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# *Cities as Carbon Pools: Three Territorial Scenarios for Soil-Regenerative Urbanism*

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Focusing on Swiss metropolitan areas, this article addresses the resistance and resilience of cities against climate change and other environmental crises. The aim is to connect new knowledge on soil-based ecosystem services, particularly carbon sequestration and its multiple co-benefits, with sustainable urban planning, design, and maintenance practices. In this regard, urban regeneration operations are considered significant opportunities.
To connect new knowledge about soil-based ecosystem services and carbon sequestration with sustainable decision-making in urban regeneration, this article mobilizes a mixed methodology. First, the main results of an interdisciplinary field survey recently conducted in Lausanne and Zurich are presented, followed by a research-by-design exploration. A series of principles for soil-regenerative urbanism are established to (1) preserve existing functional soils, and therefore the stock of organic carbon they contain; (2) regenerate soils on currently artificialized surfaces, and therefore constitute new stocks of organic carbon from the circular management of mineral and organic wastes; (3) improve and diversify the vegetation cover and related maintenance practices of both preserved and regenerated soils, and therefore enable them to gradually sequestrate more organic carbon in the future. Ultimately, three strategic urban regeneration scenarios are proposed to enhance soil carbon sequestration. Each of them relates to a specific dimension of cities understood as ecosystems: (1) urban morphology, soil preservation, and de-sealing in open spaces; (2) urban metabolism, circular management of waste to recreate soils; (3) urban biotopes, vegetation, and care practices to diversify ecological habitats.

*STUDYING AND DESIGNING THE CITY'S SOILS AS CARBON POOLS*

This article addresses the territorial adaptation of contemporary cities and presents a set of strategies for resistance and resilience against climate change and other environmental crises. Focusing on Swiss metropolitan areas, the aim is to connect new knowledge on soil-based ecosystem services, in particular carbon sequestration and its multiple co-benefits, with sustainable decisions on soil management, as an integral part of urban planning, design, and maintenance practices. In this regard, urban regeneration operations are considered significant opportunities.

The ability to sequester carbon is a function of soil that depends on its structural quality, which is determined by a given mineral texture, as well as by the action of climate and living organisms, and also often by human influences[1, 2]. As such, carbon sequestration capacity is a good indicator of the general soil health and is closely interrelated with multiple other ecosystem services that are crucial for global climate change mitigation and local adaptation[3].

There are therefore two motivations for studying carbon sequestration in soils located within metropolitan areas—referred to here as urban soils, including not only highly anthropized soils, but also pseudo-natural soils and soils under agricultural use[4]. First, although carbon sequestration occupies a special place among the wide range of soil functions, as it can be largely influenced by anthropogenic management practices, there is usually little interest in how this essential ecosystem service is provided in urban environments. This is partly due to insufficient knowledge of the variable quality of urban soils, especially regarding the past and future dynamics induced by their management. However, some studies have shown the role of technosols in carbon sequestration[5], while others have highlighted the significant quantities of carbon present in the soils of various cities (see e.g., [6, 7, 8]).

Second, general soil health, interrelating the carbon sequestration function with other ecosystem services, can be considered in terms of various socio-ecological co-benefits, such as water regulation, which mitigates heat islands and flood risks. An integrative view of particular anthropogenic impacts and environmental risks in metropolitan areas leads to defining specific needs in provisioning and mitigating ecosystem services (see SDG 11 in: [9, 10]). Those needs in ecosystem services should be regarded as crucial, as metropolitan areas host the majority of the human population[11]. Studying carbon sequestration in urban soils becomes, therefore, all the more relevant.

It is important to understand how the multiple soil management practices induced by urban planning and design—today, superficially documented and rarely acknowledged—can have both positive and negative effects on the variable organic carbon content of urban soils and on their potential for long-term carbon sequestration. From this perspective, considering soil functions in urban planning, design, and maintenance practices appears to be an innovative and transdisciplinary challenge that is key to conceiving and managing cities in a sustainable way.

1 Six et al., 1999
2 The international "4 per 1000" initiative, n.d.
3 Adhikari & Hartemink, 2016
4 Levin et al., 2017
5 Allory et al., 2022
6 Klingenfuß et al., 2020
7 Richter et al., 2020
8 Pouyat et al., 2006
9 United Nations, 2019
10 European Environment Agency, 2016
11 United Nations, Department of Economic and Social Affairs: Population Division, n.d.ss

In the context of a current "soil turn"[12], multiple approaches to political ecology and environmental humanities[13] place living ecological systems at the core of the urban question (for Switzerland, see in particular[14, 15]). Considering urbanization not only as a form of resource consumption and an environmental threat, but also as part of the solution to a necessary socio-ecological transition, directly addresses the ethical challenge of our relationship with soils. As enunciated by anthropedologists Yaalon and De Richter: "While the narrative is deeply rooted that humanity only disturbs, destroys, or even conquers nature, soil scientists are tasked to help humanity become a more sustaining soil-forming agent."[16]. Cue, the newly created Chair for Transitioning Urban Ecosystems at the Technische Universität Berlin, strives to apply this ethical dimension to the field of design.

By doing so, cue sets as main goal of its research and teaching program the agenda articulated by the members of the SUITMA research working group—standing for Soils of Urban, Industrial, Traffic and Mining Areas, as part of the International Union of Soil Science: "Building the city must also include building its soils […] A full chain of knowledge should be developed based on the cooperation of soil scientists and urban planners to answer questions such as how to build sustainable cities suitable for human well-being and preserve our soil capital, and how to get more ecosystem services from the same surface area"[17].

At the European level, the current dynamic in terms of soil management policy[18] reflects two main trends. On the one hand, the "no net land take" strategy[19, 20] aims at protecting agricultural and natural land by preventing urban sprawl. In Switzerland, this objective is reflected in the principle of Innenentwicklung or Inward Development, recently enshrined in the Swiss Spatial Planning Act[21], which promotes a "measured use of the land" and the implementation of a "compact built environment." On the other hand, the numerous climate plans adopted by European and Swiss cities in particular aim at regulating ecosystem services within metropolitan areas. As many of these ecosystem services are provided by functional soils, implementing such plans therefore requires protecting and, in some cases, regenerating soils within cities. These two trends in soil management policy may therefore appear contradictory and generate a conflict of interest regarding land use within metropolitan areas.

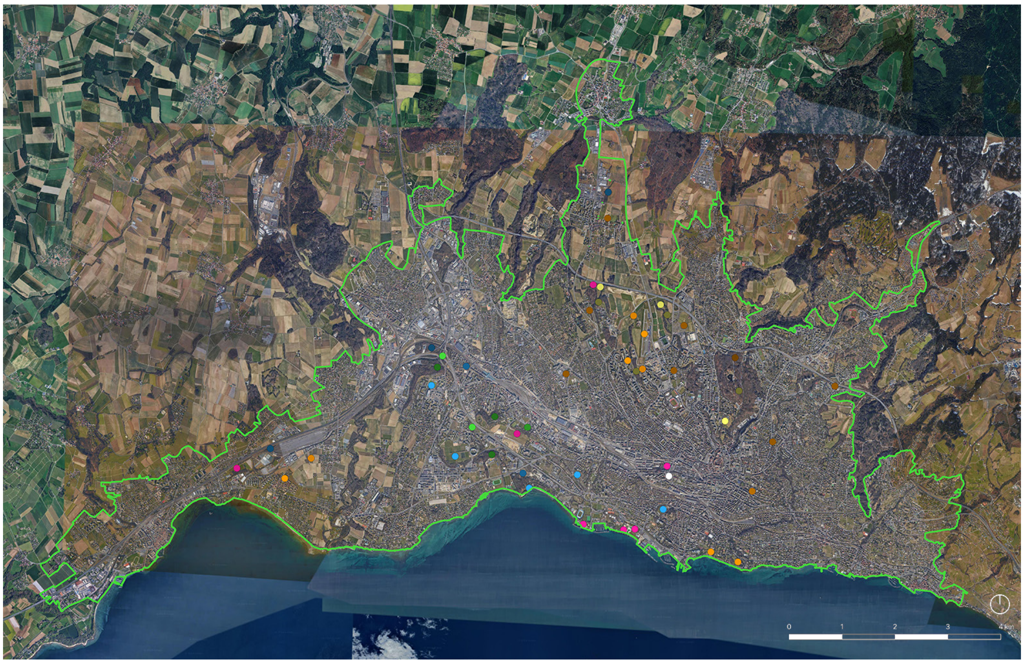
In this context, and in contrast to urban development, which refers to the expansion of cities into agricultural or natural areas, the paradigm of urban regeneration appears to be a decisive lever for action in overcoming the double bind in sustainable urban soil management. By distinction with urban renewal, which generally designates the complete replacement of built structures, we propose here a definition of urban regeneration that rather implies the redevelopment of existing neighborhoods, infrastructures, and spaces, particularly with the aim of adapting them to climate change (for a more comprehensive approach to urban regeneration, see in particular[22, 23, 24]).

12 Toland & Watts, 2025
13 Salazar et al., 2020
14 Ernwein, 2020
15 Ernwein, 2014
16 Yaalon & de Richter, 2012
17 Morel et al., 2014
18 Directive 2025/2360)
19 Idt et al., 2025
20 European Commission, 2016
21 Federal Act on Spatial Planning, 2014
22 Couch et al., 2008
23 Roberts et al., 2017
24 Altrock & Kurth, 2024

Regarding urban regeneration, the case of Swiss metropolitan areas is particularly interesting, as it is subject to a specific instrument known as agglomeration projects, which are funded at the federal level. This policy makes it possible to combine different landscape and ecological approaches with the main objectives of implementing sustainable transport infrastructure and qualitative densification measures (see e.g., the case of the Lausanne-Morges metropolitan area:[25]). The approach proposed here argues that urban regeneration operations should not only aim to preserve embodied energy in existing built structures and avoid carbon emissions associated with new construction. They should also adopt best practices in soil preservation and regeneration, thereby offering crucial opportunities to improve the carbon balance by preserving and enhancing soil sequestration.

25 PALM, 2016

To connect new knowledge about soil-based ecosystem services and carbon sequestration with sustainable decision-making in urban regeneration, this article proposes a mixed methodology coupling scientific measurements with design exploration. First, the next section presents the main results of an interdisciplinary field survey recently conducted in Lausanne and Zurich. This section summarizes how the approach presented here stems from a research project which aimed at (I), conducting a field survey across the urban land uses spectrum to measure more accurately the current urban soil organic carbon content—U SOC; (II) explaining the variations of U SOC as a function of two main drivers: soil texture and vegetation cover with related maintenance practices; and finally (III) relating the variable U SOC to the federal and local policies and practices of soil management induced by urban planning and design in Switzerland[26]. Second, the following sections present a research-by-design exploration through which cue master's students followed up on the results of the interdisciplinary research project. In the framework of an urban design studio, they were invited to establish a science-based design approach to elaborate principles for soil-regenerative urbanism, in the form of three strategic urban regeneration scenarios to enhance carbon sequestration in soils.



*01* Map of soil samples taken in the compact perimeter of the Lausanne metropolitan area (outlined in green). The colors given to the sampling points correspond to a combination of the color attributed to the different geomorphologies considered in the study (molasse and marlstone, basal till, ablation till and coarse alluvium, lacustrine and fine alluvial deposits, and anthropogenic soil filling) and the shades of gray representing the vegetation cover types (forest, vegetable gardens, meadow, and lawn). Source: Vialle et al. 2024

As illustrated in Figures 1 and 2, the field survey conducted in 2022-23 in Zurich and Lausanne yielded around 100 samples, to which data from previous studies for approximately 150 sites were added. Carbon and nitrogen contents, soil texture, and bulk density were measured in the top 20 cm of soils (for a complete contextualization of the field survey, see [26], for a summary of the quantitative results, see [27]).

26 Vialle et al., 2024
27 Vialle et al., In press

Empirical measurements have shown that topsoil SOC values of Zurich and Lausanne's green spaces are relatively typical when compared to other global cities, confirming the exemplarity of the study. These values are slightly lower than in Swiss grasslands and considerably higher than in Swiss croplands. At least from the point of view of carbon sequestration, this means that urban soils are certainly incomparable to pseudo-natural soils of the same region, but significantly healthier and more functional than soils under intensive agricultural uses, which are subject to more harmful maintenance practices. This result contradicts common representations of rural and urban areas and confirms that the environmental role of urban soils should not be overlooked.

*02* Soil sample taken in Lausanne using an auger. The black and brown colorations indicate the presence of carbon in the top 20 centimeters of the soil. Source: Photograph by the author

The study confirmed that the drivers of carbon sequestration in natural or agricultural environments also apply to urban environments: texture, particularly clay content, drives and establishes SOC content in urban soils. It has been hypothesized that this well-known logic can be further enhanced by different vegetation cover types and related maintenance practices, with varying intensities and impacts. In Zurich, a slight, fairly intuitive gradation was observed: lawns tended to have lower SOC stocks than meadows and forest soils, which contain the highest SOC. However, in Lausanne, no clear trend in vegetation's influence on SOC was identified. The absence of a clear signal distinguishing and hierarchizing the respective influence of the different vegetation cover types was attributed to the overriding factors of a wide variety of anthropic soil disturbance and maintenance practices. Such diversity of situations leads to high variability in the soil carbon sequestration performance within each vegetation cover type. These observations highlight the important role that all different types of vegetation cover can play—even the most common lawn!—and suggest room for improvement in maintenance practices. Finally, the comparison of private and public green spaces showed that privately owned gardens exhibit significantly higher SOC levels than public green spaces, also likely due to differing maintenance practices. This underscores the importance of land ownership and management in soil health and carbon sequestration.

Regarding soil management in the context of urban regeneration operations, several conclusions can be drawn from the results summarized above. This approach leads to integrating the objective of soil carbon sequestration in various aspects of urban planning, design, and maintenance policies. First, the significant existing organic carbon stocks in soils should not be underestimated or written off. Their preservation entails the protection of functional open soils in the city and therefore a shift in the implementation of urban planning policies currently aimed at densifying cities. Second, it is possible to increase organic carbon stocks in soils by improving the quality of urban soils— defined by the soil physical properties in the profile's depth—through best cultivation and maintenance practices, as a transposition of an approach already well mastered in the agronomic context. But, urban environments are characterized by a high proportion of their footprint currently covered by artificialized and sealed surfaces[28]. For example, in the West Lausanne area, artificial surfaces represent around 20% of the total surface area, i.e., twice the built-up area[29]. From this standpoint, artificial but undeveloped surfaces can be considered a significant resource deposit. Third, urban regeneration projects therefore also offer an opportunity to increase urban SOC by increasing the quantity of urban soils—defined as the overall surface covered by open and functional soil—through land-use changes and soil regeneration, understood here as the reconstitution of a functional substrate.

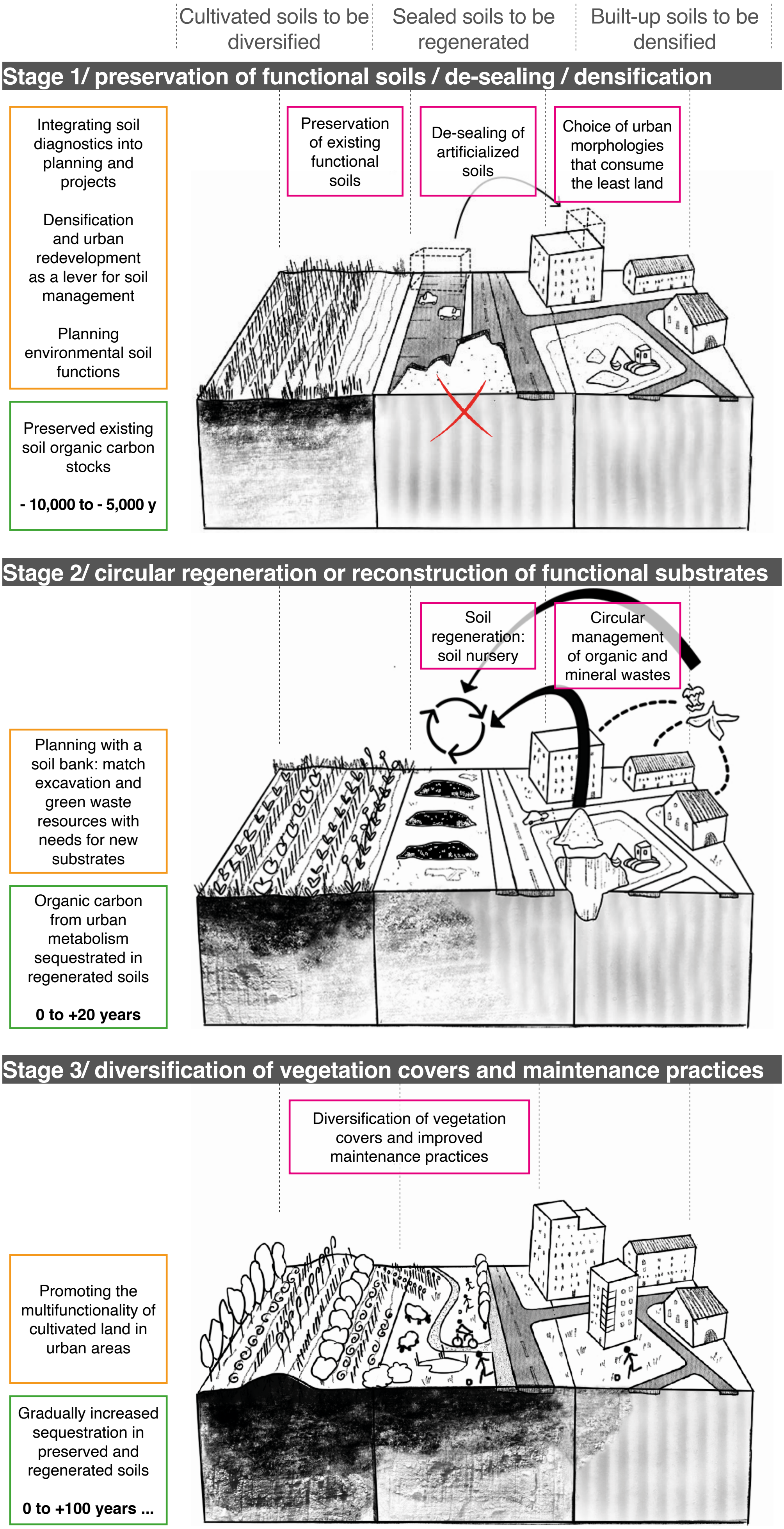
Additionally, soil science and agronomy often consider the organic matter/clay ratio as a useful metric for potential SOC improvement. A targeted organic matter/clay ratio is then established, according to an optimum for soil structure, in the search for fertility. In Lausanne and Zurich, the already high organic matter/clay ratio, significantly higher than in comparable agricultural soils, suggests that potential SOC improvement should not be defined only in term of agronomic fertility. In cities, the establishment of carbon sequestration objectives should rather consider the holistic functionality of soils as manifold co-benefits. Such objectives should be established to target the different soil functions required for climate change adaptation in cities: from filtering and infiltrating rainwater, then retaining it for vegetation growth and evapotranspiration, to supporting biomass production and the diversity of aboveground organisms. This new perspective introduces territorial adaptation as a fundamental paradigm for urban planning and design, encompassing both resistance—i.e., the ability of territories to continue to function despite disturbances induced by climate change, such as flooding, heat waves, etc. —, and resilience—i.e., the ability of territories to recover from major climate-induced disturbances.

28 Camenzind & Sfar, 2014
29 Vialle, 2021
30 Vialle & Poyat, 2024

Ultimately, the above-mentioned scientific baseline results in an alternative approach to soil management in urban regeneration operations, as initially observed in the context of the Lausanne-Morges Agglomeration Project (for a detailed analysis of the urban planning processes and policies involved in the PALM, their impacts on soils, and potential for improvement, see [30]). By extension, soil-regenerative urbanism emerges as a framework acting upon both the soil stock—increasing quantitatively the surface covered by functional urban soils—and the soil resource—improving substrate quality of urban soils.

As shown in Figure 3, the overall process of regenerative urbanism articulates three complementary and interrelated steps in a logical sequence. Although they follow a logical progression, these steps can be implemented concurrently, without necessarily following a strict linear sequence: (1) preserving existing functional soils, and therefore the stock of organic carbon they contain; (2) regenerating soils on currently artificialized surfaces, and therefore constituting new stocks of organic carbon from the circular management of mineral and organic wastes; (3) improving and diversifying the vegetation cover and related maintenance practices of both preserved and regenerated soils, and therefore enabling them to gradually sequestrate more organic carbon, to increase their SOC stock in the future. In practical terms, urban regeneration projects integrate soil engineering—consisting of technical solutions—to ecological urbanism—implementing planning and design solutions. The triptych organization in Figure 3 depicts three typical situations that apply to the urban ground. These three situations are involved in a symbiotic manner through each of the above-mentioned steps: the patches of functional soil still in cultivation, to be preserved and diversified; the mineral surfaces, to be descaled and regenerated; the built-up footprint, to be reused and densified.

In the following sections of this article, the research-by-design approach will present how the three steps of soil-regenerative urbanism will be further developed in the form of three scenarios elaborated by cue's master students as part of a Lausanne-based urban design studio. Each of these scenarios relates to a specific dimension of cities understood as ecosystems: (1) urban morphology, soil preservation, and de-sealing in open spaces; (2) urban metabolism, circular management of waste to recreate soils; (3) urban biotopes, vegetation, and care practices to diversify ecological habitats. Each scenario corresponds more or less directly to a soil management issue, with its own impact on carbon sequestration—preserving existing functional soils, regenerating artificialized surfaces, and improving and diversifying vegetation cover—and each involves very different time scales. Similarly, the changes in management and policy paradigms to which they correspond— “what if?”—raise specific methodological and operational issues in terms of urban regeneration. Finally, each scenario is materialized at different scales through an original territorial vision, an emblematic urban project, and a series of spatial prototypes.



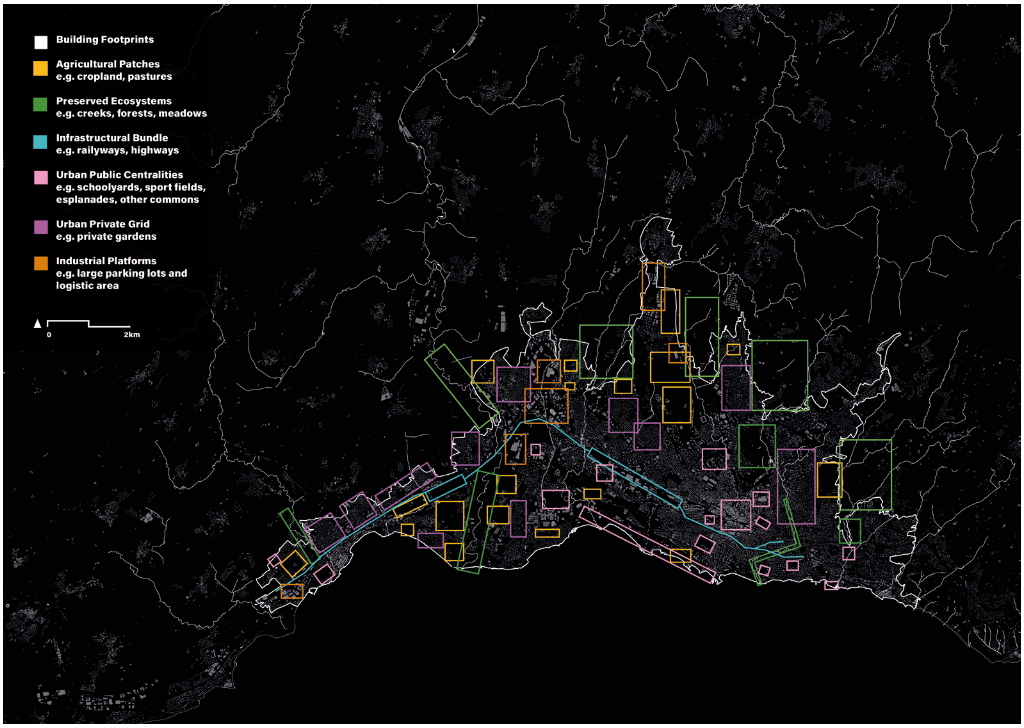

*03* Diagram of soil-regenerative urbanism, representing vertically the three steps of an overall process aiming at increasing the capacity of urban soils to capture organic carbon (in black on the profile), and climate adaptation as a co-benefit. From left to right, the triptych diagram depicts three typical situations applying to the urban ground. For each step, the pink frames explain how the implementation of the two main objectives of current urban policies, densification and urban regeneration projects, offers opportunities to improve the health and functionality of urban soils. Orange frames highlight the main methodological challenges for urban planners. Green frames mention the impact on carbon sequestration at different timescales. Source; Vialle et al., 2024

## *SCENARIO 1. URBAN MORPHOLOGY*
## *SOIL PRESERVATION AND DE-SEALING IN OPEN SPACES*

What if urban densification and regeneration policies were defined primarily based on the network of voids—open spaces—that characterizes the built environment? The first scenario promotes “Intensity over Density, and Porosity over Compacity”. As modified in 2014, the main goal of the Swiss Spatial Planning Act is to establish a “compact urban environment”[21]. In this, such a policy reflects the current consensus that densification is the most sustainable approach to urban planning and design. The principle of inward development is crucial to meet the “no net land take” objective European Commission[20] and prevent soil consumption in the natural and rural environments. However, it is becoming increasingly obvious that a simplistic approach to inward development, which consists of building all undeveloped land within cities and views urban soils solely as opportunities for densification, would be counterproductive to the necessary adaptation of cities to climate change. The ecosystem services provided by soil are indeed essential to urban climate resilience. Scenario 1, therefore, proposes a semantic transfer from soil science, which considers compaction to be one of the worst anthropogenic impacts on soil, to urban planning, to critically question the densification approach aiming at creating a “compact urban environment.”

A soil structure that is too compacted loses its viability as it cannot ensure the percolation of air, water, animals, and plant roots through the soil anymore. Just like soil, a living urban environment needs space to breathe. To be sustainable, the densification of cities should therefore not consist in filling the remaining voids in the urban fabric, but rather aiming at intensifying and interrelating the social and ecological performances of all built and unbuilt surfaces. With the primary aim of preserving existing soils, Scenario 1 addresses the timescale over which current carbon stocks were naturally formed, typically five to ten millennia for Swiss soils.

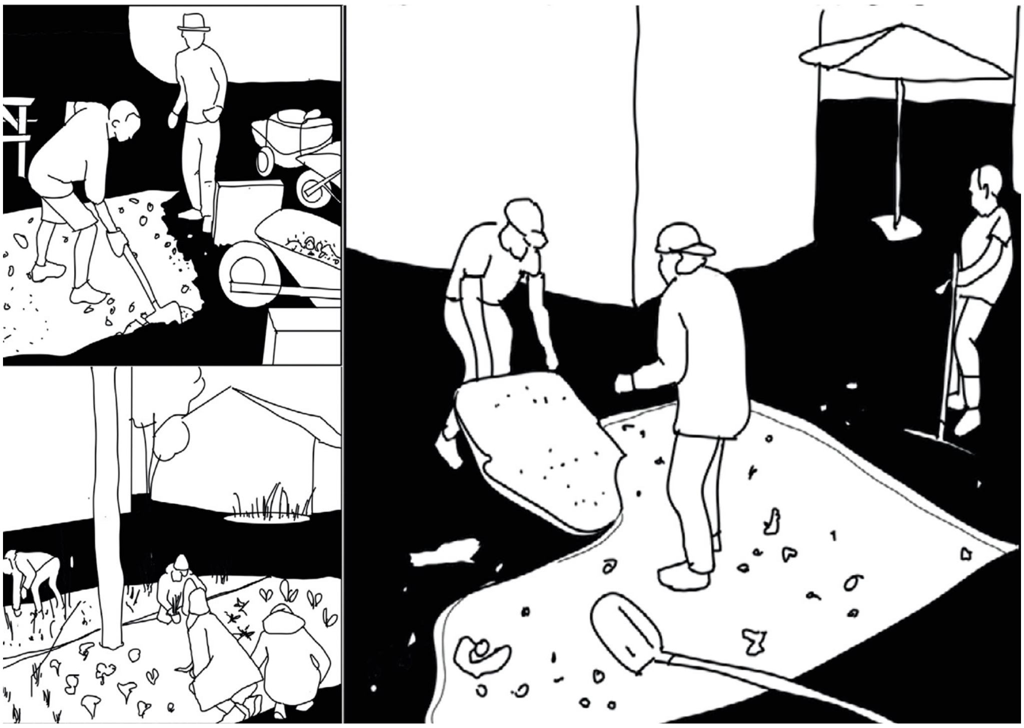
In the first place, the intensification in both urban uses and environmental functions entails identifying the different types of voids characterizing the urban fabric and the interconnections that ensure its porosity. Such a classification defines the granularity of the urban structure—i.e., the size of voids relative to the building footprint. In Lausanne, students have conducted mapping operations illustrated in Figure 4, which has revealed a complex network of voids. This system encompasses large-scale preserved ecosystems—e.g., streams and wooded strips, forests and meadows, agricultural patches—e.g., cropland, pastures, infrastructural bundles—e.g., railways and highways and their shoulders. It is complemented by smaller-scale public spaces—e.g., squares, esplanades, schoolyards and sport fields, and private properties—e.g., private gardens, backyards.




*04* Mapping of various typologies of urban voids in the Lausanne metropolitan area. Source: Anne Wilhelm, Leon Hidalgo, Merve Özyalin, Gökce Senol, Wiktor Korol, Maximilian Chappuzeau Munoz, Ferdinand Storjohann, Amelie Gadow, Julius Morgenstern, Felix Schuschan Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024


*05* The network of voids as a structural figure for the urban regeneration of the Lausanne metropolitan area. Source: Anne Wilhelm, Leon Hidalgo, Merve Özyalin, Gökce Senol, Wiktor Korol, Maximilian Chappuzeau Munoz, Ferdinand Storjohann, Amelie Gadow, Julius Morgenstern, Felix Schuschan (reworked by Anne Wilhelm and Antoine Vialle) Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024

The identification of these different types of undeveloped spaces, therefore, defines a figure of voids which structures a first territorial vision for Lausanne, represented in Figure 5. The north/south wooded strips running along rivers connect to agricultural patches and form large metropolitan parks linking the plateau to the lake shores. The West/East infrastructural bundle, which extends into the former glacial valley, becomes a large-scale backbone of public space. The meshes of private gardens form a continuum, punctuated by clusters of public spaces defining local centralities. Such a trans-scalar network facilitates the diffusion of cool air, the infiltration of water, and the circulation of biodiversity throughout the city, providing a wide range of climate-resilient leisure areas for inhabitants.



06 Redefinition of the materiality of road and public space typologies currently characterized by a preponderance of impervious surfaces. Source: Anne Wilhelm, Urban Design Studio “Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)”, Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024

Secondly, the intensification of both urban uses and environmental functions entails preserving the voids where soils remain functional, as well as regenerating or restoring the ecological value of the voids where soils have been artificialized. On the one hand, urban voids are characterized either by the presence of open soils, the quality of which varies greatly depending on historical urbanization processes and current uses. On the other hand, urban voids also consist of artificialized surfaces, often materializing areas of neglect, underutilization, and disconnection within the urban fabric.

On the metropolitan area scale, Scenario 1 should therefore be supported by an in-depth diagnosis of soil conditions and impervious surfaces, resulting in the definition of a brown network. This mapping instrument helps to identify the current soil capital and the potential for surface de-sealing and soil regeneration within the territorial and landscape structure. Such a tool helps stakeholders to prioritize and coordinate preservation and regeneration actions at the planning level, then within urban regeneration projects.

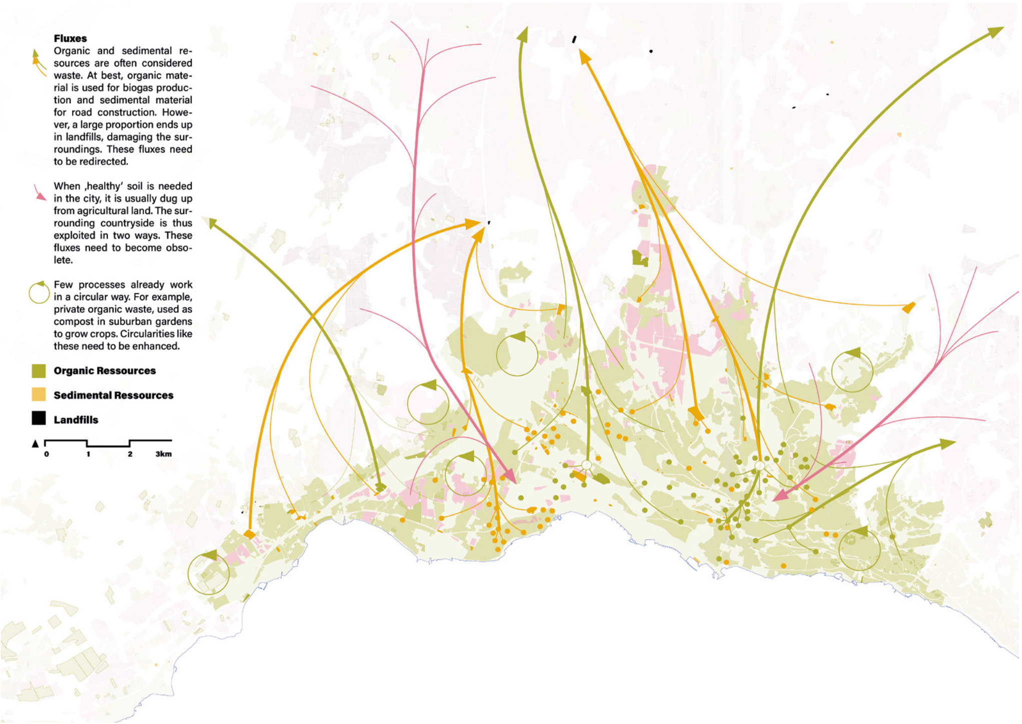
At the urban fabric level, the brown network also provides a useful basis to implement soil preservation and improvement measures through urban regeneration and densification projects. At equal densities, the variable bi- and three-dimensional configuration of buildings and surface treatment of open spaces have a greater or lesser impact on urban soils and their functions[30]. Well-conceived and properly implemented, urban morphologies that consume less soil can be a lever for consolidating the status of open spaces within the urban fabric. Densification operations and/or urban regeneration projects appear as opportunities to preserve existing functional soils and related carbon stocks. In other words, we build “around the soil”. Well-chosen urban morphologies are also a significant lever for de-sealing artificial surfaces and regenerating soils within the urban fabric. During open-space redevelopment operations, soil regeneration requires appropriate management practices to improve the soils already in place, while de-sealing involves removing the technogenic layer covering the ground. In this case, soil engineering is needed to reconstruct ecologically functional substrates with exogenous materials, as will be presented in Scenario 2.

Ultimately, the selection of soil-friendly urban morphologies contributes to redefine the usual road and public space typologies, currently characterized by a preponderance of impervious surfaces. In Figure 6, this process is illustrated as a potentially collective, low-tech appropriation of public space by local actors. Such a redefinition of the formal repertoire of public spaces implies a change of paradigm in several areas of urban planning and design: supported by a shift toward collective and soft mobility, the reduction of space devoted to individual motorized transport is a sine qua non condition. The evolution of recreational uses in public spaces, the adjustment of management techniques—surface cleaning, as well as the adaptation of run-off water management—on-site infiltration, are also prerequisites. Finally, the leeway for surface de-sealing and soil regeneration on private land is currently very limited and should be encouraged by appropriate incentives. Similarly, sustainable solutions are needed for the recycling of polluted substrates and impervious surfacing materials removed from public spaces during de-sealing operations.

## *SCENARIO 2. URBAN METABOLISM*
## *CIRCULAR WASTE MANAGEMENT TO RECREATE SOILS*

What if open-space greening policies promoted the in situ circular use of mineral and organic waste, rather than relying on fertile soil from the urban fringes? The second scenario acknowledges that “Whatever We Do, We Make Soils”. The greening of cities and the regeneration of artificialized surfaces generally involves the use of topsoil taken from excavation sites. This common practice in urban planning consumes a precious resource that should be used to regenerate soils in the rural environment, where soils have been exhausted by harmful intensive agriculture. Besides, by itself, simply displacing existing soil and the organic carbon it contains does not affect increasing soil organic carbon stocks. On the contrary, the displacement of large volumes of topsoil and possible degradation of such substrate has several negative effects, including a high energy cost. At the same time, as illustrated in Figure 7, the city is producing a large quantity of waste, which is exported outside the urban environment, thus exploiting the surrounding countryside in two ways, according to linear metabolic exchanges that should be considered obsolete. From construction sites, excavation materials—i.e., B and C horizons—become mineral waste, which threatens the quality of the soil on which they are sometimes stored, or which profoundly alters landscapes by reshaping the topography when they are sent to quarries and landfills. Likewise, biomass deriving from the management of green spaces and the domestic environment—i.e., composting of kitchen residues or, even, human waste—forms a considerable amount of organic waste. In this context, the transformation of private household residue into compost to amend soils in suburban gardens appears as a rare example of soil-oriented circular waste management in cities.

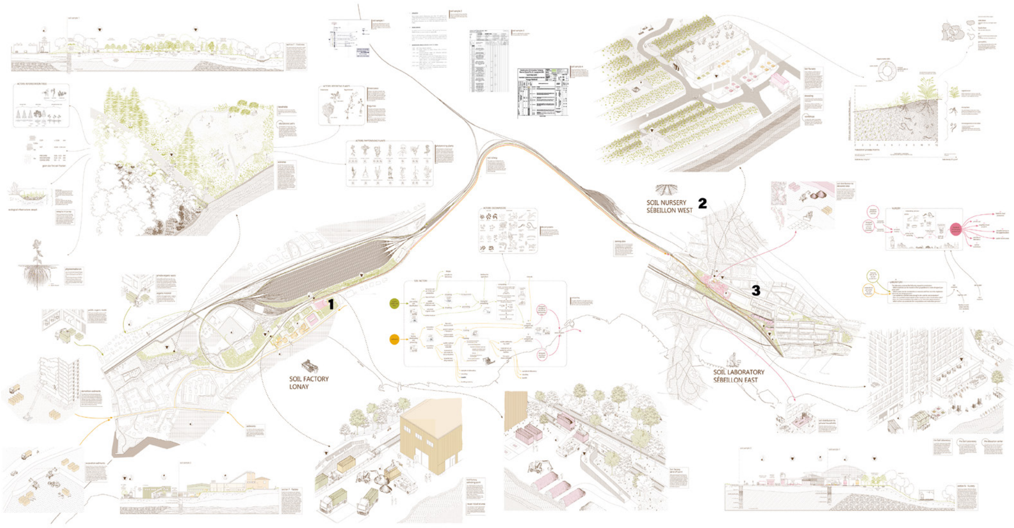
Assuming that, whether virtuous or not, urban practices inevitably transform or even produce soil, Scenario 2 proposes to reorient metabolic flows so that urban regeneration projects and related topographical remodeling become a conscious process of regenerating a living layer within the city. From this point of view, fluxes of mineral and organic waste can be considered as resources to be exploited through the implementation of a circular economy value chain. This strategy consists of systematically collecting excavated materials and organic matter, then treating them appropriately, to produce purpose-designed functional substrates that can be placed on previously de-sealed surfaces. Meeting the requirements of territorial adaptation and the objective of holistic soil functionality, these reconstructed soils become newly created carbon stocks.




*07* Mapping of the fluxes of mineral and organic wastes, to be redirected to implement a circular management of these resources within the Lausanne metropolitan area. Source: Lea Johanna Beck, Noah Simon Ehlers, Lorenz Nikolaus Hahnheiser, Leandra Leipold, Sarah Sophia Kramer, Tsvetelina Markova, Stephanie Rachel Pyalanda, Ala Talebian, Sarah Möller, Hannah Berner, Teresa Pauline Immler Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024

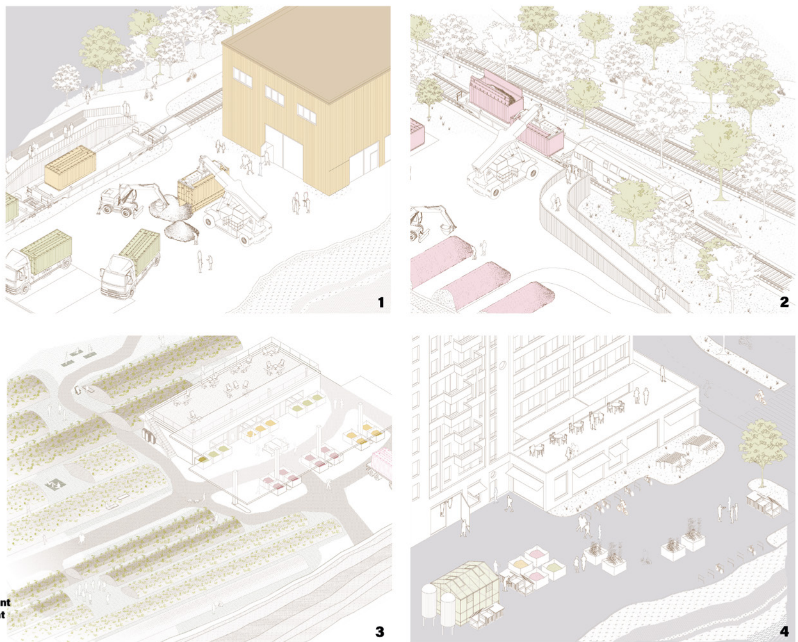
To regenerate artificial soils, Scenario 2 addresses the timescale over which new soils can be established as part of urban regeneration operations, estimated to take around 20 years. Mixing various resource flows from diverse origins and volumes, the circular management should be implemented at different scales and in multiple forms. It should articulate the public, associative, or private collection of mineral and organic waste and their treatment at the level of the metropolitan area, district, or development site and individual housing unit. Similarly, platforms for processing functional substrates should be set up in diverse locations and at variable timeframes. They can become permanent infrastructure on one or more dedicated sites or be implemented opportunistically on a case-by-case basis, as temporary installations in construction sites.

In Lausanne, students have imagined a second territorial vision that considers the entire city as soil for farming. Figure 8 shows their proposal to leverage the rail infrastructure across the metropolitan area to redirect the flow of resources and newly produced substrates. This project connects two logistics sites; one located on the outskirts and the other in the city center. Established on a former industrial site in Lonay, a Soil Factory mixes and processes waste into substrates by crushing, washing, and sorting mineral sediments and composting organic resources. The factory uses the nearby railway infrastructure to transport this material to a Soil Nursery on the former brownfield in Sebeillon. Here, this base material is piled, planted, and left to mature for a year, transforming into living, functional soil through plant growth and microbial activity.




1. Soil Factory in Lonay
2. Soil Nursery in Sébeillon West
3. Soil Laboratory in Sébeillon Est

*08* Soil farming as a territorial vision for the Lausanne metropolitan area, articulating multiple sites along the railway. Source: Amelie Gadow, Lorenz Hahnheiser, Teresa Immler, Leandra Leipold, Sarah Kramer, Leon Lohrer, Lia Reimann, Hannah Berner Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024



1. Lonay Soil Factory collecting point
2. Lonay Soil Factory send off point
3. Sébeillon West Soil Nursery
4. Sébeillon West Soil Laboratory

*09* The scenario comprises various new typologies of mixed-use ecological infrastructures, transitory urban space, and learnscapes, including a soil farm, a soil nursery, and a soil laboratory. Source: Amelie Gadow, Lorenz Hahnheiser, Teresa Immler, Leandra Leipold, Sarah Kramer, Leon Lohrer, Lia Reimann, Hannah Berner Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024

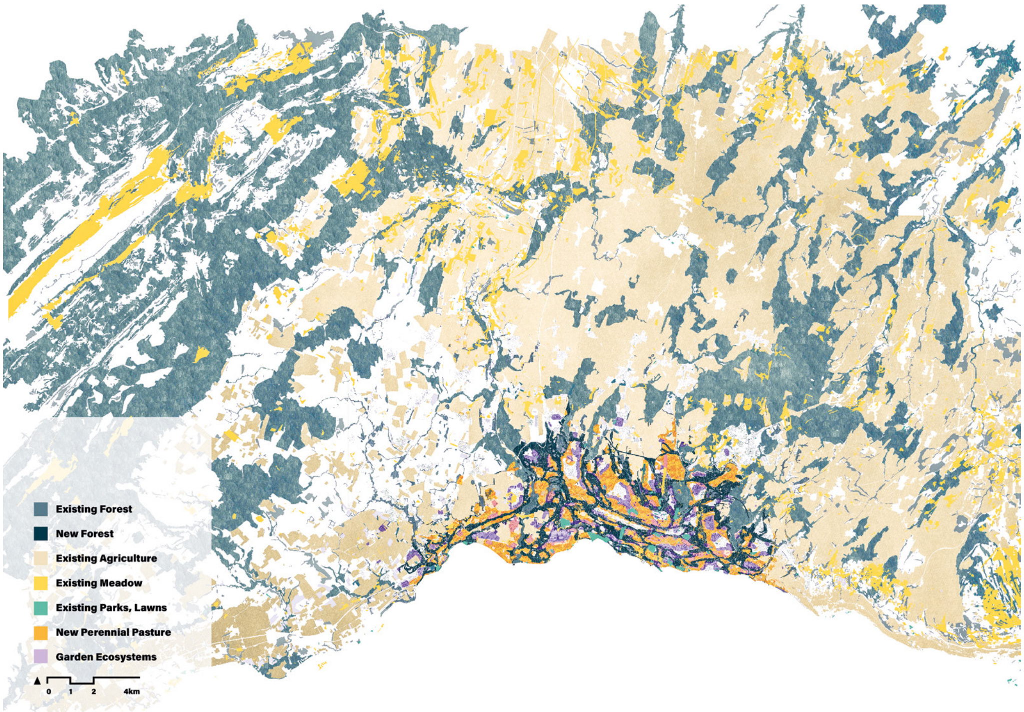
In operational terms, the treatment of waste by soil engineering aims at accelerating the pedogenetic processes that usually take place over hundreds or even thousands of years, such as the formation of humus and soil horizons. It relies on three conditions: (a) technical knowledge and know-how, which are still at the experimental stage; (b) place to spread and handle earthy materials in sufficiently large platforms, as the maturation processes can only take place at a relatively shallow depth—comparable those of soils, and generate nuisances—odors, presence of insects, etc.; and (c) time for the production of functional substrates over a sufficiently long period of several months minimum, depending on the targeted function. Such requirements have consequences for urban regeneration projects.

A strictly monofunctional approach, relegating substrate formation processes to a purely logistical space, should be avoided. Within the limits of possible cohabitations, considering potential nuisances, soil farming could take on the aspect of a proto- or transitory urban landscape associated with recreational and extensive park uses. In their temporal, spatial, and material aspects, those evolving and mixed-use urban landscapes should thus be considered ecological infrastructures. As new typologies of public spaces, such learnscapes should also feature a societal dimension. They should become a vector for enhanced literacy on current environmental challenges and involve city users as actors in circular waste management and soil care. In complement to the soil factories detailed in Figure 9, students have designed the nursery as a place of public awareness through guided tours, information boards, and workshops. It is complemented by a Soil Laboratory, hosting an educational and research center in urban pedology, where knowledge about soil production is created and evaluated.

### *SCENARIO 3. URBAN BIOTOPES*
### *CARE PRACTICES TO DIVERSIFY ECOLOGICAL HABITATS*

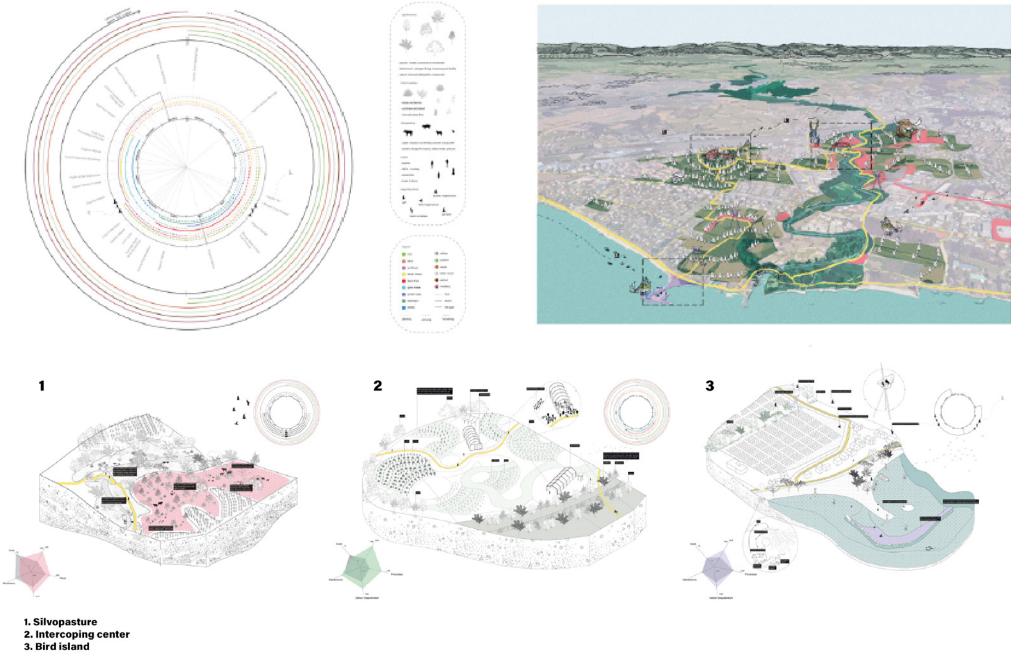
What if maintenance policies for open spaces increased the diversity of vegetation cover to implement ecological infrastructure? The third scenario proclaims that “The City is Alive”. In contrast to intensive agriculture, management practices related to leisure-oriented and ornamental greenery, as well as urban and community-based agriculture, involve less biomass export and/or greater organic matter input. Multifunctional urban uses are therefore less invasive for soils than the usual food-production-related land uses, and more favorable to the progressive accumulation of organic matter in soils. Besides, the field survey has explored the complexity of natural and anthropogenic factors involved in the maintenance of urban vegetation and soils. It has shown highly variable but overall significantly effective performance in sequestering carbon across all studied vegetation cover types, especially in privately maintained areas. This leads to the consideration that care practices for soil and vegetation in cities are well suited to supporting life in many forms, particularly biodiversity, the carbon cycle, and multiple pedogenetic processes. Scenario 3, therefore, proposes to improve the performance of all types of vegetation cover by maintaining the city as a garden. Every urban biotope should thus be considered for enhancing organic carbon sequestration in preserved or regenerated urban soils, including areas subjected to intense urban uses and high-maintenance practices.

With the aim of diversifying vegetation cover, Scenario 3 addresses the timescale over which improved maintenance conditions will enable urban soils to sequester more carbon, a process estimated to unfold over one to two centuries. The gradual diversification of ecological habitats establishes a landscape territorial structure for Lausanne as a third vision. Based on the network of voids and the brown network previously mentioned, students have imagined a green, yellow, and blue network represented in Figure 10. As an alternative to the current over-representation of lawns in open spaces, such mosaic is made up of urban forests, wetlands, meadows and pastures extending from the plateau to the heart of the city, as well as vineyards, orchards and vegetable gardens regaining their structuring role around clusters of buildings. In addition to its qualitative dimension, this approach should also take on a quantitative dimension, as an index of open soils and greenery that defines the proportion of the ground to be covered by vegetation.

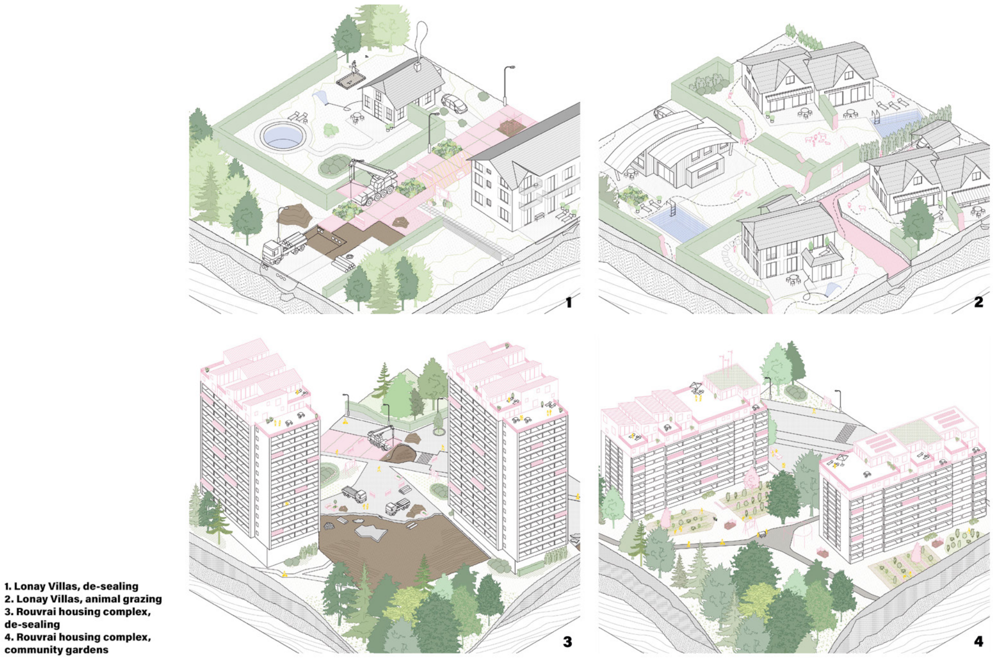



*10* Mapping of a green, yellow, and blue network as a landscape territorial structure for the Lausanne metropolitan area. Source: Abdulghani Aljajah, Rebecca Brandmayer, Rasmus Ehlers, Mersede Eyni, Seida Feldheim, Hui Miao, Lia Reimann, Rebecca Sharp, Joseph Tuegel, Theresa Zöllner Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024

Urban regeneration projects include various complementary actions to redefine open spaces as diversified ecological habitats, such as: (a) creating spots of urban wilderness in the heart of the urban fabric with little or no access for users; (b) promoting multifunctional and recreational uses on the patches of cultivated land remaining in urban areas; (c) increasing the surface area dedicated to participatory and community-based urban agriculture. When combined, these types of actions, in particular, lead to the conversion of interstitial and large open spaces into metropolitan parks, incorporating various urban uses and logistical functions. As illustrated in Figure 11, some students have developed a project for an agropark in the rural enclave, stretching from the valley of the Venoge river to the hill of Monteiron, comprising multiple typologies of agro-urban public spaces, within which soil regenerative practices coexist more or less peacefully with recreational, sporting, and cultural activities. Acknowledging that gardening the city as a mosaic of biotopes entails designing with time, students have also elaborated an almanac as a management tool articulating ecosystemic, agricultural, and socio-cultural processes within a seasonal framework. The Silvopastures area combines trees with livestock grazing, enhancing biomass and root depth while animals distribute organic matter, improving soil structure and carbon retention. In the Intercoping Center, agricultural practices, such as growing multiple crops together or in rotation, increase plant diversity and organic matter, enrich the soil and promote microbial activity, and further enhance carbon sequestration. Likewise, cover cropping, polycultures, organic farming using integrated pest management, as well as conservation tillage and composting, ensure sustainable nutrient cycling and benefit soil fertility.




*11* Project for the Venoge – Monteiron Agropark, including an almanac as a management tool articulating ecosystemic, agricultural, and socio-cultural processes within a seasonal timeframe (top left), bird-eye view of the whole project (top right), and three typologies of agro-urban public spaces (bottom). Source: Leon Hidalgo, Anne Wilhelm, Merve Özyalin, Gökce Senol, Mersede Eyni Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024




*12* The scenario comprises multiple strategies for interconnecting and regenerating open spaces as diversified ecological habitats, applying differently to the private gardens of the single-family houses in Lonay and to the Rouvrai modernist housing complex. Source: Amelie Gadow, Lorenz Hahnheiser, Teresa Immler, Leandra Leipold, Sarah Kramer, Leon Lohrer, Lia Reimann, Hannah Berner, Urban Design Studio "Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)", Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024

The mosaic of ecological habitats also extends to the fine-grained mesh of public and private land within the built-up environment. Such a transformation of the urban fabric entails rethinking the existing typologies of usual open spaces entirely. The structuring role that lawn and asphalt surfaces currently play should be transferred to long-lived and deep-rooted plants that maintain consistent soil cover, enhance soil structure, and carbon sequestration. Acknowledging the specific challenges of various types of urbanization, such as modernist housing complexes and single-family houses, students have elaborated multiple strategies for interconnecting and regenerating both public agoras and private backyards. These strategies include modifying traffic patterns to allow for de-sealing, enhancing biodiversity by consolidating ecotones, using animal grazing to maintain grassland areas and fertilize the soil, and introducing alternative cultural or recreational uses that do not rely on artificial surfaces or intensive maintenance.

## *SOILING THE CITY FROM A GROUNDBREAKING SHIFT IN URBAN SYSTEMS TO A CHANGE IN TRANS-SCALAR OPERATIONAL PRACTICES*

In sum, the three scenarios presented here, focus on different dimensions of the city as an ecosystem, respectively morphology, metabolism, and biotopes. They extend to the urban environment the continuum that Maria Puig Della Bellacasa has established between humans and humus under the term “soil communities.” To store carbon, the city must mirror healthy soils: it must be porous, circular, and alive. It is also important to note that, while these three scenarios focus on the carbon cycle, they indirectly contribute to the reactivation of the water cycle through the soil. Such co-benefit is essential for regulating heat islands and flood risks. This paper has argued that global mitigation aligns with local adaptation to climate change, establishing urban soil as a holistic landscape infrastructure.

The pair of AI-generated images by the students in Figure 13 indicates that the implementation of the preservation of voids—open spaces—, regeneration of soils, and diversification of vegetation cover as integral strategies of soil regenerative urbanism implies a groundbreaking shift in urban systems. Sanitation and transport networks, in particular, must radically switch from the current pipe logic—which is technical, centralized, and segregated—to a new soil logic—which should be nature-based, local, multifunctional, and alive. This revolution also implies a new look, a change of atmosphere, and a reevaluation of aesthetic values towards the dusty, dirty, and bushy. In this respect, the “save our soil” activism campaign, also designed by the students and documented in Figure 14, emphasizes that the transformation of the city inevitably involves promoting socio-environmental awareness and involving citizens in caring for soils.

Finally, the mixed methodology proposed here adopted a trans-scalar approach applicable to both interdisciplinary research—from field sampling to understanding the systemic drivers of carbon sequestration—and research-by-design—from territorial visions to urban regeneration projects, and spatial prototypes that contextualize the characteristics of various inherited urban conditions, such as modernist developments or neighborhoods of single-family houses. Operationally speaking, the Swiss agglomeration projects policy, funded by the Confederation, steered by the cantons, and implemented at the local project level, helps define three levels of action to implement the paradigm shift across different scales. At each of these levels of governance, different knowledge gaps and best practices are identified.

At the national level, the various offices responsible for strategies and policies should coordinate a coherent approach to soil that addresses environmental protection and territorial development challenges. Such institutions should also conduct a societal debate to revise the goal of urban densification—inward development principle—in the light of urban soils and their functions. To foster a legal and operational change in the culture of urban and territorial planning, governmental agencies should ultimately promote application-oriented research initiatives, as well as the development of coordinated data collection and their integration into publicly accessible monitoring systems.


*13* AI-generated images illustrating soil regenerative urbanism in Lausanne. Source: Lea Beck, Rebecca Brandmayer, Noah Ehlers, Rasmus Ehlers, Seida Feldheim, Julius Morgenstern, Hui Miao, Sarah Möller, Theresa Zöllner
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*14* The "save our soil" activism campaign. Source: Lea Beck, Rebecca Brandmayer, Noah Ehlers, Rasmus Ehlers, Seida Feldheim, Julius Morgenstern, Hui Miao, Sarah Möller, Theresa Zöllner
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At the regional level, decision support tools—e.g., cartographic instruments—and standard operational processes should be developed to facilitate the implementation of soil-regenerative urbanism policies, guided by qualitative and quantitative targets for preserving and restoring soil functions. Possible incentives should also be identified at this level to overcome barriers such as private landownership and facilitate de-sealing and soil regeneration, as well as improve maintenance practices.

At the level of urban renewal projects, local authorities should reflect, qualitatively and quantitatively, the objective defined at the regional level for soil protection and regeneration in planning and building regulations, as well as in guidelines and briefs for urban renewal projects. Ultimately, good examples of soil-inclusive solutions should be highlighted to encourage the involvement of local actors in the careful, multifunctional use of urban soils.

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Figures 1,3: Vialle et. al, 2024

Figure 2: Vialle, 2024

Figures 4 - 14: Urban Design Studio “Climate-Resilient Urban Soils – Case Switzerland (Carbon Scenarios)”, Technische Universität Berlin, Chair for Transitioning Urban Ecosystems, 2023-2024. For specific authors see corresponding Figure caption.

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