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Towards an Ontology of Urban Green Spaces

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Abstract

Growing interest in Urban Green Spaces (UGSs) has led to the discovery of the wide spectrum of services that they either provide or support. Yet, there is persistent confusion about what types of green spaces exist and how they should be classified. Current Land Use (LU) and Land Cover (LC) maps both at European and national levels are either lacking or misclassify various types of UGS, thus underestimating the actual amount of green space that a city offers its citizens. In this paper, we highlight reasons for green space misclassification and suggest an ontology of UGSs. Our ontology takes into account both the physical appearance of UGSs and their semantics. We characterize the physical appearance using four different LC classes while providing semantics using unique characteristics expressed as rules. The ontology proposed emphasizes in particular frequently disregarded small and heterogeneous UGSs and can be used as a basis for their precise identification and mapping.

Keywords:

ontology, urban green spaces, urban atlas, OSM

1 Motivation

'For the first time in human history, a majority of the planet's population lives in cities', yet urban areas constitute only 2% of global land use (Semeraro et al., 2021). The potential of Urban Green Spaces (UGSs) to reduce the environmental pressure that is accelerated by growing population numbers is recognized by many authors (Shahtahmassebi et al., 2021). Yet, the definition of UGSs as well as what is understood under the term 'green' remains unclear. Some authors describe UGSs as 'all natural, semi-natural, and artificial systems within, around and between urban areas' (Chang et al., 2012), while another commonly-used definition is 'vegetated areas located within built-up areas, including natural and planted trees, grass, scrubs and flowers' (Taylor & Hochuli, 2017).

Over recent decades, UGSs have undergone close investigation from various perspectives: what ecosystem services they provide, the biodiversity they harbour, their accessibility by the public, the promotion of human well-being, and others. Some studies show that different types of UGS function differently and might support or promote different ecosystem services (Niemelä et al., 2010).

Despite the wide recognition of the benefits of UGSs, specific types of UGS receive more attention than others, notably urban public parks. By contrast, small UGSs, such as urban gardens, are among UGS types that are by and large neglected (Shahtahmassebi et al., 2021). Since the definitions of UGSs vary, it can be difficult to decide whether a certain (visually) green area should be considered a UGS, or whether it should be merged into another land use category. This confusion can be clearly observed in existing Land Use and Land Cover (LULC) maps at both the continental level (e.g. Urban Atlas (UA)) and the more local level (e.g. the cartographic information system of Germany (ATKIS)). Furthermore, the role of small green spaces is not yet well understood (Semeraro et al., 2021), and even if some areas such as urban gardens are accepted as valid UGSs (Hanson et al., 2021), they do not appear within the UGS classes of any LULC map.

Such an inconsistent classification of UGS types can be misleading if we want to understand the actual status and quality of green spaces in urban areas. Moreover, it is extremely difficult to calculate the actual area of a UGS class in an LULC map due to the generalization methods applied. Therefore, in this paper, we thoroughly examine two study areas in terms of the information on green spaces that is available, present descriptive statistics of misclassified or disregarded UGS types, and propose a new ontology of UGSs that can solve the misclassification issue and deliver more precise UGS information.

The paper is structured as follows: the next section surveys the existing UGS classifications and ontologies. In Section 3 we examine existing LULC data in detail and present descriptive statistics of each UGS type. Section 4 describes the workflow to design an ontology as well as the ontology itself. We discuss the proposed ontology and draw our conclusions in Section 5.

2 UGS classifications and ontologies – the state-of-play

Although UGSs have been studied for a very long time, for most of this time they have been treated as uniform entities (Panduro, 2013). Even if this tendency is now shifting towards a more heterogeneous approach, the types of UGS highlighted in any particular study remain highly dependent on the study’s aims: authors define various UGS classes (Bell et al., 2007; Panduro, 2013), or focus on various aspects of UGSs such as accessibility (Giuliani et al., 2021). However, this multiplicity of approaches further worsens the vagueness of UGS definition, as in some cases even water is considered a UGS (Panduro, 2013).

One of the broadest classifications of UGSs is given by Bell et al. (2007), who define explicit classes of UGS for hedonic house price valuation, proposing the following classes: gardens and parks; natural and semi-natural spaces; green corridors; outdoor sports facilities; provision for children and young people; cemeteries and other burial grounds; amenity green spaces; allotments, community gardens and urban farms. This classification is further enriched with sub-classes, such as various types of garden. While such classification might be suitable for the authors’ stated purpose, it is lacking detail for other purposes such mapping, planning and maintaining UGSs.

Frequently we are interested not only in existing types of UGS but also in their semantics, such as particular tree composition, presence of benches or walking paths, proportion of vegetated areas to sealed parts. This is particularly relevant if we want to better understand and plan green spaces. The semantics of 'things' (e.g. UGSs) and related expert knowledge can be represented in an ontology (Arvor et al., 2019). Originating in philosophy, an ontology is the results of a study of things that exist (Couclelis, 2010). In the context of Computer Science and Artificial Intelligence an ontology is defined as a 'formal, explicit specification of a shared conceptualization' (Gruber, 1993). An ontology is based on a set of representational primitives, with the final aim of modelling domain knowledge. These representational primitives typically consist of classes, attributes of these classes, and relationships among the classes (Gruber, 1993). Ontologies could be designed at the top level (i.e. domain), task level or application level (Guarino, 1997). Well-designed formal ontologies provide a common vocabulary (their semantics) that is necessary for communication between computer applications as well as between computer applications and users (Guarino, 1998).

Currently, there exists no UGS ontology – a state of affairs which we intend to change in this paper.

3 Examination of the existing LULC data

In Section 1, we expressed the need for a new classification for UGSs, including types of UGS that typically have been ignored in previous studies. To provide a sound basis for our new ontology, we chose two study areas (Augsburg and Wuerzburg) and examined their LULC data thoroughly in terms of UGS information.

Augsburg is situated in southern Germany. With a total area of 146 km², it includes a considerable amount of green space that is very characteristic of the region. This is also true for Wuerzburg, with an area of 88 km². However, unlike Augsburg, the city also includes urban vineyards. We chose these two urban areas quite deliberately, highlighting the presence of permanent cultivated vegetation (vines) in one of them, because the vegetation factor will play a significant role in the design of our new ontology.

We extract information on UGSs from three freely available data sources: the Urban Atlas (UA), Open Street Map (OSM), as well as a dataset showing the distribution of green spaces (Ismayilova & Timpf, 2022). UA provides harmonized, very high-resolution, pan-European LULC data. However, UA only maps areas larger than 0.25 ha (Ludwig et al., 2021). It includes various LULC classes, among which forest, green urban areas, herbaceous vegetation, sport and leisure facilities, and agricultural land, do or could potentially include UGSs.

OSM is an open mapping project that welcomes everyone's contributions to create a digital map of the world. It includes keys and values that allow searches for different objects on a map. UGSs are predominantly stored under the 'land use' key, while some might also appear under the 'natural' key. Although inconsistencies or missing information are commonly recognized disadvantages of the OSM data (Ludwig et al., 2021), the chosen study areas do not reveal such limitations.

In order to understand the actual state of the vegetated areas in our chosen cities as well as to verify UA and OSM data, we use a dataset of green spaces produced by applying a Random Forest (RF) classification on Sentinel-2 imagery (Ismayilova & Timpf, 2022).

3.1 Augsburg

In Table 1, we present a comparison of the aerial coverage of various UGS types based on the LULC data examined for Augsburg. We first look into the UA's 'green urban areas' class. It is a composite class, which includes parks, green corridors and cemeteries, as well as smaller wooded areas. According to the UA, this class makes up 6 km². Forest is considered a separate class. It covers an area of nearly 38 km². The class 'sport and leisure facilities' is another mixed class and includes areas such as allotments. This class covers a total of 5.5 km².

In comparison to the UA, the OSM dataset includes additional land use classes, and we can thus extract more detailed UGS information from it. In the OSM dataset, forests cover 39.2 km², cemeteries account for 2.3 km², followed by parks (1.6 km2) and allotments (1.5 km²).

According to the results of an earlier classification of green spaces in Augsburg (Ismayilova & Timpf, 2022), the relative proportions were slightly different: forest (or woodland), 36.9 km²; allotments, 1.4 km²; parks, nearly 1 km², and cemeteries 0.6 km². The area includes another 13 km² of green spaces in the form of green corridors along rivers and roads; residential back and front gardens, and scattered patches of vegetation such as trees or grass. This additional information is missing in both UA and OSM data, either because these areas are privately owned or because the areas they cover individually are under the minimum mapping unit applied.

3.2 Wuerzburg

In Table 2, we present areas of various UGSs in Wuerzburg. According to the UA, forest occupies 18 km²; green urban areas in Wuerzburg cover 4.3 km², followed by sport and leisure facilities with 3.8 km². Unlike the previous study area, Wuerzburg has 2.4 km² of vineyards – i.e. large areas under permanent cultivation within the city.

Very similar figures can also be seen in the OSM dataset. Forests make up 16 km², parks 2 km², allotments 1.5 km², and cemeteries 0.4 km².

Based on the classification by Ismayilova & Timpf (2022), forest in this study area comprises 17.5 km², parks 2 km², cemeteries 0.3 km², and allotments 0.9 km². We identify an additional 23.8 km² of vegetation within the study area. These are again private green spaces or small patches of green space.

Table 1: Aerial coverage of different UGS types in Augsburg based on the Urban Atlas (UA), OSM dataset and Ismayilova & Timpf, 2022.

LULC data	UGS classes	Area (km2)
UA	Green Urban Areas	6
	Forest	38.3
	Sport and Leisure	5.5
OSM	Park	1.6
	Forest	39.2
	Allotment	2.3
	Cemetery	0.8
UGSs based on Sentinel-2 and RF classification	Park	1.0
	Forest	36.9
	Allotment	1.6
	Cemetery	0.6
	Others	13

Table 1: Aerial coverage of different UGS types in Wuerzburg based on the Urban Atlas (UA), OSM dataset and previous green space classification by the authors.

LULC data	UGS classes	Area (km2)
UA	Green Urban Areas	4.3
	Forest	18
	Sport and Leisure	3.8
	Permanent crops	2.4
OSM	Park	2.0
	Forest	16.6
	Allotment	1.5
	Cemetery	0.4
UGSs based on Sentinel-2 and RF classification	Park	2.0
	Forest	17.5
	Allotment	0.9
	Cemetery	0.3
	Others	23.8

Based on the comparisons carried out, we conclude that the existing LULC maps do not accurately display the actual UGS status of urban areas. Therefore, in what follows, we propose a new domain ontology that focuses on providing a more detailed UGS typology, which is further enriched with semantic information.

4 Development of an ontology of Urban Green Spaces

UGSs can be described with reference to their physical appearance (i.e., land cover (LC)) and additional semantics (i.e., land use (LU)). However, existing UGS classifications as well LULC datasets (e.g., the UA) do not differentiate clearly between LU and LC of UGSs. In our ontology, we therefore define classes based on their current LU and characterize them with their dominant LC and their further characteristic attributes.

4.1 Definition of LC and LU types

UGSs are vegetated areas; different UGS types will exhibit one or more vegetation characteristics. For instance, urban gardens can host horticultural crops, fruit trees, or other bushes and trees, whereas forests consist of mostly deciduous or coniferous tees. Horticultural crops and deciduous trees have very different phenological traits and thus can be very well separated from each other. We therefore distinguish four LC types in both study areas, as identified in Weigand et al. (2020).

We differentiate between high and low perennial as well as high and low seasonal vegetation cover. High perennial vegetation refers to coniferous tree coverage; high seasonal vegetation refers to deciduous tree coverage. Under low perennial vegetation, we consider vegetation with minimal seasonal fluctuations such as permanent crops or scrub. Finally, vegetation types such as cereal or vegetable crops that exhibit extreme seasonal variations represent low seasonal vegetation.

As a basis for LU types, we utilize the classes proposed by Bell et al. (2007), but we further modify and extend the list of LU classes to provide a more harmonized and inclusive list of UGSs, defining the following LU classes: forests and woodlands; parks; green corridors; urban gardens; provision for children and young people; cemeteries and other burial grounds; amenity green space; urban agriculture.

4.2 Proposed Ontology

The proposed ontology consists of two levels: level 1 includes four LC types; level 2 includes eight LU types (see Figure 1). Selected UGS types are formalized using the dominant LC as well as set threshold (%) values for certain attributes of LU. We define thresholds similar to those of Bartesaghi-Koc et al. (2019), who present percentages of various surfaces (e.g. trees, shrubs) in relation to the whole area of a LU class. Formalization is further extended by the LC types' characteristic semantic information.

- *Forests and woodlands*: minimum patch size should constitute at least 0.5 ha, and at least 60% of the area should be covered with high perennial and/or high seasonal vegetation.
- *Parks*: minimum patch size should be 0.5 ha, and a minimum of 45% of the area should be covered with high and/or low perennial vegetation, and/or low seasonal vegetation. Further characteristics are presence of footpaths and benches.

- *Green corridors*: at least 80% of their area should be covered with high perennial and/or high seasonal vegetation. This UGS type is further characterized by closeness to roads, paths and rivers.
- *Urban gardens*: less than 50% of the area is covered with one or more of: high perennial vegetation, high seasonal vegetation, low perennial vegetation, low seasonal vegetation. This type of UGS is characterized by paths, and closeness to railways, roads and/or rivers. It might also include artificial objects such as garden sheds or swimming pools.
- *Provision for children and young people*: less than 30% of the area is covered with high seasonal and/or low perennial vegetation. This UGS type is characterized by the presence of artificial objects for children (e.g., slides, swings) as well as by patches of sand and pebbles.
- *Cemeteries and other burial grounds*: more than 50% of the area is covered with high perennial vegetation, low perennial vegetation, and/or high seasonal vegetation. Paths and artificial objects such as gravestones are typical characteristics of this UGS type.
- *Amenity green space*: characterized by mostly low perennial vegetation that covers at least 85% of the area.
- *Urban agriculture*: at least 50% of the area is covered by low seasonal and/or low perennial crops.

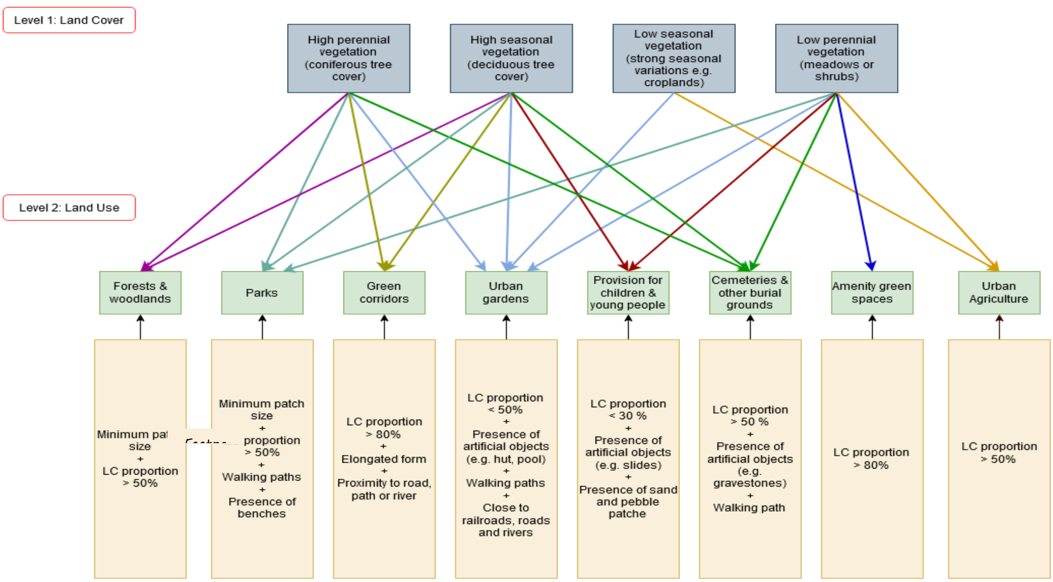

Figure 1: Proposed two-level UGS ontology, with four LC and eight LU classes and additional semantic information

5 Discussion and Conclusions

In this paper, due to the inconsistencies observed in existing UGS classifications, we propose a new ontology for UGSs. We realized that in the existing classifications and LULC maps the most overlooked and misclassified green areas are small UGSs such as urban gardens. Although a single garden alone contains only a small amount of vegetation, when considered together, urban gardens represent a significant area of greenspace in a city (Shahtahmassebi et al., 2021). We establish that this inconsistency emerges because of the vagueness of UGS definitions and because of the small minimum mapping unit of LULC maps. Precise identification of existing greenspaces in cities is crucial (Chen et al., 2021). However, this can hardly be achieved if there is no agreement on what we understand by, or accept as, an 'urban green space'.

We approach the development of the UGS ontology from two perspectives: physical appearance, and the semantics of various UGS types. In the first, we use four different LC types as they can explain most of the vegetation types in Germany (Weigand et al., 2020). We then describe each selected UGS type with its typical characteristics. We create new types of UGS by modifying and extending the existing classification by Bell et al. (2007).

Area size is a factor in determining the final LULC classes found on existing maps. For instance, the UA includes only areas that are greater than 0.25 ha. While the size of UGSs is referred to in various UGS studies (Haase et al., 2019), it is not usually clear what authors understand by, e.g., 'small green spaces'. The two main measures we refer to in our ontology are 'minimum patch size' and 'percentwise coverage of LC'. We define a minimum patch size of 0.5 ha (cf. Weigand et al. (2020)), which is, however, only relevant to the classes Forest & Woodland and Park. We use three different percentage classes for LC, similar to the thresholds defined by Bartesaghi-Koc et al. (2019). If a UGS type is densely covered with one or more LC types, we class it as having 80% coverage. If a UGS is only half covered with one or more LC types, then we allocate to it a coverage of 50%. Finally, for very heterogeneous UGS types, we specify a coverage of 30% or less.

It is clear that it is extremely challenging to design a universal ontology (Couclelis, 2010), especially when the domain is UGS, as vegetation is both spatially and spectrally dynamic. Furthermore, traditionally established perceptions about certain types of UGS might require an extension of the ontology. A typical example might be urban gardens, with their varying uses and thus varying appearances, both locally and in different parts of the world (Stephenson, 2005). Nevertheless, by limiting ourselves to two study areas, we aim to provide a clear and coherent ontology that can be extended for different study areas as appropriate. This way we comply with Gruber's (1993) main rules of ontology design: clarity, coherence and extendibility.

With the proposed ontology, we wish to demonstrate explicitly that in cities there is much more green space than is normally recognized as such. This information might be especially interesting to urban planners and policy makers. The findings of the study by Mandelbaum

(2021) suggest that 'Social and environmental injustice is an outcome of basic planning decisions'. Thus, by better understanding different UGS types and their functions, a better UGS planning framework can be developed, and social and environmental injustice avoided or mitigated.

Another use case of our ontology is in mapping UGSs. Spatial UGS analyses require the simultaneous use of different data sources, such as remote sensing or geodata. Currently, there is no single method that can classify all green spaces precisely and assign them automatically to the relevant green-space type (e.g., urban garden or park). The standard procedure is to use available vector geo-datasets for post-processing the results of the RS analysis (Haase et al., 2019), or to digitize UGSs by hand using aerial imagery.

An ontology-based classification of remotely sensed imagery is not a very common approach. Yet, implementing an ontology-based analysis might help to address many conceptual issues in the field, such as scale and vagueness of geographic terms (Arvor et al., 2019). The ontology-based classification yields similar results to those of commonly used Machine or Deep Learning methods. However, using an ontology-based approach, we can incorporate symbolic knowledge with numerical knowledge, and thus allow expert knowledge to be included in the decision-making process.

Therefore, in future work we will concentrate on using the ontology proposed here to perform UGS classification in other study areas. This will serve as a practical step for evaluation, and will potentially extend the ontology.

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