape knowledge is inherently scale-dependent (Botequilha Leitão & Ahern, 2002; Wu, 2004).

A further contribution of this research concerns the position of landscape architecture within the current digital transition of public works in Italy. Since the introduction of DM 560/2017 (Ministero delle Infrastrutture e dei Trasporti, 2017) and its subsequent consolidation in Art. 43 of the Italian Public Procurement Code, D.Lgs. 36/2023 (Repubblica Italiana, 2023), the use of BIM has become progressively mandatory for public projects above defined financial thresholds. BIM has therefore become the central environment for design coordination, documentation, model checking and information traceability across disciplines. This regulatory shift is reinforced by the national standard UNI 11337 (2017-2022)¹⁹ and the European framework EN ISO 19650 (2018-2021)²⁰, which define information management requirements across planning, design, construction and maintenance phases. Despite this system-wide shift, landscape architecture has historically occupied a marginal position within BIM-based processes, often positioned as a late-stage layer added to architectural or infrastructural models. Landscape components are frequently treated as representational additions, visualisations added towards the end of the project, rather than as primary spatial systems with ecological, social and infrastructural agency.

¹⁹ UNI 11337 - Gestione digitale dei processi informativi delle costruzioni, part 1-7, part 12. Available at <https://www.uni.com/>

²⁰ EN ISO 19650 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using BIM. Available at <https://www.iso.org/standard/68078.html>

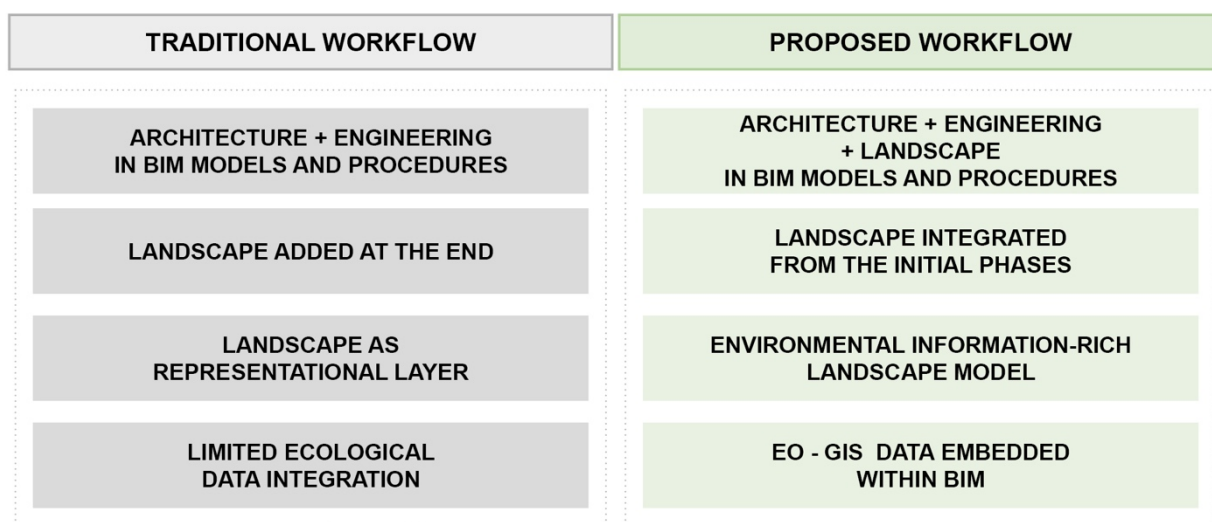
As noted in recent analyses of BIM adoption across public works in Italy (Daniotti et al., 2020; Raj et al., 2025), the workflows, model structures and software ontologies commonly in use have been shaped primarily around building and hard-infrastructure logic, leaving the landscape domain under-specified and under-parameterised.

The approach proposed in the present thesis explicitly addresses this gap. By embedding EO-derived environmental indices, land-use classifications, soil resilience indicators and spatial performance parameters directly within the BIM elements, the method positions the landscape not as a supplementary representational component but as a primary layer of project information. This allows landscape decisions, including planting strategies, soil remediation interventions and ecological corridor structuring, to be handled with the same level of traceability, interoperability and informational robustness that characterises architecture and engineering workflows.

In other words, the workflow reclaims a place for landscape design inside BIM, not just as a representation tool, but as an active part of the decision-making process, thanks to the extensive GIS-EO data integrated into it. In doing so, it contributes to aligning landscape architecture with the digital transition of public procurement, without reducing the discipline to purely technical compliance. In this sense, the contribution is not simply technical, but it is disciplinary. The workflow supports the recognition of landscape architecture as a core actor within digital project environments, aligning the discipline with current legal, procedural and informational frameworks without reducing its interpretive and cultural dimension.

Figure 5.1 represents this new approach. On the left, the traditional workflow places landscape architecture at the end of the process, as a representational layer with limited data integration. On the right, the proposed EO-GIS-BIM workflow integrates the landscape as an information-rich and decision-making domain from the earliest project phases, aligning it structurally with architecture and engineering in BIM environments.

Figure 5.1 - Position of Landscape Design in BIM Workflows: comparison between Traditional and Proposed workflows



Importantly, the workflow does not aim to automate the design process or generate deterministic solutions. Automation is used selectively, to reduce repetitive tasks such as data translation, parameter assignment and classification within BIM. This strategic automation enhances the designer's capacity to reason through environmental complexity without constraining creative or cultural interpretation. As Oxman (2008) argues, computational environments function as cognitive extensions of the designer, structuring how environmental information is processed without determining the final design outcome. Similarly, studies of design-through-making show that digital workflows can restructure the way decisions occur, extending design intelligence rather than replacing it (Sheil, 2012). In this sense, the approach positions the designer as an interpreter and decision-maker, supported, but not directed, by data.

Taken together, these contributions highlight the impact of recognising landscape as an information layer within BIM-based processes, repositioning the discipline from a marginal representational role to a central, data-informed component of digital project environments.

Within this framework, the empirical applications presented in the thesis should be interpreted with a clearly defined epistemological role. The case studies are not intended as exhaustive validation exercises, nor as statistically generalisable demonstrations of performance. Rather, they function primarily as exploratory and illustrative applications designed to test the feasibility, scalability and internal coherence of the proposed EO-GIS-BIM workflow across different spatial contexts and design conditions. In this sense, they operate as proofs of concept, demonstrating how the workflow can be operationalised and adapted at multiple scales. At the same time, they provide a form of partial methodological validation, insofar as they allow the consistency, robustness and limits of the workflow to be critically assessed through concrete design applications. This positioning reflects the nature of design-based research, in which empirical cases support methodological refinement rather than definitive validation.

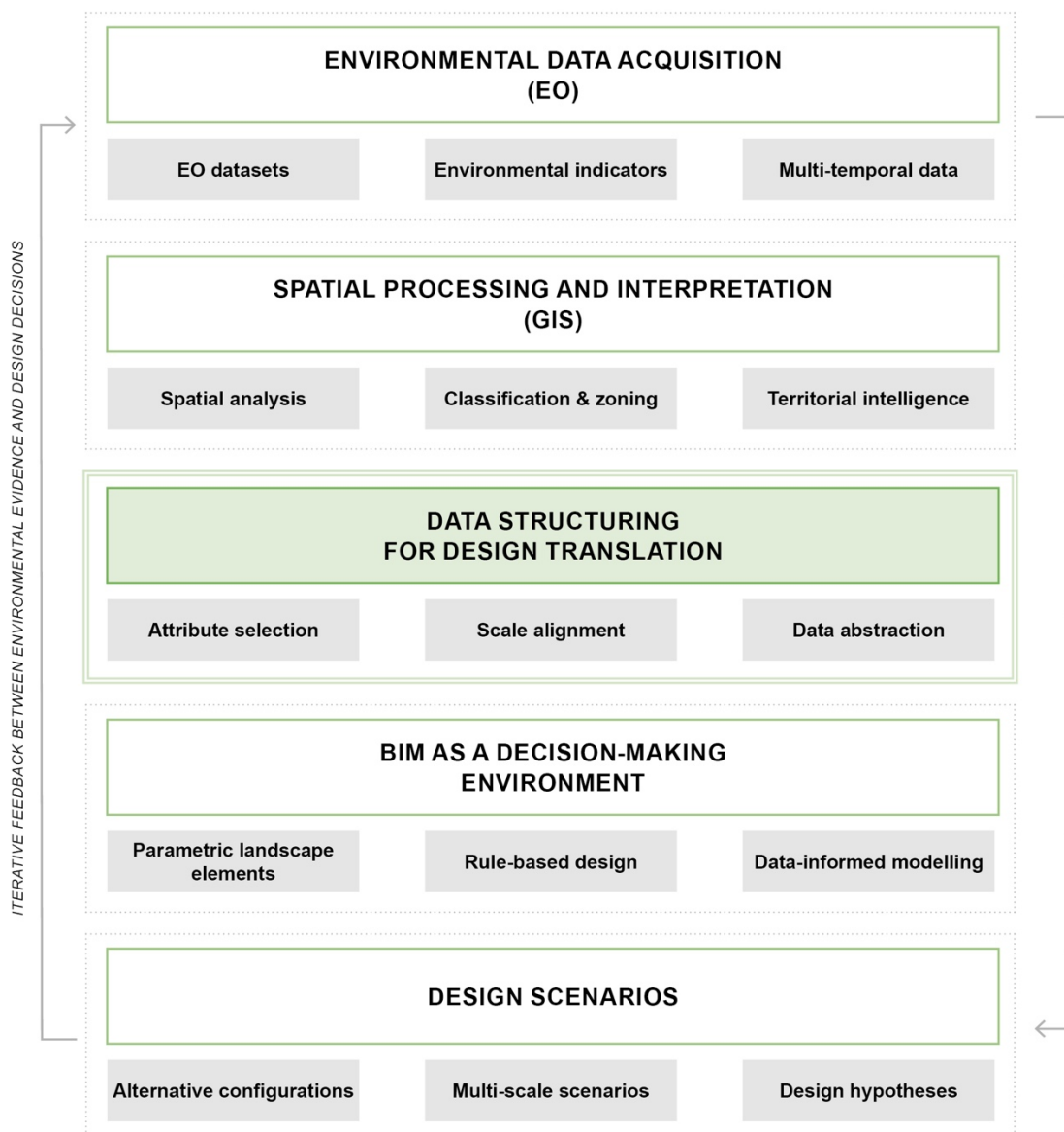
Building on these disciplinary contributions, the following section isolates the EO-GIS-BIM workflow as a formal design and methodological framework.

5.2 Structured EO-GIS-BIM Workflow as a Design Framework

While the workflow has been discussed in relation to its disciplinary contributions, it can also be abstracted from the specific case studies and formalised as an autonomous design and theoretical framework. This section responds directly to the need to make the procedural logic of the EO-GIS-BIM workflow explicit, clarifying the conditions under which it can be applied, transferred and reproduced across different contexts. The objective is not to define a rigid operational protocol, but to formalise a structure that can be adapted to diverse landscape design and planning scenarios.

Figure 5.2 illustrates the structured logic of the EO-GIS-BIM workflow, which underpins the discussion on applicability, transferability and reproducibility.

Figure 5.2 - Formalised EO-GIS-BIM workflow as a design framework for data-driven landscape design



The diagram highlights the sequential and iterative nature of the process, in which environmental data acquisition, spatial interpretation and design decision-making are connected within a single integrated framework. Rather than describing software-specific operations, the figure synthesises the logical structure through which environmental evidence is progressively translated into design scenarios, allowing feedback between analysis and project development across different scales. Starting from this structured articulation of the workflow, the following section discusses the conditions of applicability, transferability and reproducibility across different landscape design and planning contexts.

Applicability, Transferability and Reproducibility of the Workflow

The workflow is applicable both to new design processes and to the evaluation or revision of existing or built landscapes. When applied retrospectively, it provides a method for evaluating landscape performance and identifying targeted improvement strategies. When applied in early design phases, it grounds conceptual and compositional decisions in measurable environmental conditions. This dual applicability reflects the increasing need for adaptive, evidence-informed landscape frameworks, in which design functions as a hypothesis to be tested, refined and adjusted through environmental feedback and long-term performance observation in the context of climate uncertainty and ecological transition (Ahern, 2011; Felson & Pickett, 2005; Nassauer & Opdam, 2008).

In practical terms, the workflow supports two complementary modes of use. First, it can be applied to existing or completed projects as a diagnostic and improvement tool, helping to identify where planting compositions, soil conditions or microclimatic responses can be enhanced through targeted interventions. Second, it can be used in the early phases of new design, where the classification of environmental parameters directly informs species selection, soil composition strategies and spatial configuration options. In both cases, the workflow does not prescribe solutions, but supports design reasoning by structuring environmental information into a coherent decision-making space.

An additional contribution of this research concerns the conditions under which the EO-GIS-BIM approach can be applied, transferred or reproduced across different project contexts. Although the workflow was tested on three specific applications, its structure is inherently modular, making it suitable for a variety of landscape design and planning scenarios.

First, the workflow is applicable to a broad range of spatial scales and project types, from urban parks to territorial-scale ecological networks. Its multi-scalar organisation allows designers to adapt the analytical resolution to the scale of intervention: micro-scale planting and soil decisions, medium-scale restoration targeting and macro-scale ecological connectivity mapping can all be reconfigured using different raster datasets or thresholds. This adaptability supports transferability across different landscape conditions where environmental gradients shape opportunities for intervention in distinct ways.

Second, reproducibility depends on the availability and quality of environmental datasets. Many of the analyses conducted in the workflow rely on globally accessible sources, such as Sentinel-2 for spectral indices or Copernicus Land Monitoring for land-use data, allowing the workflow to be applied beyond the specific regions examined in this thesis. Other variables, such as soil organic carbon, hydrological layers, or detailed land-use classifications, may vary in resolution or accuracy depending on regional data infrastructures. For this reason, the workflow differentiates between design-driving datasets which require fine spatial detail and broader environmental indicators, which operate as contextual layers. This distinction ensures that the method remains reproducible even when data availability differs across territories.

Third, the workflow supports reproducibility through its internal structure. The GIS classification procedures, the rule sets used to assign planting or soil intervention typologies and the Dynamo scripts that transfer parameters into BIM elements are all modular and replicable. They can be adapted to different species lists, environmental conditions or project requirements without altering the logic of the workflow. Furthermore, the use of standardised georeferencing conventions and open environmental datasets supports interoperability across software, teams and institutions. In professional practice, this allows design offices to develop customised variants of the workflow aligned with their internal standards, while research institutions can extend or refine the methodology for experimental studies or scenario modelling.

From a methodological perspective, the reproducibility of the proposed workflow lies primarily in its conceptual structure rather than in the direct replication of identical software configurations. Core phases such as environmental data acquisition, spatial interpretation, raster classification, rule-based evaluation and the translation of environmental parameters into design criteria define a sequence of operations that is conceptually transferable across different research and design contexts. However, the operational implementation developed in this thesis is explicitly dependent on the availability of BIM environments that support visual scripting, rule-based logic and automated parameter management. In this research, Autodesk Revit was selected as the BIM authoring environment specifically because of its native integration with Dynamo, which enables the automation and parametric control required to translate EO-GIS-derived information into BIM-based landscape elements. Comparable implementations would require BIM platforms offering equivalent scripting and automation capabilities; such alternatives were not investigated within the scope of this thesis. For this reason, the workflow should be understood as conceptually transferable, while its practical implementation remains software-dependent and conditioned by the availability of advanced scripting environments.

In addition to its role during the design stage, the workflow sets the conceptual and technical foundations for the development of landscape-oriented Digital Twins. A Digital Twin, defined as a continuously updated digital replica of a physical asset, enriched through real-time or periodic data integration (Ellul et al., 2024; ISO, 2021), provides a dynamic environment where design intentions and environmental processes can be monitored, compared and validated over time.

Recent literature on Digital Twin applications in buildings, landscape and urban environment (Liu et al., 2024) show that this technology is no longer limited to buildings and infrastructures, but is increasingly being studied for outdoor spaces, cities and landscapes. These studies include real applications, theoretical frameworks and technological developments. Such evidence offers a credible scientific basis for advancing towards landscape-oriented Digital Twins, the direction explored in this thesis.

In this framework, EO and GIS indicators embedded into BIM elements serve as the initial condition of the model, enabling progressive updates through new satellite acquisitions, sensor networks or monitoring campaigns. Such updates can recalibrate planting typologies, highlight soil degradation, detect shifts in vegetation health or urban heat exposure, and simulate future scenarios of climate or land-use transformation. In doing so, the EO-GIS-BIM model evolves from a static information container into a living digital landscape model, capable of supporting adaptive management strategies and long-term ecological accountability. This aligns with emerging visions of territorial Digital Twins promoted at European scale (EC Joint Research Centre, 2024; European Commission, 2023), which aim to foster data-driven governance and multi-actor collaboration for climate-neutral and resilient environments.

While a complete implementation of a Landscape Digital Twin requires further development of data infrastructures, monitoring protocols and interoperability standards, the workflow presented in this thesis offers a concrete first step toward this transition, embedding the landscape within the broader digitalisation of public assets and environmental systems.

Stakeholders and Fields of Application

Beyond its methodological and disciplinary contributions, the EO-GIS-BIM workflow has implications for a wide ecosystem of stakeholders engaged in the design, management and governance of landscapes. Because environmental information becomes a structured, queryable and interoperable component of the BIM model, the workflow supports multiple forms of decision-making across public, private and multi-actor contexts.

Public administrations can constitute a primary beneficiary. The integration of EO and GIS indicators within BIM enhances the capacity of municipalities, regional agencies and environmental authorities to interpret the current landscape condition, monitor ecological dynamics and evaluate the coherence of project proposals with planning instruments and regulatory requirements. Within the Italian procurement system, these data-rich models can support Feasibility verification, climate adaptation strategies and ecological restoration policies, enabling administrations to base strategic decisions on comparable and reproducible evidence. Moreover, the digitalisation of environmental information within BIM creates a structured archive that can be shared across municipal departments, shifting from fragmented sectoral knowledge to a more integrated “control room” for territorial management.

Actors involved in territorial management, including river basin authorities, reclamation consortia, protected area agencies, utility companies and infrastructure managers, can also benefit from the workflow.

For these stakeholders, the method functions as a collaborative platform that allows different entities to compare intervention scenarios, coordinate restoration priorities and optimise resource allocation. Because the workflow aligns environmental indicators with spatial operations, it supports the development of complementary strategies across boundaries, reducing redundancy and enhancing cumulative ecological outcomes. In contexts where private investment plays a role, such as water infrastructure, renewable energy or land development, the workflow can also serve as a technical foundation for partnerships, stable consortia and joint research initiatives.

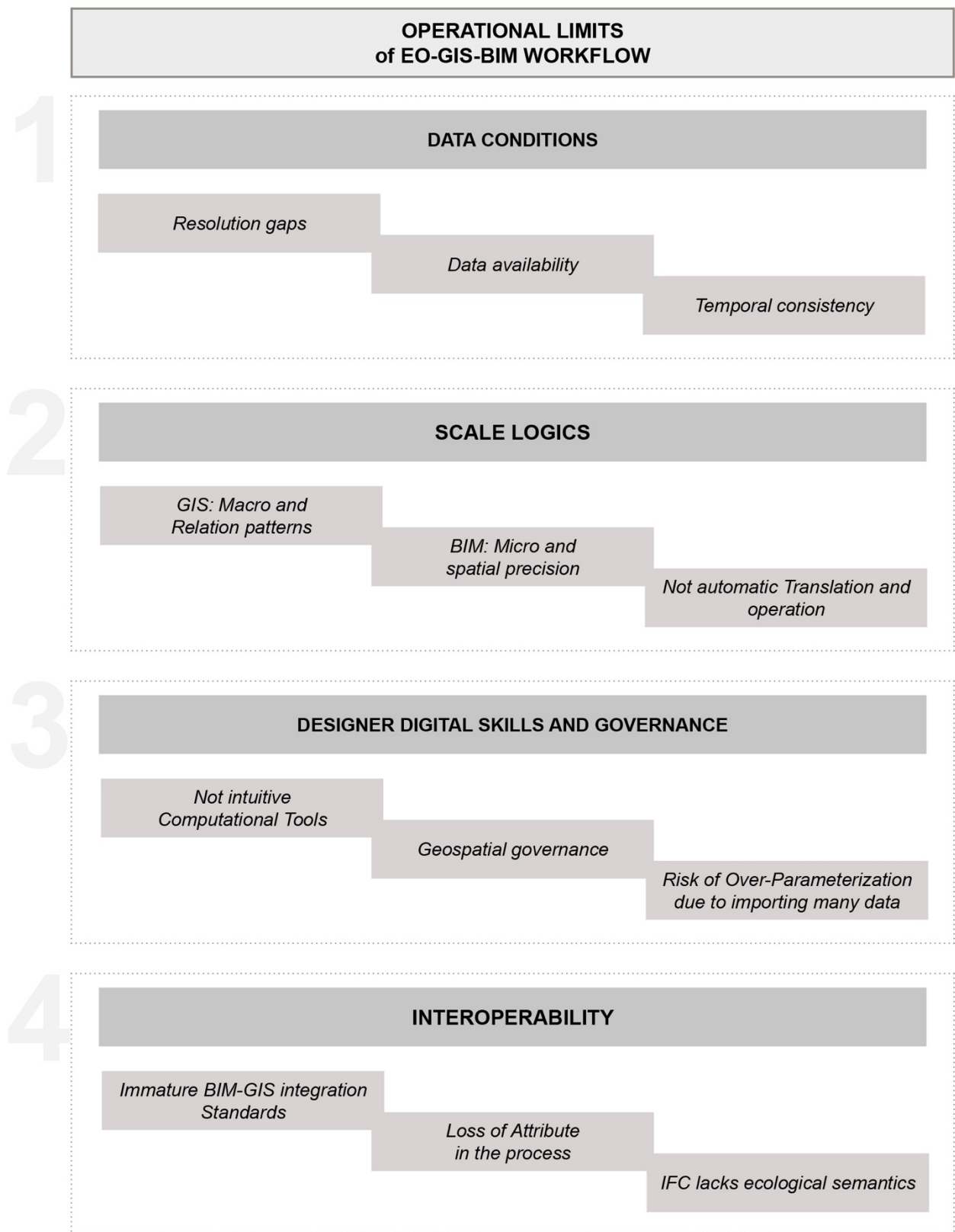
Interdisciplinary design teams represent another central category of users. Landscape architects, ecologists, agronomists, civil engineers and urban planners can work within a shared digital environment in which environmental data is explicit, structured and traceable. This reduces interpretive ambiguity and enables more coordinated design reasoning, especially in complex projects where planting, soil, hydrology and ecological connectivity interact. The workflow is particularly useful during early design phases, where parametric environmental knowledge can inform conceptual decisions and during revision phases, where it provides a robust basis for evaluating and improving existing landscapes.

Finally, construction, maintenance and facility management stakeholders can use the workflow to support long-term monitoring and adaptive management. The presence of environmental attributes within BIM elements allows maintenance operations to be guided by measurable conditions, soil moisture zones, vegetation resilience classes and heat exposure levels, rather than solely by visual inspection or predefined schedules. This supports more targeted interventions, cost optimisation and long-term ecological performance.

Taken together, these conditions show that applicability is not uniform or automatic: it depends on data availability, design objectives, team expertise and the scale of intervention. However, the workflow provides a clear structure through which different contexts can adapt, reconfigure or extend the method. Its strength lies not in prescribing a fixed process, but in offering a flexible and semantically coherent framework that can be transported across projects, territories and institutions.

Overall, the contribution of this research lies in articulating a workflow and approach through which environmental data, spatial interpretation and design judgement can be brought into sustained dialogue. It proposes a way of organising that maintains continuity across scales and phases of the project. Instead of producing a fixed solution, the workflow offers a structured means to reflect, compare, test and adjust. It presents a framework for reasoning through design within complex territorial conditions.

Figure 5.3 - Operational limits of the EO-GIS-BIM workflow: four categories of limitations influence the workflow performance



5.3 Operational Limits and Design Implications

As a structured design approach, the EO-GIS-BIM workflow operates within a set of boundaries defined by data conditions, scale effects, interoperability mechanisms and the skills required to use it effectively. Acknowledging these limitations is not a matter of reducing the value of the workflow, but of clarifying how it should be applied, in which contexts it is most appropriate and which aspects require further development.

Designing with environmental data requires moving continuously between analytical evidence and spatial interpretation. In this sense, the workflow does not aim to automate the landscape project, nor to replace the designer's judgement. Rule-based allocation and parametric classification can support the identification of suitable conditions for planting or soil interventions, yet the refinement of spatial composition remains inseparable from the designer's interpretive agency. Likewise, the workflow is shaped by the conditions of scale: certain ecological patterns are legible at the territorial or district level, while others only acquire meaning at the micro-topographic scale. Transferring insights from one scale to another is therefore never mechanical, but requires a process of translation. This shift is not simply technical, but conceptual: it involves evaluating which patterns retain meaning when scaled and which transform into different spatial relationships.

Moreover, the quality, resolution and consistency of environmental datasets influence the depth and reliability of the analyses that can be performed. In real project environments, where multiple disciplines and software systems intersect, the management of data becomes an operational task, requiring decisions about what information is relevant, how it should be structured and how it should be interpreted.

These considerations do not diminish the usefulness of the workflow. Rather, they clarify its position within the design process. The workflow does not generate a project on its own, it provides a framework for reasoning through landscape form and performance, enabling the designer to work with greater clarity, traceability and environmental awareness while retaining interpretive and creative responsibility.

Data availability and data quality represent a fundamental limitation of the workflow. Most of the indicators used at the micro and medium scale (e.g. NDVI, NDMI, MSI, etc.) are derived from Sentinel-2 EO datasets at 10-20 m resolution, which are suitable for identifying local environmental gradients but still operate as proxies rather than direct measurements. By contrast, some variables integrated into the workflow, such as Soil Organic Carbon (SOC), were sourced from Google Earth Engine at 100 m resolution, making them less appropriate for fine-scale modelling and requiring careful interpretation when applied to micro-topographic or planting decisions. Seasonal variation, cloud cover, radiometric correction and temporal data availability further influence the consistency of EO-derived information. For these reasons, ground-based surveys, site knowledge and expert ecological interpretation remain essential to validate and contextualise remote sensing outputs. The workflow therefore distinguishes between resolution-sensitive

design parameters (e.g. planting composition, soil micro-modelling), which require higher spatial detail and landscape trend indicators (e.g. SOC), which are most meaningful at broader spatial scales.

A second limitation relates to the translation of spatial reasoning across scales and software environments. The workflow demonstrates how GIS and BIM do not produce the same type of spatial knowledge:

- GIS is better suited for macro and meso-scale interpretation, where environmental gradients and patterns of ecological connectivity are legible;
- BIM, instead, supports micro and meso-scale modelling, where planting strategies, soil assemblies, drainage logics and spatial composition require precision and explicit control.

This means that not all scales should be treated uniformly. In many contexts, macro scale analyses are more effectively developed and maintained in GIS, where the landscape is understood relationally rather than discretely. However, in large landscape or territorial projects involving multiple disciplines, BIM remains advantageous even at broader scales because it enables shared model governance, collaborative decision environments and traceable data-rich coordination. The ability to query and modify environmental attributes directly in BIM through Dynamo scripting is a key factor as it allows the landscape model to be discussed and evaluated using the same decision infrastructures typically reserved for architecture and engineering. Thus, GIS and BIM in this workflow function as complementary cognitive environments, each supporting different moments of landscape reasoning.

A third limitation concerns the knowledge required to operate the workflow. Landscape architects, planners and designers increasingly engage with geospatial datasets, yet the combined literacy needed to navigate raster classification, BIM data structuring and parametric scripting is not yet common practice. Dynamo, in particular, remains a powerful but non-intuitive layer, requiring understanding of data hierarchies, list logic and model dependencies. If environmental information is introduced in BIM without clear data governance, the result can be over-parameterization, where the abundance of information produces complexity without improving decision-making. The workflow therefore presupposes a conceptual hierarchy of relevance: not all data should become parameters and not all parameters should drive design. This remains a matter of judgement.

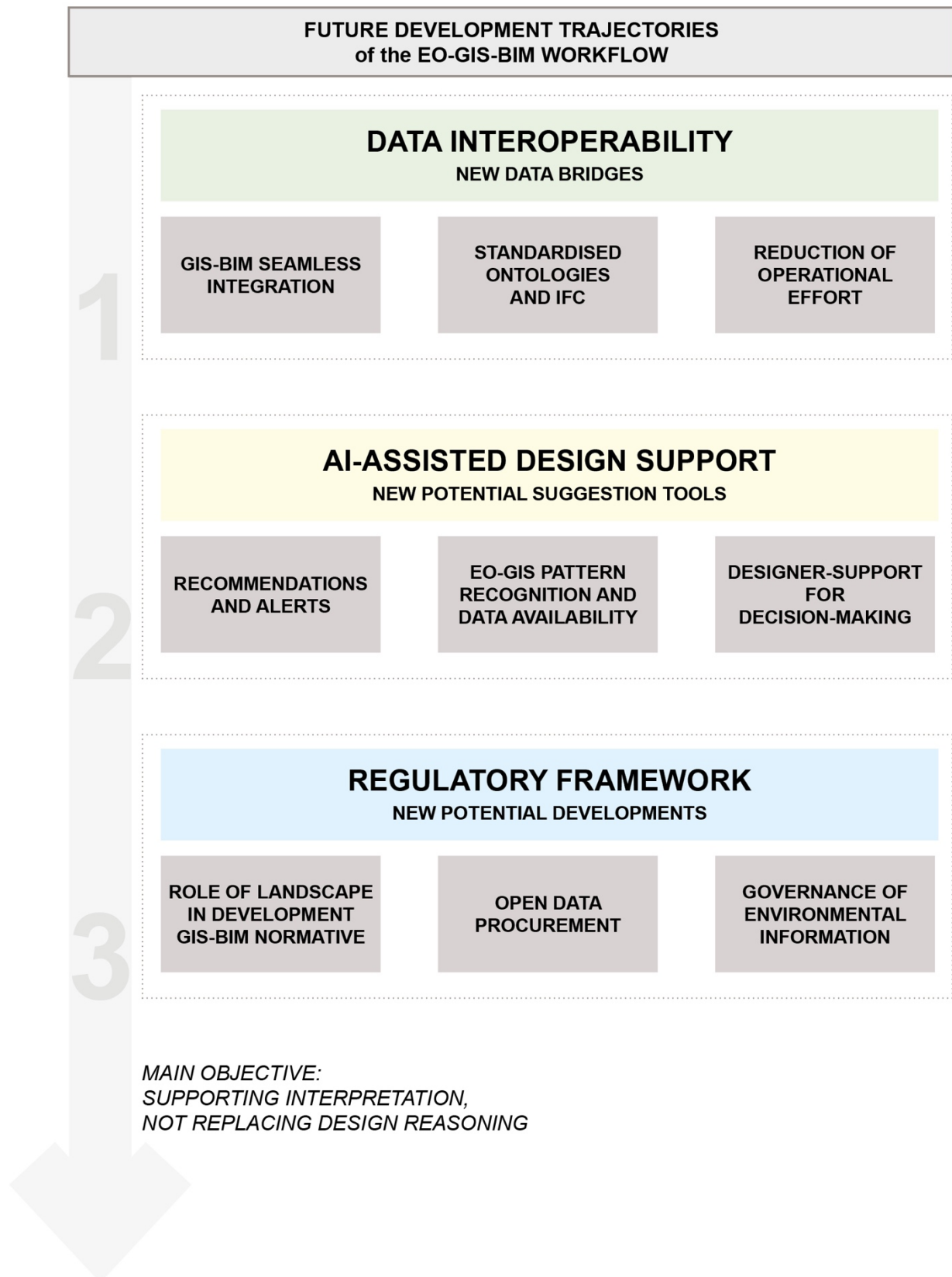
Finally, interoperability between GIS and BIM remains an evolving technical field. While openBIM frameworks such as IFC have made significant progress, they remain primarily structured around building and infrastructural components, with limited native support for ecological and vegetative entities. As demonstrated by recent studies, landscape systems are often excluded from BIM-based coordination because the data schemas do not yet possess a standardised representation of vegetation, soil bodies or dynamic ecological layers, resulting in loss of attributes or semantic simplification during data exchange (Gobeawan et al., 2021).

Similarly, attempts to extend CityGML through environmental planning Application Domain Extensions (ADE) indicate that environmental modelling and landscape architecture are not yet fully integrated into BIM governance structures, due to differences in scale logic and semantic granularity (Wilhelm et al., 2021).

Research on semantic and ontology-based integration approaches highlights that interoperability is not only a matter of file formats, but of aligning conceptual models across disciplines. Semantic web approaches demonstrate strong potential, but are not yet widely adopted in public or professional workflows (Irizarry et al., 2013). More recent developments in BIM-GIS fusion, particularly those addressing construction and territorial planning workflows, confirm that integration is technically feasible but remains operationally immature, requiring structured ontologies, shared metadata conventions and cross-platform governance (Celeste et al., 2022). As a result, while the workflow developed in this thesis is already operational, its long-term robustness depends on the continued evolution of interoperability standards and ecological data schemas.

These limitations do not reduce the contribution of the workflow, they define its scope of meaningful use. The workflow is most effective when environmental information is available and interpretable, when multi-scalar reasoning is required and when collaboration across disciplines benefits from shared model environments. Within these conditions, the workflow functions as a structured apparatus for reasoning through landscape, not as a tool for automatic solution generation. Its value lies in how it supports interpretation, comparison and iterative refinement, allowing design decisions to remain both data-informed and culturally situated.

Figure 5.4 - Three main development trajectories of the EO-GIS-BIM workflow: improved GIS-BIM interoperability, AI-assisted design support systems and the progressive institutional integration of landscape information into digital project governance



5.4 Future developments

The workflow outlined in this thesis is not presented as a fixed or closed system, but as a structured approach that can continue to evolve in response to new data environments, modelling standards and design contexts. It establishes a reproducible way of organising environmental information across scales and embedding it within BIM-based design processes. However, several directions for further development emerge. These directions do not pursue automation as an end in itself, but rather aim to strengthen the designer's capacity to engage with complexity, preserve interpretive autonomy and operate more effectively within collaborative, data-driven project environments.

Future evolution of the workflow will likely take place along three interconnected trajectories, as represented in Figure 5.4. First, the development of more robust and transparent interoperability tools can reduce the operational burden of transferring data between GIS and BIM, enabling landscape information to circulate more fluidly within multidisciplinary teams. Second, the selective integration of AI-assisted decision support systems offers the possibility of strengthening the advisory layer of the workflow, providing alerts and suggestions grounded in environmental data without constraining the designer's creative judgement. Third, as public procurement frameworks in Italy continue to expand the role of digital information modelling, the position of landscape architecture within BIM-based project governance will need to be further articulated, both technically and institutionally.

These trajectories share a common orientation, they do not seek to replace design reasoning, but to support, extend and structure it, enabling the landscape project to operate with greater clarity, ecological responsiveness and long-term adaptability.

5.4.1 Development of Interoperable Tools and Data Bridges

A first direction for future development concerns the strengthening of interoperability and semantic continuity between GIS and BIM environments. The workflow developed in this thesis already demonstrates that environmental information can be transferred from Earth Observation and GIS analysis into BIM models in a structured way. However, the process still requires a degree of manual interpretation and parameter assignment, particularly when translating ecological classifications into BIM elements such as planting families, soil layers or topographies. This is not a limitation of the workflow itself, but a reflection of the current state of digital infrastructures for the landscape discipline.

To support more stable and transparent connections between environmental reasoning and design modelling, future development should focus on the creation of shared semantic frameworks that clarify how environmental data is interpreted for design purposes. As widely discussed in research on BIM-GIS integration, interoperability depends less on file format conversion than on semantic mediation between conceptual models (Karan & Irizarry, 2015; Kim et al., 2015). This does not imply full automation, nor the replacement of interpretive judgement. Instead, it requires the construction of mapping conventions that make explicit how environmental indicators inform design choices.

For instance, a lightweight “*Landscape Data Bridge*” plug-in could perform three core tasks automatically:

- Detect and map raster-derived environmental classes (e.g., NDVI vegetation condition zones, NDMI soil moisture categories, UHI thermal stress areas) to predefined classification tables.
- Assign corresponding parameters directly to BIM elements, such as planting families, soil layers, toposolid surfaces or adaptive system components.
- Maintain a reversible link so that updates to GIS data reflect dynamically within BIM, supporting iterative design refinement rather than one-time import.

These mapping conventions would function as knowledge artefacts (structured tables, interpretive typologies, or practice-specific pattern libraries) capable of being refined and shared across projects and teams. They would not standardise design outcomes, but would make the reasoning behind decisions explicit and communicable, improving both collaboration and accountability.

At the software level, platforms such as Speckle, FME Workbench and custom Dynamo or Revit API nodes already provide partial infrastructures for reversible model exchange, demonstrating the feasibility of open-source, multi-model data streaming across design environments (Doe et al., 2024). Yet, their application to landscape semantics remains underdeveloped. Extending BIM element libraries to include vegetation strata, soil horizon profiles, hydrological corridors and ground thermal regimes would allow landscape components to move beyond representation and function as performance-aware spatial models.

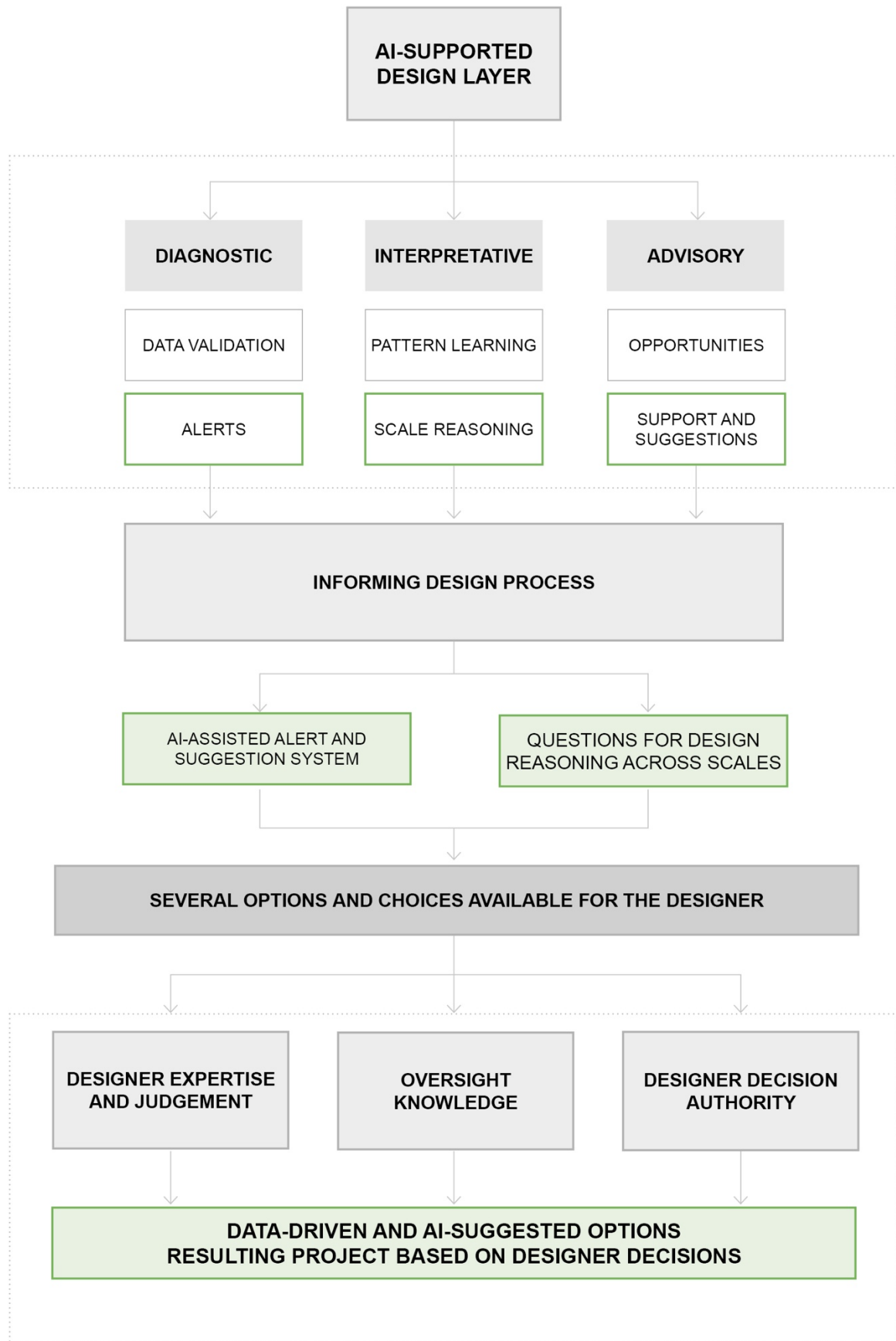
For example, tree families could be parameterised not only by species and canopy form, but also by evapotranspiration capacity, drought resilience and urban heat mitigation potential, drawing from ecological literature and EO-based environmental indices (Lin et al., 2022).

At the same time, open standards are evolving in a direction that can support these transformations. IFC 4.3 introduces richer spatial and georeferencing structures (buildingSMART, 2024); CityGML 3.0 expands the capacity to represent vegetation layers and soil volumes (Kutzner et al., 2020); OGC LandInfra provides an extensible ontology for ground conditions (Çağdaş, 2016). While these standards are not yet seamlessly aligned with BIM software interfaces, their emergence suggests that landscape data structures may soon gain first-class status, reducing reliance on workarounds or custom parameter systems.

Ultimately, the purpose of improving interoperability is not to automate the workflow fully, but to stabilise and clarify the flow of meaning across software environments. Interoperability tools should support the designer's capacity to inquire, compare and adjust, ensuring that environmental intelligence remains active within BIM-based project coordination rather than being reduced to a visual overlay.

The key concern in these developments is not merely technical efficiency, but the position of landscape knowledge and expertise within digital project environments. As long as environmental interpretation remains external to the BIM model, the landscape continues to appear as a representational layer appended after architectural and infrastructural decisions have already been consolidated. Strengthening semantic continuity between GIS and BIM, by contrast, enables ecological reasoning to enter the core of project coordination, influencing scenario evaluation, interdisciplinary negotiation and long-term performance decisions. Interoperability is therefore not an operational refinement, it is a disciplinary condition that determines whether the landscape project can function as a structuring agent within contemporary digital workflows, rather than as a visual complement or mitigation layer.

Figure 5.5 - Potential AI-supported landscape design workflow within the EO-GIS-BIM environment



5.4.2 AI-Assisted Landscape Design Workflows

The workflow developed in this thesis provides not only a structured method for integrating EO-GIS-BIM data into landscape design, but also a potential foundation for the development of future AI-driven design tools. By translating environmental information into explicit, interpretable and reusable parameters within the BIM model, the workflow establishes the conditions for an AI system to learn how environmental evidence supports design decisions and how these decisions evolve across scales. This aligns with emerging perspectives in computational design research, which argue that AI becomes meaningful only when embedded within structured decision environments. Recent studies in architecture suggest that AI-based decision support systems are increasingly explored in design contexts characterised by complexity and multivariate environments (Schubert et al., 2023). Furthermore, emerging work on AI-augmented systems emphasises that meaningful AI application depends on the structure of the system, its interpretability and its alignment with human-centred decision processes (Herath Pathirannehelage et al., 2025).

What this research demonstrates is that landscape design contains patterns, thresholds and recurring interpretive moments that can be formalised without reducing the discipline to deterministic rules. Recent contributions in architectural computation argue that AI is most effective when used to support pattern recognition, performance feedback and scenario evaluation, rather than prescriptive solution-generation (Long et al., 2019). In this sense, the organisation of environmental indices into classes, the translation of GIS information into BIM parameters and the formulation of rule-based decision pathways constitute early forms of design logic that could be used to train assistive AI systems. These systems would not generate projects, but could recognise when environmental thresholds are exceeded or when certain spatial configurations require further attention consistent with findings in AI decision-support research (Dall'Asta, 2024).

From this perspective, the workflow proposed here can be understood as a training ground for future AI tools: a structured environment in which relationships between data, spatial conditions and design choices are explicit enough to be learned, queried and expanded (Figure 5.5). If implemented within AI-assisted design platforms, these relationships could evolve into advisory systems capable of offering targeted alerts, context-specific suggestions or alternative pathways for landscape interventions always as support, never as replacement of design judgement. Recent reflections on AI-enabled design systems stress that such advisory capacities become meaningful only when the underlying computational environment is both interpretable and accountable, ensuring that designers remain in control of how inferences are produced and applied (Rai, 2020).

Rather than framing AI as an external add-on, the workflow suggests that meaningful AI applications in landscape architecture will emerge only when the underlying design environment is data-coherent, semantically structured and interpretatively transparent. This is consistent with current discussions in architectural AI, which argue that support-oriented AI becomes most effective when embedded within structured, domain-specific knowledge models that reflect design reasoning rather than override it (El Moussaoui, 2025). Following this interpretation, the EO-GIS-BIM workflow organises design logic and environmental knowledge in a way that future AI-based tools can build upon logically and responsibly, maintaining the designer's interpretive role at the centre of the process.

Within the framework developed in this thesis, AI should not be understood as a system that generates design solutions, but as a supportive intelligence that strengthens the designer's ability to interpret environmental information and navigate multiscale complexity. Whereas the previous section discussed how the EO-GIS-BIM workflow provides the structural conditions for future AI tools, this section focuses on what AI would actually do within such an environment.

In this context, AI would operate primarily as a diagnostic and interpretative layer, capable of recognising patterns, threshold exceedances or inconsistencies in the data embedded in the BIM model. Its role is not to replace the designer's judgement, but to enhance the legibility of environmental conditions that may otherwise remain implicit within dense information models. This aligns with broader reflections on designer-AI collaboration, which emphasise that AI systems are most effective when they assist designers in perceiving relevant conditions, surfacing issues and maintaining situational awareness, rather than directing outcomes (Amershi et al., 2019).

Concretely, a supportive AI could highlight where soil moisture conditions diverge from expected ranges, where thermal accumulation or low vegetation resilience suggests potential stress, or where spatial clusters indicate ecological vulnerability. Such interventions align with the principle that AI should remain interpretable, reliable and human-controlled, supporting rather than automating decision-making (Shneiderman, 2020). In this perspective, the system must be able to explain why certain alerts are triggered and how they relate to the underlying data, echoing the view that explainability is a prerequisite for meaningful human-AI interaction (Miller, 2019).

This approach preserves the inherently interpretive nature of landscape architecture. The designer remains responsible for contextualising alerts and suggestions within the ecological, cultural and projectual framework. AI simply enhances the ability to "see" data-driven conditions that might inform those decisions. Thus, AI functions as an analytical tool that amplifies clarity without narrowing the openness of the design process.

In practical terms, the contribution of AI within this workflow can be understood through a set of support functions that strengthen the continuity between environmental evidence and design reasoning. Rather than generating project solutions, AI could assist in structuring how data is read, verified and updated across platforms, ensuring that the designer is consistently informed about relevant conditions. These functions span from the systematisation of EO data collection to the verification of scale adequacy, the continuous synchronisation of GIS-BIM attributes and the identification of critical environmental patterns. To clarify these potential contributions, Table 5.1 summarises the core areas in which AI could operate as an interpretative and organisational aid within the proposed workflow.

Table 5.1 - Potential Roles of AI within the EO-GIS-BIM Workflow

Area	Potential AI Contribution	Purpose for the Designer
EO Data Systematisation	Automating the collection, organisation and pre-classification of EO datasets	Ensures consistent, comparable inputs; Reduces manual preprocessing
Scale Verification	Checking whether data resolution matches the design scale (micro, medium, macro)	Prevents misinterpretation and supports correct scale-dependent reasoning
GIS-BIM Interoperability	Monitoring and updating parameters as source data changes	Maintains data coherence across platforms; reduces divergence between analyses and models
Data Quality & Consistency Checks	Detecting gaps, inconsistencies or missing environmental attributes	Supports informed decision-making; highlights where further validation is needed
Alert Identification	Detecting threshold exceedances, pattern anomalies or risk indicators	Enhances situational awareness without prescribing solutions
Suggestion Support	Providing non-prescriptive prompts based on environmental conditions	Helps the designer reflect on alternative strategies without automating decisions

These potential roles illustrate how AI could operate as a supportive layer that structures and clarifies the flow of information across the EO-GIS-BIM workflow. Building on this foundation, the next section focuses on the most immediate of these contributions, such as the development of an AI-assisted alert and suggestion system capable of translating environmental indicators into design-relevant suggestions.

AI-Assisted Alert and Suggestion System

One of the most immediate directions in which AI could be applied within the EO-GIS-BIM workflow concerns the development of an alert and suggestion system capable of identifying critical environmental conditions embedded in the model. Because the workflow already organises environmental indicators (e.g., NDMI, UHI, BSI, SOC, etc.) as structured BIM parameters, an AI layer could use these attributes to detect potential conflicts, incompatibilities or threshold exceedances. These detections would not aim to produce solutions, but rather to generate context-aware advisory prompts that support the designer's interpretive reasoning.

In a data-rich environment, the value of AI would lie not in automating decisions but in making relevant conditions more visible. By drawing attention to relationships that might otherwise remain implicit, such as localised stress conditions, micro-heat islands or mismatches between species and site parameters, the system could help the designer maintain a more accurate overview across scales. This would align with research on human-AI collaboration, which emphasises that AI systems are most effective when they augment human awareness rather than direct the design process (Amershi et al., 2019).

Building on the structure defined in this thesis, such a system could support the identification of environmental tensions by combining multiple indicators, interpreting their interactions and translating them into design-relevant alerts. When accompanied by non-prescriptive suggestions, these alerts could function as a form of guidance, offering insights without diminishing the designer's interpretive role.

The potential role of AI within this workflow becomes clearer when these diagnostic capacities are expressed in operational terms. Table 5.2 summarises how combinations of EO-derived indicators, once embedded in BIM, could be translated into design-relevant alerts and non-prescriptive suggestions. The aim is not to automate responses, but to provide the designer with a structured, intelligible reading of environmental conditions that may merit further attention.

Table 5.2 - Potential AI-Assisted Alert and Suggestion System

Type of Alert	GIS-EO Trigger (Imported to BIM)	Implication for Design	Non-Prescriptive Suggestion
Water Stress Area	Low NDMI + Low SOC	Soil moisture deficit; low establishment potential	<ul style="list-style-type: none"> – Select drought-tolerant species – Reduce planting density – Add micro-berms or shallow infiltration zones within the toposolid
Thermal Accumulation / Local UHI	High UHI + low canopy density	Heat amplification; reduced comfort; evapotranspiration risk	<ul style="list-style-type: none"> – Increase canopy continuity – Add understory shading layers – Adjust BIM family foliage parameters
Soil Fragility / Erosion Potential	High BSI + slope discontinuities	Risk of surface erosion; unstable rooting	<ul style="list-style-type: none"> – Add slope-stabilising groundcovers – Introduce root-binding pioneer species – Reshape micro-topography to reduce runoff concentration
Low Vegetation Resilience (Medium Scale)	NDVI variability + degraded land use	Weak regenerative capacity; low ecological function	<ul style="list-style-type: none"> – Replace lawn or sparse vegetation with pioneer assemblages – Adopt staged restoration – Enrich soil layers in the BIM model
Ecological Fragmentation (Macro Scale)	Discontinuities in vegetation/connectivity grids	Loss of habitat continuity; weak corridor structure	<ul style="list-style-type: none"> – Add stepping-stone patches – Introduce buffer vegetation strips – Connect isolated patches via linear ecological corridors

The value of an AI-assisted system would lie in its ability to make environmental conditions legible, comparable and actionable, without constraining the openness of the design process. These alerts would function as prompts that enrich the designer's situational awareness, supporting reflective judgement across scales rather than prescribing fixed outcomes. In this sense, the advisory logic introduced here forms a bridge to the next section, where the focus shifts from individual alerts to the broader questions that guide landscape reasoning at micro, medium and macro scales.

Questions for Design Reasoning Across Scales

While alerts make environmental conditions visible at the level of discrete parameters, the design process ultimately operates across multiple spatial scales, each characterised by different priorities, constraints and forms of interpretation. The EO-GIS-BIM workflow developed in this thesis shows that moving from micro to medium and macro scales requires different ways of asking questions rather than different technical procedures. What AI could support, therefore, is not the generation of answers, but the structuring of these scale-dependent questions the interpretive lenses through which the designer decides how to read the site and where to intervene.

To clarify this, Table 5.3 summarises a first example of key questions that may guide design reasoning at the three scales used in this research and the corresponding forms of support that an AI-augmented system could provide within the workflow.

Table 5.3 - Potential design reasoning across scales and AI support

Scale	Primary Design Question	Focus of Interpretation	Potential AI Support
Micro (10 × 10 m grid analysis)	<i>Which species and micro-topographic adjustments are ecologically appropriate for this specific location?</i>	Fine-grained moisture gradients, exposure, soil composition, shading patterns	<ul style="list-style-type: none"> – Highlight mismatches between species and site parameters – Suggest alternative species groups – Flag micro-topo conditions needing retention or drainage adjustments
Medium (30 × 30 m grid analysis)	<i>Where should renaturalisation efforts be prioritised to restore ecological function?</i>	Landscape resilience, soil degradation, vegetation condition zones, land-use conflicts	<ul style="list-style-type: none"> – Identify high-leverage restoration cells – Classify intervention typologies – Highlight areas of low resilience requiring staged restoration
Macro (100 × 100 m grid analysis)	<i>How can ecological continuity and territorial structure be reinforced across the wider landscape?</i>	Connectivity patterns, ecological fragmentation, corridor alignment, patch configuration	<ul style="list-style-type: none"> – Map potential ecological corridors – Signal fragmented or weak continuity zones – Suggest strengthening measures such as stepping-stones or buffer areas

These questions illustrate how design reasoning shifts across scales and how each shift entails different forms of environmental interpretation. An AI-assisted workflow would not resolve these questions, but could help structure them by surfacing relevant conditions, identifying scale-appropriate constraints and clarifying where design attention may be required. In this way, the system supports the designer in maintaining coherence across micro, medium and macro reasoning while preserving the interpretive and creative dimensions of landscape architecture.

The progressive structuring of environmental information within the EO-GIS-BIM workflow suggests a further direction for future development: the possibility of evolving this system into a studio-specific knowledge model, capable of supporting the distinctive reasoning patterns of a landscape practice. As environmental data, design parameters and interpretive rules accumulate across projects, the workflow could become a repository of situated knowledge, one that reflects how the practice evaluates site conditions, prioritises interventions and balances ecological constraints with design intentions.

In such a scenario, AI would not function as a generator of design proposals, but as a means of retrieving, comparing and adapting insights derived from previous work. The system could recognise recurring situations, such as characteristic combinations of soil degradation, vegetation resilience or hydrological behaviour and relate them to precedent decisions or documented strategies. This would not standardise the design process, rather, it would allow accumulated experience to remain accessible, searchable and responsive across new contexts.

A knowledge model of this kind would support the designer in framing questions, identifying relevant environmental patterns and understanding how similar conditions were addressed in the past. It would strengthen continuity within the practice while maintaining the openness of landscape design as an interpretive and context-dependent discipline. In this sense, the potential role of AI lies not in automating creativity, but in enhancing the designer's capacity to reason across projects, to learn from environmental feedback and to articulate design choices that remain both ecologically grounded and culturally situated.

5.4.3 Potential developments of the Italian Regulatory Framework

The workflow developed in this thesis intersects with a broader transformation underway in Italy's digital regulatory environment, where the integration of geospatial and environmental information into BIM-based processes is gaining increasing institutional relevance.

Recent reforms of public procurement, specifically Article 43 of (D.Lgs. 36/2023) explicitly emphasise the role of georeferenced territorial information in the early stages of project definition, requiring that feasibility studies incorporate GIS-based analyses to ensure that design decisions are grounded in spatial evidence. These phases, Feasibility Document of Design Alternatives (Documento di Fattibilità delle Alternative Progettuali - DOCFAP) and the Technical-Economic Feasibility Study (Progetto di Fattibilità Tecnico-Economica - PFTE), are conceived as evidence-based decision stages in which GIS-derived environmental analyses, land-use constraints, risk maps and territorial characterisation must precede any modelling activity, ensuring that projects are rooted in spatially coherent knowledge (Repubblica Italiana, 2023). This orientation is further supported by evolving standards such as UNI 11337 framework, particularly Part 12 published in June 2025, which dedicates a specific section to the relationship between GIS data and the BIM process for infrastructure projects, recognising that territorial datasets constitute an essential component of the information ecosystem that underpins digital design coordination.

In parallel, sectoral professional publications underline that GIS and BIM are no longer separate environments but complementary systems that must operate in synchrony, particularly for projects concerning ecological transition, territorial adaptation and the management of environmental risk (Perego, 2025). The assumption, increasingly reflected in both technical norms and public tender guidelines, is that the digital model cannot be detached from its territorial context and that environmental intelligence, the kind of information traditionally processed in GIS, must accompany the project from its earliest phases.

Within this evolving framework, the EO-GIS-BIM workflow developed in this thesis offers a concrete demonstration of how environmental information can be translated into structured, queryable BIM data capable of supporting design reasoning, interdisciplinary coordination and long-term decision-making. While current regulations acknowledge the importance of geospatial information, they do not yet prescribe how environmental datasets, such as land-use classifications, EO-derived indices or soil conditions, should be articulated within BIM models for landscape and territorial projects. The operational methodology developed in this work therefore anticipates a likely regulatory direction: one in which landscape information ceases to be a supplementary representational component and becomes instead an integral part of the information model required by digital public procurement. By demonstrating how Earth Observation indices, land-use classes, soil layers and environmental parameters can be translated into structured BIM information, the workflow provides a practical method for embedding landscape knowledge into the digital governance increasingly emphasised in Italian procurement processes.

Future regulatory developments may evolve toward a more explicit and structured integration of environmental intelligence in BIM workflows. This evolution could involve defining clear information requirements for landscape components (vegetation systems, ecological indicators, soil bodies, hydrological layers) within the UNI framework, thereby extending model uses beyond the architectural and infrastructural domains currently dominate. The workflow proposed in this thesis offers an operational foundation for such an evolution, illustrating how environmental data can be systematised within BIM in ways that support both present practice and emerging regulatory expectations.

At the level of interoperability, the research also highlights a series of gaps and opportunities. Although openBIM formats such as IFC 4.3 and CityGML 3.0 represent important steps forward in spatial representation and georeferencing, their native schemas still offer limited semantic support for vegetation, ecological structures or dynamic landscape processes (Jusuf et al., 2017; Kutzner et al., 2020; Lam et al., 2024). The workflow demonstrates that, in the absence of formalised standards, designers can rely on custom parameter systems, classification tables, Dynamo scripts and semantic mappings to maintain the interpretability and environmental relevance of BIM models. These practices may inform future extensions of IFC or the development of domain-specific ontologies for landscape architecture within Italian digital standards.

The progressive alignment between Italian procurement practices and European policies further reinforces the relevance of this methodological direction. EU strategies such as the Biodiversity Strategy for 2030 (European Commission, 2020), the EU Climate Adaptation Strategy (European Commission, 2021a) and the Green Infrastructure Strategy (European Commission, 2013) all aim to data-driven, multi-scalar, ecologically integrated approaches to territorial planning. This trajectory is consistent with the broader ambitions of the EU's Horizon Europe programme, particularly Pillar II on "Global Challenges & European Industrial Competitiveness." Within this framework, "Cluster 4: Digital, Industry & Space" promotes advanced digital infrastructures, key digital technologies and geospatial innovation, while "Cluster 6: Food, Bioeconomy, Natural Resources, Agriculture & Environment" supports research on ecological resilience, soil monitoring, environmental forecasting and integrated land management (EU Commission, 2021b).

The EO-GIS-BIM workflow developed in this research responds directly to these priorities by enabling environmental indicators, restoration dynamics and ecological connectivity structures to become operational within BIM models. As European environmental and digital policies are progressively incorporated into the Italian regulatory framework, workflows of this kind may serve as methodological references for defining and supporting ecological performance criteria, environmental obligations (e.g. Minimum Environmental Criteria)²¹, landscape-relevant data requirements and interoperable modelling practices within future norms.

²¹ Minimum Environmental Criteria, Italian original version *Criteri Ambientali Minimi (CAM)*, are mandatory environmental standards established by the Italian Ministry for the Environment and they are required in all public procurement procedures.

In this sense, the approach proposed in this thesis not only aligns with current EU research directions but also opens potential avenues for future multidisciplinary collaborations and innovation programmes centred on environmentally informed digital design.

In summary, the evolution of the Italian regulatory framework is moving toward a more integrated, environmentally informed and interoperable digital ecosystem. The workflow developed in this thesis anticipates these transformations by demonstrating how landscape intelligence can be structured, parameterised and made operational within BIM. Rather than adapting to norms retroactively, it provides a forward-looking model that illustrates how future regulations may support, formalise and expand the role of landscape architecture within the national digital agenda.

5.5 Towards a Data-Merged Landscape Practice: Concluding Reflections

The research presented in this thesis demonstrates that environmental information, when structured, interpreted and transferred across EO, GIS and BIM environments, can serve not merely as a background layer for design, but as an operative infrastructure that supports reasoning, coordination and decision-making in landscape architecture. By repositioning landscape data within BIM-based processes, the workflow proposed contributes to a broader disciplinary shift: from a conception of the landscape as a representational component, often appended to architectural or engineering models, to an understanding of the landscape as an information data environment, ecologically grounded system embedded within the core of the digital project environment.

Several insights emerge from the multi-scalar structure of the workflow. At the Micro scale, environmental indices reveal spatial gradients that directly inform planting and soil design, at the Medium scale, classification patterns support the identification of strategic areas for restoration, at the Macro scale, territorial connectivity becomes legible as an ecological structure rather than a cartographic abstraction. These results align with long-established principles in landscape ecology that emphasise the role of scale, pattern and process in shaping actionable design knowledge (Forman, 2014; Wu, 2004). They also resonate with design-through-scenarios approaches that consider landscape form as an evolving condition shaped by ecological, hydrological and socio-territorial dynamics (Di Giulio et al., 2017, 2018).

A second conclusion concerns the role of computation in structuring design reasoning. The workflow does not aim to automate landscape design, nor to replace professional judgement. Rather, it uses selective automation to reduce repetitive tasks and clarify the relationships between environmental evidence and design choices. As Oxman (2008) notes, computational systems are most effective when they augment the designer's ability to organise and interpret complex information. Contemporary territorial conditions can no longer be understood as purely "natural" or purely "artificial", but as hybrid ecologies shaped by the continuous interplay of environmental dynamics, human actions and technological infrastructures (Emanueli & Lobosco, 2016b). The EO-GIS-BIM workflow developed in this thesis aligns with this conceptual shift: by treating environmental indicators, spectral signatures and soil conditions as active design agents within BIM, the workflow presents the landscape not as a static substrate but as a hybrid techno-ecological system whose performance is continuously shaped by data, interpretation and intervention.

In this sense, the approach establishes the conceptual and operational foundations for embedding environmental intelligence directly within BIM environments, an evolution that enables landscape architects to work with the data that already structures ecological, agronomic and territorial reasoning. By transferring these data into a shared, parametric and queryable digital space, the workflow anticipates a new generation of landscape design practices increasingly grounded in interoperable, data-informed and digitally coordinated methodologies.

The thesis workflow acts as a cognitive framework that supports inquiry, comparison and refinement, while preserving the interpretive and cultural intelligence of design practice.

The integrated workflow also highlights the potential for more coherent interdisciplinarity in large-scale environmental and infrastructural projects. By enabling architects, engineers, ecologists, agronomists and public bodies to operate within a shared data environment, it addresses some of the fragmentation traditionally associated with territorial decision-making. This echoes recent calls for design-based approaches to scenario evaluation and resilience planning, in which multiple actors collaborate through structured spatial knowledge (Emanueli & Lobosco, 2016a; García-Mayor & Nolasco-Cirugeda, 2023). The workflow contributes to this agenda by making environmental information interoperable, readable and traceable across disciplines.

The limitations identified in this thesis, related to data resolution, interoperability, workflow complexity and the need for technical literacy, should not be understood as constraints, but as productive openings for future research. They indicate where disciplinary advances are most urgently needed: improving semantic frameworks linking GIS and BIM, developing environmental ontologies for vegetation and soil systems within open standards and exploring AI-supported design tools capable of recognising environmental thresholds, generating alerts and assisting with scenario evaluation. These directions align with broader debates positioning digital technologies as catalysts for new forms of ecological reasoning, rather than as neutral instruments (Zhang & Cantrell, 2023).

The thesis framework holds potential to contribute to both national and European agendas on digitalisation, climate adaptation and ecological restoration. Within the Italian context, where BIM has become a mandatory environment for public procurement, the integration of environmental intelligence into preliminary processes suggests pathways for strengthening the ecological dimension of digital project governance.

In conclusion, this research does not propose a definitive model, nor a closed method. Instead, it articulates a way of organising environmental information, spatial interpretation and design judgement into a coherent, iterative and multi-scalar workflow. Its value lies less in prescribing solutions than in enabling designers and institutions to reason through complexity and construct landscape proposals grounded in measurable ecological evidence. As landscape architecture confronts the challenges of climate change, ecological transition and digital transformation, the framework developed in the present research offers a foundation, flexible, extensible and evolving, upon which future methodological, technological and disciplinary innovations can build.

Figure 5.6 - *The Landscape as a Structured System*: cover image from *Natural Textures* (Sommariva, 2003), illustrating a layered and selective organisation of natural structures, a metaphor for data-driven landscape modelling



I. Appendix I - Dynamo Scripts, Packages and Python codes

This appendix documents the set of Dynamo scripts, Python routines and external packages developed or adopted during this research to support the proposed EO-GIS-BIM interoperable workflow. The scripts operate as the computational backbone of the methodology, enabling the acquisition, structuring, translation and transfer of environmental information into the BIM environment for design-driven purposes.

Each script is presented in a consistent format, including:

- Purpose and context of use within the multiscale workflow;
- Inputs and outputs, including data formats and Revit element categories;
- Main logical structure, described through images of flows, nodes and functions;
- Cross-references to paragraphs in the thesis where the script is applied.

The aim of this appendix is to ensure clarity, traceability and reproducibility of the computational components underpinning the research. By openly documenting the scripts and their dependencies, the work aligns with principles of scientific transparency and contributes to the dissemination of digital tools for landscape architecture.

Although the included scripts have been tailored to the specific case study and software configurations used for this research, they have been structured to allow adaptation and future development in different landscape and project contexts.

All scripts and related assets will be deposited in the institutional Zenodo repository of the University of Ferrara, precisely within the Community “University of Ferrara Zenodo Community - UnifeZen”²² upon publication of the thesis, where they will be freely accessible and version-controlled.

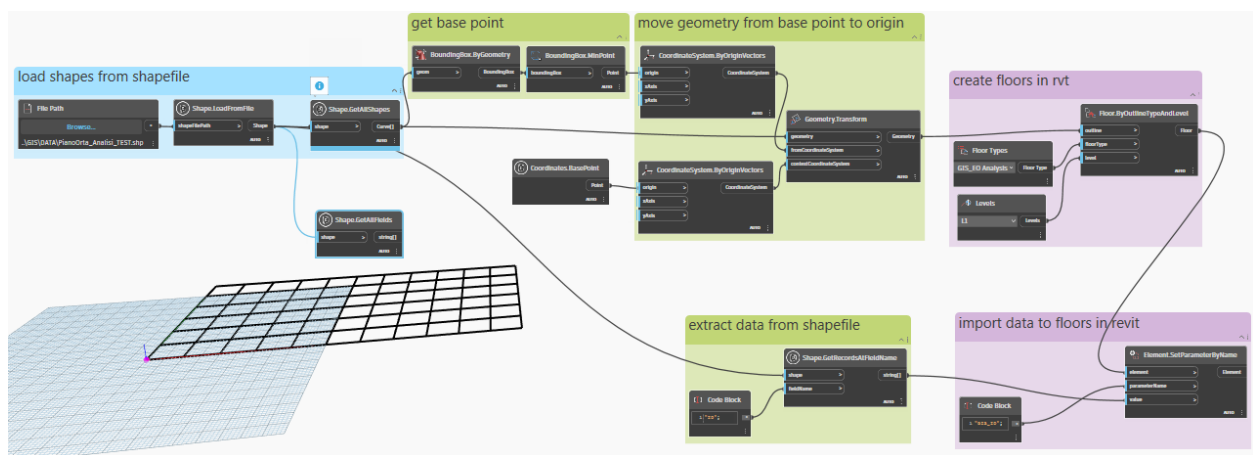
²² University of Ferrara Zenodo Community - UnifeZen, available at: <https://zenodo.org/communities/unifezen>

GIS Data into BIM: Revit Floors by Geometry and Information

This script converts the vector geometries contained in a GIS shapefile into Revit Floor elements while preserving their spatial position relative to the project base point. It performs the transformation between GIS world coordinates and the Revit coordinate system, ensuring consistency between the georeferenced analysis conducted in GIS and the parametric modelling environment. The resulting Floor objects act as the primary BIM carriers for environmental and analytical data, enabling further classification, parameter assignment and design operations.

Inputs	Outputs
– Shapefile (.shp) containing polygon geometries	– One Floor instance per GIS polygon
– Revit Base Point (automatically referenced)	– Model geometry aligned to site coordinates
– Pre-selected Floor Type and Level from the Revit project	– Environment-ready BIM elements for parameter population in subsequent scripts

Figure I.1 - Dynamo workflow for the creation of Revit floors with geometry and information



Thesis Chapters Reference

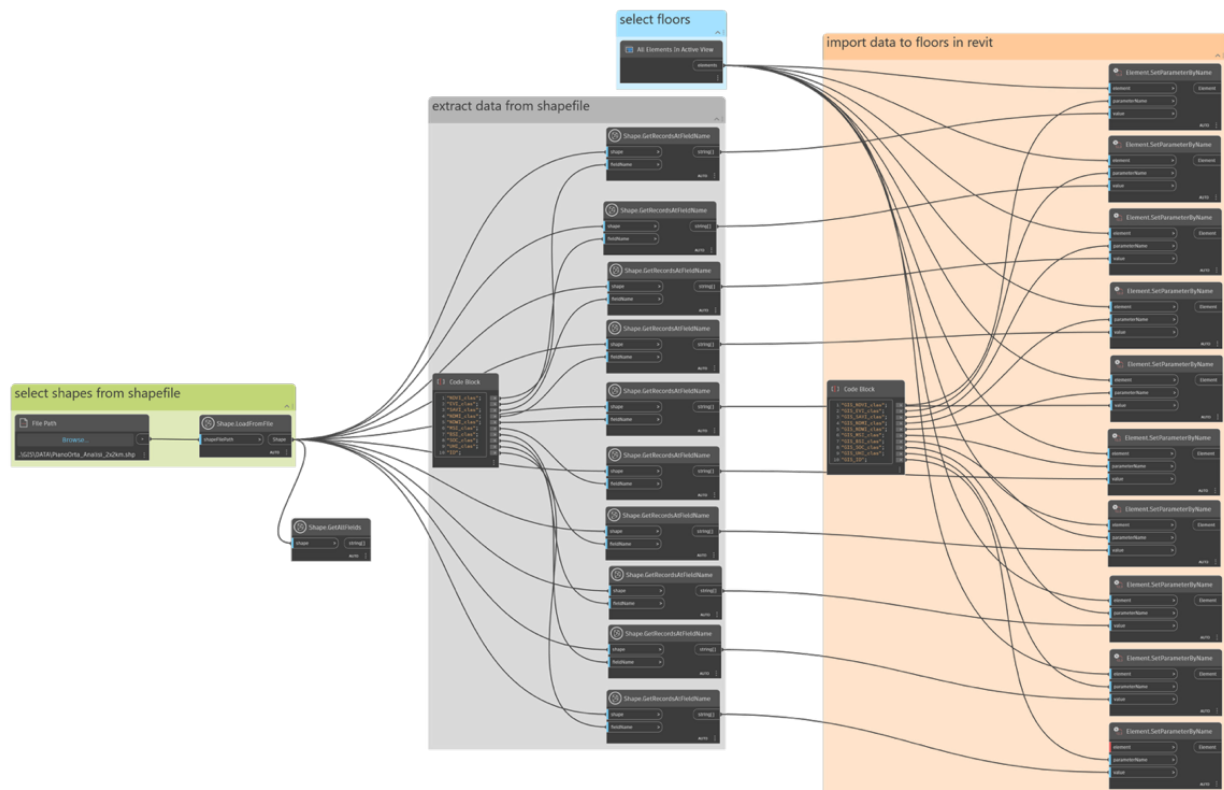
3.4.2.2 - GIS data into BIM: Revit Floors by Geometry and Information

GIS Data into Existing Floors: Transfer Information in Elements

This script links GIS-derived polygon data to existing Floor elements already modelled in Revit. Unlike the previous script, which creates new Floors directly from shapefile geometries, this routine performs a spatial matching operation that identifies which GIS geometry corresponds to each Floor in the BIM model. Once matched, it assigns the relevant GIS attributes as Revit parameter values. This enables the integration of analytical information into pre-existing design models while preserving original geometry and project structure.

Inputs	Outputs
<ul style="list-style-type: none"> – Existing Floor elements in Revit – Shapefile (.shp) representing environmental classification polygons – Attribute fields (e.g. GIS_ID, classes of EO indices) to be imported into BIM 	<ul style="list-style-type: none"> – Parameters written on Floor elements, ready for data-driven visualisation and tagging – Persistent connection between GIS analytical layer and BIM design components

Figure I.2 - Dynamo workflow showing how specific attributes derived from GIS analyses are extracted from the shapefile and transferred to the selected Revit Floors within the dedicated project parameters



Thesis Chapters Reference

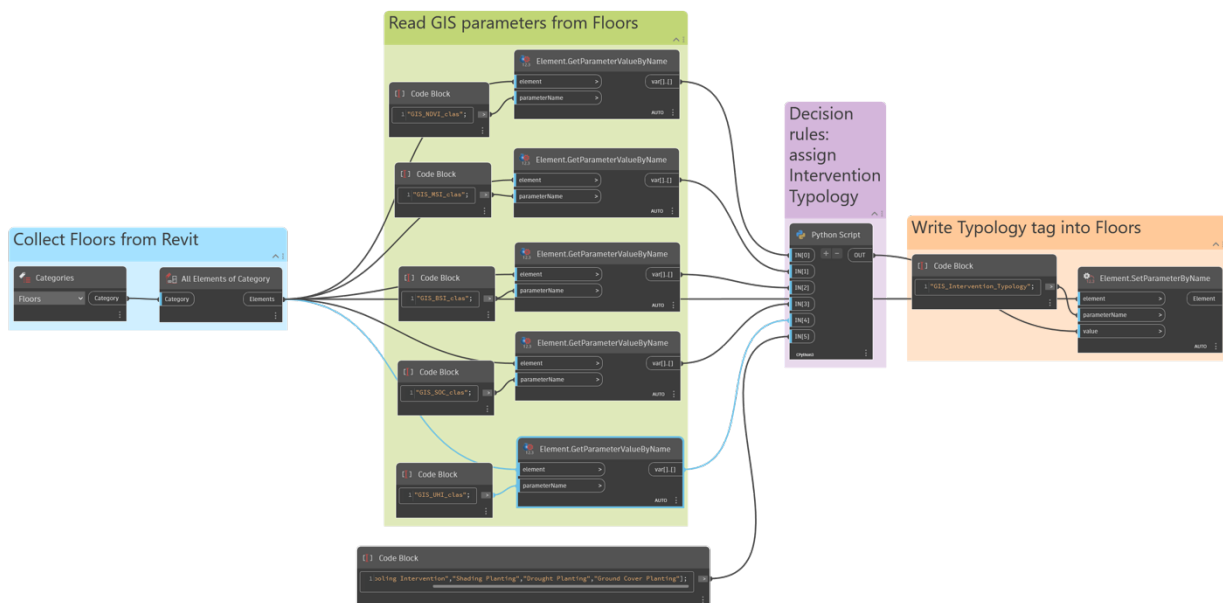
3.4.2.3 - Update of Information inside Revit Elements

Identification of Strategic Areas

This script classifies existing Floor elements in Revit based on environmental indicators imported from GIS and EO datasets. By translating data values into a set of predefined intervention categories (e.g., Soil Remediation, Cooling Intervention, Ground Cover Stabilisation), the script establishes the first design-oriented layer of the interoperable workflow. At this stage, environmental information stops being only descriptive and begins to guide scenario-based decisions within the BIM environment.

Inputs	Outputs
<ul style="list-style-type: none"> – Revit Floors with GIS parameters already assigned – Classification thresholds derived from GIS-EO analysis (e.g., <i>NDMI_class</i>, <i>NDVI_class</i>) – Custom intervention taxonomy defined in Chapter 3.3 	<ul style="list-style-type: none"> – Parameter <i>Intervention_Typology</i> set for each Floor – Visual filters and tagging enabled within Revit – Base layer for generative planting and micro-grading strategies in subsequent scripts

Figure I.3 - Dynamo workflow for assigning Typology Tag into Revit Floors



Thesis Chapters Reference

3.5.1 - Identification of Strategic Areas

4.2.2.1 - Strategic Areas Scenario

4.3 - Medium Scale: Environmental Recovery Based on Data

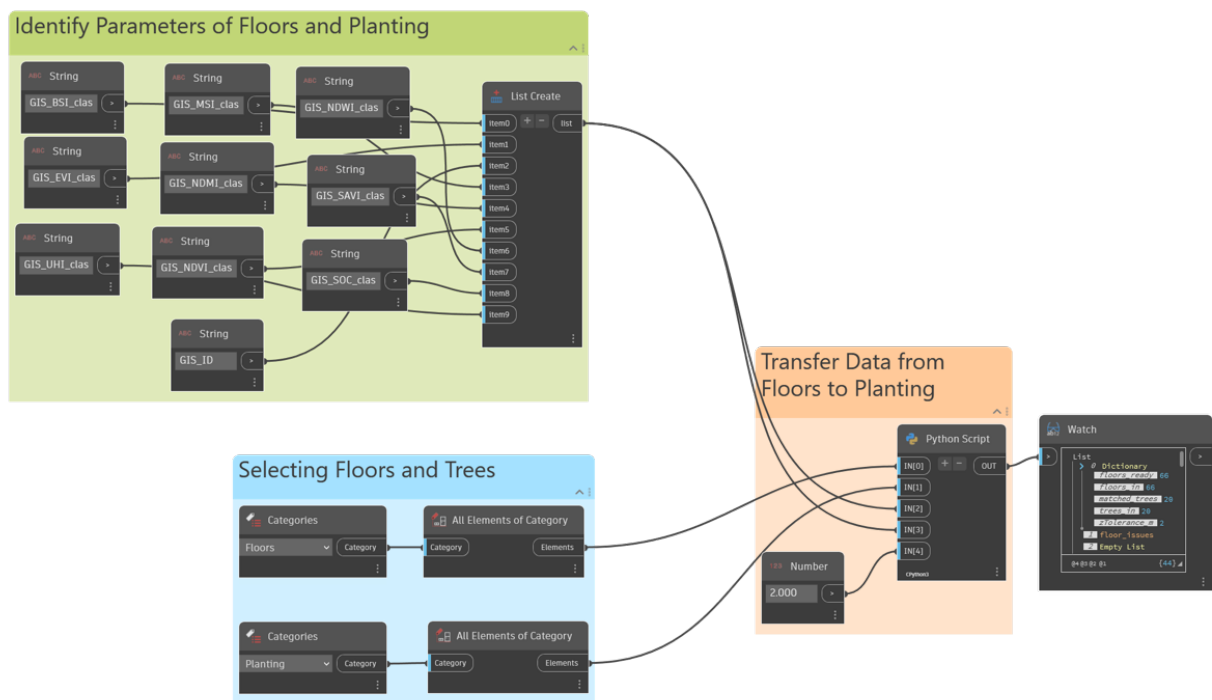
4.4 - Macro Scale: Potential Interventions on the Territory

Planting Verification and Compatibility

This script ensures that all planting elements generated in previous phases inherit the environmental information initially assigned to Floor elements. Using spatial correspondence or identifier-matching, the script retrieves environmental parameters (e.g. *GIS_ID*, *NDVI_class*, *Intervention_Typology*) from Floors and writes them into the instance parameters of tree families. This maintains the full interoperability chain and enables environmental querying, scheduling, and filtering directly on planting components.

Inputs	Outputs
<ul style="list-style-type: none"> – Planting Families (trees) of existing layouts – Floor elements with GIS-EO parameter sets – Matching logic (IDs or spatial proximity) embedded in the script 	<ul style="list-style-type: none"> – Tree instances enriched with GIS-EO attributes – Full semantic continuity of environmental data across model objects – Automatic compatibility across view filters

Figure I.4 - Dynamo workflow for real-time Data Transfer for the Compatibility check



Thesis Chapters Reference

3.5.2.1 - Compatibility and Verification

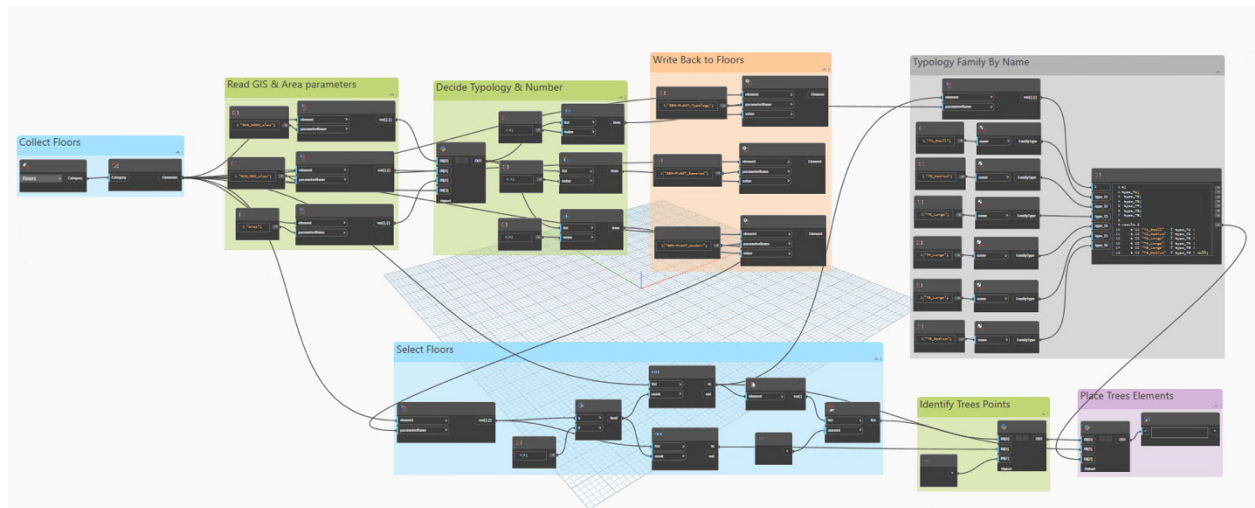
4.2.1 - Not Data-Driven Design: Compatibility and Verification

Generative Planting - Low-Maintenance Irrigation Scenario

This script generates tree instances inside Revit based on the intervention strategy previously assigned to each Floor element, specifically the Low Irrigation scenario. Starting from the parameterised environmental classification, the script defines planting density rules and places tree families automatically inside each classified area. The operation transforms environmental evidence into tangible design geometry, enabling rapid scenario testing and visual, quantitative evaluation directly within BIM.

Inputs	Outputs
<ul style="list-style-type: none"> – Floor elements classified with <i>Intervention_Typology</i> = Low Irrigation – Tree Family type(s) selected in Revit (e.g., drought-tolerant species) – Density and spacing rules defined in the script (e.g. grid distribution) 	<ul style="list-style-type: none"> – Tree instances distributed over eligible Floor areas – Data retained through family parameters for counting, schedules and filtering – First simulation of a design scenario informed by EO and GIS analysis

Figure I.5 - Dynamo workflow for generative planting under the “Low-Maintenance Irrigation Scenario” strategy



Thesis Chapters Reference

3.5.2.2 - Data as a Driver for Planting Selection

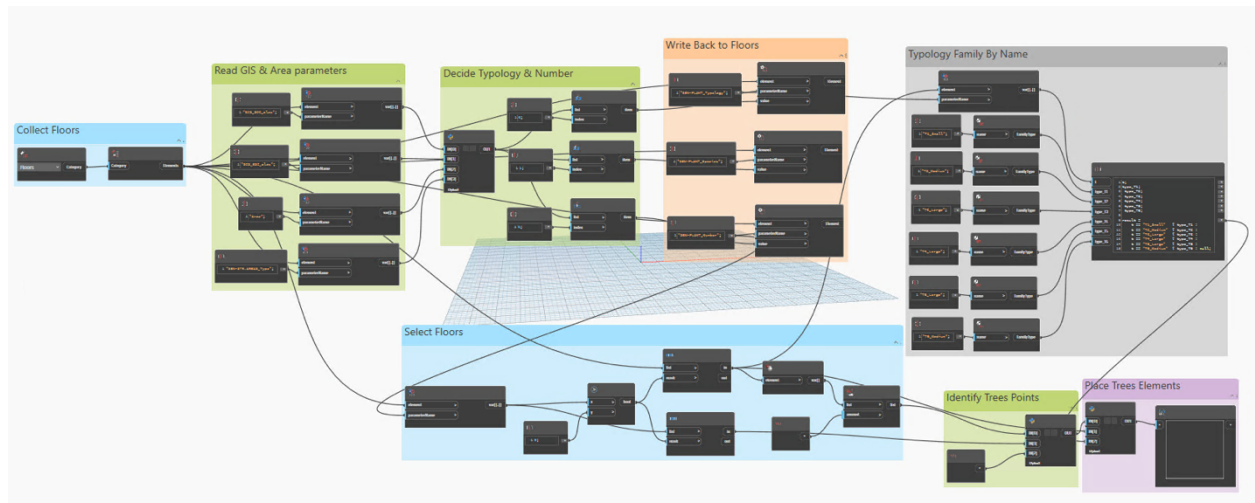
4.2.2.2 - Planting Scenario

Generative Planting - Soil Fertility Enhancement Scenario

This script automatically generates tree instances within the BIM model for all Floor elements classified under the Soil Fertility intervention category. It applies a planting strategy specifically oriented towards improving soil conditions, typically through species with deeper rooting systems or capable of enhancing soil organic matter. The planting operation is spatially informed by the results of the environmental analysis and directly contributes to scenario-based testing in the BIM environment.

Inputs	Outputs
<ul style="list-style-type: none"> – Floor elements classified with <i>Intervention_Typology</i> = Soil Fertility – Revit tree families selected based on ecological purpose – Density, spacing and insertion rules embedded in the script logic 	<ul style="list-style-type: none"> – Parametric tree instances positioned on the eligible Floors – Updated model with quantifiable ecological interventions – Design scenario suitable for comparison against alternative planting strategies

Figure I.6 - Dynamo workflow for generative planting driven by “Soil Fertility Enhancement Scenario” interventions



Thesis Chapters Reference

3.5.2.2 - Data as a Driver for Planting Selection

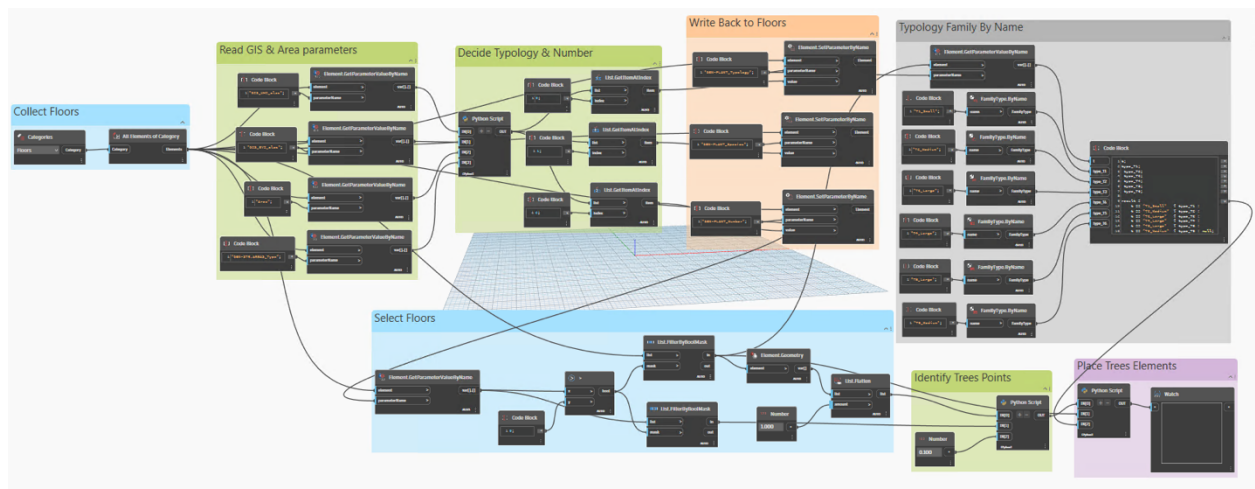
4.2.2.2 - Planting Scenario

Generative Planting - Cooling and Shading Scenario

This script generates tree instances for the areas identified as requiring Cooling and Shading interventions. Based on environmental indicators (e.g., heat exposure, low canopy presence), it places trees with large canopies and cooling ecological functions in order to mitigate Urban Heat Island (UHI) effects and increase comfort conditions. The result is a scenario-driven design iteration where shading efficiency can be visually and quantitatively evaluated in BIM.

Inputs	Outputs
<ul style="list-style-type: none"> – Floor elements classified with <i>Intervention_Typology</i> = Cooling & Shading – Tree families representing large-canopy species – Spacing and density rules consistent with shading optimisation logic 	<ul style="list-style-type: none"> – Adaptive planting positions targeting microclimatic improvement – BIM model enriched with quantifiable cooling strategies – Basis for solar/thermal comfort analysis in later phases

Figure I.7 - Dynamo workflow for shading-driven “Cooling and Shading Scenario” tree generation and microclimatic mitigation



Thesis Chapters Reference

3.5.2.2 - Data as a Driver for Planting Selection

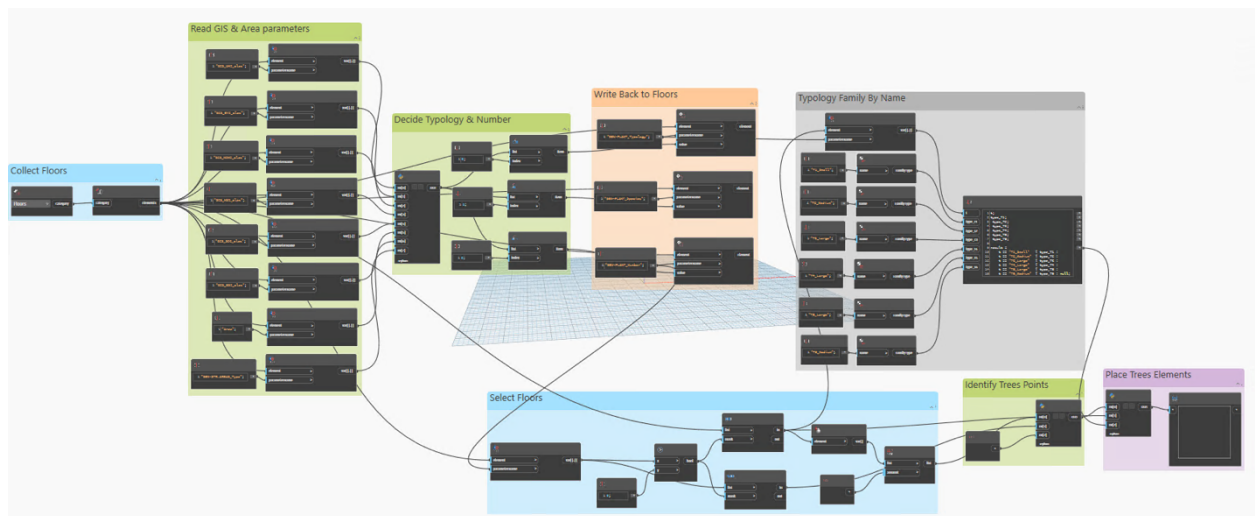
4.2.2.2 - Planting Scenario

Generative Planting - Integrated Final Scenario

This script aggregates all previously defined intervention strategies, Low-Maintenance Irrigation, Soil Fertility Enhancement and Cooling & Shading, into a single integrated planting scenario. It automatically generates tree instances over the entire site, applying different rules for spacing, species selection and density according to the specific intervention typology assigned to each Floor. As a result, multiple environmental objectives are orchestrated within one unified BIM environment, supporting comprehensive design reasoning and rapid scenario comparison.

Inputs	Outputs
<ul style="list-style-type: none"> – Floor elements classified with Intervention_Typology parameter – Tree families assigned to each ecological strategy – Spacing/density rules tailored per intervention category 	<ul style="list-style-type: none"> – Complete planting layout representing the overall ecological strategy – BIM environment ready for quantitative evaluation (e.g., counts, cost, coverage) – Scenario useful for interdisciplinary coordination and design refinement

Figure I.8 - Dynamo workflow for the integrated generative planting scenario



Thesis Chapters Reference

3.5.2.2 - Data as a Driver for Planting Selection

4.2.2.2 - Planting Scenario

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List of abbreviations and Acronyms

BIM & Information Management

Abbreviation	Full Term	Description / Reference
ACDat	Ambiente di Condivisione dei Dati	Italian term for CDE used in public works as a controlled collaborative environment.
AIR	Asset Information Requirements	Information needed to operate and maintain the built asset effectively.
BEP	BIM Execution Plan	Defines roles, responsibilities, data structures and coordination workflows.
BIM	Building Information Modelling	Data-driven method to structure and manage information across project lifecycle.
CDE	Common Data Environment	Single source of truth where authorised project data are stored and shared.
CI	Capitolato Informativo	Italian document defining information deliverables and modelling rules. Equivalent to EIR.
EIR	Exchange Information Requirements	Document specifying the client's information needs and deliverables before BIM work begins.
GID	Gestione Informativa Digitale delle Costruzioni	Digital information management mandated for Italian public procurement.
IFC	Industry Foundation Classes	Open standard schema for interoperable BIM data exchange.
OIR	Organizational Information Requirements	Organisational information needs enabling asset and risk management.
OGI	Offerta Gestione Informativa	UNI Italian equivalent to OIR, defining information governance in Italy.
PGI	Piano di Gestione Informativa	Italian specific information requirements for a single project. Equivalent to BEP.

Normative & Policy Framework

Abbreviation	Full Term	Description / Reference
D.Lgs.	Decreto Legislativo	Italian Legislative decree establishing regulatory frameworks including public procurement.
DM	Decreto Ministeriale	Italian Ministerial decree defining digital transition obligations (e.g., BIM adoption).
DOCFAP	Documento di Fattibilità delle Alternative Progettuali	Pre-feasibility document assessing design scenarios in early phases, within Public Procurement Code D.Lgs. 36/2023.
PFTE	Progetto di Fattibilità Tecnico-Economica	Feasibility design phase requiring integrated geospatial and BIM data, within Public Procurement Code D.Lgs. 36/2023.
INSPIRE	Infrastructure for Spatial Information in the European Community	EU directive enabling standardised environmental and geospatial data sharing.
ISO	International Organization for Standardization	Responsible for BIM and geospatial standards (e.g., ISO 19650, ISO 19100).
SDGs	Sustainable Development Goals	UN global framework for sustainable environmental, social and economic targets towards a sustainable future.
UNI	Ente Nazionale Italiano di Unificazione	Standards body issuing UNI 11337 on digital processes in construction.

GIS and EO domain

Abbreviation	Full Term	Description / Reference
BSI	Bare Soil Index	EO index detecting bare or degraded soils using visible/NIR bands.
CLC	Corine Land Cover	EU land cover classification dataset for spatial planning and monitoring.
CRS	Coordinate Reference System	Spatial reference framework ensuring correct geolocation of geographic datasets.
DEM	Digital Elevation Model	Raster surface representing bare-earth elevation for hydrology and slope analysis.
DSM	Digital Surface Model	Raster surface including vegetation and buildings used for exposure and shading analysis.
DTM	Digital Terrain Model	Accurate terrain model derived from filtered elevation data excluding objects.
EO	Earth Observation	Satellite/aerial/UAV data acquisition for monitoring Earth processes.
ESA	European Space Agency	Manages Copernicus missions providing environmental satellite data.
ETRS89	European Terrestrial Reference System 1989	European geodetic datum used for accurate CRS definition.
EVI	Enhanced Vegetation Index	Vegetation index improving performance in dense canopy conditions.
GEE	Google Earth Engine	Cloud-based geospatial computation platform for EO data analytics at scale.
IoT	Internet of Things	Network of connected sensors providing real-time environmental data.
MODIS	Moderate Resolution Imaging Spectroradiometer	NASA instrument capturing global land cover, heat and vegetation dynamics.
MSI	Moisture Stress Index	EO index indicating vegetation water stress using NIR and SWIR bands.
NDMI	Normalized Difference Moisture Index	Moisture estimation index for vegetation and soil.
NDVI	Normalized Difference Vegetation Index	Standard index for vegetation health based on NIR/red reflectance.
NDWI	Normalized Difference Water Index	Estimates water content in vegetation and surface water features.
RNDT	Repertorio Nazionale dei Dati Territoriali	National catalogue of geospatial datasets in Italy, supporting standardised access and interoperability.
SAVI	Soil Adjusted Vegetation Index	Vegetation index compensating soil brightness in sparse vegetation areas.
SOC	Soil Organic Carbon	Soil health indicator linked to carbon sequestration and fertility.
UAV	Unmanned Aerial Vehicle	Low-altitude aerial platform for high-resolution mapping and monitoring.
UHI	Urban Heat Island	Urban thermal phenomenon caused by impervious surfaces and morphology.
UTM	Universal Transverse Mercator	Metric map projection widely used for EO-GIS interoperability.
WGS84	World Geodetic System 1984	Standard global geodetic CRS used for satellite positioning.

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