

Incorporating soil ecosystem services into urban planning: status, challenges and opportunities

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Abstract

Context Traditionally soils have not received much attention in urban planning. For this, tools are needed that can both be understood both by soil scientists and urban planners.

Purpose The purpose of this paper is to enhance the role of soil knowledge in urban planning practice, through the following objectives: (1) identifying the role soil plays in recent urban plans; (2) analysing the ecosystem services and indicators used in soil science in an urban context; and (3) inferring the main challenges and opportunities to integrate soil into urban planning.

Methods Seven urban plans and reports of world cities that include sustainability goals were analysed using text-mining and qualitative analysis, with a critical view on the inclusion of soil-related concepts. Secondly, the contribution of soil science to urban planning was assessed with an overview of case

studies in the past decade that focus on soil-related ecosystem services in urban context.

Results The results show an overall weak attention to soil and soil-related ecosystem services in the implementation and monitoring phases of urban plans. The majority of soil science case studies uses a haphazard approach to measure ecosystem service indicators which may not capture the ecosystem services appropriately and hence lack relevance for urban planning.

Conclusions Even though the most urban plans assessed recognize soil as a key resource, most of them fail to integrate indicators to measure or monitor soil-related functions. There is a need to develop soil-related ecosystem services that can be easily integrated and understood by other fields.

Keywords Soil · Ecosystem services · Urban planning · Sustainable development · Integrated planning

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Introduction

Cities are important economic, social and cultural hubs characterised by continuous population dynamics that lead to a multitude of pressures and impacts that need to be managed by the local governments. These dynamics impact on land use change and,

therefore, keep presenting challenges to urban planners and policy makers, in particular, the integration of environmental aspects with the new urban areas (Hurlimann and March 2012). Such problems are exacerbated by the United Nations estimation of an increase in the global population of 2.5 billion people by 2050 (United Nations 2014). Even though 90% of the estimated increase in population is projected to be concentrated in Asia and Africa, recent studies show that urban growth is likely to continue to be relevant on all continents due to migration to bigger cities (Lauf et al. 2016). Considerable soil sealing is already taking place (Seto et al. 2011) leading to environmental concerns such as loss of agricultural area (Gardi et al. 2014) or loss of infiltration areas (Di Sun et al. 2018). Many of these concerns are soil-related, and may affect achieving the Sustainable Development Goals (SDG's) in urban areas. The ecosystem services concept is gaining considerable traction for studying these human–environment interactions in an integrated way.

Ecosystem services (ES) are understood as the benefits that humans obtain from the environment (Millennium Ecosystem Assessment 2003). Addressing the SDG's in urban areas necessitates a combination of socio-economic and environmental monitoring tools. ES can serve as the framework to achieve that combination. Despite increasing interest to use the ES concept as a means to transfer knowledge from environmental sciences to decision makers and planners (Haase et al. 2014), only initial steps have been taken in studies/plans to do integrated assessments on the links between urban functionalities and environmental aspects (Guerry et al. 2015). Examples of urban environmental challenges that could benefit from integrated ecosystem service assessments are water retention and regulation (Stürck et al. 2014), climate regulation (Ghaley et al. 2014) or biomass production (Larondelle and Haase 2012). Soils play a crucial role in providing these urban ecosystem services (Setälä et al. 2014; Morel et al. 2015). Soils are one of the hot topics in recent environmental scientific literature and, at the same time, one of the most unknown natural resources for civil society (Baveye et al. 2016; Keesstra et al. 2016). The integration of soil knowledge into planning practice is still a challenge, in particular in urban areas where sustainable soil management measures are often not or

not fully integrated in planning strategies (Artmann 2014).

One area where integration of soil knowledge could help urban planning is in considering the role soils play in water cycle regulation, a function that gets lost when soils are sealed (McGrane 2016). Exploiting this role of soils will become increasingly important as climate change exacerbates current issues, for example it is expected that precipitation events become more intense, resulting in floods in residential areas with large impacts (McGranahan et al. 2007). Such prospects require a complex management of environmental resources, hence magnifying the need for integrated planning. Spatial planning can be understood as the “decision-making process aimed at realizing economic, social cultural and environmental goals through the development of spatial visions, strategies and plans and the application of a set of policy principles, tools, institution and participatory mechanisms and regulatory procedures” (UN-Habitat 2015). Therefore, urban planning in this article refers to the planning of a spatial/geographical unit, with a focus on the urban/city scale.

The 17 Sustainable Development Goals (SDG's) of the United Nations include three goals that have a strong focus on cities and functions of soil. The goal “Sustainable cities and communities”, “Responsible consumption and production” and “Life on earth” are linked to a better management of soil (van Haren and van Boxtel 2017). While decision-making at national and international level is important to prioritize and set sustainable development goals, the local and regional scale are critical in achieving those targets. Regional and urban planning needs to integrate sustainability goals into local policies and priorities, and therefore requires not only strategic targets but also working with concrete local characteristics (Wilson 2006).

Soil scientists have in the past decades promoted the critical importance of soil in solving global issues such as food security or water scarcity (Mol and Keesstra 2012). However, many more efforts still need to be made to better transfer the knowledge acquired on other benefits of soils to society (Lang et al. 2012; Keesstra et al. 2016). There is already an extensive knowledge on the properties and performance (in terms of productivity) of soil and more recently many advances have been made regarding the development of soil ecosystem services frameworks (Dominati et al. 2010; Schwilch et al. 2016). However, there is a

limited knowledge transfer of soil-related ES into urban planning practices (Gómez-Baggethun and Barton 2013).

The main goal of this paper is to address where and how urban planning and soil science communities can be complementary and learn from each other. In particular, this paper focuses on reviewing and assessing the status, challenges and opportunities of soil in the urban context. It addresses the following research questions: (1) What is the role of soil in urban planning?; (2) What is the state-of-the-art of ES in soil knowledge transfer into urban planning?; and (3) What are the main challenges and opportunities to integrate soil into urban planning? The first research question is addressed by an in-depth review of the role of soil in seven case studies of recent sustainable urban planning strategies. This review seeks to identify in what contexts (if any) soils are mentioned in the plans. We deploy both quantitative data mining and qualitative assessment approaches to consider the relative importance of soil as an environmental resource in urban plans as well as better understand the context in which reference is made to soil. The second question is addressed with a focused literature review on soil-related ES frameworks and an inventory of case studies into soil-related ES assessment in urban areas. Based on the results from questions 1 and 2, the last question is addressed by compiling the level of attention to soil and soil-related ES in plans, across planning phases, ES covered and relevance of indicators, and identifying opportunities to create better links between soil science and urban planning.

The role of soil in urban planning

The urban planning context

Urban planning is essential for the development of cities and urban communities because it is the technical and political process concerned with the future development and use of land (Savery and Chastel 2009). Up until late in the 20th century, planning practices focused mainly on urban functions, such as development of industrial areas and infrastructure (Simmonds and Hack 2000). Green areas were seen as vital for the population, but they were regarded by urban planners as an urban feature, mainly for recreational purposes. As such, traditionally, there

was a focus on urban functionality and less on environmental aspects. An exception was the Garden Cities movement, in the beginning of the 20th century, which intended to focus more on integration of green areas and their wider benefits for urban residents. However, as a theory, it was not widely used amongst the planning community (Clark 2003).

Since the last decade of the 20th century, urban planning suffered structural changes in the planning theories that lead to disruptive changes (Friedmann 1998). The United Nations Conference on Environment and Development, in 1992, contributed to a change on the world perspective on the importance of the environment and its natural resources (Campbell 1996). This conference also had a big impact on planning, not only on the definition of sustainability goals but also on the tools and processes used. Yet, even though there has been an increased focus on environmental performance indicators, there is still a paucity of knowledge about soils in an urban context (Artmann 2014). In summary, planning is historically targeted at the socio-economic functions cities provide (Scott 2001). Due to this emphasis, environmental considerations received less attention. We hypothesize that this is one of the reasons that has led to a weak linkage with soil.

An initial approach: text mining

Planning theories are moving towards a better integration of sustainable development goals into urban planning practices, which has led to an integration of natural resources into planning. Reports and urban plans are the main tools in urban planning, but, due to their local and goal-specific nature it is difficult to compare different case studies. To tackle this question we made a selection of seven recent urban planning reports (Table 1) that include sustainable development targets and identified soil-related topics. The reasoning for the selection of the case studies was: (1) Location—to provide a wide coverage and understanding, at least one case study from each continent, except for Antarctica; (2) Relevance—cities with size, history and relevance that are also a role-model within a (inter)national context; (3) Goals—Reports or plans that focus on sustainable development goals for the city; (4) Accessibility—data and language accessibility by the authors; and (5) Time frame—not older than 10 years.

Table 1 Identification of the urban plans used as case studies

Plan	City	Continent	Pop. (1×10^6)	Year
Sustainable Sydney 2030	Sydney	Australia	4.9	2014
Plano Diretor de Ordenamento Territorial do Distrito Federal	Brasília	South America	2.9	2009
The London Plan	London	Europe	8.6	2016
Cape Town Spatial Development Framework	Cape Town	Africa	3.7	2012
Urban Development in Tokyo	Tokyo	Asia	13.6	2011
Ontwikkelingsbeeld 2040 voor de Metropoolregio Amsterdam	Amsterdam	Europe	2.4	2007
Strategic Plan 2015–2020	Boston	North America	4.6	2015

An initial overall assessment of the content of the reports was performed by applying a text mining technique (RapidMiner 2016) to identify and rank the most frequently used words and expressions of each document (Table 2). From the assessment, it is clear that “land” and “water” are deemed important aspects for sustainable urban development given the consistent high rank of these words across all plans assessed (Fig. 1). Even though the words “land” and “water” are often used, there are fewer mentions of specific risks and opportunities related to soil. Furthermore, while mentions of water properties, such as “water quality”, are distributed evenly across the reports, attention to some words is much more skewed. The

word “food” has the most unbalanced distribution of the ranking and word count across the different documents, indicating that “food” might not have the same relevance in the future goals defined in each document.

The urban plans: in-depth description

To assess and discuss the role of soil across the selected urban plans in more depth, the information of each plan was analysed and grouped on five transversal topics: (1) Goals related with soil (functions or properties); (2) Soil references in the Appraisal section—i.e. the section where the current problems

Table 2 Assessment of selected urban planning reports based on text mining RapidMiner (2016)

	Boston Rank ^a	Cape Town Rank	London Rank	Sydney Rank	Tokyo Rank	Brasília Rank	Amsterdam Rank	Sum of ranks ^b
Water	3 (167)	2 (64)	2 (201)	1 (96)	2 (13)	1 (413)	1 (62)	12
Land	2 (508)	1 (437)	1 (255)	3 (26)	1 (75)	4 (29)	2 (17)	14
Flood (risk)/flooding	10 (10)	3 (27)	3 (103)	2 (63)	4 (1)	8 (1)	5 (6)	35
Soil	5 (80)	7 (2)	9 (3)	5 (3)	3 (5)	2 (174)	7 (3)	38
Food	1 (3328)	6 (9)	4 (41)	4 (12)	10 (0)	8 (1)	9 (1)	42
Food production	4 (111)	10 (0)	6 (4)	5 (3)	10 (0)	3 (36)	9 (1)	47
Water quality	8 (26)	7 (2)	5 (8)	7 (1)	10 (0)	6 (3)	5 (6)	48
Agricultural resources	6 (32)	7 (2)	10 (0)	10 (0)	10 (0)	10 (0)	5 (6)	58
Ecosystems	9 (24)	5 (20) ^c	9 (3) ^c	10 (0)	10 (0)	5 (22)	10 (0)	105
Natural resources	7 (28)	5 (20)	9 (3) ^c	10 (0)	10 (0)	10 (0)	7 (3)	105

^aRank of the words/expressions according to the word count within each document. In parenthesis the absolute number of words in the document is indicated

^bThe “Sum of Ranks” is the result of adding all rank values. Such approach allows comparing the relation between different words, e.g., the smaller the value, the bigger the importance in the overall ranking of the word

^cIn case of equal word count, both words obtained the same rank and the lowest of the two ranks was selected to ensure that words with no reference across the document were assigned a rank of 10

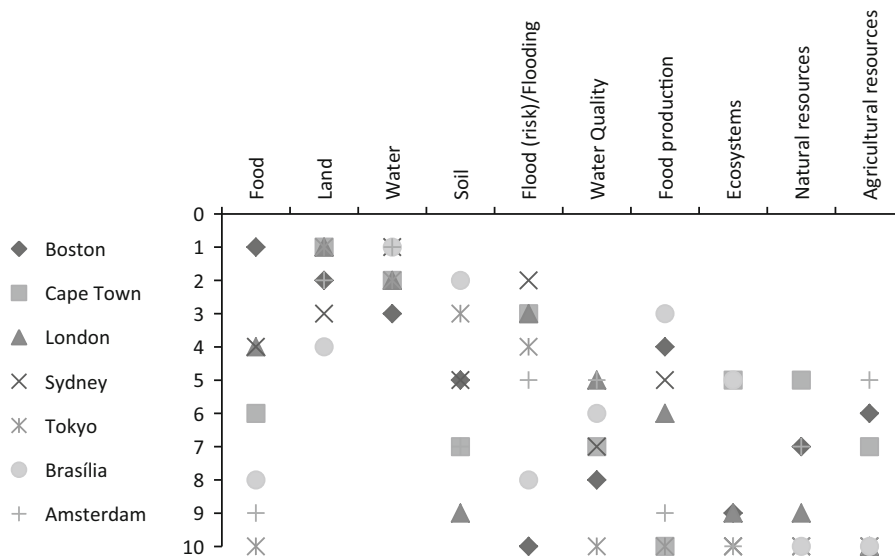


Fig. 1 Word count ranking distribution

are identified; (3) Soil references in the Plan section—i.e. the section where goals or concrete measures are proposed; (4) Soil references in the Monitoring section—i.e. the section where strategies to monitor the implementation of the plan are proposed; and (5) Monitoring indicators/ecosystem services proposed. Below is a brief description of the findings, presented for each city.

Sydney

The Sustainable Sydney 2030 plan was developed by the City of Sydney and aims to define a long-term sustainable strategy for the city. The scope of the plan is intended to be broader than just defining environmental goals by, for example, also defining community goals. The plan focuses on visions and goals, rather than concrete measures. One of the main goals of the plan is to turn the city of Sydney into “a leading environmental performer” and international reference, by tackling climate change mitigation and adaptation and assuring the quality of life for the population. The broad scope of the plan and the lack of concrete measures lead to weak references to soil.

Most of the references to soil are made indirectly, e.g. through proposed goals to create additional space for urban green and food production. There is a clear reference to the potential of using ecosystem service

indicators as a tool for climate change impact assessment. Ecosystem services are considered in the plan as a tool to assess environmental impacts, but as well as a tool to monitor the performance of the environment and wellbeing of the population. Some general indicators are suggested (cultural, social, environmental, economic and demographic) but are not proposed in detail; instead the report suggests developing them further in future annual reports. In the proposed measures, soil functions are mentioned indirectly, through the goal to increase areas to promote biodiversity and food production in and around the city of Sydney.

Cape Town

The Cape Town Spatial Development Framework has the main objective “to guide and manage urban growth, and to balance competing land use demands, by putting in place a long-term logical development path that will shape the spatial form and structure of Cape Town” (City of Cape Town 2012). This plan assumes that urban expansion is inevitable, so the main focus of the framework is also to integrate the urban expansion with the city’s needs in terms of economic, natural and social resources. The main goals are ambitious and supported by a vision—“Cape Town Vision 2040”—which make the goals very

broad. Soils are mentioned indirectly, e.g. “identification of areas suitable for new urban development based on the impact on natural resources”. The report has a clear focus on providing guidelines for the implementation of the “Vision 2040”, resulting in a very detailed description of measures to be implemented and a lesser focus on the current issues and future monitoring possibilities.

Soil is addressed in the report mainly indirectly, via its functions or implications, such as the contribution of impervious areas to increased stormwater runoff. When looking to the individual sections of the plan (appraisal, plan and monitoring) it is also possible to identify the lack of soil-related concepts or weak links between them. For example, the appraisal section refers mainly to water-related problems and drivers, such as water demand management, water quality or the implication of climate change in flood risk areas. In this section, soil is also indirectly addressed as a concern in urban fringe areas due to the loss of agricultural areas to new urban developments. In the plan section, there are many suggestions of measures to be implemented with the plan; notwithstanding, the link between the soil-related issues identified in the first part and the proposed measures is not always clear. For example, one of the proposed measures is “protect and enhance the city’s rural environment” and it is detailed as sub-measures “develop and manage rural gateways” or “rationalise and proactively manage smallholdings”; however, there are no guidelines or indications on the implication for the natural resources.

Tokyo

With a population of over 13 million people, Tokyo is a megacity and a metropolitan area with a major importance both in the Japanese context and internationally. The plan Urban Development in Tokyo has the ambition of “creating an attractive and prosperous environmentally-leading city that will serve as a model for the world” (Tokyo Metropolitan Government 2011). The focus throughout the document is, however, mostly on urban projects, such as detailing new urban development projects per district, and less on the environmental properties. In particular, soil is rarely addressed either directly or indirectly (soil-related functions), as the main focus of the plan is on the already highly developed districts.

The main soil-related references in the plan are in the general goals for the future of Tokyo: (1) Promotion of comprehensive flood control measures; (2) Greenery network; and (3) Water resources and effective use. However, despite the three goals defined, there are no further references to soil besides the proposed measure “creation of Green Production Districts”. This measure aims to protect identified areas with relevance for the city, mainly due to their scenic and recreational value. The document aims to present the main urban projects for the future of the city, and therefore lacks information on the actual environmental problems of the city and on future monitoring strategies.

Brasília

Brasília is one of the few megacities in the world that has had urban planning strategies since its beginning. It was planned to be the capital of Brazil and it has grown to be the fourth biggest city in the country with an estimated population of 2.9 million in 2016 (IBGE 2016). The Regional Spatial Master Plan (Governo do distrito Federal 2009) aims at defining the future urban strategies by promoting a sustainable use of the land functions and a balance between social, economic and environmental dimensions. Soil, as other natural resources, is within the overall target of protection and valorisation of the natural resources and heritage.

The Brasília Master Plan is a comprehensive and detailed plan, i.e., with an extensive appraisal section and, in particular, a variety of proposed measures for the metropolitan area of Brasília. Most of the issues identified are related with the sensitivity of soils to erosion and water availability for agriculture and human consumption. The plan also identifies the challenges in soil management at the urban fringe due to the pressure of the new developments. There are three main proposed measures to mitigate the identified threats: (1) identification of critical areas for water management; (2) promotion of agricultural activities; and (3) creation of more management plans. Even though the Brasília Master Plan is very extensive on the appraisal and proposed measures the plan completely lacks a monitoring strategy or indicators to assess the performance or implementation of the plan.

London

London is one of the biggest (around 8.6 million people) and most influential cities in Europe. The London Plan (Greater London Authority 2016) is a detailed document that aims to be a reference in sustainable development goals for cities worldwide. The main goal of the document is to transform London into a “world leader” city with effective measures to improve the environment locally and globally. Specifically, the plan aims to tackle climate change issues by reducing pollution, developing a low carbon economy and reducing the consumption and effective usage of natural resources. Despite ambitious goals regarding the effective usage of natural resources, there are very few direct references to soil in the document, even questioning if soil is seen by the authors of the plan as a relevant natural resource.

The London Plan is a strategic document that focuses mainly on the proposed measures, since it only provides general statements about the current situation and does not specify many details on any of the natural resources, including soil. However, both the proposed measures and monitoring indicators are addressed in the plan. There is a focus on measures to mitigate climate change, such as floods and urban heating. Nevertheless, there is also concern with losses of open land areas and agricultural activities. The London Plan proposes 24 indicators for all subjects. These indicators do not have, however, concrete measure specifications and rather describe the individual target for each indicator. In the plan it is proposed indicators to assess the rate of loss of unsealed soils to new developments and to improve the water infrastructure in the city.

Amsterdam

The metropolitan region of Amsterdam with about 2.2 million people is one of the biggest and more dynamic urban areas in The Netherlands and in the Randstad region. The Strategic Vision for Amsterdam 2040 (Metropoolregio Amsterdam 2008) is a plan developed in collaboration with multiple stakeholders within the region (e.g. municipalities and water authorities) and aims to provide strategic goals for the future of the metropolitan area. Due to the scope and effort of multiple and different stakeholders the plan aims to support not only urban planning strategies

but integrate different strategies from the different stakeholders. Such an effort leads to a document with ambitious, overarching goals and only few concrete proposed measures.

The report does not have a clear separation between the appraisal, plan or monitoring sections due to its overarching strategic aim. There is a clear description of the priority visions for the future (until 2040) and some information on the current and past issues, but concrete measures to implement or to monitor the performance of the plan are lacking. One of the reasons could be that the plan needs to be a working document for multiple stakeholders, such as institutions and municipalities. As for soil-related issues, it addresses the need to support more climate resilient strategies by protecting valuable areas (reference is made to green and blue quality networks). The most concrete measure in the document is the need to increase the water storage capacity of the peat areas in the area north of Amsterdam.

Boston

The Metropolitan Area Planning Council of Boston is the main responsible for the regional planning strategy, the “MetroFuture: Making a Greater Boston Region” (Reardon 2008). The MetroFuture is an extensive strategic plan that is composed of two main documents: “MetroFuture: goals and objectives” and “Metrofuture implementation strategies”; making it the most extensive plan of the seven case studies. The plan’s vision was built on the inclusion of multiple institutional and community stakeholder’s perspectives and presents 65 specific goals for the metropolitan area. Overall, the main target of the document is to achieve a sustainable growth of the region by targeting a high quality of life for the community. Unsealed soil is addressed as a relevant part of the region to be protected from conversion to urban developments.

The “MetroFuture implementation strategies” document lists 13 different strategies to implement the plan and has several detailed goals and measures. Out of the 13 strategies, there are two more relevant from the environmental perspective: (1) Protect Natural Landscape and (2) Conserve Natural Resources. The first strategy is mostly focused on planning strategies, but also has some very specific soil-related measures. For instance, a “No Net Loss” policy is proposed, forcing institutions that convert land with high value

for agriculture or nature to other urban uses, to protect at least another area of the same dimension and value. The second strategy focuses on water-related issues and energy. For example, amendments to soil with organic content are addressed here as vital to reduce the need of irrigation on agricultural fields.

The role of soils in the urban plans assessed

Key findings of the case studies analysed are summarized in Table 3 below. For each city we appraised if and to what extent soils are included in urban planning. The qualitative method followed to assess the role of soil focused mainly on identifying soil-related functions and strategies in the urban plans and reports of the case studies. The analysis showed in general a weak presence of soil in documents guiding future sustainable strategies for leading cities in the world. The strategic nature of some of these urban planning documents leads to overarching strategies that lack concrete measures for natural resources, in particular for soil-related functions, with the exception of Boston. Another issue identified is the lack of monitoring indicators (except for London) to assess the performance of the implementation of the plan and the impact on soil.

A comparison between the results in Fig. 1 and Table 3, i.e. the text mining and the qualitative assessment of the plans, reveals a discrepancy between concepts, functions and focus of the plans. While most plans frequently used words such as “food”, “land” and “water”, soil functions are not addressed equally in the plans. Even though there are some goals in the

plans to increase local food production, no direct link between soil functions and “food” is established. Moreover, there is a difference in presence in references to soil functions between sections, i.e., while there are references to soil functions in the goals and appraisal sections, in the monitoring section there are few concrete actions regarding soil. This seems to indicate that there is a lack of capacity to propose or implement indicators that can be integrated into monitoring (for example, even though the London plan suggests indicators, these are measured by spatial net losses for new developments). Being able to assess soil-related functions requires monitoring systems with indicators providing information on, and ideally quantifying, the contributions of soils to sustainable urban development.

The role of ecosystem services in soil knowledge-transfer

Brief context on soil-related ES

Biodiversity and environmental conservation awareness have been continually evolving and increasing in importance amongst decision-makers and politicians (Egoh et al. 2007). In parallel, ES have been frequently used to assess and measure environmental performances (Chan et al. 2006; Scarlett and Boyd 2015). ES has become a mainstreamed concept with wide practical application, guided by four main frameworks: Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2003), TEEB(Kumar

Table 3 Summary of references in the urban plans to soil-related functions, by section (goals, appraisal, plan, monitoring and indicators)

Plan	Goals	Appraisal	Plan	Monitoring	Monitoring indicators
Sydney	+	+	+	+	–
Brasília	+	++	++	–	–
London	–	–	+	+	+
Cape Town	+	+	+	–	++
Tokyo	+	–	–	–	–
Amsterdam	+	–	+	–	–
Boston	++	++	++	++	+

(++) Soil is directly mentioned and plays a clear role, (+) There are indirect references to soil or soil-related functions, definitions can be not very clear, (–) There are few indirect references to soil or soil-related functions and definitions are not very clear, (–) Soil is not mentioned in the text

2010), CICES (Haines-Young and Potschin 2012) and IPBES (Díaz et al. 2015). For example, the MA has put together the contributions of more than 1360 worldwide experts with the purpose to set an integrated framework to assess ecosystem change. The general framework presented by the MA proposed the arrangement of the ES in four different categories: (1) support; (2) provision; (3) regulating and (4) cultural. However, the different scope of each frameworks as led to a long search for a common ground in the approaches (Boyd and Banzhaf 2007; Maes et al. 2016).

Attention to soil-related ES started in an agricultural context where soil quality is normally addressed in terms of soil productivity (e.g. capacity to support high quantity or quality of crops). Thus, necessarily, soil quality assessment requires a methodology that not only considers soil properties per se but also an understanding of the soil's functions (Carter et al. 1997). One of the most widely used definitions of soil quality that is still in use is “the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health” (Doran and Parkin 1994). Even though many definitions have been proposed the concept of soil quality has been stable and mostly confined to agricultural functions (Lima et al. 2013). Even though soils play a key role in supporting, provisioning and regulating food provision, soils provide other services that are relevant to society, such as the capacity to store water. However, such multitude of services provided by soils are not fully developed in the main ES frameworks (Dominati et al. 2010).

Baveye et al. (2016) extensively reviewed the history of soil-related ES and argue that the focus on soil services and multi-functionality amongst the scientific community emerged earlier than the interest in ES, with some articles published as early as the 1960s. Soil scientists have indeed tried to better understand the role of the various functions and characteristics of soils, as well as the interrelationships between the different factors. Baveye et al. (2016) also discuss that major scepticism to the use of the concept of ES by soil scientists came from the difficulty in combining soil and ecosystem concepts, mainly due to the interdependence of soil functions (Swinton et al. 2007). In the frameworks applied to the soil functions, soil is seen as a complex system that interacts with its

surroundings (e.g. through the water cycle), independently of the scale of analysis. Instead, ES frameworks tend to consider nature (or its natural resources) as isolated ecosystems or a mosaic of different ecosystems.

Soil-related ES in an urban context

Urban expansion and changes in land use not only alter landscape structures but also affect the ecosystems in these landscapes and their ability to provide benefits to humans (Niemelä et al. 2010). As seen in the previous section, soil is mostly not included or understood in urban planning regarding its capacity to provide or support essential services. On the other hand, in the past years there have been many advances in the study of ES in the soil scientific community, in particular as a tool to transfer knowledge to practice and communicate with different stakeholders. In this section, we give an overview of soil-related ES examples with practical application, as found in literature, with the purpose of taking stock of possible strengths and weaknesses for their use in an urban context.

The development in soil science towards a better transfer of knowledge and the importance of soils through the use of ES is seen in the development of many frameworks proposed over the last years (Dominati et al. 2010; Robinson et al. 2013; Jónsson and Davíðsdóttir 2016; Schwilch et al. 2016). The framework proposed by Schwilch et al. (2016) builds on already existing frameworks for soil-related ES and aims at providing a more suitable platform for stakeholders by defining a consistent and accessible terminology. This framework was used in this article to collect case studies of soil-related ES (Table 4), with the purpose of assessing the body of research addressing soil-related ES, the diversity of indicators and relevance to urban planning. In compiling case study applications of soil-related ES assessments, we prioritised those studies that have either a spatial application and/or make a quantification of the ES. We distributed the case studies across the three main services provided by soils proposed in the framework and tried to identify examples for all the proposed soil-related ES.

Table 4 shows a clear concentration of most of the case studies on particular ES categories. The strong link between soil and agricultural productivity studies is evident from the high number of case studies that

Table 4 Examples of soil ecosystem services case studies with urban focus published since 2008 for the soil-related ES categories

Category	Ecosystem services	Scope	Indicator	Units	References
Provisioning	Biomass production	Valuing post-mining landscapes	Agricultural productivity	Ha	Larondelle and Haase (2012)
		Valuing post-mining landscapes	Net primary production	g/m ² /a	Larondelle and Haase (2012)
		Knowledge transfer	Agricultural production	%/km ²	Bateman et al. (2013)
		Landscape services mapping	Crop production	Yield potential index	Ungaro et al. (2014)
		Land use transitions in Europe	Food, feed and fibre	MJ/ha	Mouchet and Lavorel (2012)
		Decision making support	Food	kg ha ⁻¹ year ⁻¹	Ghaley et al. (2014)
		Decision making support	Fodder	kg ha ⁻¹ year ⁻¹	Ghaley et al. (2014)
	Economic valuation of E.S.	Food	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)	
	Water production	Valuing post-mining landscapes	Groundwater recharge	ft ³ /s	Larondelle and Haase (2012)
		Landscape services mapping	Water supply and regulation	%/ha	Ungaro et al. (2014)
	Supply of raw materials	Valuing post-mining landscapes	Forest productivity	Ha	Larondelle and Haase (2012)
		Land use transitions in Europe	Raw material	m ³ /km ² forestry/year	Mouchet and Lavorel (2012)
		Decision making support	Wood chips	kg ha ⁻¹ year ⁻¹	Ghaley et al. (2014)
		Decision making support	Wood	kg ha ⁻¹ year ⁻¹	Ghaley et al. (2014)
Economic valuation of E.S.		Raw materials	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)	
Physical base	Economic valuation of E.S.	Soil formation	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)	
Regulating and maintenance	Air quality regulation	N.D.	N.D.	N.D.	N.D.
	Waste treatment	Land use transitions in Europe	Water purification	Ton of nitrogen removed/km/year	Mouchet and Lavorel (2012)
	Water regulation and retention	Valuing post-mining landscapes	Settlements in floodplains	ha	Larondelle and Haase (2012)
		Supply and demand of E.S.	Flood Regulation Supply	Supply Index (STREAM model)	Stürck et al. (2014)
		Supply and demand of E.S.	Flood regulation demand	Demand Index (DSM model)	Stürck et al. (2014)
		Decision making support	Water holding capacity	mm	Ghaley et al. (2014)
	Economic valuation of E.S.	Hydrological flow	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)	

Table 4 continued

Category	Ecosystem services	Scope	Indicator	Units	References
	Climate Regulation	Valuing post-mining landscapes	Above-ground carbon storage	MgC/ha	Larondelle and Haase (2012)
		Valuing post-mining landscapes	Potential evapotranspiration	ET class	Larondelle and Haase (2012)
		Decision making support	Greenhouse gases	Ton/km ²	Bateman et al. (2013)
		Land Use Transitions in Europe	Climate regulation	C/Km ² /year	Mouchet and Lavorel (2012)
		Decision making support	Carbon sequestration	Ton ha ⁻¹ year ⁻¹	Ghaley et al. (2014)
		Economic valuation of E.S.	Carbon accumulation	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)
	Maintenance of Soil Fertility	Decision making support	Nitrogen fixation	Kg ha ⁻¹ year ⁻¹	Ghaley et al. (2014)
		Economic valuation of E.S.	Soil fertility	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)
		Economic valuation of E.S.	Nitrogen fixation	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)
		Economic valuation of E.S.	Mineralization of plant nutrients	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)
Erosion control	Decision making support	Erosion prevention	Ton ha ⁻¹ year ⁻¹	Ghaley et al. (2014)	
Pollination	Historical land use change	Pollination—potential nesting sites	m ²	Lautenbach et al. (2011)	
	Economic valuation of E.S.	Pollination	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)	
Biological control	Environmental indicator	Pesticide leaching risk	Risk Index	Lindahl and Bockstaller (2012)	
	Economic valuation of E.S.	Biological control of pests	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)	
Lifecycle maintenance Habitat	Valuing post-mining landscapes	Shore development	m/ha	Larondelle and Haase (2012)	
	Decision making support	Wild bird-species diversity	Number/km ²	Bateman et al. (2013)	
	Landscape services mapping	Habitat for species	%/ha	Ungaro et al. (2014)	
Gene pool protection	Decision making support	Earthworm count	No m ⁻²	Ghaley et al. (2014)	
Cultural Enabling of spiritual and aesthetical experiences	Valuing post-mining landscapes	Recreational areas	Number	Larondelle and Haase (2012)	
	Decision making support	Recreation	Number/km ²	Bateman et al. (2013)	
	Land use transitions in Europe	Leisure	Recreation potential Index	Mouchet and Lavorel (2012)	
	Economic valuation of E.S.	Aesthetics	US \$ ha ⁻¹ year ⁻¹	Sandhu et al. (2008)	

Table 4 continued

Category	Ecosystem services	Scope	Indicator	Units	References
		Historical land use change	Outdoor recreation	m ²	Lautenbach et al. (2011)
	Provision of inspiration	Landscape services mapping	Visual appreciation	Number/ha	Ungaro et al. (2014)
	Representation of cultural heritage	N.D.	N.D.	N.D.	N.D.

include an assessment of provisioning soil-related ES, such as biomass production (Sandhu et al. 2008; Lautenbach et al. 2011; Larondelle and Haase 2012; Mouchet and Lavorel 2012; Bateman et al. 2013; Ghaley et al. 2014; Ungaro et al. 2014) or supply of raw materials (Sandhu et al. 2008; Larondelle and Haase 2012; Mouchet and Lavorel 2012; Ghaley et al. 2014). Besides the soil-related provisioning services, there is an already broad coverage of other ES. Nonetheless, to the best of our knowledge some soil-related ES remain fairly unexplored, such as lifecycle maintenance or representation of cultural heritage. Cultural ES supported by soils have high relevance to urban planning due to its implications for urban residents' quality of life. One example of the contribution of soil to cultural ES are burial grounds, which hold great cultural meaning and value to the local population.

The assessment and distribution of the literature in the framework proposed by Schwilch et al. (2016) helped identify some issues with actual approaches of soil-related ES case studies. Firstly, most of the case studies are focused on production and do not prioritize other relevant services that could be used by other stakeholders, such as urban planners or city decision-makers. Secondly, even though there are soil-related ES frameworks, they primarily serve to systematically account for multiple ES without offering guidance on how to link different indicators (as seen, for example, in Table 4 with multiple quantification methods for similar ES). Such inconsistencies can be a barrier for the application of the knowledge by other stakeholders, such as urban planners or decision-makers. Thirdly, the indicators and the valuation methods chosen across all soil-related ES assessed are very different, even within the same category, e.g., the differences in units between similar indicators, such as biomass production. Differences in quantification

methods can most likely be justified by the scope of each study, but point to difficulties in comparing and aggregating results across studies. Lastly, access to data seems to be a limitation for the quantification of some services, such as cultural services. Table 4 suggests that the development of some indicators seem to be limited by the availability of data, which can derive in a poor quantification of the ES.

Challenges and opportunities to integrate soil into urban planning

In line with increased high-level attention to sustainable development, the relevance of soil is growing more and more in the agenda of many urban planning initiatives. One of the EU initiatives that has enhanced this interest is the European Green Capital Award (European Commission 2017). Out of the 12 key indicators appraised for the award, 6 can be directly related with soil: climate change, green urban areas incorporating sustainable land use, nature and biodiversity, water management, waste water management and integrated environmental management. Therefore, urban planning needs to become more engaged with soils because sustainable development of cities also depends on sustainable use of soil resources. This calls for a closer look at the barriers and steps that need to be taken in order to promote the integration of soil into urban planning.

Our analysis shows that soil is evidently still not widely understood or taken into consideration in recent urban plans, even for globally leading cities. On the other hand, soil scientists have been making an effort to provide information and tools that can improve the transfer of knowledge about the functions soils provide to a multitude of new stakeholders. However, the major focus on specific functions,

notably biomass production, shows that there are still many steps to be taken in providing soil information that covers a wider spectrum of soil-related ES tailored to an urban context, in particular cultural and regulating services.

The ES concept holds significant relevance as an approach to better integrate soil information into urban planning. Acknowledgement of the importance of ES in international policy has triggered an increasing interest in ES globally. There is nonetheless a need to frame soil-related ES in broader concepts, such as the SDGs, to increase the recognition of the importance of soil in other sectors besides agriculture. Such approaches would benefit from a proposal of indicators that are clear on the benefits for the community and its quality of life. Ongoing efforts, e.g. by the IPBES, to make ES indicators more relevant to policy and planning (Díaz et al. 2018) may spur important progress. In particular, we recommend that new urban plans should include indicators that allow to assess and quantify the soil quality and the multitude of benefits provided by urban soils.

ES could also easily be used to monitor developments in plans and, at the same time, strengthen awareness about soils within the urban planning community. In planning sustainable urban development there is a need to be able to assess trade-offs and synergies between environment and development. ES indicators can be integrated in scenario analyses, for example to make ex-ante assessments of plans investigating if nature-based solutions (Kabisch et al. 2016) are cheaper than engineering solutions.

Efforts of developing awareness about soil-related ES and functions are essential to promote the inclusion of such factors into urban planning. It is important to do so not only through isolated scientific efforts but by involving and working together with relevant stakeholders. High level goals (such as SDG's) are frequently mentioned in the urban plans. This hierarchical embedding offers an opportunity for cities to learn from each other.

Integrating ES in urban planning may provide a framework for bridging the different fields of expertise, and may even drive a transformation beyond current fragmentary technical and disciplinary knowledge. The analysis performed allowed to unveil a lack of knowledge on how to integrate and operationalize soil-related ES into planning practices. Such is evident from the lack of soil-related references in the

monitoring and actions sections in the plans reviewed. Defining a common ground is absolutely necessary, for example through establishing indicator systems that transcend technical and discipline-specific meanings. The accessibility and use of the information provided through soil-related ES should also be taken in consideration in future studies. The success of such integration will depend on data availability. Therefore, we expect that a combination of data-driven approaches and operationalisation of the ES concept can provide a clear roadmap to integrate urban planning and soil science.

Conclusion

In this paper, we identified the importance and opportunities to integrate soil-related ES into urban planning practices and approaches. From this review, the following conclusions and recommendations are drawn:

Although the analysed urban plans focus on delivering sustainable strategies, and regardless of whether the plans propose any concrete or strategic measures, most plans do not address soil directly as a critical natural resource in itself. Instead, they mostly identify several soil functions as important.

Most of the plans identified monitoring and the use of environmental indicators as a critical step in assessing the performance of the implementation of the plan. However, most plans did not present concrete and measurable indicators. Nevertheless, the integration of such soil-related ES could be directly linked with monitoring indicators and, therefore, integrated in the plans measures. The environmental indicators used and developed in recent and on-going studies presented in this paper offer ample opportunities for integration in these plans.

A wide range of soil-related ES studies was identified. Most of the soil-related ES case studies focus on provisioning services and revealed to be little developed on other functions provided by soils. The soil-related ES indicators identified require different methods to quantify the ES. Such multitude of methods can represent barriers to the ease of application for users without advanced technical knowledge or limited access to specific data, equipment or techniques. An improvement of data collection

methods suitable to urban areas also seems to be critical to aid the uptake of most soil-related ES.

The need for a greater and widespread awareness of the soil functions and services in urban planning is evident. To achieve this, we think that there are several requirements. Further efforts are required to raise awareness of the importance of soil in an urban context, especially amongst urban planners and local decision-makers. Integration of soil-related ES indicators in decision-support systems would help to show the importance of soil functions for sustainable development in an urban context. On the other hand, there is also a need to better consider the demand for soil-related ES indicators from the planning perspective. In particular, soil-related ES indicators in urban areas that focus on lifecycle maintenance and cultural benefits of soil to society. This could be improved by more involvement of different stakeholders.

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