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Quelle gestion des sols pour l'aménagement de la nature en ville ?

Sous la direction de Séraphine Grellier

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WHICH SOIL MANAGEMENT TECHNIQUES FOR URBAN GREENING PURPOSES?

Sustainable ecological solutions to restore urban soils fertility: towards a new operational methodology.

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Formation par la recherche, Projet de Fin d'Etudes en génie de l'Aménagement et de l'Environnement

La formation au génie de l'aménagement et de l'environnement, assurée par le département aménagement et environnement de l'Ecole Polytechnique de l'Université de Tours, associe dans le champ de l'urbanisme, de l'aménagement des espaces fortement à faiblement anthropisés, l'acquisition de connaissances fondamentales, l'acquisition de techniques et de savoir-faire, la formation à la pratique professionnelle et la formation par la recherche. Cette dernière ne vise pas à former les seuls futurs élèves désireux de prolonger leur formation par les études doctorales, mais tout en ouvrant à cette voie, elle vise tout d'abord à favoriser la capacité des futurs ingénieurs à :

- Accroître leurs compétences en matière de pratique professionnelle par la mobilisation de connaissances et de techniques, dont les fondements et contenus ont été explorés le plus finement possible afin d'en assurer une bonne maîtrise intellectuelle et pratique,
- Accroître la capacité des ingénieurs en génie de l'aménagement et de l'environnement à innover tant en matière de méthodes que d'outils, mobilisables pour affronter et résoudre les problèmes complexes posés par l'organisation et la gestion des espaces.

La formation par la recherche inclut un exercice individuel de recherche, le projet de fin d'études (P.F.E.), qui se déroule en dernière année de formation des élèves ingénieurs. Le travail présenté correspond à la réponse à une problématique proposée par le lieu d'accueil de l'étudiante dans le cadre de son contrat de professionnalisation.

Le travail de recherche, dont l'objectif de base est d'acquérir une compétence méthodologique en matière de recherche, doit répondre à l'un des deux grands objectifs :

- Développer toute ou partie d'une méthode ou d'un outil nouveau permettant le traitement innovant d'un problème d'aménagement ;
- Approfondir les connaissances de base pour mieux affronter une question complexe en matière d'aménagement.

Afin de valoriser ce travail de recherche nous avons décidé de mettre en ligne sur la base du Système Universitaire de Documentation (SUDOC) les mémoires à partir de la mention bien.

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Preamble

This work takes place within the framework of a work-study program for the last year of my engineering degree in Planning and Environment in Polytech Tours. It comes as a multi-purpose research work as it intends on one hand to satisfy academic standards and on the other hand to give an answer to issues faced by the employing company.

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INTRODUCTION

Contextualisation

The threshold of 8 billion people living on Earth has just been crossed this November. The world's population keeps growing faster than ever. In addition, the United Nations (2018) assess that more than half of the world's inhabitants are living in urban areas: around 55%. This fast demographic development which started around 1950 during the Great Acceleration, coupled with economic growth, led to an exponential growth of energy and material consumption as well as greenhouse gas emissions. As a result, humanity will have to face big challenges in the years to come, especially with climate change and resource scarcity. Climate change specifically is enhanced by nowadays unsustainable and consumption-based lifestyles, especially from people living in the cities.

Speaking of urban areas, this slight population rise is also enhancing a phenomenon of city expansion called urban sprawl, which is usually defined as the development of urban spaces which involves land consumption in order to build individual housing, transport infrastructures and tertiary or commercial buildings (Haaland & van den Bosch, 2015). This process is mainly characterised by soil sealing. Sealed soil can be defined as soil "covered by an impermeable layer which impedes exchanges between aboveground and belowground worlds" (Turbé et al., 2010). The majority of sealed soils are today linked to anthropogenic activity and urbanisation, as aforementioned (Tobias et al., 2018). To give some figures, it is said that an area as large as the surface of a department - the size of the Drome - is urbanised and sealed every twenty years in France (Grisot, 2021). Land consumption is for the most part motivated by housing purposes - 68% in France -, before transport networks and infrastructures (Cerema, 2021). Around 8% of the French metropolitan surface is impermeable according to data from the French ministry of ecological transition and territorial cohesion (2019), and 60% of the world's soils are degraded (ADEME, 2020). This intensive land use causes problems related to a "non-efficient use of resources, e.g. of land and energy causing a larger urban footprint, loss of biodiversity, environmental problems and social inequalities" (Haaland & van den Bosch, 2015).

In addition to other processes caused by the significant acceleration of our consumption (e.g. erosion, contamination, over-exploitation, salinization…), soil sealing is often talked about as one of the most major threats to soil quality (Maienza et al., 2021; Tobias et al., 2018; Turbé et al., 2010), leading eventually to soil degradation (Drenning, 2021; Turbé et al., 2010). Indeed, the additional layers of artificial impenetrable materials such as asphalt or concrete covering soils are thus depriving them of their functionality (Drenning, 2021; Tobias et al., 2018). Soil, as a combination of organic and inorganic material, tiny spaces filled with air and water, is a huge biodiversity habitat (Turbé et al., 2010), hosting billions of living organisms and providing many functions to both humanity and the environment. Making the soil impermeable changes its physical, chemical and biological characteristics and further leads to many impacts over the following parameters: heat, biota, gas, water cycles, landscape (Scalenghe & Marsan, 2009). The elements affected are presented in Figure 1 below.

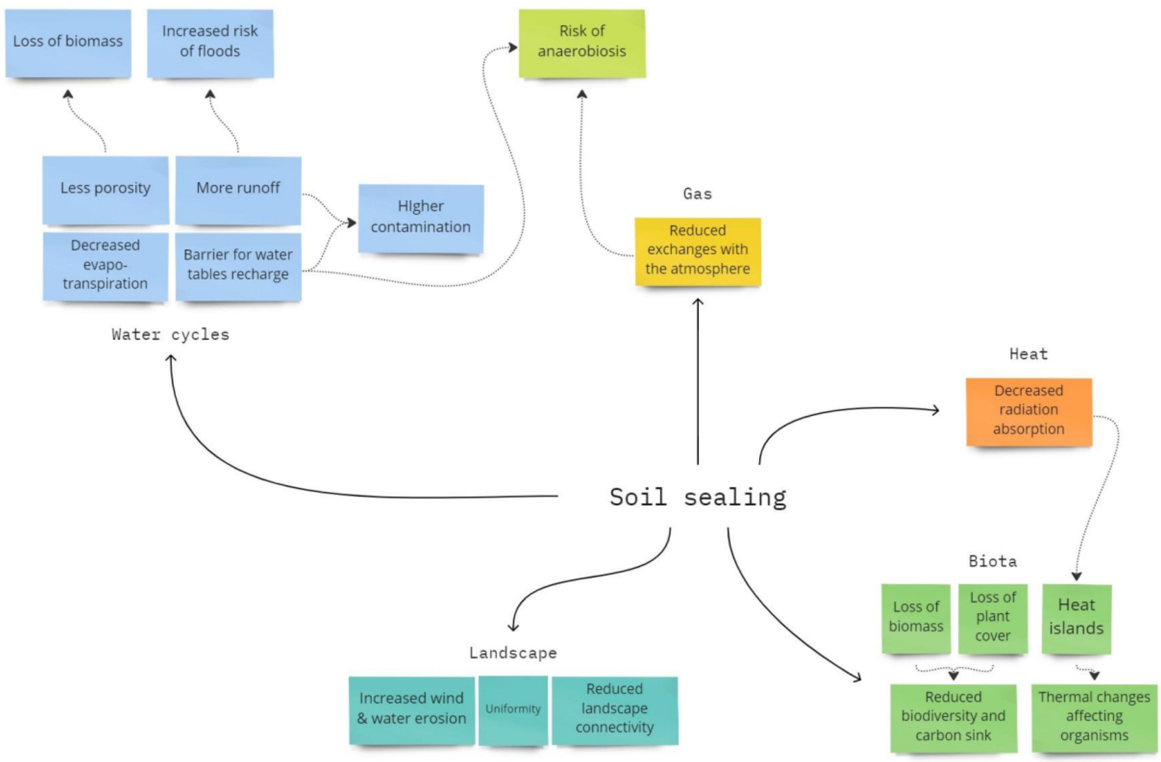

Figure 1: Impacts of soil sealing

Those effects are getting further amplified nowadays with climate change. Indeed, the water cycle modification earlier mentioned does not help for preventing cities from floods. Water cannot get infiltrated through the soil layers - as it would in natural soil - but runs off over the sealed surface rather than joining groundwater (Tobias et al., 2018). Another easy link to climate change is the creation of heat islands. Darker surfaces such as concrete or asphalt have a low albedo which means they have a low reflective power of sunlight and thus store a lot of heat (Scalenghe & Marsan, 2009; Tobias et al., 2018). This energy is not being returned during the night which prevents the city from refreshing. It contributes to the increase of the air's temperature within urban spaces, and this is one of the parameters participating in the formation of urban heat islands.

While urbanisation increases heat islands, water runoffs, flood risks and pollution, urban nature comes as an answer to environmental and public health stakes (Cerema, 2022). Just like the French ecological agency ADEME[1] in June 2021, planning organisations publish guidelines to struggle against urban heating. They often rely on nature-based solutions aiming to improve the urban greening rate and water management quality thanks to the implementation of e.g. parks, trees, turfgrass, green roofs (ADEME, 2021). It is by the way observed that the demand for urban green space within the cities has become stronger than ever (Fabbri et al., 2021). Nature indeed provides many benefits to society and lots of services to human beings - influencing both physical and mental health. It also positively affects climate change mitigation thanks to ecosystem services (ES) which improves environmental quality.

[1] Agence de l'Environnement et de la Maîtrise de l'Energie

In the same time, soil being often designated as a non-renewable but vital resource by scientists (Breure et al., 2018; Deeb et al., 2020; Fabbri et al., 2021; Turbé et al., 2010), governmental institutions seem to be increasingly aware that it becomes necessary to preserve it. They therefore developed a growing interest for soil preservation and established new norms and regulations aiming to enhance a fight against urban sprawl and its associated soil sealing. According to an objective of "No net land take by 2050" decided in 2011, Europe aims to face land consumption and soil sealing. A similar norm was raised in France with the 2018 Biodiversity Plan, which tends to achieve the goal of Net Zero Sealing (ZAN in French). Furthermore, the European Commission adopted in 2006 the Thematic Strategy for Soil Protection. It is "a regional policy with a cross-sectoral approach [which] lays down strategies for protection and sustainable use of soil through preservation of the ecological functions of soil, prevention of soil degradation, and restoration of degraded soil" (FAO, 2022). At the global scale, those orientations aiming to reduce soil degradation were addressed in the Land Degradation Neutrality target of the United Nations which is a project from the Convention to Combat Desertification seeking "to keep land as healthy and productive as possible (UNCCD, s.d.). In 2015, the member states of the United Nations also adopted 17 Sustainable Development Goals (SDGs) which strive by 2030 to struggle against social or economic inequalities and to fight against climate change and our planet's degradation. It was noticed several times that soil management is the key to achieve most of the SDGs, as those "rely considerably on plant production [and] depend on soil processes" (Lal et al., 2021). Besides, the European Commission expects to restore at least 15% of degraded ecosystems within the framework of its Biodiversity Strategy and expand the concept of Green Infrastructure (GI) to fight land fragmentation. It is clear that with this goal of 75% of healthy soils by 2030, it will be imperative to restore and manage them sustainably (Lal et al., 2021). In France, the Biodiversity Plan mentioned above does not only address concerns about soil preservation but also focuses in its first axis on the development of urban nature. At the territorial and local scale too, local authorities develop strategies that are based on both soil un-sealing and renaturation (Cerema, 2019), such as the metropolitan area of Lyon which places those subjects in the heart of the orientations guiding the actual mandate (Miguet, 2019).

In order to actually set up their strategies, political institutions need to develop tools and concrete actions. Green infrastructure, mentioned above, is one of those tools. Green infrastructure was defined by Naumann et al. (2011) as "the network of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services." According to the European Commission (2012), green infrastructure has the ability to deliver many functions and goes further than only promoting biodiversity as it can perform other roles: "protecting ecosystems state and biodiversity, improving ecosystem functioning and promoting ecosystem services, promoting societal wellbeing and health, supporting the development of a green economy, and sustainable land and water management". We can hence consider that urban greening or green space in urban areas are part of green infrastructure. It is commonly claimed that green infrastructure provides a lot of benefits to both humans and the environment (Minixhofer & Stangl, 2021; Naumann et al., 2011; Yilmaz et al., 2018), although not all types of GI are giving the same amount of services (Tang et al., 2021). Indeed, "green infrastructure features can be completely man-made, such as green roofs and green walls, or can be based on an existing ecosystem with some intervention, such as parks, urban farms and bioswales" (Deeb et al., 2020). One thing is that green infrastructure, or urban greening,

cannot exist without a correct soil fertility. Life duration and quality of urban greening depend on numerous parameters, including essentially soil quality - as it informs about water and nutrients availability for biodiversity to survive in it (Minixhofer & Stangl, 2021). The depletion of topsoil resources, due to an overconsumption, is an obstacle to growing nature in urban areas. Not only the amount of arable soil resources is being reduced, but the little left is being degraded, as explained before, and soil health - or soil fertility - which is defined by physical, chemical and biological indicators (Blanchart et al., 2018), is decreasing too. This explains why it becomes crucial to consider soils in planning projects.

Despite soil quality being imperative to grow green space, soil is not being accorded as much attention as it should. Soil quality is defined by Minixhofer & Stangl (2021) as the "multifunctionality of soil to sustain its environmental capacities, hence to provide soil-related ES". And yet, planning actors often only consider soil as a surface quantity for land use, they see soil as a two-dimensional element which constitutes a place for buildings and infrastructures (Blanchart et al., 2018; Minixhofer & Stangl, 2021). An approach considering soil as a volume would only appear to study geotechnical properties, in order to support those infrastructures, or to assess some pollution level. However, soil should be identified as a genuine resource, as a "potential living, fertile and tri-dimensional compartment of the urban ecosystem able to perform highly diversified functions and provide ecosystem services" (Blanchart et al., 2018). As a result of this inaccurate vision, there is a disconnection in planning between services and functions provided by soil and the land use it is intended to. And yet, "in earlier times, with less available technology, land use was largely determined by the functions that could be performed by the natural soil" (Scalenghe & Marsan, 2009). Coming back to a sustainable soil management means making this relation again, as it was before last century.

Currently in France, the information level about soil quality is quite variable within planning documents. Soil thematic, despite a low apparition for the word "soil" in documents - compared to other words such as "transport", "housing", or "water" (Blanchart et al., 2019) -, is treated through different angles. One of them is the qualitative approach, when policy considers agricultural and natural resources to conserve them and anticipates soil pollution risks within future urbanisation zones. Planning choices are then guided by soil characteristics as soil is seen as a natural and agricultural resource. Documents increasingly take this into account as their preservation becomes vital. SCoT[2] and PLU[3] tools consider soil quality as it can help making a diagnosis and establishing the land use attribution. The delimitation in the PLU, or zoning, requires a certain knowledge about soil characteristics. Besides, planning documents consider risks related to pollution technological risks or technical constraints - especially thanks to SAGE[4] that give a zoning to protect water resources from pollution and the PPRT[5] giving information about potential soil contamination. Quality of soils is also being considered with regards to their archaeological heritage, for which PLUs and their PSMVs[6] require studies and measures to develop a better knowledge. It is however important to notice that pollution risks are often weakly anticipated: diagnoses are not much detailed and only risks are given - no quantitative levels -, aiming to inform rather than enforcing real specifications. Another approach

[2] SCoT: "Schémas de cohérence territoriale" for "Territorial cohesion plans"
[3] PLU: "Plan local de l'urbanisme" for "Local urbanism plan"
[4] SAGE: "Schéma d'aménagement et de gestion de l'eau" for "planning and water management scheme"
[5] PPRT: "Plan de prévention des risques technologiques" for "technological risks prevention plan"
[6] PSMV: "Plan de sauvegarde et de mise en valeur" for "Valorisation and preservation plan"

in spatial planning regarding soils can be quantitative, according to their bi-dimensional vision - with laws taking into account space consumption and nowadays aiming to avoid and limit it. They furnish obligations to consider soils in order to provide numerical limits and objectives. The existing SRU[7] law from December, 2000 - introducing SCoT and PLU - already expected planning documents to ensure that natural areas were used reasonably. Other laws then came to reinforce this idea, such as the 2nd Grenelle (2010), a law based on national engagement for the environment (named ENE), which initiates the regional schemes for ecological cohesion as well as the French blue and green infrastructure. This ENE law is inciting SCoTs and PLUs to assess the level of consumption of natural, agricultural and forest spaces and to give quantitative objectives for future consumption of those spaces. A second law, ALUR[8], emerged in 2014, introducing the densification concept. It indicates that planning documents must consider the densification capacity of to-be redeveloped urban spaces.

According to the scientific observations with regards to climate change and according to the orientations given by the institutions, it becomes necessary to build the city on itself - meaning densify - and to bring urban nature. But those two directions raise challenges for urban planners (Haaland & van den Bosch, 2015). In fact, it is difficult to always host more people within the urban territories while ensuring a convenient quantity of urban green space. Many infrastructures are built for this growing population, leaving little space left for green infrastructure. Moreover, ethical and social equality questions can be raised due to an uneven repartition of green spaces between the different neighbourhoods. Despite an interesting approach of the problems raised by densification affecting the implementation of green space, it should be noticed that no mention of the challenges related to topsoil were found in the article of Haaland & van den Bosch (2015). There are for instance difficulties related to the limited availability and the rising degradation of soils. Strategies are only mentioned there in order to help planning green space in densified cities: preserving existing green areas, using norms and standards to achieve a better quality, improving processes of planning, calling for public participation, etc. Those definitely need to be considered, but do not provide the keys for a practical execution, and for soil management.

This observation is similar to many works studied. It happens that scientific literature in general often focuses on how it should be planned, but scarcely on how it is in fact technically made up. It may seem quite easy to recommend ways of setting up urban greening, but it comes in practice way much more difficult to apply. There are imperative links to establish between both approaches. Soil scientists and urban planners should cooperate and work together to settle a co-construction program by sharing their ideas and using the same vocabulary (Blanchart et al., 2018).

Research question(s) and objectives

Therefore, we can wonder which soil management would be the best to integrate nature within spatial planning projects. A gap of knowledge was indeed identified from the planners' side. Many experiments are being led but a few are actually based on scientific research and there are no standards for technical management. The subject of this report is first to study scientific literature to produce a state of the art on the topic. The second objective is to produce a tool which can be used in different contexts to guide operational urban planning in the implementation of urban nature.

[7] SRU: "Solidarité et renouvellement urbains" for "urban solidarity and redevelopment".
[8] ALUR: "Accès au logement et urbanisme rénové" for "access to housing and refurbished urbanism"

Methodology

Scientific research was first established to develop a state of the art of the actual knowledge of the topic. The literature considered was published either in English or in French. Following keywords were researched on the database from the CNRS (bib.cnrs): “urban soils”, “urban soils” AND “management”, “living soils”, “urban” AND “living soils”, “green infrastructure”, “green infrastructure” AND “soils”, “technosols”, “technosols AND “urban greening”, “soils” AND “ecosystem services”, “waste recycling” AND “urban greening”, “soil sealing”, “unsealing”, “unsealing” AND “urban”. During first searches it was also requested the keyword “review” in order to collect the key articles already giving literature reviews. This was useful to pick up the general ideas linked to urban fertile soils and to identify what has already been studied as well as what are the research gaps. The research question could be better established as a result of this first step. Further research was then launched to find and study more detailed information and case studies. After collecting all this scientific material, non-scientific information was added too, and everything had been organised into a mind map. This is in fact a very large topic that involves a lot of other actual stakes, and the data collected needed to be structured to figure out which direction and organisation should be given to the project.

After the state-of-the-art production, a personal methodology has been established for guiding the technical management of fertile soils within urban greening projects. Existing guides and methodology that review the thematises of excavated material valorisation and degraded soil ecological regeneration were first collected. The approach was constructed according to this documentation with regards to its gaps, focusing specifically on soil quality management for greening purposes. An identification of the different tools available and the actors to involve was realised at the same time.

Plan

In the first part the diverse functions ensured by urban soils will be introduced thanks to the study of their ecosystem services. The different types of services will be treated, before a list of the already existing tools aiming to optimise them within urban planning projects is presented. It will then be demonstrated how soils are nowadays not being taken enough into consideration. In a second time, a systematic review will take place, addressing the existing and tested solutions to bring topsoil in the urban spaces for green infrastructure, coming as alternatives to bringing fertile soil from arable land surfaces. There are quite efficient practical and ecological ways to face the rarefaction of topsoil resources: unsealing (or desealing) on-site soil, building engineered Technosols, or recycling waste or excavated material from the cities. Finally, the real object of this report was to elaborate a decision-making tool to help the operational actors to manage soil during their projects. This work will be presented in the form of a new approach, an operational methodology defining the steps to follow, the actors to involve and the tools to use or consult.

1. CHARACTERISTICS OF SOILS AND THEIR RELATED ECOSYSTEM SERVICES

1.1. Soil general characteristics

1.1.1. Soil biodiversity

"Soil health is essential for human health" (Lal et al., 2021). In fact, as mentioned earlier, nature is providing numerous benefits to humanity, such as "food, fibres, construction materials, clean water, clean air and climate regulation" (Naumann et al., 2011). All those elements have one thing in common: they could not exist without soils, particularly without soil biodiversity. Scientific literature addresses that soil biodiversity and its related soil functions is critical in the provision of ecosystem services (Breure et al., 2018; Drenning, 2021; Lal et al., 2021; Minixhofer & Stangl, 2021).

Soil is a complex ecosystem. It is defined by the World Reference Base for Soil Resources (WRB) as "any material within two metres of the Earth's surface that is in contact with the atmosphere, excluding living organisms, areas with continuous ice not covered by any material and water bodies deeper than two metres" (Blanchart et al., 2018). Soil is composed of both biotic - living organisms like plants and insects - and abiotic elements - physical or material geochemistry, such as minerals, water and air (Drenning, 2021). This is in fact the living organisms that are mainly driving the soil processes. They contribute to the formation of what is called the soil biota (Drenning, 2021) or the soil biodiversity (Turbé et al., 2010). Soils are indeed home to a huge number of living species that can be divided into three functional groups according to Turbé et al. (2010): chemical engineers, biological regulators and ecosystem engineers. Chemical engineers are part of microfauna, they are microorganisms such as bacteria, fungi, or protozoans in charge of the decomposition of organic matter into nutrients necessary for plant growth. Mesofauna can also be found in soil, with the biological regulators - like mites, springtails, potworms. They provide food to other soil organisms by distributing microbes in the rhizosphere (Drenning, 2021). The last category of organisms is composed of ecosystem engineers, macrofauna - earthworms, ants, spiders, termites. They create resistant aggregates and pores in soils which are forming habitats and hotspots for microbial activities. This pedofauna contributes to the soil biological activity and organic matter formation which are the basis of soil fertility thanks to the provision of mineral nutrients (agriculture.gouv, 2016). The main fertility indicators are related to carbon and azote concentration of soils and to its biological state: soil respiration, microbial biomass, enzyme activities, presence of pedofauna.

A natural soil profile is organised as a superposition of some layers, called horizons, which are shaped thanks to pedogenesis and living organisms' activities. All layers are identifiable as they present differences in their characteristics, colour and composition. Usually there is first the topsoil at the surface, which is mostly made of organic material, as it is the result of organic matter decomposition, creating a humus. Then there is the subsoil, and as the horizons go deeper, material goes more mineral. Below the subsoil can be found a substrate made of rock.

1.1.2. Focus on urban soils

We will focus this work on urban soils that are designated in opposition to natural soils. Natural soils are, according to Montana standards, soils that have developed in place through natural processes, to which no fill material has been added. Urban soils can be defined as the pedologic cover of urban spaces which makes us consider every soil located in an urban area as an urban soil. In addition, urban soil is also designating anthropogenic soil, which has been strongly influenced and

often disturbed by human activities (Lothodé et al.,2019). This second definition will rather be used in this report, as it appears important to highlight that some pedologic covers in urban areas can be almost unmodified by humans. Urban soils are the place of a large range of uses (e.g. support for housing or tertiary buildings, leisure activities, biomass production for gardens and parks…) and are hence being distinguished by a large range of covers. A major part is indeed sealed, but there are a lot of partially sealed or planted covers (Lothodé et al., 2019). These numerous uses, frequently overlaid in time, enhance big modifications of the initial state of soils, which is leading to a great heterogeneity in both horizontal and vertical physical, chemical and biological composition (Blanchart et al., 2019). They vary "from natural to fully artificial" (Deeb et al., 2020). The diversity of urban soil is shown below (Figure 2) with the photos of two different urban soil profiles.

Illustration of the diversity of soils from urban areas: a) Pseudo-natural soil in urban green space with a natural cover; b) hnosol profile with several layers of anthropogenic inputs with a sealed cover (asphalt mix, pavement base and sub-base layer). Photo credit : C. Schwartz, UL-INRAE.

Figure 2: Diversity of urban soil profiles
Source: Lothodé et al., 2019

Regarding soil fertility, many studies compared urban soils characteristics to other types of soils (Lothodé et al., 2019). One opportunity is that they are presenting a high potential for hosting biodiversity habitats and contributing to carbon storage. Furthermore, it was not observed or measured significant differences between urban and natural soil with regards to their phosphore and total azote average concentration, although there is a high contrast between different sites as mentioned before with a heterogeneity of profiles. Furthermore, urban soils usually have a higher concentration in organic carbon and a higher level of pH, which is due to the frequent use of concrete. However, it was shown that heavy metals are often found at a high rate in urban soils. But despite disturbances due to anthropogenic activities and artefacts, urban soils still play an important role in providing services (Blanchart et al., 2018; Montgomery et al., 2016; O'Riordan et al., 2021).

1.2. Soil ecosystem services

1.2.1. Identification and classification of soil functions

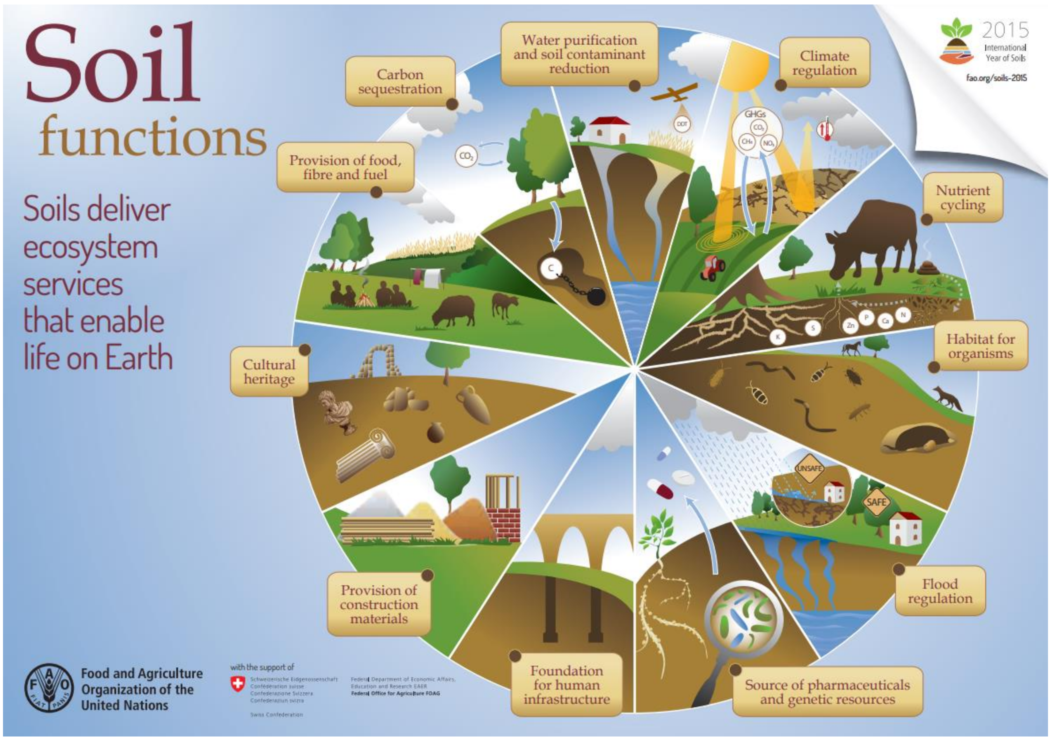

Figure 3: Soil ecosystem services as proposed by the FAO
Source: FAO, 2015

Based on an ancient idea, the concept of "ecosystem services" emerged around 50 years ago and became increasingly recognized over the last decades. This expression designates the benefits delivered from ecosystems to humans (Blanchart et al., 2018; Drenning, 2021; O'Riordan et al., 2021). They are usually classified into three (Blanchart et al., 2018; Minixhofer & Stangl, 2021) or more often four (Drenning, 2021; O'Riordan et al., 2021; Tobias et al., 2018; Turbé et al., 2010) categories. Services provided by soils are divided into provisioning services - providing goods (e.g. biomass, fibres, raw materials) -, regulating services - which contribute to the regulation of processes like water cycles -, supporting services - essential for all other services to function -, and cultural services - which are non-material benefits. One of the representations of soils ES was given by the FAO, see figure 3. A classification of them is provided in figure 4.

Categories	Services
Provisioning services	Provision of food, fibres and fuel Provision of energy Provision of raw materials Support for infrastructures Source of pharmaceuticals and genetic resources
Regulating services	Water purification and soil contaminant reduction Flood mitigation Carbon storage and greenhouse gas emissions mitigation Control of pests and pathogens Erosion control
Supporting services	Nutrient cycling: storage, filtration and transformation Habitat for biodiversity and biological activity
Cultural services	Archeological heritage archive Platform for recreation activities

Figure 4: Proposition of classification of soil ES
Sources: Blanchart et al., 2018; Drenning, 2021; Longato et al., 2021; O'Riordan et al., 2021; Turbé et al., 2010

1.2.2. Consideration of soil services in spatial planning and urban greening

Scientists tried to investigate the representation of soil ecosystem services within the publications about Green Infrastructure and soil function loss linked to GI (Minixhofer & Stangl, 2021). The assessment of ecosystem services is the second most common focus topic (14%) in the publications about green infrastructure, especially "when it can help prevent natural hazards such as floods". The first treated topic is indeed stormwater management - 45% of the publications -, as GI allows a better water infiltration and retention. Another frequent topic is related to the cultural and social services provided by soils. However, only 4% of publications addressed soil sealing and restoration. It was demonstrated by Minixhofer & Stangl. (2021) that loss of ES related to soil degradation had not been much covered by scientific literature, as well as the restoration of sealed surfaces. Green infrastructure measures can contribute to confining sealing in cities and promote urban greening.

1.2.3. Existing services optimisation tools in Europe

These soil-related ecosystem services, understood by many actors of spatial planning, could be taken into account in urbanism thanks to decision support systems. They "depend on soil quality" (Blanchart et al., 2018), which is commonly evaluated thanks to several chemical, physical and biological indicators. Blanchart et al. (2018) based their work on three existing tools from Europe - aiming to optimise the ES provided by soils within urban areas - to give a list of ecosystem services to take into account for soil management and to propose a new operational approach for planning. They

especially developed the DESTISOL decision support system in cooperation with the French environmental agency ADEME, aiming to put the emphasis on soil as a resource rather than a land surface.

The first one of the three projects is the Urban Soil Management Strategy tool introduced in 2008 by a project reuniting research institutions and local authorities from seven European countries. The main objective is to develop applicable soil management strategies and to inform decision makers about the importance of soil resources. The tool "is based on a multi-criteria analysis and estimates the ability of soils to fulfil varying land uses" (Blanchart et al., 2018). The second one, UQualiSol-ZU, led between 2010 and 2012 in France, aimed to put into perspective planning policies with the scientific knowledge about soil quality. The objectives were to assess the potential integration of soil quality indices within land use planification, to identify the knowledge about soils useful for planners, and to produce a case study in Provence. In the end, it aims at placing soil characteristics in the heart of urban planning documents. Then the authors mention the European ENVASSO (Environmental Assessment of soil monitoring) project, which offers a strategy to monitor soil, by selecting many indicators to assess soil functions/services. All indicators are classified according to the threats affecting soil quality. The authors grouped the indicators from all three approaches (figure 5), although they find some limits to the tools. They blame for example an application to the topsoil only or a high complexity of the indicators making the implementation complicated for other case studies.

	Indicators	Assessment tool for soil quality
Global soil properties	Soil depth	*Urban SMS, UqualiSol-ZU*
	Slope	*Urban SMS, UqualiSol-ZU*
	Sealed surface	*ENVASSO*
	Soil surface state	*UqualiSol-ZU*
Physical indicators	Texture class	*Urban SMS, UqualiSol-ZU*
	Clay content	*Urban SMS, UqualiSol-ZU*
	Sand content	*Urban SMS, UqualiSol-ZU*
	Bulk density	*ENVASSO*
	Total porosity	*ENVASSO*
	Water storage capacity	*UqualiSol-ZU*
	Saturated hydraulic conductivity	*Urban SMS, UqualiSol-ZU*
	Hydromorphy	*UqualiSol-ZU*
	Soil erodibility	*UqualiSol-ZU, ENVASSO*
	Mechanical resistance	*UqualiSol-ZU, ENVASSO*
	Magnetic susceptibility	*UqualiSol-ZU*
	Air capacity	*ENVASSO*
	Drainage condition	*ENVASSO*
Chemical indicators	Organic matter	*Urban SMS, UqualiSol-ZU, ENVASSO*
	Total nitrogen content	*Urban SMS, UqualiSol-ZU*
	C:N ratio	*ENVASSO*
	Total phosphorus content	*UqualiSol-ZU*
	Exchangeable phosphorus content	*Urban SMS*
	Exchangeable potassium content	*Urban SMS*
	pH	*Urban SMS, UqualiSol-ZU, ENVASSO*
	Cation exchange capacity	*UqualiSol-ZU*
	Total $CaCO_3$ content	*UqualiSol-ZU*
	Electrical conductivity	*UqualiSol-ZU*
Biological indicators	Bacterial diversity	*UqualiSol-ZU, ENVASSO*
	Macro fauna diversity	*ENVASSO*
	Meso fauna diversity	*ENVASSO*
	Micro fauna & microflora diversity	*ENVASSO*
	Soil respiration	*UqualiSol-ZU, ENVASSO*
	Biogenic structures	*ENVASSO*
	Enzymatic activities	*UqualiSol-ZU, ENVASSO*
	Organic matter degradation amount	*ENVASSO*
Contamination indicators	Trace elements content	*Urban SMS, UqualiSol-ZU, ENVASSO*
	Persistent organic pollutants content	*UqualiSol-ZU, ENVASSO*

Figure 5: Inventory of soil indicators used in existing assessment tool for soil quality
Source: Blanchart et al. (2018)

The authors (2018) give guidelines and recommendations for soil management strategies as well as for the development of a decision support system making the link between land use and soil quality. Based on these, the DESTISOL decision-helping tool comes as a new integrative approach in considering soil services previously to designing projects. It suggests the evaluation of on-site soil ES to question the scheduled planification and optimise soil functions and costs. The system is supposed to guide planners without constituting a technical or economic constraint but rather an opportunity to reduce material importation, treatment costs, etc. (Lothodé et al., 2019).

The principle of the tool is explained through the figure 6 below. In the beginning, there is a site to be urbanised for which we can see the mass plan ("Projet 1" in the upper right-hand corner). Thanks to studies on the site (step 1), a zoning is defined, with different soil profiles (step 2). Analyses are led for each zone: measures of indicators and assessment of soil functions. Step 3 then allows the determination of the scheduled cover layers compatibility with soil properties. According to those

conclusions and to optimise the project, planners can either decide to modify the properties of the soil to welcome the covers (for a better functioning), or to modify the covers - and their location on site - to make them match with the functions provided by soil. Ecosystem services are calculated on the basis of the selected planning project. All projects can be compared with regards to this evaluation of their ES.

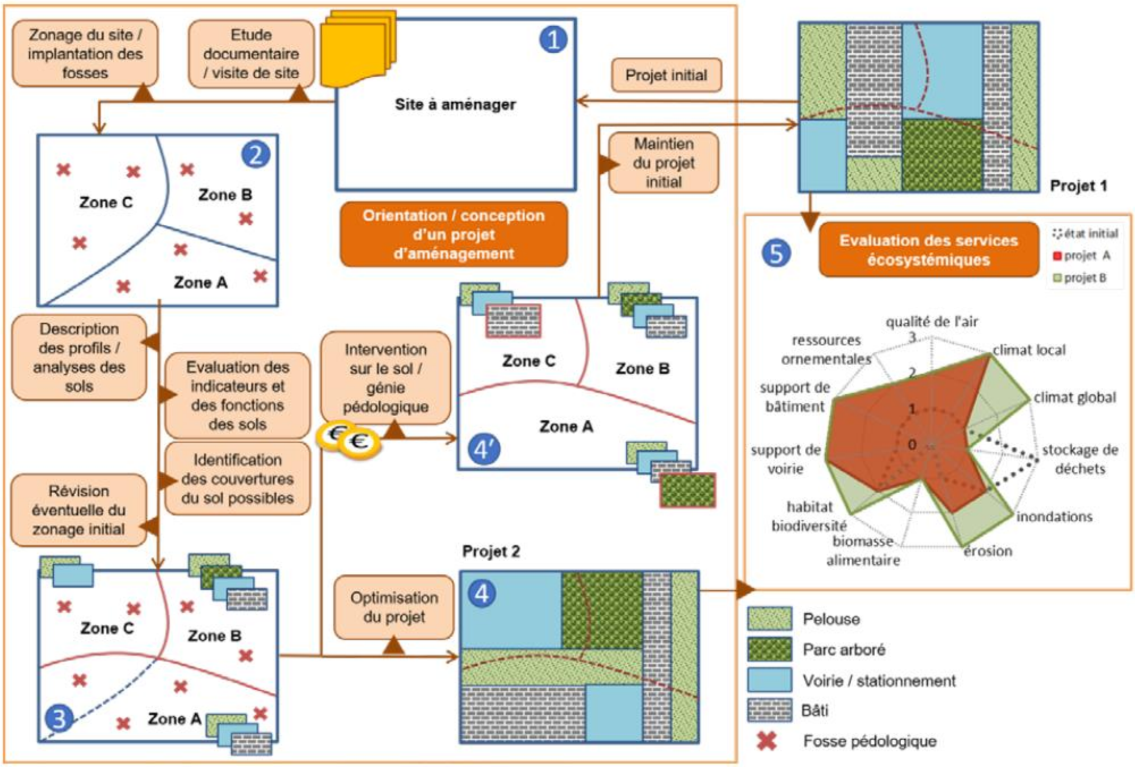

Figure 6: Presentation of the DESTISOL approach
Source: Lothodé et al., 2019

There is therefore a growing interest from planning actors (e.g. engineers, scientists, local authorities) for the consideration of services provided by urban soils, especially as they can contribute to climate change mitigation which is an important concern nowadays. Tools and systems are actually developed to improve planning practices towards a more sustainable management with regards to the environment. Handling soil in order to implement green infrastructure is often complicated and planners are not always aware of how they could do it.

2. WHICH SOLUTIONS FOR URBAN GREENING REGARDING SOILS?

2.1. Bringing topsoil from agricultural arable land: a controversial solution

Bringing arable topsoil from agricultural surfaces is nowadays the most applied solution when it comes to integrating nature within the cities, representing in France 3 million of cubic metres every year (Deeb et al., 2020). The topsoil from the in-city planned area is completely removed and then replaced with imported natural soil. But however, those practices enhance soil degradation, particularly where it is most needed to grow food, and a loss of its functions. As the United Nations stated (2022): “A full 90 per cent of the Earth’s precious topsoil is likely to be at risk by 2050, according to the UN Food and Agriculture Organization, FAO.” Every year globally billion tons of arable land disappear and this number amounts to 950 million within the member states of the European Union (Roots Arte, 2022). Formation of a fertile soil is considered as a slow process though (Breure et al., 2018): many hundreds of years are needed to create only one centimetre of topsoil (Drenning, 2021). We can therefore affirm that soil is a limited resource. This is the reason why it is not considered as sustainable anymore to import topsoil from far away agricultural land (Yilmaz et al., 2018). Another reason this becomes even more unwise is an economic reason: fertile topsoil is transported from peri-urban areas to cities over many kilometres, which not only generates greenhouse gas emissions but also has a cost, especially with nowadays rapidly growing transportation costs due to fuel prices (Deeb et al., 2020). As an answer to that, numerous studies and experiences were led to find alternatives and turn towards a sustainable management of soil in order to design urban greening.

2.2. Alternative solutions

2.2.1. Un-sealing in-site soils

Soil sealing contributes strongly to land degradation and has a high impact on soil’s ecosystem services (Tobias et al., 2018). In 2018, almost 5% of the European surface is covered with artificial material. This proportion changed by more than 7% between 2000 and 2018 (Copernicus, 2018). To restore soil’s lost functionality because of soil sealing in order to grow nature on urban degraded soil, it is critical to take action on it. One of the means to do that is to unseal soil where the project is planned: it often means changing the top cover layer into a more permeable material (Cerema, 2019). Besides, moving from sealed to de-sealed soils is a great way to improve water management as it enhances a better infiltration of stormwater. This limits water runoff which is often the source of water resources contamination as the flows are carrying pollutants to evacuation networks. The amount of water which is running through rainwater management systems is thus reduced and rather increases the volume flowing towards groundwater. There are even incentive measures and subventions set up by the French water agencies to help the local authorities to restore water cycles at a municipal scale (40€ per square metre of a freshly created permeable surface). De-sealing soils is a way to do it.

In their state of the art, although they find scientific literature does not address enough the development of vegetation after soil unsealing or restoration measures, Tobias et al. (2018) show that certain parameters of soil can be restored within 15 years for plant growth thanks to nowadays techniques. Despite a lack of research on the topic, as opposed to impacts of soil sealing, many experiments were technically launched demonstrating “that replacing a sealed surface with soil to restore ecosystem services is always beneficial for humans and nature”. Vegetation can therefore be regained on unsealed sites. However, the authors recommend to always prefer a preservation of natural soil because unsealed soil only disposes of a limited multifunctionality, especially because of

subsoil compaction (Tobias et al., 2018). The natural restoration of soil can be slow and its pedological properties are not always entirely recovered, especially if only the first layer of soil is depraved.

In another article from Maienza et al. (2021), it is demonstrated the possibility of giving back fertility to soil instead of moving topsoil from non-urban areas, which improves the "sustainability of urban regeneration projects". The study was supported by the EU LIFE Program through the project SOS4LIFE - Save Our Soil for Life. They monitored biological and chemical characteristics of soil after de-sealing measures, as well as its concentration regarding some pollutants: zinc, copper and lead. They also measured those metal's concentrations in the plant leaves of the shrubs planted. They studied de-sealed areas in Italy, the former usage of which was either public car parks or waste management companies. Topsoil was unpaved thanks to a caterpillar, subsoil was extracted and two different treatments were applied, according to the graphical representation presented below (figure 7). On one half of the sites, they reimplemented de-sealed soil at the bottom and topsoil at the top. On the other half, the material was only the de-sealed soil. The topsoil used "was sampled in the periurban areas of each municipality", coming mainly from agricultural fields. Moreover, each plot of the three sites was planted with ornamental shrubs and irrigated with a system programmed automatically to irrigate every day for ten minutes, along a period of six months (from April to September). The experiment lasted three years, which is quite short term if we compare it to the conclusions given by the previous article (Tobias et al., 2018) which mentioned a restoration within fifteen years.

Figure 7: Schematic representation of the two different compositions of unsealed soil
Source: Maienza et al. (2021)

The measures of the experiment focused on chemical analyses - with total soil carbon and total nitrogen, total organic carbon, total concentration of toxic metals (Zn, Pb and Cu) - soil biological quality index - with a microarthropod extraction to observe and assess their morphology - soil respiration, soil microbial biomass and different enzyme activities - and finally microbial stress thanks to the metabolic quotient value.

The results showed that as no significant differences were observed between the two treatments (for every site), bringing an imported topsoil is not critical to recover soil quality and fertility. What is also very interesting is that they planted shrubs which "enriched soil organic carbon through leaf litter and rhizo-depositions" (Maienza et al., 2021). De-sealed soil, without the additional layer of an exogenous topsoil, particularly showed a high chemical fertility, with regards to its bulk density, pH and total organic carbon values. Concerning the biological quality, shrubs participated in feeding primary decomposers which increased the QBS index and facilitated biomass production. There was a metal rate growth over the experiment that could be explained by the pollution of anthropogenic activities which take place in urban environments. This confirms that urban soils often show a higher contamination rate than other types of soil (Lothodé et al., 2019). But hydrological

parameters as well as compaction or other perturbations could increase soil metal concentration too. Furthermore, soil microbial activities - microbial biomass, soil respiration and enzyme activities - were sustained by plant rooting and rhizo-depositions from shrubs in all the soils studied. In addition, metal concentrations in leaves were quite low. Those two observations indicate that unsealing urban soil can be successful in growing vegetation and ensuring a certain quality.

SCE is actually leading a project about unsealing too, funded by the French environment agency (ADEME). It is called DESSERT for “Désimperméabilisation des sols, services écosystémiques et résilience des territoires”, which means “Soil unsealing, ecosystem services and territorial resilience”. The aims of the program are to get a better knowledge of the functioning of urban unsealed soil and their ES, to assess the conditions of unsealing for urban greening by collecting feedbacks from projects and following test sites, to follow laboratory experiments in order to optimise unsealing processes. The ultimate objective of all of that is finally to develop an integrative tool which will help to design urban soil unsealing projects.

2.2.2. Recycling waste or excavated material: construction of Technosols

2.2.2.1. Led studies to test Technosols

One other alternative to using topsoil from peri-urban agricultural areas is reusing waste material to create fertile soils (Yilmaz et al., 2018). Constant urban redevelopment is generating demolition debris and the proportion of waste which is recycled, although it increases over the years - growth of 11% in France between 2008 and 2018 - (ADEME, 2020), is still not important enough with regard to the actual stakes related to resource scarcity. For example, 240 million tons of waste were produced in France in 2018 from civil engineering activities (ADEME, 2020), in addition to compost and green wastes coming from maintenance of urban parks and gardens (Yilmaz et al., 2018). Those could be used in order to build living soils adapted to grow urban nature, which are commonly named “Technosols”. Technosols can be designated as “deliberate mixtures of organic and mineral wastes and by-products constructed to meet specific requirements”, they are said to contain at least a volume of 20% of artificial materials (Deeb et al., 2020). This practice can reduce GI implementation costs and limit resource consumption in a way that respects the circular economy approach. But to do that efficiently, it is necessary to ensure that some conditions are respected in the way that the urban soil can deliver its required functions. It must for instance dispose of a “bearing capacity, agronomic properties, drainage capacity” and needs to avoid contaminating groundwater tables (Yilmaz et al., 2018). One disadvantage raised by scientists is the possible transfer of pollutants from wastes such as lead to the ground (Deeb et al., 2020). However, it was also shown that it was possible to grow plants in technosol made with for instance coal waste, sewage sludge and rice husk ash (Firpo et al., 2021): the metal concentration was within the limits of natural variation, the pH was and nutrient levels were found satisfactory.

In some work, various waste materials mixed with organic debris were tested for greening applications in urban environments as an alternative to the consumption of natural resources, such as the SITERRE research program (Yilmaz et al., 2018). This program supported by the ADEME selected eleven wastes, according to their availability and production in France and their potential fertility (Rokia et al., 2014; Vidal-Beaudet, 2019). Rokia et al. (2014) studied the creation of soils adapted for urban greening in 2014, it resulted that there are two types of mixtures in order to create two types of horizons: growing materials with high physical and chemical fertility due to high water infiltration

and storage capacity, or structural materials which are less fertile but dispose of satisfying bearing and water drainage capacities (Yilmaz et al., 2018). In the experiment of Yilmaz et al. (2018), hydrodynamic properties of soil - solute transfer, evapotranspiration, plant water supply - are studied as they are not often addressed usually but quite useful for stormwater management. This was part of the SITERRE program, creating soils that can offer critical functions for a better urban ecosystem: fertile support for the vegetation, water storage for the plants, resources in nutritive elements such as phosphore, filtration of pollutants filtration, erosion withstanding, human activities support, etc. (Vidal-Beaudet, 2019). On two sites were tested the implementation of constructed soils in order to grow trees and lawns and support light traffic (Yilmaz et al., 2018). Growing material technosols are created thanks to brick manufacturing waste and composted sewage sludge and green wastes. Structural material soil was made of excavated coarse mineral material. Yilmaz et al. (2018) concluded that vegetation such as trees and lawns could indeed be supported by technosols made of recycled artefacts. In addition, these affect positively the water infiltration and retention ability of the soils and they improve their chemical properties. They affirm it is important to implement organic material and to cultivate or to compost wastes previously to integrate them to soil, as “mixed waste materials need a specific time period to form a stable structure” and they also need time for the pedogenesis (soil formation, aggregation) to be done and to develop behaviours similar to natural soil (Deeb et al., 2020). Another study also using recycled waste from the city to develop technosols demonstrated that their fertility level could be very high, even in comparison to natural soils (Fabbri et al., 2021). Gonçalves et al. (2022) demonstrated that using technosols allows to recover degraded areas such as brownfields, and to obtain a faster recovery without any other type of intervention. The engineered soil showed a similar behaviour as a natural soil, with regard to structuring, settlement and subdivision.

In a review about Technosols for GI implementation, Deeb et al. (2020) give recommendations to reach a certain quality of the constructed soils. These characteristics are presented in the table 1 below, though they are more or less important depending on the intended functions of GI.

Characteristics required	Aim/Impact
Adapted chemical fertility	Suitable for specific GI
Sufficient soil depth	To support vegetation anchorage
Low concentration of contaminants	To respect standards depending on the use of GI: health risks and land use
Bearing capacity	For traffic, trampling or parking
Permeability	For water infiltration (to limit floods)
Sufficient water storage capacity	To support vegetation without the need of an irrigation system
Low bulk density and shallow root system depth	For some specific substrates used on buildings such as green roofs
Stable soil structure	To limit erosion and dust respiration
High hydraulic conductivity	For efficient stormwater management systems
Moderate ratios of mineral and organic content (maximum 30% of organic matter)	To avoid loss of organic matter by oxidation or leaching which can change soil volume

Table 1: Characteristics for efficient Technosols constructed with green infrastructure implementation purposes, based on the work by Deeb et al. (2020)

The same review addresses the need to assess the properties of waste before to use it for constructing technosols in order to allow living organisms to colonise the soil (Deeb et al., 2020), and they recognize the relevance of using construction and demolition waste mixed with organic waste, as well as mixing waste formulations and plants. It is important to mix mineral and organic material to create complexes with the ability to become a reserve for nutrients. Mineral material disposes of a high pH and a high bulk density, whereas organic material is recognized for a high water and nutrient availability (Rokia et al., 2014). Scientists raise the awareness about the necessity to consider every element in designing technosols: "ratio and composition of waste, order of horizons, environmental conditions, choice of plant species, implementation methods, need to foster pedogenic processes" (Deeb et al., 2020).

A summary of waste materials characteristics that need to be acknowledged for constructing Technosols can be found in the Table 2 below.

<table>
<tr><th></th><th>Types of waste</th><th>Characteristics</th></tr>
<tr><td rowspan="6">Mineral materials</td><td>Acidic earth material</td><td rowspan="2">High water storage capacity
Poor in nutrients</td></tr>
<tr><td>Basic earth material</td></tr>
<tr><td>Bricks</td><td>Low mechanical properties
Bringing clay and thus creating a surface for exchanges with nutrients
Satisfactory porosity</td></tr>
<tr><td>Crushed concrete</td><td>Better porosity which enhances vegetation rooting
High bearing capacity</td></tr>
<tr><td>Demolition rubble</td><td rowspan="2">High bulk densities
Adequate geomechanical properties for structural soils</td></tr>
<tr><td>Track ballast</td></tr>
<tr><td rowspan="5">Organic materials</td><td>Compost</td><td rowspan="2">High porosity
Increase phosphore and azote concentration
High biomass production</td></tr>
<tr><td>Green wastes</td></tr>
<tr><td>Paper-mill sludge</td><td rowspan="3">Hydraulic conductivity
Water retention capacity
Potential of organic matter decomposition thanks to fungal and bacterial activities</td></tr>
<tr><td>Street-sweeping wastes</td></tr>
<tr><td>Sewage sludge</td></tr>
</table>

Table 2: Characteristics of waste materials for engineered Technosols, based on the works from (Pruvost et al., 2020; Rokia et al., 2014)

Different mixes have been tested for different types of GI or in general greening purposes (Deeb et al., 2020; Pruvost et al., 2020; Vidal-Beaudet, 2019; Yilmaz et al., 2018). Here are some of the highlights coming as a result of these studies:

- Materials should be a mix of mineral and organic wastes (Deeb et al., 2020; Pruvost et al., 2020) ;
- Coarse grain sized wastes should be crushed (Rokia et al., 2014) ;
- Concrete and bricks have a satisfactory behaviour for urban trees planting, especially if mixed with e.g. compost (Pruvost et al., 2020) ;

- ❖ Green waste compost increases biomass production but should not be used at a higher rate than 20 or 30% (Pruvost et al., 2020) ;
- ❖ Excavated material from deep soil horizons should be mixed with crushed concrete and green waste compost as "acceptable results were obtained for both survival and growth" thanks to this substratum (Pruvost et al., 2020) ;

A study led in Vienna also consisted in modifying excavated soil material in order to create a living soil for green infrastructure applications such as turfgrass and green roof (Minixhofer et al., 2022). The authors used excavated materials from a construction site and used them as vegetation and sub-base layers in the soil profile, which represent the 30 to 40 first centimetres. In addition, they used, like Maienza et al. (2021) did, an irrigation system. They monitored the soil to assess its plant growth and structural stability: it was again proven efficient. The interesting element about this work is that they consider the engineered soil during its whole life cycle, and examine the idea of excavating it too and reusing it in other projects, hence introducing a circular soil concept as they name it.

2.2.2.2. Raising initiatives for reusing wastes in Technosols

- *A valorisation platform*

According to the fact that constructed soils coming from recycled waste were proven efficient for urban greening, circular initiatives are rising at a territorial scale. In Lyon's metropolitan area was born the project "Terres Fertiles 2.0", which is a partnership between private and public actors - landscape planning companies, soil experts, landscape and building actors, green waste producers and local authorities - to create a soil recycling platform. The project leaders - landscape planning companies - observed that fertile soil resources were becoming scarce instead of an increasing demand for urban greening - around 100 000 cubic metres of topsoil are used every year for urban greening on the territory - and that thousands cubic metres of excavated material from this region were evacuated although they could be reused. The idea is to recycle this material to transform it into a fertile substrate that could be implemented in the planning projects within the metropolis. A schematic representation of the initiative can better explain the process, which is based on the circular economy theory (figure 8). Private and public projects within the Grand Lyon often generate non fertile earth surpluses which, if they are non-polluted, can be delivered to the Terres Fertiles platform and classified according to their nature - e.g. clay, sand, limon. They are stored on the site and treated to be revitalised or fertilised thanks to the input of green wastes. These composted materials are composed of the biomass collected from the collectivity wastes. Fertile soil is then created and sold for the implementation of nature in both private and public planning projects on the territory. This initiative can appear similar to the Circular Soil Concept of Minixhofer et al. (2022), in the extent that we easily see it as a circular approach too.

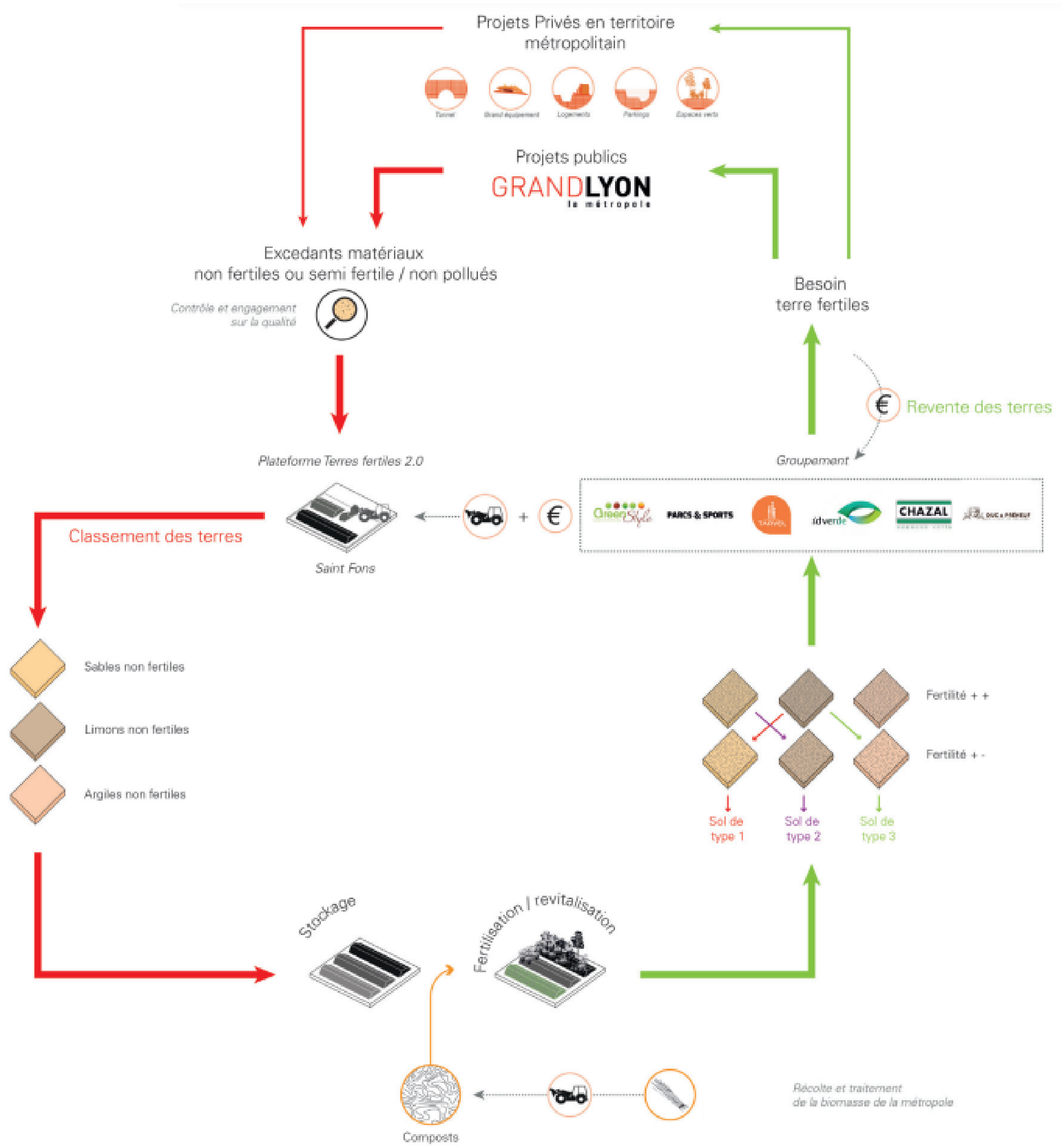

Figure 8: Concept of the recycling platform "Terres fertiles 2.0"
Source: Terres Fertiles 2.0 (2017)

The platform receives non-polluted excavated soil coming from both private and public construction sites after it is controlled to verify if it meets quality standards (figure 9). Then the material is treated - which means mixed with green wastes when non-fertile - or stored on the platform before being used for the creation of different fertile soils which are implemented on project sites. This project was raised after a call for projects but was later abandoned. The project leaders thus modified their initiative and transformed the platform into an engineering company which identifies the potential of excavated valorisation material within construction sites, to direct them towards sites that need materials with a certain agronomic quality.

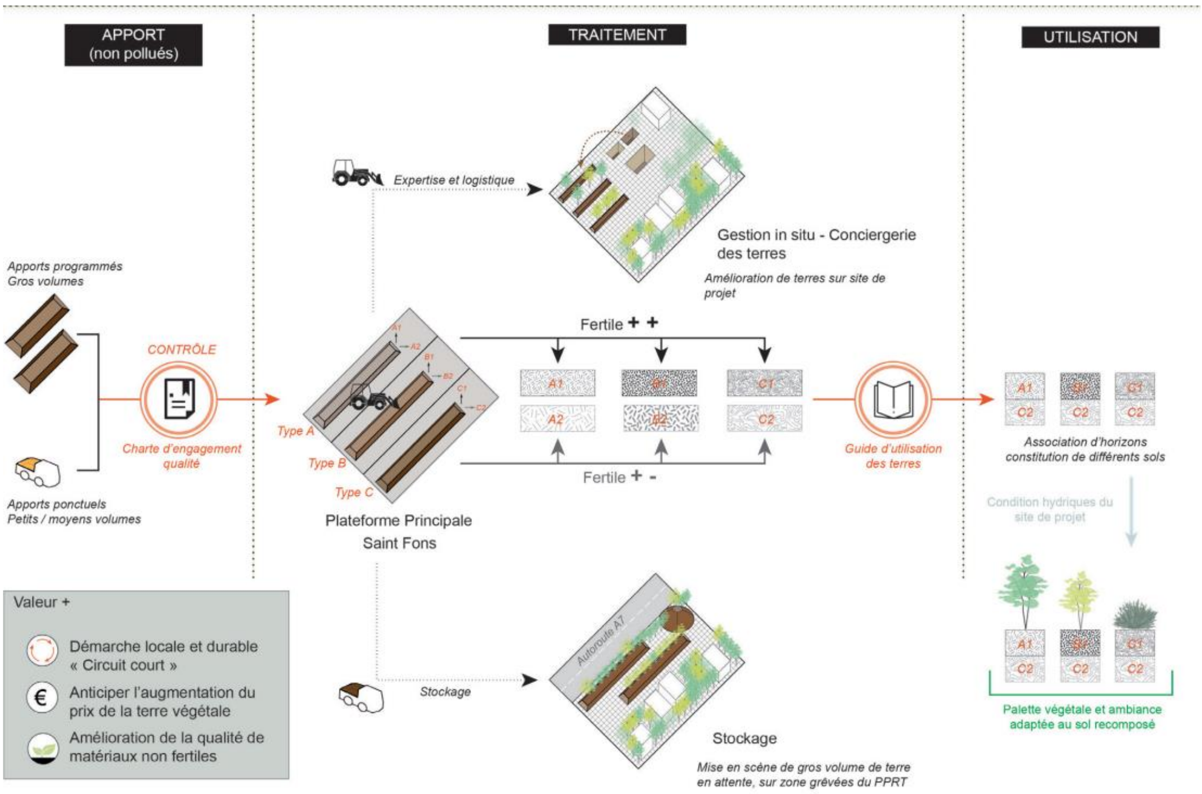

Figure 9: Process for topsoil recycling
Source: Terres fertiles 2.0 (2017)

- *One SCE's initiative*

The engineering company SCE coordinated the Gratte-Terre project in Villeurbanne, nearby city of Lyon, within the framework of which they could test creating technosols. It is a place of experimentation where they try to develop urban agriculture, soil renaturation and sustainable water management. In 2019, the SERL - a semi-public company working for urban planning in the metropolitan area of Lyon - called for projects to temporarily occupy an urban brownfield which is intended to become a neighbourhood. The brownfield area is about 1000 square metres and the occupation will last four years. Two objectives are willing to be met with this project. The first one is to form a fresh island in the heart of the Gratte-Ciel district, by constructing living soils in this densified urban area and creating an urban plant nursery. On the second plan, the idea is to form a place of collaboration to meet and learn. Indeed, different initiatives take place on the site: one pedagogic garden which is self-managed by inhabitants and the group called "Gratte-Terre", fertilisation of construction debris through plant coverings, integrated management of stormwater, realisation of a tree nursery from seeds coming from trees located maximum 500 metres away. Most of the materials used for urban agriculture come from construction waste and are thus reused. Half of the soils come from construction debris from Lyon's region. For the growing site area, fertile topsoil is entirely made of materials taken from reusing deposits in the region.

This idea of fertilising on-site construction debris can be replicated in urban planning projects such as ZACs, which are planned for many years. This kind of project has the advantage of disposing of available land for numerous years (at least 2 years) to bring back fertility to soils as well as matching with the operation programme. This could also allow an anticipation of the future uses of the soils.

3. A NEW OPERATIONAL METHODOLOGY

3.1. Tools that already exist: guides from the ADEME and the French ecological ministry

It is often engineering companies which are in charge of the technical conception of public spatial planning projects. But they often face difficulties when it comes to implementing urban nature as they do not know how to manage soils and their fertility for vegetation growth. Below is presented a methodology based on scientists recommendations and actual guides from French ministries in order to sustainably manage soils for urban greening (Figure 13). The idea is to use a systemic approach which permanently ensures that the planned uses of the site are meeting soil functions.

To establish a new operational methodology guiding the planning actors for a sustainable soil management in the implementation of urban greening, the approach was based on existing documents - guides, methodologies and expertises - published by French national organisations. First of all, the Ministry of Ecological Transition and Solidarity edited two guides in 2020 for the valorisation of excavated material coming from potentially contaminated soil and sites - or coming from non-contaminated soil and sites - within spatial planning projects. Both guides rely on the national methodology for managing contaminated soil and site from 2017, which is introducing an approach for the characterization of pollution sources - through historical or documentary studies, specific studies and diagnoses, field surveys - and the identification of the issues to be protected and preserved. Moreover, it is giving the different choices available for soil treatment and de-pollution and the step for the conception of management plans. The two guides presented above are the reference for what is relating to off-site valorisation of excavated material in the framework of planning projects, in accordance with the waste nomenclature from April 25, 2017. They hence apply to excavated material, for which the use in urban planning is proven useful, in order that those projects are not only considered as a substitute for landfilling. The elements addressed are only treated under environmental and sanitary angles, and do not mention geotechnical aspects or construction of fertile soils.

Another document which was useful for creating the methodology is a guide elaborated from the national geological service (BRGM) in association to the Ministry of Ecological Transition and Solidarity. It is called the guide for the characterization of excavated material within the framework of their off-site valorisation in spatial planning projects and for transport infrastructure uses (Coussy & Dubrac, 2020). It comes as a complement to the previously-mentioned guides and addresses the approach to identify the excavated materials and the valorisation zones on the receiving site.

Finally, we used an expertise report from the ADEME about the stakes of regenerating brownfields and the assessment method for the ecological rehabilitation of degraded soil (Taugourdeau et al., 2020). It is addressing the links between the stakes of soil ecological restoration, the assessment of restored soils functions and the assessment of related ecosystem services, all of this integrating the regulatory aspects relating to excavated material inputs as well as the national methodology for the management of contaminated soil and sites. The document is based on the feedback from an experiment on a pilot site, and establishes an agronomic, physico-chemical and biological diagnosis of soils. It is reporting the improvement of restored soil functions after setting up technical solutions for its ecological regeneration. It is clearly mentioned in this guide that no document with environmental recommendations for soil building projects is existing to this day, and

that such a guide could rely on the approaches from the guides mentioned above and add technical specifications about the sustainability of the installations and their traceability. They mention it should refer to both environmental and rural codes.

All those guidelines were built on actual French norms about soil quality, but they stay general as they do not focus specifically on reusing excavated material in fertile soil construction for urban greening purposes. The idea of the actual guide is to combine all existing specifications to create an approach which is easily applicable and replicated by every stakeholder concerned. It is supposed to give recommendations about the other actors to involve, the tools to mobilise. Particularly, this approach is focusing on the reconstruction of fertile soils - technosols - using excavated material or private and public wastes to grow urban nature within spatial planning projects.

3.2. Towards a new approach

3.2.1. Step 1 - A complete preliminary diagnosis of existing soil

The first critical action to take when we imagine a planning project is to establish an entire diagnosis of existing soil (Figure 10). This should be done during the preliminary study and diagnosis phases according to the "loi MOP". These phases include the first studies to identify the characteristics of the site to have a better knowledge. Indeed, when a collectivity decides to launch a spatial planning project, it often uses the expertise of a private cabinet which has the technical skills to organise it and actually make it happen. This kind of contract is directed by a famous law in France: "Loi MOP". The law n°85-704 from July, 12th 1985, called "MOP" for "Main d'Œuvre Privée", organises the relationships between the project ownership, also known as "MOA" - e.g. municipality, metropolis - and the project management, known as "MOE" - e.g. private engineering company. According to this law, the MOA has to set precisely the objectives for the operation and the needs that are required to be satisfied, all kinds of constraints - social, architectural, functional, technical, economical, landscape integration and environmental conservation. This law also defines the different phases of such projects. The first phase within the presented approach consists of two steps.

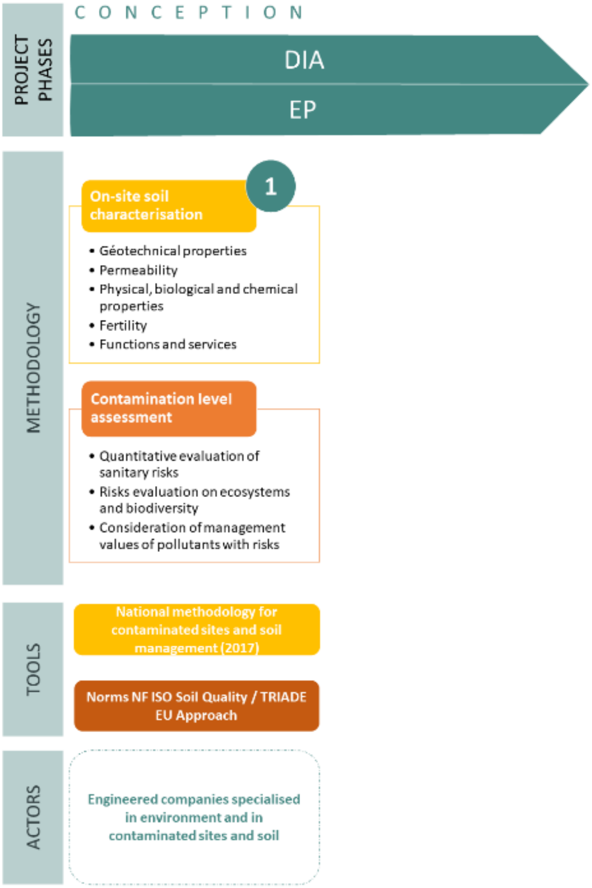

Figure 10: Step 1

3.2.1.1. Pollution consideration

First, it is necessary to assess the contamination level of soils, according to the French national methodology for contaminated soil and sites management (2017), which means carrying out a quantitative assessment of sanitary risks and taking into account threshold management values for pollutants that present sanitary risks. The site could be a former industrial site which became a brownfield. It is also mentioned to evaluate the risks that can affect ecosystems and biodiversity as referring to the Norm NF ISO 19 204. This norm provides the French site-specific ecological risk assessment procedure for soil contamination which relies on the european TRIADE soil quality approach. Planners should use the services of a specialised engineering office, which is certified in the field of polluted sites and soils whenever possible (Taugourdeau et al., 2020).

3.2.1.2. Soil characterisation

Then it is important, early in designing the project, to characterise the existing soils according to their agronomic and geotechnical properties, their permeability, and their fertility (physical, biological and chemical properties). It is essential to integrate soil preservation as one of the main goals of the projects. There could be issues that rely on their maintenance: we must therefore be attentive to them and identify them. For example, relocating certain soils could endanger ecological continuity and the survival of century-old trees that provide many benefits. Indicators must be chosen, according to the future usage of the site, in order to obtain the characteristics needed. Table 1 from the previous section could be useful for choosing indicators. Besides, it was recommended by Blanchart et al. (2018) to make soil quality assessment on large geological pits, of minimal 1 metre deep, 1 metre large and 1.5 metre long.

3.2.2. Step 2 - A cartography as a decision support for the project's adjustments

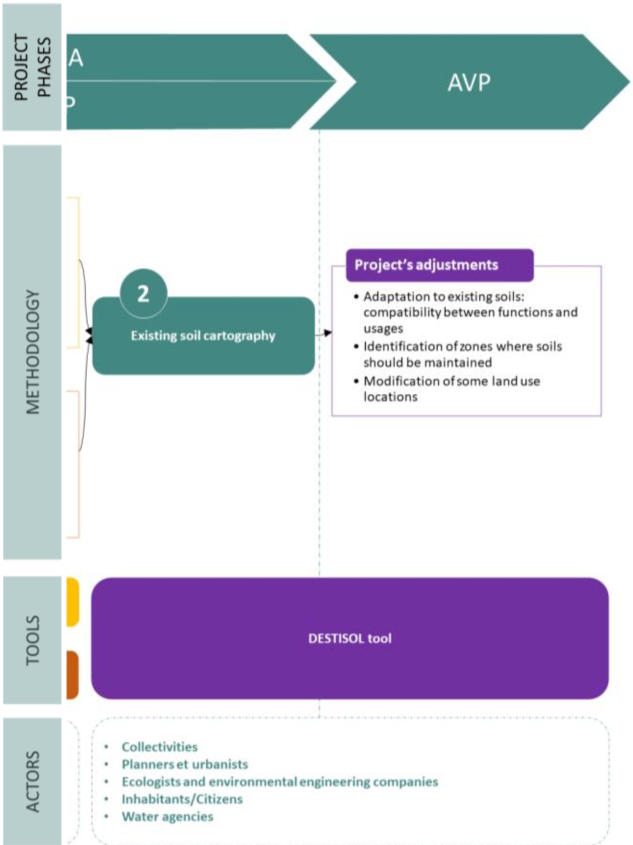

Figure 11: Step 2

Thanks to the previous step, a soil cartography of the site should be established with soil characteristics and contamination levels (Figure 11). Based on this graphical representation of the site, all actors should get mobilised and consulted to discuss the project. It should make possible the identification of the zones which must be conserved, the uses that need to be relocated, or the soils that could be modified. In the following project phase, the AVP[9] - for "avant-projet"-, they can therefore come up with adjustments to the project and optimise the services or functions that the soils provide, similar to what is done with the aforementioned DESTISOL tool. Actors involved should be: planners and urbanists - for the stakes related to e.g. densification -; ecologists or environmental engineers - bringing up expertise regarding ecological continuity and soils as a biodiversity habitat -; inhabitants - as they have specific needs to improve their comfort and well-being, as they often request leisure and recreational spaces -; water agencies - because they can help with stormwater management issues and they can provide subventions -; local authorities - they are the ones who define the general objectives of the project. This update should result in a clear representation of the new outlines of the project. The answer to the following question has to be clear: is soil quality there adapted to the planned land use?

[9] Project phase which aims at the first dimensioning of the project.

3.2.3. Step 3 - Choosing a management method

Answering the previously asked question should help to choose a soil management method (Figure 12). This takes place within the next phase which is the PRO for "project". It is used to finalise the project and set an overall schedule.

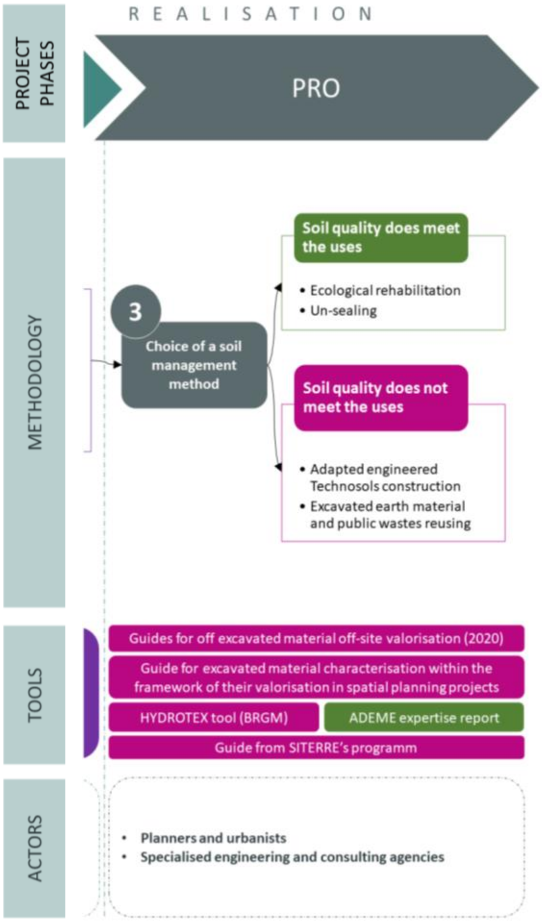

Figure 12 : Step 3

3.2.3.1. When soil quality does meet the uses

In case the soil functions are meeting requirements for planned land use, then we can decide to only use ecological engineering to give soils a better fertility. The idea is, as the Valorhiz company did within the BIOTUBES project, to mechanically de-compact soil, and to improve its fertility thanks to the input of organic matter such as green waste compost, which will result in an increase of biomass production (Taugourdeau et al., 2020). If the topsoil material is impermeable, we must depave it to perform un-sealing. A supply with living organisms and organic material alone will allow the substrate to grow vegetation better.

3.2.3.2. When soil quality does not meet the uses

In the opposite situation, which is the case where soil characteristics do not match the future usages of the site, we can create adapted engineered Technosols thanks to waste recycling, as it was presented in the second part of this report. These techniques of soil construction are part of pedological engineering. Nowadays, the valorisation of excavated material and wastes is very often considered rather than automatically thrown away. Indeed, as it is reminded by the article L. 541-1

from the environmental code, all reusing options should be considered before sending wastes to an authorised waste treatment installation or disposal facility.

But attention should be paid when recycling wastes and excavated materials in order to create Technosols. We must identify the required materials, by taking into account the needs for efficient mixtures and considering the scientific recommendations mentioned earlier. We must evaluate the available resources from construction debris or public wastes within the local territory. Searches can be made on on-going construction sites as they may dispose of interesting resources. We have to pay attention to the location of those construction sites, as well as to their program compared to the receiving site's planning calendar. It is important to take into consideration the available volumes of material, but especially their quality. The guides for excavated material valorisation insist on the fact that no polluting substances or invasive species should be brought from input materials to the receiving site (MTES, 2020). We must identify pollutants individually to verify the levels according to legal thresholds. This is why the policy framework is really important. According to the guide from the French geological service, three conditions must be respected:

- Excavated materials show compatibility with the future uses of the site;
- Bringing materials does not affect the receiving site's soil quality or its ecosystems;
- Neither does it affect the water resources.

A tool was by the way designed by the BRGM with regards to the last condition, in order to evaluate the contamination of groundwater when valorising excavated earth material. This is the HYDROTEX tool, a calculation sheet which ensures the water resource quality preservation during the excavated material valorisation operations. It calculates the future concentration of pollutants in groundwater at some distance from the receiving site, based on the measured concentration in the input materials. Another critical aspect for excavated material and waste recycling is their traceability. A tool was set up according to the national decree 2021-321 from March 25, 2021: TERRASS. It defines the obligations to which the actors are subject when they excavate material or create wastes and when they intend to reuse them on other sites. They have to register material's information on databases, which afterwards is useful to determine if the recycling operations are presenting risks for receiving soils.

3.2.4. Step 4 - A long-term monitoring of soil behaviour

After considering all of this, the actual realisation can begin. But lastly, to ensure that green spaces are really developing over those new fertile substrates, we recommend monitoring their physical and biological properties, months and years after their construction (Figure 12). The efficiency of the management techniques has to be verified, in a way that the strategies can be afterwards adapted and optimised. We can carry out an agronomic analysis and observe characteristics such as water retention capacity, pollution evolution, microbial and enzyme activities, development of nematodes. We can also verify their technical properties: grain-size distribution or pore volume, structural stability. Help from specialised engineering companies will probably be welcome, as they might have developed surveillance programs.

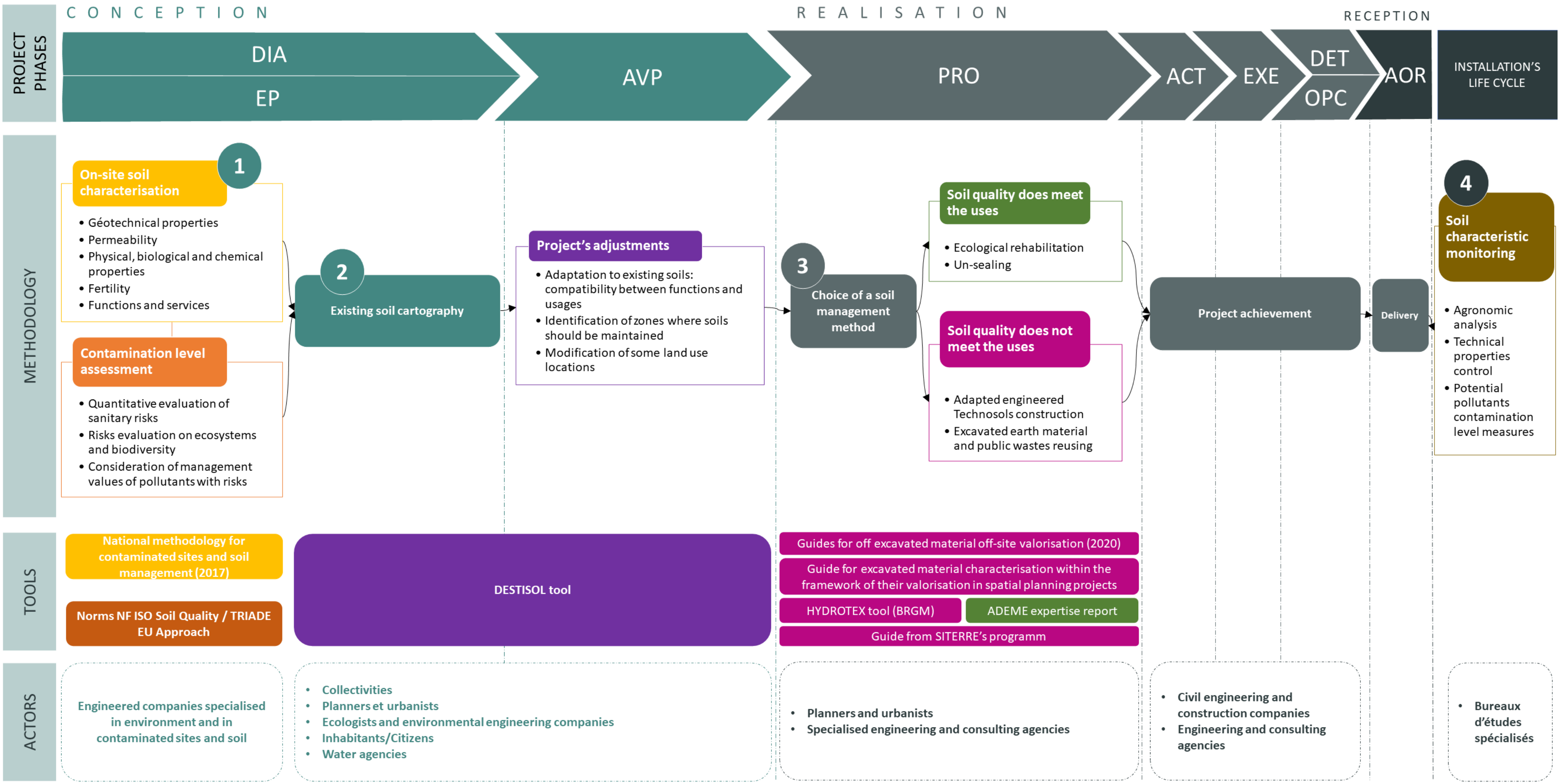

Figure 13: The entire methodology for a sustainable soil management approach in urban greening

CONCLUSION

To conclude, the sustainable management of fertile soils is critical for the deployment of urban nature, which has become a major issue for the health and well-being of the population, as well as for the preservation of biodiversity and the fight against climate change. Soils play a fundamental role in plant growth and contribute to improve air and water quality; through all the services and functions they provide. However, urban soils are often degraded because of anthropogenic activities, with urbanisation leading to an intensive use and systematic artificialisation. It becomes therefore necessary to find sustainable management techniques to preserve them further.

This state of the art has shown that awareness about the importance of soils and their functions is rising and that their preservation is increasingly integrated into planning policies. Consequently, the research carried out shows that this issue is becoming an important concern in the sphere of both planners - through the development of initiatives and tools for soil optimisation - and scientists – through numerous studies and experimentations. New techniques are emerging and proved efficient for urban greening, such as ecological soil rehabilitation, unsealing, or the construction of engineered Technosols adapted to the intended use, coming from the recycling of construction materials or wastes.

The methodology elaborated in the last section of this report is aiming to give a general view of most of the means, techniques and tools that the project actors can mobilise when they want to implement green infrastructure within the cities of France. While this approach is supposed to provide a general framework to be replicated, it is necessary to acknowledge that every local context is unique, possesses its own specificities and thus may require adjustments to the methodology. Cooperation and concertation between all planning actors are definitely primordial to turn towards a more sustainable soil management and to address the numerous issues simultaneously, such as rainwater management, urban greening, roads construction. Soil is a fundamental element in our ecosystem and hence deserves attention. This is why we need to foster research and experimentation in this field to find even more ways to optimise its services and to develop the ability to adapt to local conditions.

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2022-2023

WHICH SOIL MANAGEMENT TECHNIQUES FOR URBAN GREENING PURPOSES? Alternative solutions to imported topsoil to restore urban soils fertility: towards a new operational methodology.

Abstract: The soil quality management for urban greening purposes has become a great issue in urban planning. Population in urban areas is constantly increasing, driving urban sprawl and thus soil degradation. At the same time, the demand for green spaces within the cities rises with the awareness of the number of services they provide. Nevertheless, these two effects together lead to challenges as the weathered soil quality is not satisfactory enough to grow urban nature. This report aims at reviewing the necessity to preserve urban soils and the different techniques currently used to tackle those issues. New innovations allow the creation of fertile substrates without having to import topsoil retrieved from peri-urban agricultural land. A global approach is also presented and highlights the necessity of cooperation between all actors, the consideration of soil functions within planning projects and the monitoring of soil behaviour to assess the efficiency of the chosen management technique.

Keywords: excavated material, green infrastructure, sustainable soil management, unsealing, urban greening, Technosols