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## Describing urban soils by a faceted system ensures more informed decision-making

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2

3 **KEYWORDS:** urban soils; soil information transfer; ecosystem services; soil functions; facets

4

5 **ABSTRACT**

6 Urban areas are increasing worldwide at a dramatic rate and their soils definitely deserve more atten-  
7 tion than they have received in the past. In urban environments, soils potentially provide the same  
8 ecosystem services as in rural and wild environments, although in some cases they are depleted of  
9 their basic functions, such as when they lose their productive and filtering capacities because of seal-  
10 ing, and become mere supports for infrastructures. In other cases, soils of urban areas acquire new  
11 functions that are unique to these environments. Current soil classifications fail to effectively account  
12 for the complexity of urban soils and the information that is required for their management. Addi-  
13 tionally, the survey of urban soils is difficult, due to fragmentation and rapid land use change and the  
14 fact that due to human pressure their properties seldom vary linearly and predictably according to  
15 landforms, which hinders the effectiveness of geostatistics. The conventional practice of grouping  
16 similar soils and transferring their information in a concise manner is not viable for urban soils. We  
17 advocate the introduction of a faceted system – i.e. a scheme using semantic categories, either general  
18 or subject-specific, that are combined to create the full classification entry – to organize the infor-  
19 mation on urban soils to support decision-making. The facets that such a system should be based on  
20 are not only the intrinsic physical and chemical properties that are usually used to describe any soil,  
21 but also other tangible or even immaterial properties that are particularly meaningful in an urban  
22 context, such as landscape metrics, or aesthetic, social and historical values. As well as providing  
23 more adequately the information of the type requested by urban planners and policymakers, a faceted  
24 system of classification of urban soil resources would have the flexibility to accommodate all avail-  
25 able or future scattered, rapidly changing, or incomplete data.

## 26 **1. Introduction**

27 Soil provides food, biomass and raw materials to humankind. It is a platform for human activities, a  
28 main component of the landscape, an archive of heritage, a filter for groundwater quality, and the  
29 most important terrestrial storage of carbon and biodiversity. Soil stores, filters and transforms many  
30 substances, including water, nutrients and carbon (Commission of the European Communities, 2006).  
31 A thorough review of the literature about soil properties and the associated ecosystem services has  
32 been just compiled by Adhikari and Hartemink (2016). Soil sustains an expanding population that is  
33 increasingly living in cities (Anonymous, 2010; United Nations, 2014). As a consequence, urban  
34 areas are experiencing a progressive enlargement that involves peri-urban soils, completely removing  
35 or converting them to *urban* soils (Figure 1). In urban contexts, soils potentially provide the same  
36 ecosystem services as other soils but their role of physical support for infrastructures frequently over-  
37 comes all others (Grimm et al., 2008). In most cases, urban soils experience serious depletion of their  
38 basic functions, in particular biomass production, biodiversity conservation, and carbon sequestra-  
39 tion. Therefore, urban soils are different, in many aspects, from their agricultural, forest or natural  
40 counterparts (e.g. Biasioli et al., 2006; Ellis, 2011; Pickett et al., 2011), so much so that the traditional  
41 approaches for describing and mapping them often seem inappropriate.

42 While in the countryside land use is mostly planned on the basis of the soil's intrinsic properties, in  
43 cities soil uses essentially depend on site location. However, cities are highly dynamic environments  
44 where soil use changes rather frequently due to the continuous reorganization of the urban tissue  
45 (Hollis, 1991; Norra and Stüben, 2003; Rossiter, 2007). Topsoil horizons are often reworked and  
46 obliterated, mixed with, or even replaced by, allochthonous materials (Nehls et al., 2013;  
47 Scharenbroch et al., 2005). Buildings and other infrastructures progressively sprawl in the country,  
48 sealing an increasing proportion of soils, making them unsuitable for performing crucial environmen-  
49 tal purposes, such as draining rainwater or producing biomasses (Nuisl et al., 2009; Scalenghe and  
50 Ajmone-Marsan, 2009; Schmidt et al., 2004). As a consequence, urban soils appear fragmented and  
51 of very variable quality (European Environment Agency, 2011; Han, 2010; Kasanko et al., 2006;  
52 Kent, 2009). The patches of unsealed soils often experience some forms of degradation. For instance,  
53 a highway junction (Figure 1) degrades the soils of the area it includes by changing their hydrology  
54 and imposing severe contamination from traffic, but also dramatically affecting the access to animals  
55 and seeds. Overall, the functional, ecological and aesthetic meaning of the area is drastically modi-  
56 fied. On the other hand, the issue of city sprawl (Anonymous, 2010) calls for a smarter, more com-  
57 pacted city design and encourages the reclamation and reuse of dismissed soils (Hou and Al-Tabbaa,  
58 2014). Vast urban and peri-urban industrial areas are being dismissed in Western countries as a result

59 of the evolution and delocalization of manufacturing activities. Such areas, usually called *brown-*  
60 *fields*, are sometimes reconverted to other uses after remediation action aimed at removing undesired  
61 or dangerous features.

62 Parks and gardens are another example of how urban soil functions are modified by urbanization.  
63 Green areas are highly appreciated in cities, where they improve air quality, mitigate urban heat and  
64 provide an agreeable environment for citizens (Qin et al., 2013; Tzoulas and James, 2010). They also  
65 play a role in enhancing the value of the neighbouring houses (Maruani and Amit-Cohen, 2013; Pan-  
66 duro and Veie, 2013). The *biomass production* function in urban settlements can then be as valuable  
67 as outside the city, but it acquires distinct features. The soils of parks and gardens, rather than pro-  
68 ducing an agricultural yield, are expected to provide welfare.

69 In reality, in urban settings the soils often fail to provide a suitable habitat for plants. Soil ecology  
70 and nutrient cycling in urban green areas are altered because of soil turbation, compaction, and pol-  
71 lution. Lorenz and Lal (2009) have reviewed data about the biogeochemical cycles of carbon and  
72 nitrogen in urban soils and revealed a great horizontal and vertical variability of both elements in  
73 view of the many human activities that can directly or indirectly alter those cycles. Carbon variability  
74 is usually much lower in the soils surrounding cities, in spite of the different requirements of crops  
75 (Scalenghe et al., 2011; Vasenev et al., 2014).

76 Contamination is another common feature of urban soils (Andersson et al., 2010; Costa et al., 2012;  
77 Giusti, 2011; Guillén et al., 2012; Qiao et al., 2011; Schwarz et al., 2012). The mapping of urban soil  
78 pollution was proposed as a medical tool for prevention purposes (Abrahams, 2006). Ajmone-Marsan  
79 and Biasioli (2010) collated a vast array of data about heavy metals' contamination in soils from 140  
80 cities worldwide and found that most cities are contaminated by one or more trace elements. Organic  
81 pollutants are also common in the soils of urban and peri-urban areas (Morillo et al., 2007; Wang et  
82 al., 2013), confirming the environmental relevance of the urban soil system.

83 In summary, urban soils are required to provide more, and different, services than the classic ecolog-  
84 ical and productive functions for which the most widely used soil classification systems were born  
85 and have been developed. That is what makes it difficult to use these classifications with urban soils.

86

### 87 1.1. Soil classification in the urban context

88 Classification is a procedure to group material or immaterial things on the basis of shared character-  
89 istics. In hierarchical classifications, groups are distributed in ranks or categories, where the range of  
90 diagnostic properties of any group narrows as the system becomes more detailed. Soils are particu-  
91 larly difficult to categorize and map, since the variation of their properties in the landscape are more  
92 often continuous than discrete, which means that boundaries have to be arbitrarily established.

93 Soil classification was anecdotally born in 1877 in St Petersburg, Russia, when Vasily Vasili'evich  
94 Dokuchaev conducted the first pedological investigation (Arnold, 2006). The observation of zonal  
95 properties of climate, geology and vegetation was sufficient, at that time, to determine or infer general  
96 soil properties and the driving processes of soil formation on a large scale. Since that first rough form  
97 of classification, the *production function* of the soil was the pivot around which many of the ensuing  
98 classifications have been developed, given the importance of agriculture to humankind. One example  
99 is the Fertility Capability Soil Classification System (FCC), which classifies soils on the basis of  
100 attributes important for plant growth (Sanchez et al., 1982, 2003), or the Land Use Capability (LUC),  
101 which is mainly based on potential land uses (e.g. Curran-Cournane et al., 2014). There are other soil  
102 classifications. Some are of interest in engineering and geotechnics and are centred on the ability of  
103 soil to support buildings and roads or to deform because of earthquake-induced vibrations. Such clas-  
104 sifications are based on soil texture (e.g. Chatterjee and Choudhury, 2013) or other properties related  
105 to the physical behaviour of soil (e.g. Boaga, 2013). Attempts have been made to classify soils ac-  
106 cording to their *filter*, *buffer* and *reactor* function, which allow transformations of components or  
107 solutes. In the case of landfill planning, soil productivity, biological activity, and soil permeability  
108 are normally the key parameters for sorting classes of suitability in this regard (Kara and Doratli,  
109 2012; Moeinaddini et al., 2010). Vilček and Bujnovský (2014) have proposed a soil environmental  
110 index (SEI) to categorize soil's ability to retain water, immobilize pollutants and eventually transform  
111 them into less harmful forms. Such an index can be used for the assessment of ecological systems,  
112 planning of land use, and for expressing the economic benefits of individual ecosystems. The *re-*  
113 *source function*, the capability to supply raw materials, is typically fatal to soil as it involves its total  
114 removal, and this would be the case for a drastic yes/no classification. The *habitat function*, i.e. the  
115 ability of soils to provide a living environment for plants and animals, is mirrored in the concept of  
116 soil biodiversity. The available information, however, is fragmented and a systematic organization of  
117 soils on a biological basis has not been hitherto attempted (Gardi et al., 2013; Jeffery, et al., 2010).

118 Modern soil classifications ( IUSS Working Group WRB, 2014; Soil Survey Staff, 2014) are of the  
119 domain-analytic type and therefore are knowledge intensive (Hjørland, 2013a). They are based on  
120 the identification of a *diagnostic horizon*, i.e. a layer whose properties unequivocally reveal the com-  
121 bination of the chemical, physical and biological processes that transformed the original materials  
122 into a soil (viz. the *pedogenesis*).

123 Soils are usually named and classified directly in the field, based on the description of the sequence  
124 of genetic horizons and their pivotal properties (Table 1), as well as the identification of one or more  
125 diagnostic horizons. Soil properties are assumed to be homogeneous for a given area and their spatial  
126 homogeneity is usually inferred from site features, such as landforms, lithology, drainage, vegetation,  
127 land use, or surface soil features, such as colour or stoniness (Holmgren, 1988). On that basis, large-

128 scale and progressively more detailed soil maps have been produced (Hartemink et al., 2013). A  
129 quantum leap in soil classification and mapping occurred with the use of computers and numerical  
130 classifications (Deng, 2007; Fitzpatrick, 1967). The general principles and scopes, however, remained  
131 focussed on agriculture. Soil science subsequently introduced geostatistics to define the boundaries  
132 of soil properties, based on an adequate number of samples and measurements. Soil mapping is better  
133 achieved by regionalizing the variables, rather than interpolating between points in space, using a  
134 stochastic model that considers the diverse spatial trends of the soil property of interest, e.g. the con-  
135 centration of a single plant nutrient or pollutant. Such a method, known as *kriging*, is based on the  
136 assumption that near things are more interconnected than the distant ones (Cattle et al., 2002; Heu-  
137 velink and Webster, 2001).

138 Whatever the scope or the method, the current soil classifications are not able to account for the  
139 variety of soils occurring in urban settings (Figure 2). Perhaps more importantly, such classifications  
140 do not take into account many features and properties crucial for describing the potential and limita-  
141 tions of soils in the urban context, where diversity is so high that one could even conclude that soils  
142 *sensu stricto* are missing (Dudal et al., 2005). In extra-urban environments, several conceptual frame-  
143 works for the quantification of soil functions/ecosystem services have been successfully proposed  
144 (e.g. Kabisch, 2015; Schulte et al., 2014), but they are not applicable to cities, where random sampling  
145 of soils and representation of their unpredictable distribution are difficult goals. The requirement of  
146 identifying a diagnostic horizon to name soils at the highest hierarchical levels is a serious hindrance  
147 to classifying urban soils, as the original horizons are often being cancelled by human disturbances,  
148 or soil sampling is prevented by the superimposed artefacts. If a statistically representative sampling  
149 of soils is prevented, assuming spatial homogeneity is incorrect. Often, the recognition of urban soils  
150 as discrete entities (Aparin and Sukhacheva, 2014; Lebedeva and Gerasimova 2011; Lehmann and  
151 Stahr 2007) is implausible, as seldom do soil properties in urban settings show a linear, or any other  
152 type of regular variability, which is the *sine qua non* of geostatistics. In fact, soil surveys and mapping  
153 tend to exclude urban areas (Brevik et al., 2015), except for some local issues such as parks or other  
154 unpaved areas. Conventional soil maps represent urban areas as indistinct grey or black polygons that  
155 do not capture the internal soil complexity (Sanchez et al., 2009). On the scale of the European Soil  
156 Database 2.0, urban and peri-urban soils appear unsorted as endemic soil minorities (Ibáñez et al.,  
157 2013). Even in the more advanced means of cartographic representation, such as the smartphone app  
158 *mySoil* (Natural Environment Research Council, 2013), organized information about urban areas is  
159 often missing.

160 The crucial point is whether the diagnostic horizons and any soil features that are usually utilized to  
161 classify agricultural, forest or unmanaged soils are sufficient and all-meaningful for appropriately

162 describing urban soils. As postulated by Bouma and Droogers (2007) a *regionalization of the ap-*  
163 *proach to soil issues*, i.e. the development of methods that address local problems – and more specif-  
164 ically urban soil features – would facilitate contact with stakeholders and policymakers. A faceted  
165 system framework, i.e. a scheme using semantic categories, either general or subject-specific, that are  
166 combined to create the full classification entry, seems highly functional for categorizing urban soils  
167 and this paper discusses its viability (Figure 3). Contrary to classical enumerative classifications,  
168 which contain a full set of entries for all concepts, faceted classification (FC) systems use a set of  
169 semantically cohesive categories that are combined as needed to create an expression of a concept.  
170 In this way, a faceted classification is open, and not limited to already defined concepts.

171

## 172 **2. A faceted classification for urban soils**

173 The multiform and rapidly changing urban environments demand a new type of flexible soil catego-  
174 rization, functional for various and dynamic purposes (Arnold, 2006). Farmers are usually interested  
175 in soil fertility, hence in soil properties such as nutrients' supply, water retention, pH, organic matter  
176 content or particle size distribution, and these are generally provided by ordinary classifications,  
177 which also account for the soil formation processes. Urban soil users and stakeholders require addi-  
178 tional or alternative information, which, in most cases, is peculiar to urban settings and is not taken  
179 into consideration by current soil taxonomies. A piece of land in the urban context can be evaluated  
180 from different points of views by different stakeholders, often representing contrasting interests. Nev-  
181 ertheless, none of them may be interested in the information about that soil provided by the classic  
182 classifications. For example, a property developer will mainly take the extent and the beauty of the  
183 area of interest and its surroundings into account, while a land planner will focus more on the topog-  
184 raphy of the area and the geochemical properties of its soils. Residents and potential buyers, on the  
185 other hand, are mainly interested in the beauty of the place and the type of facilities it benefits from  
186 (number and type of green areas, proximity to other services, i.e. degree of fragmentation/dispersion,  
187 distance to the nearest railway station and so on). A local Environmental Protection Agency pays  
188 attention to the type and degree of contamination to implement reclamation measures, while a mu-  
189 nicipality responsible for distributing allotments for private horticulture takes into account the size  
190 and shape of the area, soil fertility and contamination and, of course, the property rights. With time,  
191 financial, economic, demographic, and social changes may modify the interests of the various stake-  
192 holders towards a given urban soil more swiftly than any classical classification system (e.g. Brevik  
193 et al., 2015) can attest. The urban ecosystem depresses the importance of a few basic functions of  
194 soil, but often it broadens widens the variety of services that soil has to provide. The related infor-  
195 mation a classification must provide on urban soils must hence be even larger than that provided by

196 normal soil classifications, in particular expanded to other characteristics. A faceted system seems to  
197 be the best tool for fulfilling this goal.

198 Faceted classification was proposed by Ranganathan (1967) to organize information about books and  
199 was used to classify various items, such as computer software, patents, books, and artworks (Kwas-  
200 nik, 2002). Faceted classification is an advanced method of knowledge organization and information  
201 design and offers powerful and flexible information browsing and searching, and is particularly suit-  
202 able for the Web (Slavic, 2008). A FC consists of reciprocally exclusive and jointly exhaustive cate-  
203 gories, each one focused on a single aspect – a *facet* – of an item of an ensemble (Frické, 2013;  
204 Hjørland, 2013b; Perugini, 2010). Faceted classifications are widely used in e-commerce (Kwasnik,  
205 2002; Vickery, 2008); for instance, amazon.com uses brand, price, seller, as individual facets but also  
206 has facets that are specific to the current result set (Table 2). In the case of soils, each one would be  
207 tagged with a set of attributes and values related to its natural, economic, technical, material or sym-  
208 bolic qualities, and its final characterization would hence depend on how the user accesses the faceted  
209 system. The soil *unit* for which the information is collected and retrieved can be identified on different  
210 bases. It can be a cadastral parcel or a Land Unit (the smallest unit of land that has a permanent,  
211 contiguous boundary, a common land cover and land management, a common owner), or any other  
212 subdivision or soil entity that is necessary or desirable to tag. A database of such objects and tags can  
213 be flexibly interrogated in various ways, according to the desired information retrieval. The ad-  
214 vantages of a faceted classification applied to soils over other systems parallel those reported for  
215 bibliographic classifications (Broughton, 2006), i.e. i) the capacity to synthetically express the com-  
216 plexity of the object – and urban soils all in all are definitely very complex systems; ii) a syntax that  
217 allows for new facets to be easily introduced; iii) a logical structure that is compatible with both  
218 computer manipulation at whatever level (with geographical information systems in particular) and a  
219 graphical interface for end-user navigation and query formulation; iv) the facility to allow approaches  
220 from different angles (i.e. cross-domain query) and retrieve the set of all instances far more rapidly.

221 However, Hjørland (2013a,b) has pointed out two main limitations of a FC system when applied to  
222 general knowledge organization, viz. i) the lack of an empirical basis and ii) a speculative ordering  
223 of knowledge which is not based in the development of theories. Its basic assumption that relations  
224 between concepts may be set a priori and not through models or theories appears to be questionable.

225 ~~On the other hand,~~ sSoil facets must be carefully chosen to make the system work properly. Discrete  
226 variables can only be used as facets or classes of continuous variables. Also, the facets need to be  
227 independent of each other so that any combination of values across facets is possible. This is not  
228 always true, e.g. for soil chemical properties, as some of the variables are correlated. In this case, just  
229 one of the correlated properties should be chosen as a facet. Within a facet, the values each facet may



230 assume need to be dependent, i.e. they have to be mutually exclusive and, while this is true for chem-  
231 ical or biological properties, care must be taken that other properties are chosen to comply with this  
232 requirement.

233 Vickery (1960) proposed a faceted classification of soils based on 18 facets (in SI, Table 1S), mostly  
234 agriculture-oriented, but it was never fully developed. Here, we want to endorse the appropriateness  
235 of preparing and using a faceted system for the organization of knowledge about urban soils. Below  
236 we report a reasoned non-exhaustive list of facets that we feel are particularly meaningful for urban  
237 soils.

238

#### 239 *Physical and chemical properties*

240 Soil thickness, stoniness, and particle size distribution appear to be crucial for urban soil description.  
241 Organic matter content, pH, and electrical conductivity (for salinity) are the most significant chemical  
242 soil traits. All of them are usually measured as continuous variables but can also be expressed as  
243 classes. For example, soil pH can be reported as acid, slightly acid, basic and so on, while the particle-  
244 size distribution can be reported as clay, silt-loamy, sandy, etc.

245

#### 246 *Pollution*

247 The extent and degree of soil pollution and type of pollutants (heavy metals, hydrocarbons, radionu-  
248 clides, etc.) are fundamental information for the use and management of urban soils. Basic threshold  
249 values can be the legislative concentration limits for contaminated soils. Further grades can, however,  
250 be adopted based on the results of an environmental risk assessment. A faceted system is particularly  
251 recommended for soil contamination in light of its adaptability to changes in legislation and the pos-  
252 sibility to include values as they are obtained or other variables, i.e. previously ignored or unknown  
253 contaminants.

254

#### 255 *Landscape metrics*

256 Landscape metrics are numeric measurements that quantify spatial patterning of land cover patches,  
257 land cover classes, or entire landscape mosaics of a geographic area (Lüscher et al., 2014; McGarigal  
258 and Marks, 1995). For example, the Class Area metric is a measure of landscape composition; spe-  
259 cifically, how much of the landscape is comprised in a particular patch type (e.g. accessibility to main  
260 roads or proximity to nearby cities, as in Puertas et al., 2014).

261 The number of patches of a particular patch type is a simple measure of the extent of subdivision or  
262 fragmentation of that patch type, while the edge density is the edge length on a per-unit-area basis  
263 and facilitates comparison among landscapes of varying size (e.g. Borgogno-Mondino et al., 2015).  
264 Several other metrics can be used as facets of urban soils.

265

266 *Ownership and other property rights*

267 The faceted system for urban soils in terms of ownership may be based on a simple division into  
268 private and public, or include more information, such as right of way, partial usufruct, etc. Any in-  
269 formation in this regard can be useful, for example, to a city administration that needs to tag soils  
270 with its ownership (temporary lease of rights, limits on the intended use, ownership conflict) or other  
271 planning characteristics.

272

273 *Aesthetical value of the area*

274 It is hard to think that the aesthetical value of an urban area does not have an influence on the judge-  
275 ment of its soils. Bartie et al. (2010) elaborated and proposed visibility modelling algorithms for  
276 urban environments, while Chamberlain and Meitner (2013) suggested a visibility analysis based on  
277 several simple landscape features, such as slope, aspect and distance from the observer, all of which  
278 could be facets for urban soils. An indirect method based on landscape pictures uploaded by users on  
279 the Internet has been proposed by Casalegno et al. (2013). Aesthetics will eventually influence the  
280 housing market, hence the relative soil facet might be based, at least partly, on the commercial value  
281 of the neighbouring houses.

282

283 *Specific ecological functions*

284 Modern urban planning envisages the creation of ecological (green) corridors, which represent pre-  
285 cious shelters and connectors for wildlife (Groome, 1990). The soils of green corridors are, of course,  
286 expected to be safe and as fertile as possible, to sustain plant growth without the input of any chemi-  
287 cals and allow a healthy life for people and animals. To be part of a green corridor and to not be  
288 completely surrounded by sealed surfaces should be acknowledged as a highly positive feature of an  
289 urban soil.

290

291 *Economic value*

292 Urban land price is a result of natural, economic and social factors, and represents a source of infor-  
293 mation for planning (Hu et al., 2013). Monetary value is the most frequently quantified property of  
294 an urban soil, so facets can be derived from its multiple expressions, be they either real or estimated.

295

296 *Social value*

297 Given the mass of people gravitating to urban areas, here more than elsewhere soils may assume a  
298 high social value. Public green spaces play an important social role in the multifunctional and cultural  
299 services of urban ecosystems (Lundy and Wade, 2011), such as providing spiritual and psychological

300 benefits as well as leisure and recreation opportunities. The most striking example of such an im-  
301 portant role is perhaps that of community vegetable gardens, which are a unique intervention that can  
302 narrow the divide between people and the places where food is grown (Litt et al., 2011; Semenza and  
303 March, 2009). Indirect facets (e.g. human appropriation of net primary production, HANPP) can be  
304 used to account for the social value of urban soils (Niedertscheider and Erb, 2014), which is usually  
305 determined by hedonic pricing and contingent valuation (Brander and Koetse, 2011).

306

### 307 *Historical value*

308 The intrinsic value of an urban soil can be chiefly due to the presence of valuable ancient artefacts,  
309 and also by the impalpable past occurrence of a memorable event of public relevance. Beyond the  
310 constraints imposed by the government, it would be senseless, for example, to consider the couple of  
311 hectares of meadow within Rome occupied by the Circus Maximus (Figure 1) as any other equivalent  
312 piece of land. Some past events occurred in given areas just because of the characteristics of their  
313 soils (i.e. duels and battles on soils selected just because of their high or poor bearing capacity), which  
314 should therefore be acknowledged and preserved. In other cases, urban soils are the result of efforts  
315 aimed at making them suitable for specific purposes, such as the creation of historical gardens (Del-  
316 gado et al., 2007). Such efforts, including the provenance of the soil material, where this is alloch-  
317 thonous, should be acknowledged in classifying those soils, just because of their value as historical  
318 memories (Beach et al., 2015).

319 Additional facets may deal not with soil *per se*, but with the conditions affecting its ecology and  
320 fertility, such as, for example, the extent of solar radiation it receives all year long; Italian legislation  
321 includes a *shadow* tax that relates to the shape of buildings and their interference on solar irradiation  
322 of adjacent soils (Gazzetta Ufficiale, 1997). Also, proxy indicators of ongoing peri-urbanization pro-  
323 cesses based, for instance, on a differentiation into displaced-urbanization, ex-urbanization, anti-ur-  
324 banization and hidden-urbanization could be used as facets for our purpose (Zasada et al., 2011).

325 The organization of soil information – including that provided by canonical classification – in a facet  
326 repository undoubtedly helps in overcoming the problems of spatial data resolution highlighted by  
327 Schmit et al. (2006). When interrogated, a faceted system for urban soils would produce a list of soils  
328 that are, for example, silty, acid, not contaminated by heavy metals, with a tolerable content of hy-  
329 drocarbons, smaller than 100 m<sup>2</sup> and with a rectangular shape, flat, surrounded by buildings on just  
330 two sides, state-owned, insignificant from the aesthetical and historical points of view but socially  
331 and ecologically valuable. The result would be meaningful in terms of urban planning and highly  
332 useful for easily intercepting potential land uses. The organization of soil data in facets would make

333 it easy to create thematic maps for individual properties (e.g. land metrics, specific pollution, prop-  
334 erty, economic value, mapping error estimates ...), regardless of data standard format and complete  
335 availability.

336 A faceted system would be particularly convenient where the information about soils is missing or  
337 scattered, as frequently happens in urban settings (Figures 2 and 3). The system can in fact work with  
338 any amount of information and progressively host new data, when they are, for example, obtained or  
339 imported from other city services (e.g. the cadastre may feed its data into the system while the envi-  
340 ronment department is still making investigations). In fact, it is becoming possible and desirable to  
341 update soil map information (Sun et al., 2015). The FC system is also flexible in accepting changes  
342 in the limit values of the classes, as when the legal thresholds for contamination are changed (Table  
343 2). This implies advantages for the local administration, which would deal with a much more under-  
344 standable and easy-to-apply system. Armentano et al. (2014) have in fact reported that the use of a  
345 faceted system allows a search engine to be devised that produces user-friendly presentations for non-  
346 expert users.

347 It has been postulated that a post-coordination approach, i.e. mixing different properties – facets – in  
348 an unusual way, may allow new associations of elements to be discovered (Elliott et al., 2000; Kwas-  
349 nik, 1999), hence generating new knowledge. A faceted system would be highly appropriate for fol-  
350 lowing the evolution of open data sets, integrating territorial systems with the concept of learning  
351 territorial networks (Finka and Kluvánková, 2015). Environmental data sharing, remote sensing, and  
352 visualization tools and practices can also support next-generation ecosystem service modelling (Bag-  
353 stad et al., 2013). Archives that contain a huge mass of soil information in a digital format are avail-  
354 able worldwide, but a combined exploration of this large collection of soil data is hindered by their  
355 multivariate nature (Beaudette et al., 2013) and a faceted system would help in exploiting the data.  
356 Crowd-mapping, a combination of social activism, citizen journalism and geospatial information, is  
357 rapidly growing and urban soil mapping should benefit from it. This approach, which was first applied  
358 to arable/natural soils, is now expanding towards urban areas. Combining crowd-mapping and a fac-  
359 eted system of nomenclature could be a winning strategy to improve the knowledge of urban soils.

360

### 361 **3. Conclusions**

362 Current systems of soil classification show some limitations in accounting for what is commonly  
363 needed for the use and management of urban soils, mostly because they were built on a genetic base  
364 and for agricultural purposes. Temporal and spatial variability of soil in the urban context is so high  
365 and unpredictable compared to agricultural or natural soils that systematization and transmission of  
366 the information on urban soils becomes an overwhelming task. This is the main reason why unsealed

367 urban soils are currently mapped as indistinct areas included in the patches representing urban settle-  
368 ments.

369 A faceted system of categorization based on both tangible and immaterial features and values could  
370 more adequately account for the complexity of the world of urban soils than classic soil classifica-  
371 tions. In addition, it would show the flexibility necessary to progressively accommodate the flow of  
372 scattered, rapidly changing, sometimes incomplete, data that are being continuously collected. If con-  
373 stantly updated once new information is provided, such a system of classification of urban soils would  
374 be a pivotal tool for urban and peri-urban landscape planning and management.

375

376

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617 **Table captions:**

618

619 **Table 1.** Soil properties that are currently observed and annotated in the field for conventional soil  
620 classification (modified from Schoeneberger et al., 2002)

621

622 **Table 2.** A faceted classification as employed by Amazon.com and which could be used for urban  
623 soils

624 Amazon numbers brand, price, and seller as individual facets. The first two columns on the left show  
625 a search made on Amazon.com; the first one in particular shows the results from a search using the  
626 keyword ‘computer’. Amazon also have facets that are specific to the current result set, which are  
627 shown in the second column where the results of the first column are filtered using the word ‘Win-  
628 dows 8’ (in parentheses are the number of items found). A plausible example of search through an  
629 urban soil database organized by facets using the keyword ‘Urban Soil’ is the one reported in the  
630 third column, which in the fourth one is filtered by the keyword ‘Ownership’.

631

632 **Figure captions:**

633

634 **Figure 1:** a–e) examples of soils in an urban and peri-urban environment; g) the ancient Roman  
635 chariot racing stadium *Circus Maximus* (photo: Ministero dell’Ambiente e della Tutela del Territorio  
636 e del Mare; location 41°53’9.26”N, 12°29’8.53”E) h) a road junction encompasses soils that are sub-  
637 tracted for any other use (photo: Google Earth; location 45°01’20”N; 7°35’52”E). (The expression  
638 ‘peri-urban’, first used in France [and Switzerland], describes spaces shaped by the urbanization be-  
639 tween the city and the rural area, in the urban fringe. Peri-urban both in a social [e.g. lifestyle] and in  
640 a physical [e.g. land use change] sense).

641

642 **Figure 2.** A statistically representative sampling of urban soils appears to be impossible. A grid is  
643 superposed on a city map in order to plan a systematic survey. However, only the areas in green are  
644 open soils and they would not provide a statistically sound representation of soil spatial variability.

645

646 **Figure 3:** Facets vs canonical soil categorizations. In a non-urban context (a): soil is sampled, then  
647 the data of all concerned property useful for its classification is spatialized and a soil scientist can  
648 draw a soil map. From these maps a land planner or any stakeholder can infer soil properties of non-  
649 observed points from their taxonomic classification. In an urban context (b): the city (dark area) does  
650 not allow for a representative sampling of soils, the spatialization of data can be made only in open  
651 soil areas. Within the urban area, there is not sufficient information to be able to assign a proper soil

652 classification to an area, only an individual point can be classified, if it is observed directly. It is not  
653 possible to extract any plausible information from non-observed points. In an urban+peri-urban con-  
654 text (c): the city (dark area) and areas that have been, e.g. brownfields, or will become urban (grey  
655 areas) do not allow a mapping of the soils due to the unfeasibility of spatialization punctual taxonomic  
656 categorization. In an urban+peri-urban context (d): the city (dark area) and areas that have been, e.g.  
657 brownfields, or will become urban (grey areas) are continually being dug/surveyed/explored for dif-  
658 ferent purposes. The number of observations is very high; the characteristics of the collected data are  
659 heterogeneous and independent from a formal framework of any existing classification systems. The  
660 organization of these data in facets makes it possible to create thematic maps for individual properties  
661 (e.g., land metrics, specific pollution, property, economic value ...), depending on the data availability  
662 only.