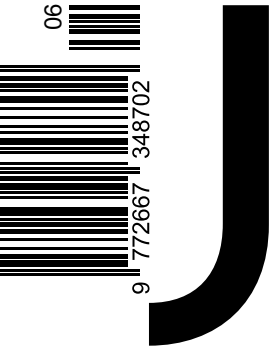


Fall | Winter 2025

Issue #06 Depletion



DU

Journal of Delta Urbanism
Delft University of Technology

*Soil as a process.
Anthropo-pedogenesis
and regenerative
design in post-mining
landscapes*

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This article reframes the role of soil in urbanism through the lens of anthropo-pedogenesis—the process by which human activity interacts with, alters, and co-produces soil. Rather than treating soil as a static support or a neutral background, the study positions it as a living, evolving medium shaped by complex interplays between ecological processes and socio-technical systems. Within this framework, soil becomes both an archive of past transformations and a substrate for future territorial projects.

The empirical focus is the Sulcis-Iglesiente region in southwestern Sardinia, a former mining district marked by extensive soil disturbance, infrastructural remnants, and post-industrial fragilities. By analyzing its stratified deposits, infrastructural logics, and patterns of contamination and regeneration, the study reveals the emergence of a new “technical thickness”—a hybrid terrain where natural and artificial layers overlap.

From this condition, the article proposes a project of anthropo-pedogenesis: a soil-oriented design approach that embraces long temporalities, partial recoveries, and adaptive transformations. It argues for a shift from remediation to coexistence, from erasure to care, calling on urbanism to engage with disturbed soils not as waste, but as living, negotiable materials. In doing so, it offers a framework for regenerative design rooted in the metabolic reconfiguration of post-extractive landscapes.

1. REFRAMING SOIL IN URBANISM

This first section serves both as the Introduction and Methodology. It introduces the theoretical framework of anthropo-pedogenesis, positioning it as an interpretative lens and a design method. The aim is to study the genesis of anthropogenic soils and envision transition trajectories rooted in ongoing soil-forming processes.

- 1 Ellis & Mellor, 2002
- 2 Gobat, Aragno, & Matthey, 1998
- 3 Topalović, 2018
- 4 Brenner, 2017
- 5 Brenner & Katsikis, 2020
- 6 Escobar, 1999
- 7 Dudal, 2004
- 8 Howard, 2017

1.1 URBANISATION AS ANTHROPO-PEDOGENESIS

In the Anthropocene era, human activity has become a powerful geomorphological force, capable of reshaping the thin layer of the Earth where life unfolds. This layer—the soil—acts as the planet's epidermis, mediating the exchange of matter and energy between the atmosphere and the lithosphere^{1,2}. Its alteration corresponds to a reorganisation of the terrestrial metabolism itself. Among the many forms of anthropization, urbanisation has become the most pervasive and lasting. It always entails a modification of the ground³: it consumes, alters, and generates soils at once. It consumes them through sealing, excavation, and extraction; it alters them through contamination, compaction, and deep modelling; and it generates new soils through accumulation, backfilling, and technogenic layering. Each urban act therefore intervenes in the ground's capacity to filter, breathe, and host life.

These transformations now unfold on a planetary scale. The processes of urbanization extend far beyond metropolitan centers, encompassing agricultural hinterlands, extractive regions, and logistical corridors within a single global fabric⁴. The boundaries between urban and rural, center and periphery, natural and artificial have become porous, dissolving into a continuous operational landscape⁵. In this continuum, even the distinction between natural and anthropogenic soils becomes increasingly ambiguous: all soils bear traces of human activity, and many so-called artificial soils retain biological and ecological functions that tie them back to natural cycles⁶. The transformation of soil—its exhaustion, reorganization, and recomposition—thus appears as a planetary process, inseparable from the material flows of production, extraction, and circulation that sustain contemporary urbanization. Modern anthropization processes now interfere with all five classical soil-forming factors, parent material, climate, topography, organisms, and time, modifying their action or introducing entirely new conditions. As such, human agency is increasingly understood as a sixth pedogenetic factor⁷. Through excavation, deposition, sealing, and contamination, urbanization no longer merely alters existing soils but actively contributes to their genesis, producing hybrid formations that resist traditional classification. These anthropogenic soils, ranging from compacted urban layers to mine tailings, from landfill cap layers to compost-based constructs, arise from predominantly artificial conditions yet retain ecological properties and partial ecosystem functions⁸.

Within this framework, the very definition of soil requires reconsideration. What was once conceived as a stable, natural substrate is now understood as a product of interaction—a living archive of socio-technical history and a site of potential regeneration. The soil is not an inert foundation but a living body, a dynamic and relational thickness constantly shaped by human and non-human forces². Rethinking soil in

this way implies a paradigmatic shift for urbanism: from managing land as a passive support to engaging with the slow, adaptive processes of soil formation and transformation^{9, 10}.

According to the new soil classification, urbanization gives rise to Technosols and Anthrosols that diverge from natural profiles in structure, function, and composition, but that nonetheless retain ecological properties and offer partial ecosystem services¹¹. Reframing soil as a dynamic process rather than a static substrate¹² calls for a paradigmatic shift in urban design: one that interprets depletion as an open and unfinished cycle, and design as a tool for ecological co-evolution¹³. This shift repositions urbanism as a discipline that must intervene in the spatial organization—what happens “on top” of the soil—and its vertical thickness. Urbanism can reconstruct lost profiles, supporting the de-sealing and activation of new pedogenetic conditions. Material interventions, such as reshaping the ground, enriching the substrate, or introducing vegetation, may trigger soil formation, consolidate incipient processes, or sustain slow recoveries. In this light, urbanism becomes a driver and catalyst of anthropo-pedogenesis. The term anthropo-pedogenesis—the formation of soil through human activity—provides a framework for understanding the dual role of human intervention: both as an agent of degradation and as a potential contributor to soil formation¹⁴. Urbanization is thus a process of erosion, sealing, and contamination, as well as layering, accumulation, and potential regeneration¹⁵. While anthropo-pedogenesis has long been acknowledged by soil scientists, primarily through the identification of urban soils, Technosols, and Anthrosols, it is increasingly entering the vocabulary of designers and planners, offering a conceptual tool to engage with transformation from within¹⁶.

1.2 TECHNOSOLS AND ANTHROSOLS

The recent inclusion of Technosols and Anthrosols in soil classification systems reflects a growing recognition of anthropogenic soils as distinct objects of scientific inquiry^{17, 18}. This act of naming is not neutral. By giving these soils a name, we acknowledge their generative properties and open up a field of research and intervention⁸. In this sense, classification becomes the first design act, setting the stage for exploring transformation trajectories, assessing ecological potential, and designing soil-oriented projects. Anthropogenic soils, especially those in post-industrial or post-extractive contexts, often defy traditional taxonomies. Their horizons are not the product of slow, biophysical layering but violent displacements, mixtures, and contaminations. Understanding these processes from a pedotechnical perspective means reading the ground not only as damaged, but as reworked matter, subject to new genesis, chemical reorganization, and microbial life¹⁹. These are soils that require both scientific interpretation and design attention.

Integrating soil-making processes into urban and territorial design raises critical questions: What kinds of soils do we inherit? What forms of life do they support? Moreover, how can spatial practices contribute to their regeneration rather than exhaustion?

Within this framework, soil is no longer treated as a neutral support to be erased, flattened, or sealed. It becomes an active archive of past interventions, a medium for negotiation, and a substrate for adaptive

- 9 Peleman, Viganò, Barcellona Corte & Ronner, 2021
- 10 Viganò, 2024
- 11 Levin et al., 2017
- 12 Capra, 2010
- 13 Hurxkens, Fahmni, & Mirjan, 2021
- 14 Meulemans, 2020
- 15 Barcellona Corte & Boivin, 2021
- 16 Capra, Ganga, Grilli, Vacca, & Buondonno, 2015
- 17 IUSS & FAO, 2015
- 18 Soil Survey Staff, 1994
- 19 Séré, Schwartz, Ouvrard, Sauvage, Renat, & Morel, 2008

management²⁰. The project of the soil is not just about delineating ecological limits, but about shaping shared ecologies and building new alliances between species, functions, and forms of governance²¹. This reframing forces a revision of the tools and temporalities of design to accommodate the slow rhythms, feedback loops, and uncertainties inherent in pedogenic processes. Regeneration, unlike construction, unfolds gradually, depending on microbial life, seasonal cycles, material thresholds, and social engagement. As such, soil-based design must become adaptive, capable of accommodating long durations, intermittent actions, and non-linear trajectories.

Viewing soil as a process also invites us to reflect on time as a variable in the project. Anthro-pedogenesis is never immediate: it is triggered by human action but unfolds through degrees of care and responsiveness. As landscape architect Michel Desvigne suggests, a landscape project should be observed after 30 years to reveal its true form. The vegetated structures he draws are sustained by soils that evolve in tandem. What, then, is the time scale of a soil project? It is contingent on conditions—scale, contamination, exposure—and thus necessarily plural²². Some soils may respond within years; others may require decades. In this sense, soil design must operate at the intersection of urbanism, landscape architecture, and pedology. While urban design offers the tools to read and shape spatial organization, and landscape architecture brings sensitivity to ecological dynamics and time, the contribution of pedology lies in revealing the hidden logic of horizons, porosities, and reactions. Together, these fields can help produce strategies for soil activation, from phytoremediation to compost-based soil building, from water-sensitive design to constructing thick vegetated filters.

1.3 METHODOLOGY

The research adopts a trans-scalar approach, combining cartographic reconstruction, fieldwork, and photographic documentation to investigate the spatial and material legacy of mining activities. The study began with the analysis of archival sources from the regional mining archive, cross-referenced with geological and pedological maps to reconstruct the historical palimpsest of extraction. This operation enabled the identification, in cartographic form, of the material traces left by the mining industry and their correlation with current soil conditions. For this part of the work, the visit to the Historical Mining Archive of Monteponi (Iglesias) was fundamental. It holds an extensive technical and documentary heritage, including thousands of mining plans, geological maps, and cross-sections of galleries and shafts, often accompanied by illustrative reports and detailed studies.

Extensive fieldwork was conducted through repeated visits, alternating exploratory surveys with interviews involving local actors and technical staff. Particularly, on-site inspections with mining engineers proved crucial to understanding the procedures of remediation and safety currently in place. The visits to the coal-mining complexes provided valuable insight into ongoing experiments concerning the stabilization and regeneration of Technosols, revealing the potential of such soils as testing grounds for adaptive design.

To complement the cartographic analysis, vegetation indices were processed to highlight patterns of spontaneous ecological recolonization and the gradual expansion of vegetated areas in relation to environmental dynamics.

The photographic campaign combined ground-based and aerial perspectives, using drone imagery to document the new morphologies

20 Viganò, 2020
21 Viganò & Guenat, 2021
22 Bonvehi Rosich & Denizen, 2025

of the terrain shaped by extraction and earth-moving operations. Aerial photography was conceived not as an all-seeing or aesthetic gesture, but as a situated and analytical tool. Each image was treated as both a cartographic datum and a narrative fragment, anchored in time and coordinates. Rather than monumentalizing extraction through the rhetoric of the industrial sublime, the aerial view functions here as a form of territorial witnessing, a means to observe the material consequences of exploitation and the slow reformation of the soil. The drone thus becomes an instrument of measurement and interpretation, reinforcing the continuity between observation, mapping, and design. Finally, the construction of the design framework was developed through a research-by-design methodology. This part of reflection originates from the development of a master's thesis in urbanism at the Politecnico di Milano, which proposed the recovery of disused mining sites in Sardinia through the design of a new territorial structure. The project engaged with issues of ground design, adaptive reuse, selective demolition, and the gradual accompaniment of ruin as a strategy of ecological and spatial regeneration²³,²⁴. This phase translated analytical findings into a set of spatial hypotheses, exploring how remediation and reactivation strategies could be scaled up to the territorial level. The design component, therefore, functions not as a prescriptive tool but as a speculative framework for imagining soil-oriented operations of care, repair, and transformation.

1.4 INTRODUCING THE CASE

The Sulcis-Iglesiente is a historical region in the south-western part of Sardinia, an island in the Mediterranean Sea. It covers a wide area between the Gulf of Oristano and the island of Sant'Antioco, encompassing the central municipalities of Iglesias, Carbonia, Buggerru, Gonnessa, Porto Scuso, and Sant'Antioco. The territory is characterized by a varied topography of rugged hills, narrow valleys, and coastal plains, shaped by a complex geological substratum rich in mineral materials.

This region has long been one of the most intensively mined areas in Italy, with a history of extraction dating back to ancient times and continuing into the late twentieth century. Its geological structure, comprising Palaeozoic formations, volcanic rocks, and granitic intrusions, has made it a strategic location for the exploitation of metals such as lead, zinc, silver, and coal. The legacy of this extractive history is still visible in the landscape, which bears the marks of intensive industrial use and infrastructural development. The case discussed in the following sections enables us to explore these questions in an area where soils have been extensively mined, displaced, contaminated, and left abandoned. Rather than focusing exclusively on damage or risk, the analysis considers how new pedogenetic dynamics—both spontaneous and intentional—emerge within this compromised ground. Pioneer vegetation, Technosols, composted backfills, and informal pathways all point to latent ecological agencies that design can engage with, rather than suppress. In this framework, the project becomes less about imposing form than guiding an articulated configuration of transformations: calibrating access rhythms, negotiating exposure, and managing recovery cycles. Design becomes an act of care and risk management. The soil emerges as an adaptive infrastructure, capable of hosting biodiversity, filtering pollutants, buffering floods, and supporting habitation. From this perspective, the urban project is no longer detached

from the earth it occupies. It begins, rather, with an acknowledgement of soil as both memory and potential: a substance that stores not only the traces of extraction, but the capacity to regenerate.

25 Ortu, 1998
26 Rollandi, 1976
27 Peghin, 2016

2. THE MINING ARCHIPELAGO

This section represents the core of the research, reconstructing the material, spatial, and ecological transformations of the Sulcis-Iglesiente region. It includes an in-depth analysis of mining basins, waste soils, and the paradox of dismantling.

2.1 A NEW THICKNESS

The territories at the core of this investigation are the former mining landscapes of Sardinia, where industrial development—imposed mainly from the outside—laid down a complex and layered palimpsest. The decisive impulse for the capitalist expansion of extractive industries came with the extension of the Savoy Mining Law to the island in 1848²⁵. This legislation established the legal separation between land ownership and subsoil rights, the latter becoming state property and thus subject to private concessions. The new legal framework attracted a substantial influx of capital, primarily from continental and foreign investors, whose profits, like the extracted minerals, were exported off the island²⁶. These investments focused narrowly on production, generating a technical soil defined by extractive rationalities and industrial function.

While mining occurred in various island regions, the Sulcis-Iglesiente emerged as its most significant and long-lasting epicenter (Figure 1).

A once-continuous system of mines, villages, processing plants, and railways now survives in disconnected fragments, scattered across the territory like an archipelago. Each former mining site has become an island, suspended in a new geography: separated by distance, abandonment, and the dissolution of the connective tissues that once held them together.

figure 01 — page 18



This fragmented and stratified territorial condition is not simply the outcome of neglect. It is the product of a century and a half of ground transformation. Extraction in Sulcis-Iglesiente was never limited to mineral removal: it involved an entire industrial metabolism inscribed into the landscape through shafts and galleries, washing facilities, waste basins, energy infrastructure, and housing²⁷. From the subsurface to the ridgelines, every element of the terrain was reorganized using mineral logic. Among the operations that reshaped the surface, one of the most decisive was the construction of a logistical network to move raw materials between remote mines, washing plants, and coastal ports. This network, composed of narrow-gauge railways, cableways, and internal roads, not only ensured the functioning of extraction but also integrated Sardinia into global circuits of production. Although now largely dismantled, its traces remain legible in the embankments, paths, and voids that cut across the landscape.

Over time, a technical thickness emerged: a hybrid and heterogeneous stratum composed of sterile backfills, compacted terraces, engineered slopes, drainage systems, and sedimentation ponds. Many of the processing plants, particularly the laverie, were built on platforms of accumulated waste.

Located along hillsides to exploit gravity, these structures generated large, terraced surfaces and introduced new flows of water and material, with lasting impacts on topography and soil composition (Figures 5, 7). Wastewater, often contaminated with toxic substances, contributed to the long-term pollution of soil and groundwater.

figure 05 — page 23



figure 07 — page 24



Central to this system were the waste dumps—accumulations of material excavated to reach the metalliferous veins. These deposits included both completely barren waste and fractions with varying metal content. As miners approached the mineral body, the percentage of recoverable minerals in the extracted material increased. Moreover, the tailings from early gravity-based separation processes often retained significant mineral traces (Figure 4). With technological advancements, such as flotation techniques, many of these surrounding deposits were subsequently reprocessed, transforming the perimeter of the mines into secondary resource fields.

figure 04 — page 22



The widespread adoption of froth flotation in the early 20th century²⁸ marked a turning point, as this technique separated useful minerals from low-grade ore and existing waste (Figure 8). It also produced large volumes of fine, chemically active sludges channeled into decantation basins, forming unstable, toxic surfaces that remain critical in today's remediation debates.

figure 08 — page 25



At depth, the void: a dense network of tunnels and galleries carved into the substratum. Above ground, a matching accumulation: heaps of rocks, tailings, slags, and fine-grained industrial muds. These materials fall into two broad categories: inert waste, which is removed to access mineral seams, and residual waste, generated during the processing. The latter—often volatile and pollutant—was deposited in open basins or spread directly across the terrain, where it remains exposed to air, erosion, and runoff.

The cessation of production in the late 20th century did not mark a closure, but the beginning of new, unintentional processes. Without regular maintenance, slopes degrade, walls collapse, and vegetation struggles to colonize soils still rich in heavy metals. Rainfall infiltrates fractured surfaces, mobilizing contaminants²⁹. Erosion becomes a vector of redistribution. A second, unintended pedogenesis begins to unfold: a slow, uneven formation of new soil profiles, driven not by cultivation, but by decay, toxicity, and ecological persistence.

This mining archipelago cannot be read as neutral or ruined ground. It is a geography of unfinished formations composed of overlapping material operations and environmental reactions. The design of new forms of inhabitation and regeneration must begin with this condition: a stratified interference between industrial intention and environmental response.

To understand it, one must consider its principal extractive basins: the metalliferous and carboniferous systems. Each of these systems has left behind distinct material signatures and morphologies. The metalliferous basin, located further north, extends from Iglesias to Arbus and is characterized by a more intricate orography and a dense network of underground galleries. It represents the oldest phase of extraction in Sardinia, shaped by centuries of mining activity centered on lead, zinc, and silver. Further south lies the Carboniferous basin, which extends from Bacu Abis to Carbonia. It developed later, following the growing demand for energy required for the refining of the metals extracted in the northern district. Its expansion was consolidated during the autarchic policies of the early twentieth century, when the state sought to enhance domestic energy resources as part of a broader project of industrial self-sufficiency. As the following sections will illustrate, the two systems produced markedly different landscapes, both as a result of the distinct geological structures of their substrata and of the specific extractive processes that acted upon them.

2.2 THE METALLIFEROUS BASIN

One metalliferous site is embedded in the foothills and valleys of the Ilesiente mountains, where geology dictated the location of mineral veins and the organisation of extraction. For example, in the valley of the Rio San Giorgio, the mining complex unfolds along the slopes: the galleries intercept the veins mid-slope, while the terraced platforms host machinery, offices, and housing (Figure 2).

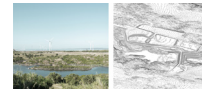
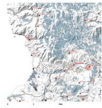
figure 02 — page 20



Monteponi, perhaps the most emblematic site, exhibits a complete redefinition of topography. The original peak of the mountain has been removed entirely, replaced by a gaping void. Here, the architecture of mining is not only functional but geomorphic: it excavates above and below simultaneously, producing negative and positive volumes, platforms and hollows (Figure 8). The landscape of these sites is structured around the logic of mineral sorting. As mineral material is separated from gangue, so too are the residues sorted: coarse tailings are piled into terraces; fine sediments are deposited in basins; toxic muds are directed into containment areas (Figure 7). A multilayered stratum of waste emerges: a soil that is at once constructed, contaminated, and infrastructural. Terraces are made of inert rock but serve as foundations. Channels cut for drainage double as boundaries. Every topographical feature corresponds to a function in the production cycle.

2.3 THE CARBONIFEROUS BASIN

One Carboniferous site, by contrast, is located on a vast plateau that gently slopes toward the coast. The Nuraxi Figus Mine—Italy's last active coal mines until its closure in 2013—exemplifies this morphology (Figure 3). Its footprint is extensive: two large coal storage areas, a power plant connection, a processing facility, and a complex waste management system. The site includes a landfill that receives not only mining residues but also ashes from the adjacent power station and inert municipal waste (Figures 5, 11).



This intermixing of materials creates a composite Technosol, layered with varying porosity, and biological resistance. One of the key infrastructural elements is the sediment basin, designed to contain the fine residues of coal processing. At Nuraxi Figus, this basin was constructed by exploiting a natural depression, reinforced by a dam that captures and stores water. Other sites, like Seruci, developed more monumental solutions: six circular dams were erected around the plant to contain coal-processing waste sequentially (Figures 12, 13). Over time, these basins were filled, sealed, and replaced by new ones. One of them now stands empty, a hollow arena where a spontaneous vegetal layer has begun to take hold. These basins form a striking architecture of waste. Their circular form, monumental scale, and spatial arrangement express a logic of repetition, containment, and saturation.

figure 12 — page 27

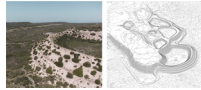


figure 13 — page 28



3. SOIL AS A PROCESS

This final section integrates Results and Conclusions. It synthesizes insights from empirical and theoretical work, proposing soil-based design strategies: anthro-pedogenetic projects grounded in long-term care, adaptive protocols, and territorial justice.

3.1 POST-EXTRACTIVE SOILS

With the cessation of extractive cycles, these new thicknesses have entered a new phase. No longer maintained, their technical composition interacts with natural agents: rainfall causes erosion, slopes begin to collapse, and contaminants are mobilized through runoff. Pedogenesis resumes, but in altered conditions (Figure 9). On some sites, pioneer species colonize the terraces and the tailing basins³⁰. On other sites, vegetation remains scarce, constrained by toxicity or compaction. What emerges is a slow, uneven process of reworking. The technical substratum, once hyper-controlled, is now subjected to open-ended processes. Multispectral satellite imagery was analyzed to calculate vegetation indices across post-mining residues. Maps 10a and 10b show the distribution of these indices in relation to the underlying soil categories. Together, they provide a spatial reading of soil cover conditions, highlighting patterns of spontaneous vegetation and degrees of ecological response across compromised substrates (Figure 10). In this sense, these sites are not merely abandoned; they are transitional: spaces where engineered matter meets atmospheric, biological, and human dynamics. Informal uses have developed around certain sites, including paths, scrambles, and temporary gardens. Others remain fenced and inaccessible, regulated by legal restrictions or unresolved contamination.

figure 10 a,b — page 26



We can imagine this territory not only as a terrain of ruins but also as a geography of unfinished formations. Designing within it means understanding the stratified dialogue between ground and activity, extraction and recolonization (Figures 6,9,15). The mining landscape becomes a space of negotiation: between memory and invention, regulation and adaptation, toxicity and care.

figure 06 — page 23



figure 09 — page 25



figure 15 — page 29



Understanding these soils requires moving beyond the rhetoric of emptiness or damage¹⁰. The layered thickness of the Sulcis-Iglesiente is not an obstacle to regeneration, but its very condition. Its platforms, basins, and sediments are not dead matter, but the base for new metabolic cycles, if properly engaged. In this context, design is not the imposition of form but the choreography of transformation. It means acknowledging what already exists, and working with the ground's inherited materials, rhythms, and resistances.

The archipelago, then, is not only a spatial figure but also a temporal one: a constellation of sites moving at different speeds, with different futures. Some will erode, some will decay, some will reforest, and others may be reactivated, repurposed, or simply watched as they slowly change. Soil, here, is not a backdrop but a protagonist: a living stratum that records extraction and hosts regeneration, even when silent.

In the context of post-industrial remediation, alongside rigid regulatory protocols, a growing interest has emerged in ecological and low-impact regeneration strategies^{31, 32}. These approaches do not aim to eliminate contamination solely through removal or isolation, but rather through interventions that activate evolutionary processes within compromised soils.

Among these, Technosols and phytoremediation have gained traction as promising experimental fields, especially within the Sardinian context. Their goal is not to return the soil to its original state, but to restore its ability to support vegetation and primary biogeochemical cycles. Rather than seeking zero-risk conditions, these practices embrace the possibility of controlled coexistence with residual contamination, activating slow recovery processes and limited ecosystem services.

This reflection arises from the Sardinian post-mining context, where compromised soils and abandoned infrastructures—some of considerable architectural value—are widespread, while available resources for recovery remain limited. This imbalance necessitates a targeted approach. From a remediation perspective, this means characterizing contaminated soils and assessing varying risk levels to define differentiated intervention and access strategies³³. From an infrastructural and architectural perspective, it becomes clear that not everything can be preserved or reused³⁴. In fact, some structures may be allowed to decay deliberately, encouraging nature's reappropriation and fostering a contemporary ruin aesthetic³⁵. In the post-extractive landscapes of Sulcis-Iglesiente, anthropo-pedogenesis is not an

- 31 Bacchetta, Boi, Cappai, Giudici, & Piredda, 2017
- 32 Boi, Cappai, De Giudici, Medas, Piredda, Porceddu, & Bacchetta, G. (2021)
- 33 Langella et al., 2018
- 34 Lanzani, Merlini, & Zanfi, 2014

abstract concept. It is a situated process, shaped by the interaction between residual infrastructures, climatic forces, and experiments that range from spontaneous vegetative colonization to scientific and technical manipulation. The soils found across the mining archipelago are not natural in origin: they are constructed, amended, displaced, and stratified, both materially and temporally. These processes, while heterogeneous and uncoordinated, highlight the latent capacity of these territories to support new soil ecologies. However, they remain fragmented and lack a territorial vision.

Urbanism, a discipline capable of synthesizing spatial, ecological, and operational dynamics, should coordinate these induced transformations into a broader care, repair, and regeneration project. The legacy of extraction exerts multiple pressures on soil bodies. Physically, compaction and excavation alter porosity and drainage. Chemically, heavy metal contamination, from lead and zinc to arsenic and cadmium, creates toxicity gradients that limit microbial activity and plant growth. Biologically, the absence of organic matter and root systems undermines the soil's ability to retain moisture and sustain food webs. However, within these compromised environments, signs of recovery emerge. An important and consolidated research field conducted by the University of Cagliari has documented the presence of native Mediterranean species in abandoned mining areas. Shrubs such as *Pistacia lentiscus*, *Cistus monspeliensis*, and *Erica arborea* demonstrate the ability to tolerate high concentrations of metals and to retain contaminants within their biomass and litter, effectively performing a function of in-situ phytostabilization³¹. These spontaneous dynamics have given rise to a new, fragile vegetative thickness. The abandonment of mining sites has led to a reconfiguration of ground conditions, including sedimented surfaces, ephemeral wetlands, and new soil morphologies. In some cases, the landscape assumes the quality of a garden, albeit unintentionally, yet functional. These findings call for a design practice that recognizes the ecological potential of even the most compromised soils and identifies pathways of accompaniment.

Experimental manipulations conducted by the University of Sassari have investigated the reconditioning of degraded soils by adding compost and biochar³⁶. In one study, researchers treated the surface layer of a mining landfill to support vegetation growth, enhance water retention, and reduce runoff. The success of this intervention suggests that technical containment can become the starting point for longer processes of regeneration. More importantly, these experiments suggest a recursive maintenance model: biochar can be produced from pioneer vegetation growing on these sites and reintroduced into the same soil³⁷. This cycle of growth, pyrolysis, and amendment offers a long-term logic of care and adaptation that can inform soil-based design practices. However, these interventions remain punctual and disconnected from a broader territorial framework. They need to be reinterpreted within a design agenda that can sustain them over time.

A different but equally revealing case is that of the Carbosulcis coal site at Nuraxi Figus. The company implemented a surface treatment of the coal stockpile area (carbonile) through shallow tilling, compost addition, and seeding of nitrogen-fixing legumes. Although conceived to improve the site's visual impact and reduce costs, the intervention produced unintended ecological benefits, such as reduced dust dispersion, improved soil structure, and a vegetative cover to consolidate the surface. Simultaneously,

- 35 DeSilvey, 2017
- 36 Garau, Roggero, Diquattro, Garau, Pinna, & Castaldi, 2021
- 37 Garau, Garau, Sizmur, Coole, Castaldi, & Pinna, 2023

internal research at Carbosulcis revived an idea from the 1960s: reusing coal washing residues as soil amendments to develop a local substrate production system. Although not yet implemented at scale, the initiative highlights the latent potential of industrial waste as a regenerative resource.

These practices, emerging from cost-efficiency strategies and legal compliance with mining restoration laws, highlight another critical issue. The law often requires restoring sites to their "original" conditions—a notion that, if applied literally, would lead to the dismantling of complex infrastructures such as the tailings dam at Serucci (Figures 13,14). This would erase a technical apparatus with ecological potential and a material archive of industrial history. This tension between engineered substrates and ecological reappropriation sets the stage for the following design inquiry: not how to erase these soils, but how to inhabit and transform them from within.

figure 14 — page 29



3.2 METAMORPHOSIS

In territories where the extent of compromised soils and abandoned infrastructures is substantial, and where the economic and technical resources for recovery remain limited, a different approach becomes imperative, one that reconsiders our relationship with industrial legacies and explores the conditions under which cohabitation with the remains of extractive modernity may be possible^{34, 27, 38}. While public perception often favors preservation, especially in the case of architecturally or symbolically significant structures, the widespread decay already underway suggests that not everything can, nor should, be saved. This asymmetry calls for a new paradigm grounded in selection, care, and co-evolution, rather than comprehensive restoration.

The project of metamorphosis begins by treating the existing landscape not as a problem to be solved but as a fertile condition to work with. Rather than envisioning a final form or state of completion, it aims to transform long-term processes, aligning with ecological timeframes and embracing uncertainty. In this framework, remediation shifts from an eradication model to a precise diagnosis and adaptation mode. So-called "precision remediation" focuses not on volumes of contaminated material, but on how contaminants are bound within the soil, their bioavailability, and the associated risks of environmental dispersion³³. Within this approach, the space of metamorphosis also becomes a space of experimentation. In the face of the current political and economic inertia that prevents systemic change, these sites offer an opportunity to test new forms of action that may temporarily escape existing regulatory frameworks. Like Viganò's notion of the prototype, the metamorphic project operates through exploration rather than prediction¹⁰. It accepts incompleteness, reversibility, and the possibility of failure as constitutive conditions of innovation.

Here, transformation does not stem from predefined solutions but from the iterative testing of new techniques in soil treatment, ecological restoration, and adaptive reuse, whose outcomes can inform broader strategies of transition. The metamorphic space thus acts as a laboratory for the transition,

where design is both a diagnostic and projective act, enabling the emergence of practices and knowledge that can later be formalized or scaled up.

Similarly, architectural and infrastructural remnants are reinterpreted not as burdens to be erased, but as latent agents of transformation. Some may be reused or consolidated; others may be allowed to decay. Decay is not synonymous with abandonment—it can be a generative condition³⁵. When left ungoverned, industrial ruins interact with soil, water, and plant life to produce novel, hybrid ecologies. These emerging landscapes challenge the disciplinary boundaries between nature and artefact, opening new design possibilities.

The dismantling of the tailings dam at Serucci exemplifies the stakes of this choice. Originally constructed to contain waste material from mining operations, the dam had ceased to serve its technical function. Over time, it had become an ecological niche: its central depression collected rainwater, while spontaneous vegetation, including wetland species, had taken root (Figure 12). This process of unplanned anthropo-pedogenesis was erased when the dam was demolished and the materials reused to fill other basins (Figure 13). The intervention, framed as a safety measure, effectively eliminated an evolving ecosystem and a space of memory and transformation. A landscape that was becoming something else was forcibly returned to a neutralized, flattened condition—ready, perhaps, for solar panels, but stripped of its temporal and ecological depth.

Metamorphosis, in contrast, calls for an imaginative stance. It begins with the detailed observation of mapping what exists, naming what has emerged, understanding how forms, materials, and life processes are entangled. From here, the project identifies potential triggers—discreet gestures, minor manipulations, or infrastructural cues—that might catalyze change over time. Rather than designing a definitive image, it organizes conditions for transformation. The project becomes a practice of care and choreography, not imposition. A project of metamorphosis may thus be articulated around four key operations, aimed at both accompanying existing transformations and triggering new ones.

Accessibility

Post-mining terrains should not only be made safe, but also restructured in terms of access and proximity. A new territorial framework might combine continuous paths for everyday use, vantage points offering visual proximity without physical intrusion, and zones of inaccessibility where vegetative buffers reinforce ecological thresholds. This layered accessibility accommodates both safety concerns and the 'slow reappropriation of these sites by populations.

Soil

Compromised soils are not inert waste, they are thick, living archives with potential ecological functions. They can host vegetation, sequester carbon, retain water, and support microbial life if treated as dynamic media. Soil-based interventions might range from incremental vegetative covers to small-scale topographic manipulations that channel rainwater or encourage sedimentation. Even the simplest gesture - a ditch, a cut, a mound - can initiate long-term change. Accommodating transformation is not a form of indeterminacy, but an assertion of design through time³⁹.

Reuse, demolition, and decay

Intervention strategies must distinguish between sites that can be

reused (based on accessibility, urban proximity, and technical feasibility), those that warrant consolidation (due to their monumental or mnemonic value), and those where decay is the most appropriate outcome.

Importantly, decay should not be synonymous with neglect—it must be curated. Selective demolition, isolation, and vegetative overgrowth can become part of a broader protocol for managing architectural surplus and integrating waste into a new territorial metabolism^{40, 41}.

Temporality

Metamorphosis is not an event—it is a process. It unfolds over decades, often outside of institutional timelines. Design, therefore, must extend beyond implementation, incorporating long-term observation, adaptation, and maintenance¹³. Time becomes a design material, and care becomes a central practice. What is proposed is not a return to a former state, but the cultivation of new co-existences, emerging through negotiated durations and partial interventions⁴².

The metamorphosis project does not offer a fixed image of the future. Instead, it reframes designing in post-industrial landscapes as an open-ended negotiation with matter, memory, and becoming.

Where dismantling seeks erasure, metamorphosis seeks alliance with the residues of the past and the possibilities of the yet-to-come.

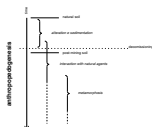
3.3 TOWARD A PROJECT OF ANTHROPO-PEDOGENESIS

The case explored in this article has made it possible to engage with anthropo-pedogenesis both as an analytical lens and as a design framework. As a lens, it allows us to read the landscape through the emergence of a new anthropogenic thickness as an accumulation of compromised soils, infrastructures, and residues that embody the material legacy of extractive modernity. This perspective enables a deeper understanding of how these soils were formed, their ecological functions, and the spatial configurations they generate today.

As a project, anthropo-pedogenesis provides a framework for imagining transformation not from scratch, but from what is already present. It invites us to observe and work with existing ecological processes—such as spontaneous colonization, sedimentation, or degradation—and to design strategies that support or reinforce them. These transformations are not aimed at restoring a previous condition, but at initiating forms of regeneration that are grounded, situated, and open to evolution.

This approach adopts the concept of long-term horizons. Regeneration is not a punctual event or the achievement of a fixed state, but a long-term process in which change is slow, layered, and adaptive (Figure 16). In this context, design is not only about form-making: it is about defining degrees of care, recognizing that even non-intervention, when consciously framed, can become a meaningful design act. Maintenance, monitoring, and selective inaction all become part of a choreography of landscape transformation.

figure 16 — page 30



39 Dalnoky & Desvigne, 1995
40 Merlini, 2020
41 Rusci, 2021
42 Berger, 2008

In this framework, urbanism can reclaim a central role as a coordinating practice capable of holding together ecological intelligence, technical knowledge, and spatial imagination. Urbanism can help articulate differentiated strategies of access, use, and protection. It can define interaction protocols with fragile soils, manage the coexistence of contamination and life, and shape long-term transition trajectories.

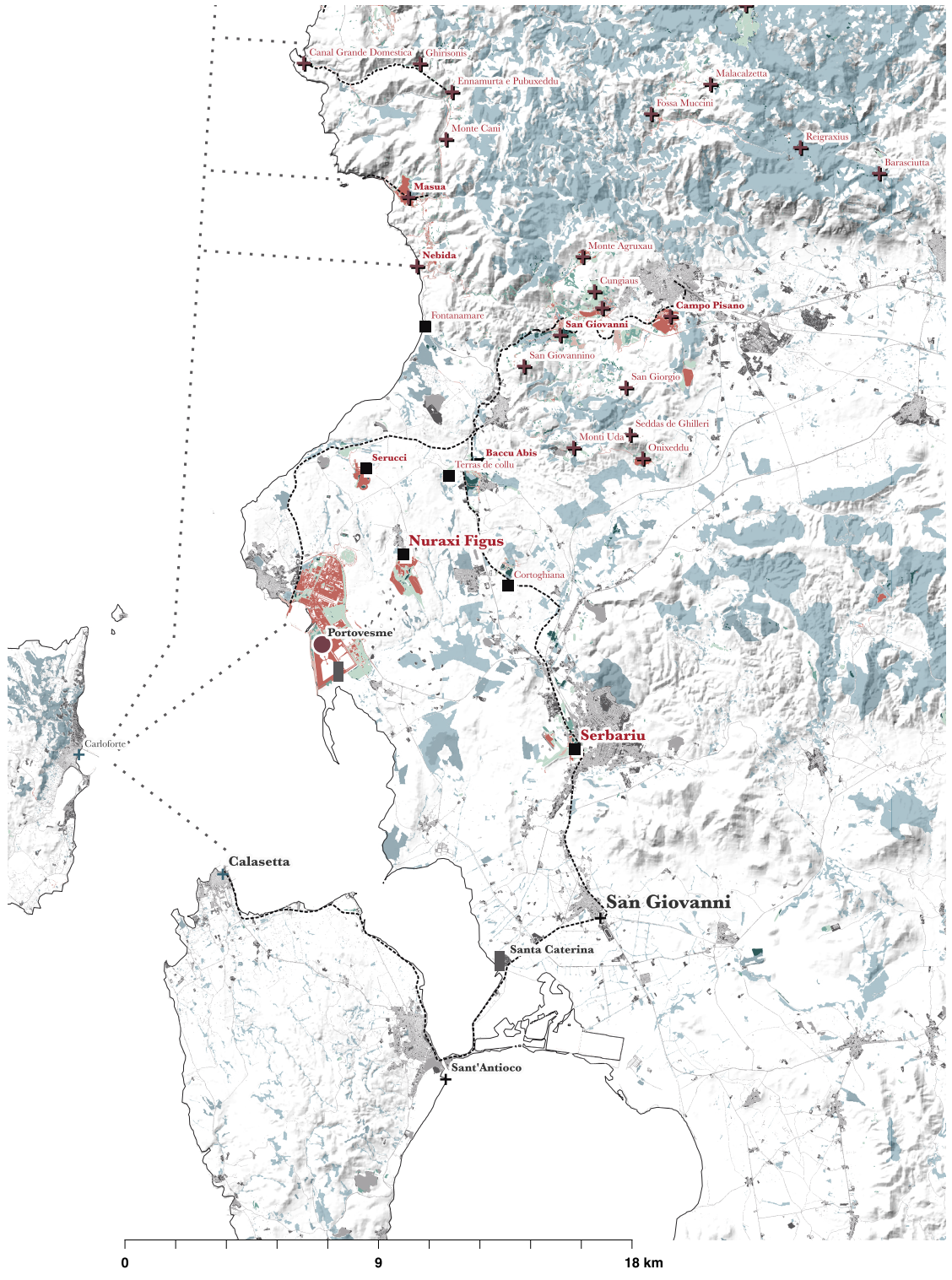
Urbanism can operationalize anthro-pedogenesis as a methodology:

- by establishing observation protocols and soil monitoring systems as integral parts of the design process;
- by defining time-based strategies of remediation, from temporary uses to productive fallows;
- and by coordinating multi-scalar governance between ecological processes, infrastructural reuse, and collective space.

The Sardinian case, particularly the post-extractive landscapes of the Sulcis-Iglesiente, illustrates the potential and the limits of this approach. Here, the challenge is not only to clean, repair, or restore, but to remain with the compromised ground, recognizing its ongoing metamorphosis and transforming abandonment into care. The situation resonates with other post-industrial territories, where the management of soil degradation, subsidence, and contamination similarly demands long-term, adaptive, and cross-disciplinary forms of project.

Through anthro-pedogenesis, we glimpse a model of design that does not seek closure but cultivates conditions for life to return—sediment by sediment, process by process—redefining the role of urbanism as an active agent in the ecological transition.

The Figures in this Paper were conceived as visual clusters, structured to support morphological comparison rather than linear reference. As such, the Figures referenced in the article do not follow the strict numbering order.

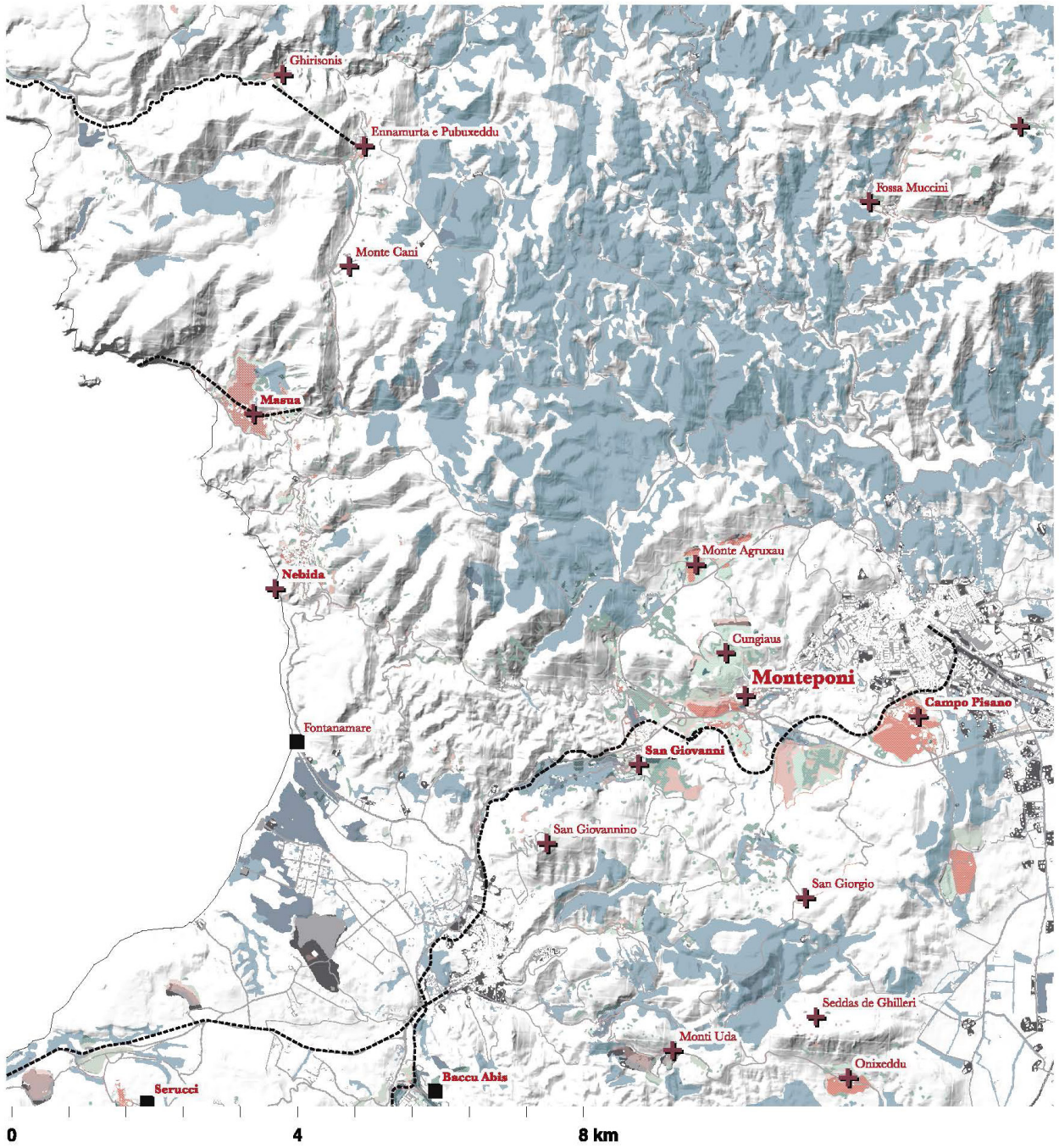


01

01 Sulcis-Iglesiente Archipelago. The two basins—metalliferous in the north and coal-bearing in the south—connected by the historical mining railway network. The map shows mining soils and their vegetation cover, as well as urban soils classified by permeability.

- | | |
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| <p>mining soil cover</p> <ul style="list-style-type: none"> sealed meadow shrubland conifers and broadleaf <p>urban soils</p> <ul style="list-style-type: none"> sealed permeable <p>forest</p> <ul style="list-style-type: none"> broadleaf trees conifers | <p>infrastructure</p> <ul style="list-style-type: none"> railway facilities + lead/zinc Mine ■ coal Mine routes mining railway power plant ● metallurgical pole + port + terminal + industrial plant |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|





03



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05



06

05 The Nuraxi Fighis landfill and the emerging wind energy infrastructure

06 Final landfill layer at the Nuraxi Fighis: capping operations



07



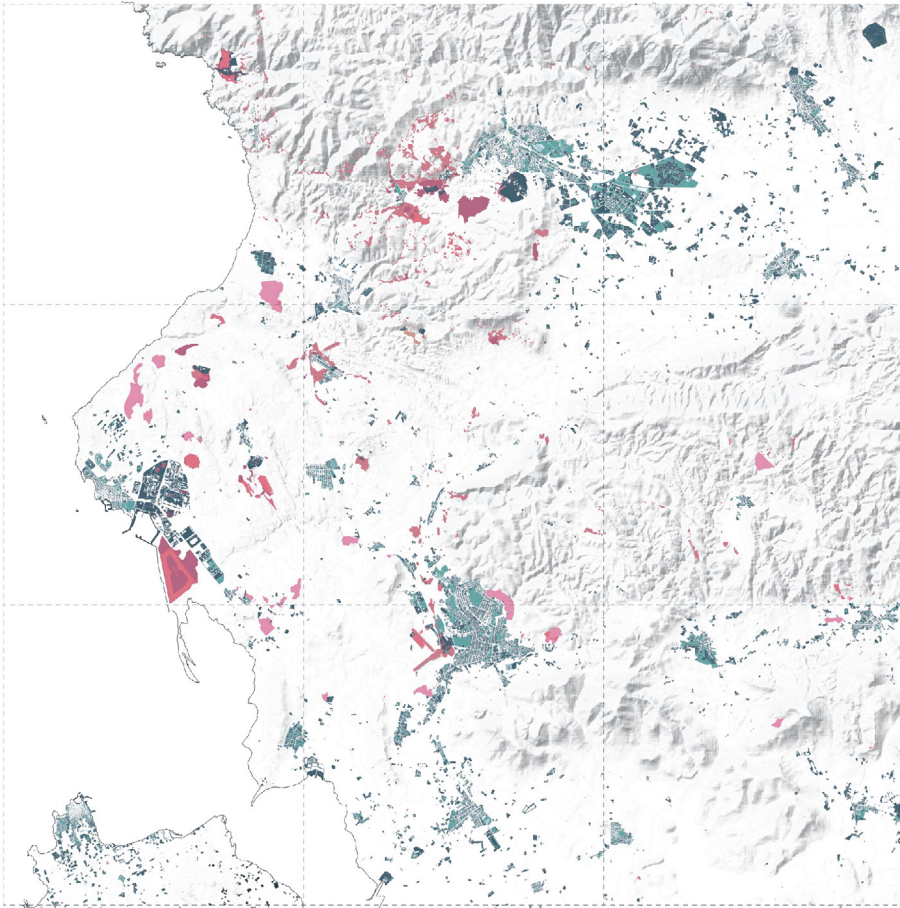
08



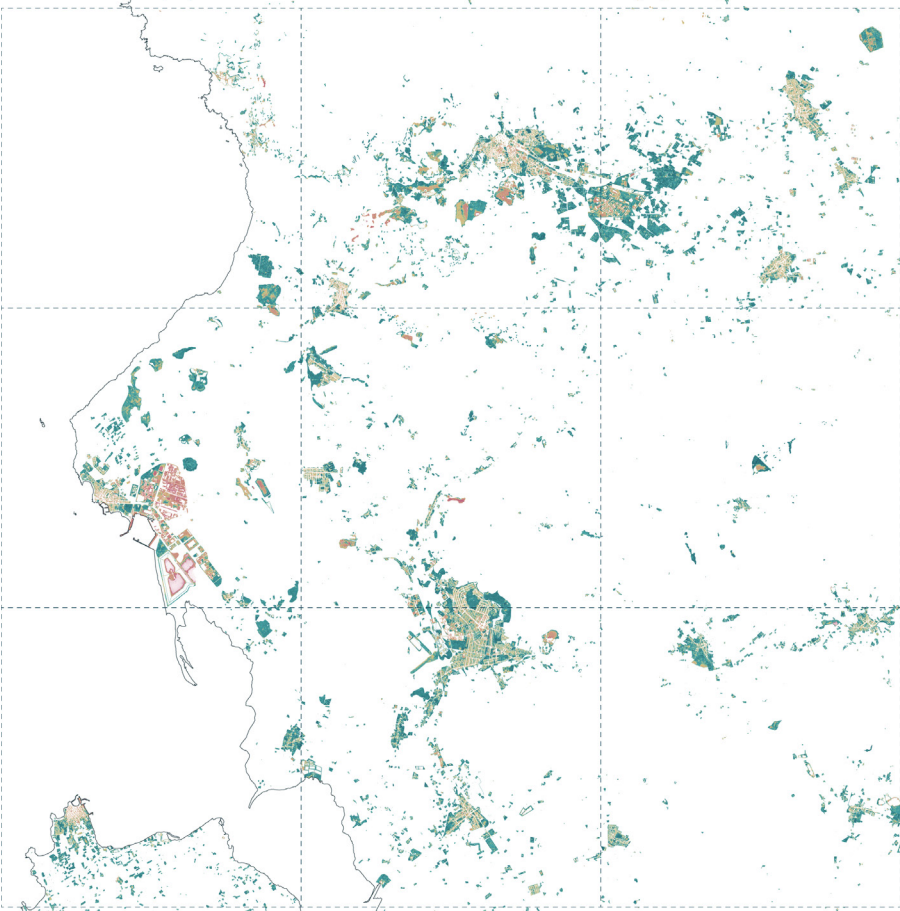
09

08 The Monteponi mine

09 Meadow on mining soils: the Campo Pisano dump



10a

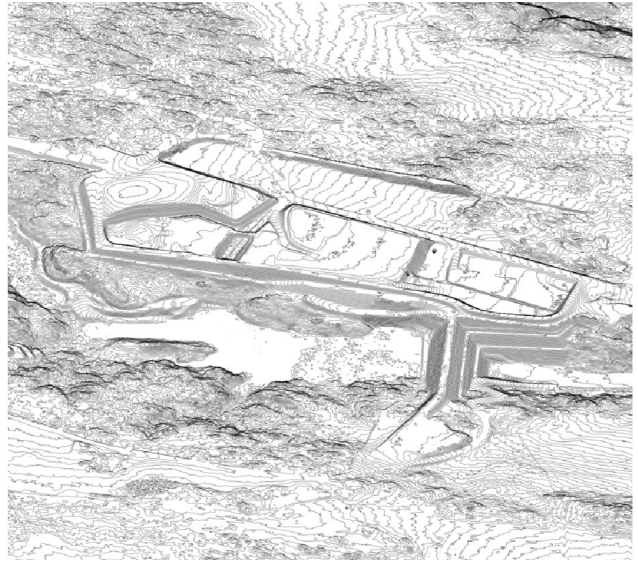


10b

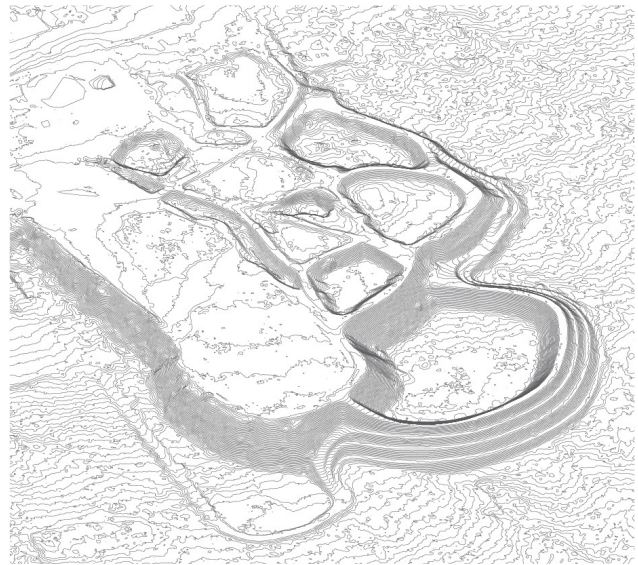
10 a,b Mining and urban soils with vegetation index overlay



11



12



11 The Nuraxi Figus landfill

12 The Serucci dump



13



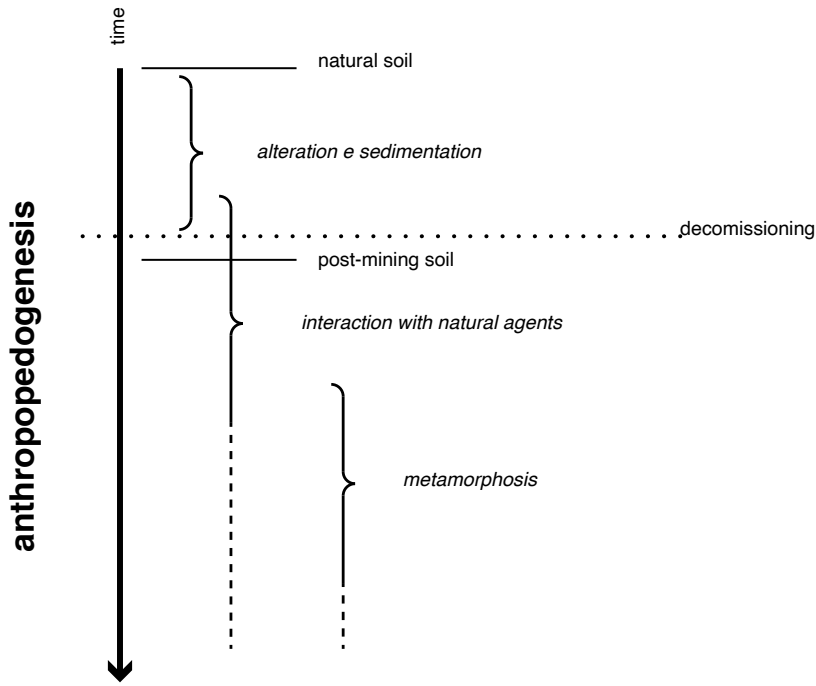
14



15

14 The mining site of Serucci after dempolition, 13/06/2023

15 Meadow on mining soils : the Serucci dump



16

16 Diagram of anthropo-pedogenesis in post-mining landscapes. The scheme illustrates the succession of soil states—from natural to post-mining and metamorphic conditions—showing how alteration, sedimentation, and spontaneous ecological processes gradually reshape the ground. The metamorphosis phase unfolds within the ongoing interactions between anthropogenic soils and natural agents, extending the regenerative dynamics already in motion.

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FIGURE REFERENCES

Figures 1, 2, 3: Author's elaboration based on data from the Regional Geodatabase and the ISPRA database.

Figures 4, 5, 6, 7, 8, 13, 14, 15: Photographs by the author.

Figure 10 a,b: Author's elaboration based on data from the Regional Geodatabase and multispectral Sentinel satellite data.

Figures 11, 12: Author's elaboration based on DTM data from the Regional Geoportal.

Figure 16: Author's elaboration.

JDU is a project by Delta Urbanism Research Group and DIMI Delft Deltas, Infrastructure and Mobility Initiative Delft University of Technology

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Graphic Layout

bruno, Venice (Italy)

Typefaces

Union, Radim Peško, 2006
Jjannon, François Rappo, 2019

Publisher

TU Delft OPEN Publishing
<https://www.tudelft.nl/library/openpublishing>

Frequency: 1 volume per year

Publication Funding

TU Delft Delta, Infrastructure and Mobility Initiative

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For any further information:
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<https://journals.open.tudelft.nl/jdu/>
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N.6 | Depletion | Paper | 01
Winter / Spring 2026

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Keywords

anthropocene urbanism; anthro-pedogenesis; post-mining landscape; mining soils; technosols; project of the soil; regenerative design;

Dates

Submitted: 14/06/2025
Reviewed: 15/09/2025
Accepted: 13/11/2025
Published: 03/04/2026

Citation

Simoni, D. (2026). Soil as a process. Anthro-pedogenesis and regenerative design in post-mining landscapes. *Journal of Delta Urbanism*, (6). 10.59490/jdu.6.2025.8093

Reviewed by

Cecilia Furlan, University of Natural Resources and Life Sciences, BOKU
Tahira Toffah, University of the Witwatersrand
All published contributions are submitted to a Double Blind Peer Review process except for the sections Dialogues and Dictionary.

Type of license

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Funding Information

The research was conducted during my doctoral studies at IUAV University of Venice, where I was the recipient of a PhD scholarship.

Data Access Statement

The study is based on a combination of fieldwork, archival and bibliographic sources, and spatial analysis using publicly available institutional datasets. Derived maps and interpretations were produced by the author. No proprietary or confidential data was used.

COI

The author declares no conflict of interest.

Contributor Statement

Not applicable. The manuscript was authored by a single author.

Use of AI

Generative AI tools were used for language editing and stylistic refinement of the manuscript. The author reviewed and validated all content. No AI tools were used for data analysis or interpretation.