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Original article

Disentangling the connections: A network analysis of approaches to urban green infrastructure

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ABSTRACT

During the last two decades, a mounting body of research has emerged on the value, use and overall importance of urban green infrastructure. From the contribution to human well-being and sustainable development, urban green infrastructure is positioned as a relevant concept within ecosystem services and nature-based solutions.

Our research objective is to identify the main scientific approaches to urban green infrastructure, while accounting for different comparative criteria, such as subject of analysis, methods used, location or scale. We used an analysis of scientific literature in order to identify trends on urban green infrastructure research. We designed a study consisting of peer-reviewed articles and conference proceedings, published between 2005 and 2017 and listed in Science Direct database. We identified 497 peer-reviewed articles and conference proceedings, of which we validated 490 papers that included keywords. We used network analysis to identify significant patterns on the keywords co-occurrence in the scientific literature. Our main results identified the most used, powerful and influential keywords, while comparing the European network with the rest of the world. We found that terms such as: *green infrastructure*, *ecosystem services* and *urban forestry* are among the most used keywords in the ongoing body of literature.

Our study tries to better understand the directions used so far to analyse urban green infrastructure and the differences that occur between areas or scale of analysis. Main findings suggested by our results could anticipate shortcomings or future research, while better establishing the importance of urban green infrastructure as a nature-based solution.

1. Introduction

Faced with numerous environmental, economic and social challenges, modern cities have tried to re-direct themselves towards sustainability, resilience and improved quality of life (McDonnell and MacGregor-Fors, 2016; Wigginton et al., 2016). In the past few decades, urban green infrastructure (UGI) was often considered for both immediate (Elmqvist et al., 2003; Niţă et al., 2017a) and long-term solutions to the challenges of urban environments (Gómez-Baggethun et al., 2013; Lafortezza et al., 2017; Liu and Jensen, 2018).

Regardless of their different objectives and local settings, UGI is defined by multi-functionality and connectivity (Cameron et al., 2012; Iojă et al., 2014; Rolf et al., 2017; Niţă et al., 2018) and these characteristics determine the capacity of ecosystem services provisioning and how UGI is used (Hansen and Pauleit, 2014). UGI is represented at the urban level by a network of central areas (urban forests and parks), linear (such as street trees or water bodies) and stepping stone corridors (private gardens, green roofs) (Niţă et al., 2017b).

UGI originated from the concept of green spaces, meant especially to improve the aesthetics of cities, and subsequently to protect living spaces and to provide recreation (Bekkouche, 1997). Later on, urban green spaces were associated with health and environmental benefits (Benedict and McMahon, 2006; Tzoulas et al., 2007) and with the capacity to be connected and to provide several functions (Landscape Institute, 2009; European Commission, 2012).

Now, UGI is part of larger concepts, such as ecosystem services (Gómez-Baggethun and Barton, 2013) and is a key element for providing a more healthier environment, for tackling challenges such as climate change, air pollution, water management (Kabisch et al., 2016a) and social injustice (Kabisch et al., 2017). Furthermore, being a constantly evolving bio-cultural system, where biological and social features are developed simultaneously (Vierikko et al., 2016) and where the structure and functionality of UGI are constantly influenced by humans, the concepts associated with UGI are determined by their

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relationship with society. Current approaches are shifting towards nature-based solutions, defined as solutions to societal challenges that are inspired and supported by nature (Raymond et al., 2017), where UGI plays a major role in tackling environmental problems in urban settings.

As a result of its relevance, based on ecological, social and economic benefits (Tzoulas and James, 2010; Seamans, 2013) UGI is also a key instrument for city management and policy making (De Groot et al., 2010; Niemelä et al., 2010; Young and McPherson, 2013; Capotorti et al., 2017), helping cities towards a more resilient and sustainable development. An important feature of UGI role and functionality is related to the temporal and spatial scales at which they are addressed, aspects which can change the benefits they deliver (Badiu et al., 2016) or create a strong variation between policy levels (Davies and Lafortezza, 2017). Integrative approaches consider also the synergies occurring at different scales and societal objectives at urban level (Capotorti et al., 2017). The capacity of providing ecosystem services or benefits and also the way UGI are managed are aspects that are scale dependent (Ahern, 2007; Demuzere et al., 2014) and this can be seen in the literature. The scientific literature includes studies that analyse UGI from a neighbourhood or city level (Kaczynski et al., 2008; Sanesi et al., 2016; Badiu et al., 2018), to regional (Badiu et al., 2016) and national scale (Niemelä et al., 2010) all the way to continental (Kabisch et al., 2016b; Zwierzchowska et al., 2018) and global studies (Luederitz et al., 2015).

In the last decades, due to their increasing use in cities and promotion at planning and policy levels, UGI have also become a hot research topic, especially related with ecosystem services provisioning for quality of life improvement and sustainability of urban development (Breuste et al., 2015; Niţă et al., 2018). Studies involving UGI, varied from spatial and quantitative analysis of the availability and accessibility of green spaces in cities (Badiu et al., 2016; Kabisch et al., 2016b), analysis of health benefits (Tyrväinen et al., 2014), overall ecosystem services provisioning (Baró and Gómez-Baggethun, 2017), evaluating intrinsic, relational and instrumental aspects of nature (Jacobs et al., 2016, 2018) or monetary valuation (Brander and Koetse, 2011). Besides specific types of studies in the literature, UGI was also the subject for various comprehensive reviews, with objectives varying from concept analysis and integration with other scientific approaches (Tzoulas et al., 2007), comparative analysis of UGI principles in planning practices (Davies and Lafortezza, 2017), investigating the most used types of UGI and associated ecosystem benefits (O'Brien et al., 2017), critical reviews of the conceptual evolution of UGI (Wang and Banzhaf, 2018) or analysis on the citation and co-citation of authors (Ferrer et al., 2018).

The importance of evaluating UGI is also reflected by the diversity of policies advanced by the European Commission on green spaces (European Commission, 2013, 2014). Europe's approaches to UGI start from the promotion of social, economic and ecological benefits, with an emphasis on multi-functionality and connectivity, the role of UGI to mitigate and tackle urban environmental problems and UGI as an important tool to provide ecosystem services in urban areas. Thus, is it important to establish if the scientific literature and the policies are aligned and how these approaches differ between Europe and the rest of the world.

When analysing UGI, approaches can be classified in either theoretical (Kabisch et al., 2015; Alavipanah et al., 2017) or practical studies. Our study aimed to determine whether UGI approaches within published research are differentiated by regions or schools of thought or if the same concepts and ideas are recirculated at national, regional or continental level. While the literature was recently enhanced with scientific reviews on the evolving concept of UGI or its role in providing ecosystem services, we propose an evaluation that can fill the knowledge gap about areas where the concept of UGI is not extensively researched, if there is a predilection for analysing green spaces at a certain spatial scale or biased analyses towards certain benefits provided for society. Moreover, our study wanted to identify current trends on UGI research, reflected by the keywords co-occurrence network.

The aim of our study was to evaluate the similarities and differences in the scientific approaches of UGI based on a literature review. The specific objectives of the study were to: (1) assess differences in UGI approaches at different spatial scales; (2) delineate the most frequent keywords used in relation to the UGI concept and (3) analyse the most frequent benefits and types of UGI, presented in the scientific literature.

2. Methods

2.1. Data collection and analysis

We used a review of scientific literature (Borenstein et al., 2009; Seto et al., 2011) in order to identify trends on UGI research at different scales. We designed a study consisting of peer-reviewed articles and conference proceedings published between 2005 and February 2017 and listed in Science Direct database. We did not use book chapters or books because we considered the peer-reviewed articles and conference proceedings to be easily comparable since their structure is similar. Also, because our main analysis is focused on keywords network analysis, we excluded books and book chapters since most of them lack these features. The systematic literature review was conducted using a step-by-step approach similar to other studies (Ferrer et al., 2018).

We searched the Science Direct database for articles that contained in their abstracts, title and keywords the term *urban green infrastructure*. We identified 497 peer-reviewed articles and conference proceedings, of which we validated 490 papers that included keywords (7 articles were eliminated because they did not present keywords and could not be used in the network analysis). Besides extracting the keywords of each paper, we developed a database listing information on authors' affiliation, journal, the spatial scale at which the analysis was done and methodological approaches used, details on benefits provided by urban green spaces, future research insights and problems associated with urban green space evaluation. The articles were analysed by one coder and we used pre-defined categories for coding most of the information mentioned above (Table 1).

2.2. Keywords network analysis

Special focus was given to the keywords extracted from the articles,

Table 1
Pre-defined categories for analysing the selected articles.

Field	Pre-defined categories
Authors affiliation	Universities/research Public administration Private entities
Spatial scale[a]	Global Continental Multinational National Regional Local
Methodological approaches	Experimental methods Literature review Participatory process Field research Spatial analysis (GIS/remote) Social survey (questionnaire) Statistical methods
Benefits provided by UGI[b]	Ecological benefits Economic benefits Social benefits

[a] The geographical scale or extent for which the analysis was done.
[b] We also mentioned if the benefits were absent, presented at theoretical level, presented with qualitative assessment or presented with quantification.

which were analysed using a network approach. Network analysis has been mostly used in social studies (Borgatti et al., 2013), medicine (Basler et al., 2016), biology (Barabasi and Oltvai, 2004) but lately is becoming more and more useful in solving environmental issues (Berardo et al., 2016; Bodin, 2017) such as managing protected areas (Manolache et al., 2018) or improving partnerships established for conservation projects (Nita et al., 2016; Rozylowicz et al., 2017). Since keywords can be defined as words which act as the key of research articles, while also reflecting the methodological approaches and concept which they revolve on, their analysis is representative for research purposes (Madani and Weber, 2016). This is why, we used this type of analysis as it is a proper method to map (knowledge) structures of research areas (Schodl et al., 2017).

By applying keyword network analysis, our paper identified significant patterns and trends of keywords used by researchers in articles that primarily target UGI. This investigative technique is an efficient way to map knowledge and research structures and also to explore new research arenas for important topics (Dotsika and Watkins, 2017; Schodl et al., 2017).

After gathering all data, we extracted the keywords of 490 research articles, unified them and obtained a total number of 1197 unique keywords for analysis. Next, we created a matrix to apply network analysis to a keyword-based one-mode network (Rozylowicz et al., 2019). For the resulted network we applied cohesion measures to find the main patterns of the structure, like diameter, which shows the largest geodesic distance within the network illustrating how far keywords are from each other, therefore showing how compact the keyword network is and also level of fragmentation of the network (Hanneman and Riddle, 2005). We also performed centrality metrics which allowed us to elaborate a positional keyword analysis that helped us find which are the most used keywords (i.e. *degree* centrality*)*, which keywords stand between other important keywords, occupying a favoured position within the network (*i.e. betweenness* centrality), which keywords are most influent within the network (*i.e. eigenvector* centrality) and which are the most well connected with other powerful keywords (i.e. *beta* centrality – *Bonacich power*) (Borgatti et al., 2013; Rozylowicz et al., 2017) All network analyses were performed using UCINET 6.631 (Borgatti et al., 2002).

We sorted the articles by country of analysis and created 2 new matrices (region-specific-networks) – one for Europe, containing 560 keywords gathered from 180 articles and one for the rest of the world, gathering the connections established between 830 keywords from 310 articles. The obtained networks created were used for structure comparison and to spot UGI research differences between Europe and rest of the world in terms of most common, connected, important and influent keywords. The Europe network refers to where the research was conducted and the rest of the world network is represented by studies conducted anywhere but in Europe. Because we wanted to see if the current studies set up in Europe are in line with the European policies and if these approaches are different from the rest of the world studies, our research focused on this comparison. We used Netdraw 2.161 (Borgatti et al., 2002) and VOSviewer 1.6.6 (van Eck and Waltman, 2010) to map the entire network of keywords by *eigenvector* centrality. For a proper visualization, the graphs included only the keywords that have a *degree* larger than 10 – meaning that the term was found in more than 2 or 3 articles.

We also mapped the global keyword network, in order to highlight differences between the most important and influential keywords within the network, at local, regional, national, multinational, global and continental scale.

3. Results

3.1. Patterns of research articles

Articles were found in a wide variety of journals (Table 2), the most prevalent ones being *Landscape and Urban Planning*, *Urban Forestry & Urban Greening* and *Ecosystem Services*.

Table 2
List of journals with over 10 articles in the final database.

Journal	No. of articles
Landscape and Urban Planning	85
Urban Forestry & Urban Greening	85
Ecosystem Services	20
Ecological Engineering	19
Ecological Indicators	17
Building and Environment	14
Science of the Total Environment	14
Journal of Environmental Management	13
Procedia – Social and Behavioural Sciences	12
Journal of Cleaner Production	10
Land Use Policy	10
Renewable and Sustainable Energy Reviews	10

The average number of authors per article was 3.53 [± 2.35] and the highest proportion of them was represented by authors with an academic affiliation followed by authors from administration and private companies.

The timeline distribution of articles has increased continuously from 2012 to the present day. From the articles which had a clear national, regional or local focus, the highest number (Fig. 1) focused on countries such as the United States of America, China, Australia, Germany or United Kingdom.

3.2. Centrality metrics of urban green infrastructure related keywords

The keyword network analysis was performed on a one-mode network composed of 1197 unique keywords, with a density (matrix average value) of 0.0079 (stdev = 0.11), showing a low connection between keywords at the level of the entire network (Table 3), being slightly increased in the case of the rest of the world network (density = 0.0103, stdev = 0.12) and also registering a higher value in Europe (density = 0.0137, stdev = 0.13). Furthermore, the Europe network registered the highest value with respect to fragmentation, while the diameter 6 for all networks illustrated that a keyword can reach any other keyword in the network by using maximum 6 others.

By applying centrality metrics, we discovered that the most used keyword in the entire network was *green infrastructure,* obtaining the highest *degree* (228), this also being the search term. The other important keywords were *ecosystem services (degree = 187), urban forestry (degree = 175), green roof (degree = 140*), *green spaces (degree = 116)* and *urban green spaces (degree = 113)*. A similar trend was recorded in terms of *eigenvector* centrality, from the influence perspective within the keyword network. The situation remained the same in the top three of the most influential keywords. The 4th position was occupied by *urban planning* from the influence point of view, keyword which in terms of *betweenness* is located on the second position (Fig. 2).

From the *Bonacich power* perspective, our analysis found other keywords that appear in top 5, namely: *storm water* (position 4) and *water* (position 5), these being linked to the most important nodes in the network. From the same point of view, *urban planning*, *urban green spaces* and *urban forestry* descend to the next positions.

Performing keyword network analysis for articles from European network, we found that *ecosystem services* leads in terms of influence (*eigenvector* and *Bonacich power* centrality), displacing *green infrastructure*, which occupies the first position only as the most used keyword (*degree* 89) (Fig. 3).

Compared to the whole network, from the perspective of the influence, the metrics showed that in top ten, keywords such as *GIS* and *urban heat island* appear. The pattern changed also in terms of most well connected with other influential keywords within the network, namely: *green spaces, land use planning, urban ecosystem services, spatial patterns,*

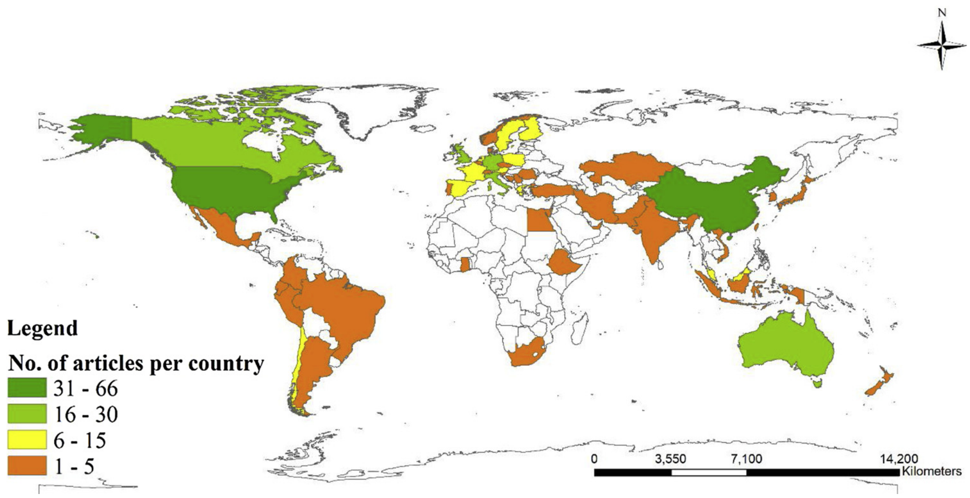

Fig. 1. No. of peer-reviewed journal articles and conference proceedings per country, found within Science Direct database.

Table 3
Cohesion measures of analysed networks.

Cohesion measures	Entire network	Europe network	Rest of the world network
Average degree	8.478	7.189	7.725
Density	0.007	0.013	0.010
Connectedness	0.941	0.863	0.902
Fragmentation	0.059	0.137	0.098
Closure	0.154	0.272	0.187
Diameter	6	6	6
Compactness	0.324	0.288	0.309

biodiversity, and *urban heat island* were included also in a top ten ranking.

For the rest of the world network (Fig. 4), *green infrastructure* obtained the highest values for *degree*, *eigenvector* and *betweenness*, the second position being occupied by *urban forestry,* which gathers more connections and plays a more important role within the network than *ecosystem services,* which is in 3rd position. We also found *storm water* to occupy a key position according to the *Bonacich power* results, obtaining the highest value from this point of view, while in terms of *eigenvector* and *best position within the network* it is placed on the 10th position.

We also analysed the occurrence of all keywords of the network by type of scale addressed within the article (i.e. continental/ national/ multinational/ local/ global/ regional) (Fig. 5), for which we found significant differences. If analysing the importance and influence of each type of scale, taking into account their centrality metrics, we obtained the following trend: local – most important, followed by global, regional, national, multinational and continental.

Thus, at a local scale, *storm water* was the main keyword best related to influential and important words in the network, namely: *green infrastructure*, *urban forestry* and *green roof* (top three ranking for *degree* and *betweenness*). Although on the 4th position from the perspective of the two-central metrics previously mentioned, *ecosystem services* registered the second place in terms of *eigenvector* centrality.

At regional scale, we found that *urban forestry* was on the 1st position considering the values obtained for *betweenness*, even if it had fewer connections than *green infrastructure* and a smaller value of the *eigenvector* than *ecosystem services*, which was well connected to the most influential keywords in the network. At national scale, the

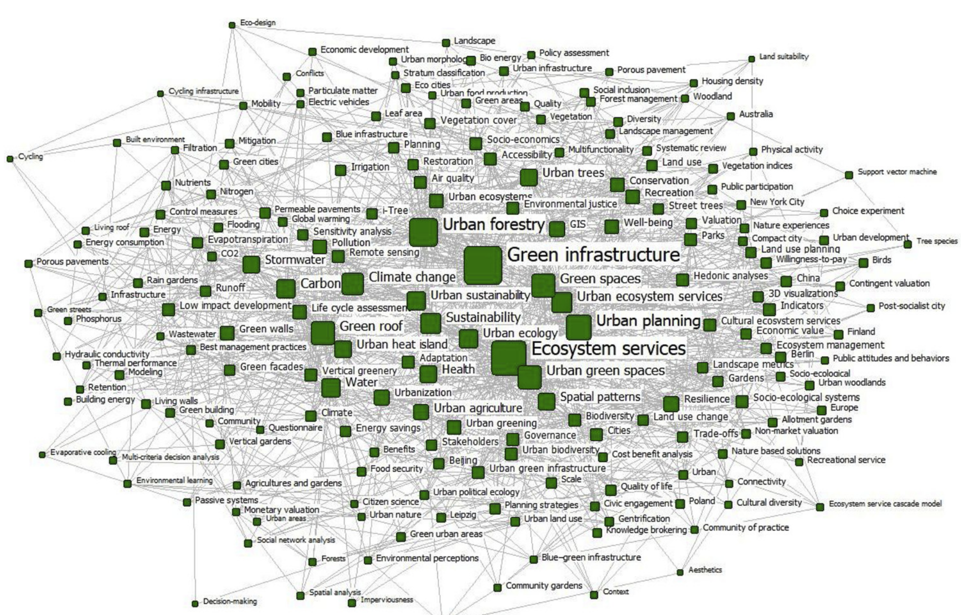

Fig. 2. Keywords network for all analysed articles (size of the nodes and labels by eigenvector, the keywords with a degree < 10 were removed for proper visibility).

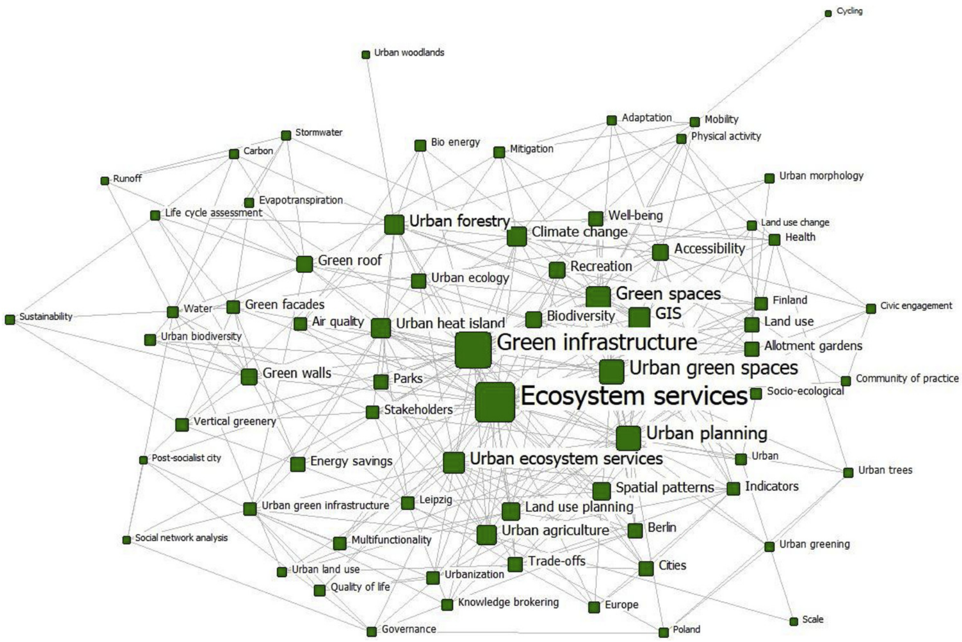

Fig. 3. European keywords network (size of the nodes and labels by eigenvector, the keywords with a degree < 10 were removed for proper visibility).

keyword *ecosystem services* recorded the highest scores for *degree* and *betweenness*, *monetary valuation* was on the first position in terms of *eigenvector* and *Bonacich power*, while *green infrastructure* was placed on the last position according to the centrality metrics.

At multinational scale, again the keyword *ecosystem services* occupied the first position in terms of highest number of connections, influence and importance. Here, new words appeared in top, as follows: the keyword *parks* was the second most connected keyword, while the keyword *indicators* registers the second highest value in terms of influence (eigenvector centrality). At global scale, *ecosystem services* and *green infrastructure* were in first and respectively second position for all centrality metrics, and the third *Bonacich power* value is registered by *resilience,* which in any other situation did not appear in the top five. At continental scale, the results were slightly different than presented for the other scales. Here *green infrastructure, ecosystem services* and *urban forestry* did not appear at all, on the first two positions being *Urban Atlas* and respectively, *urban ecosystem services*.

3.3. Typologies and benefits related with urban green infrastructure

Regarding the types of studies, only a small number of articles where functional studies, focusing their objective on a specific challenge addressed by UGI: ecosystem services provision (31), water management (30), climate change (27), biodiversity (11), social aspects (8) or air protection (6). Most of them were either general studies on UGI (n = 189) or focused on a specific typology (n = 182). The most encountered typologies of UGI were represented by urban forests (94), urban parks (92) and green roofs (68) (Table 4).

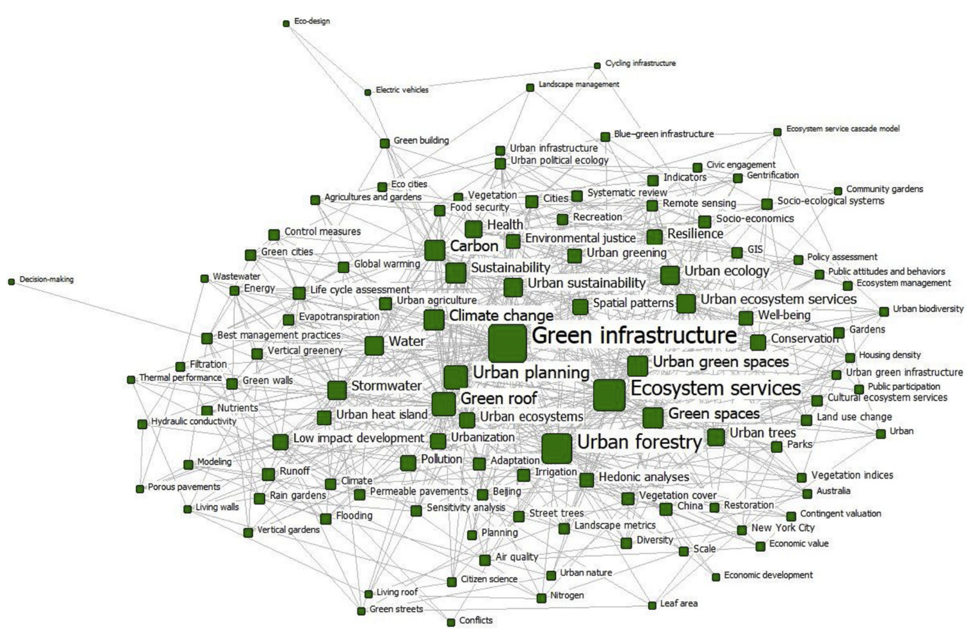

Fig. 4. Rest of the world (everywhere but Europe) keywords network (size of the nodes and labels by eigenvector, the keywords with a degree < 10 were removed for proper visibility).

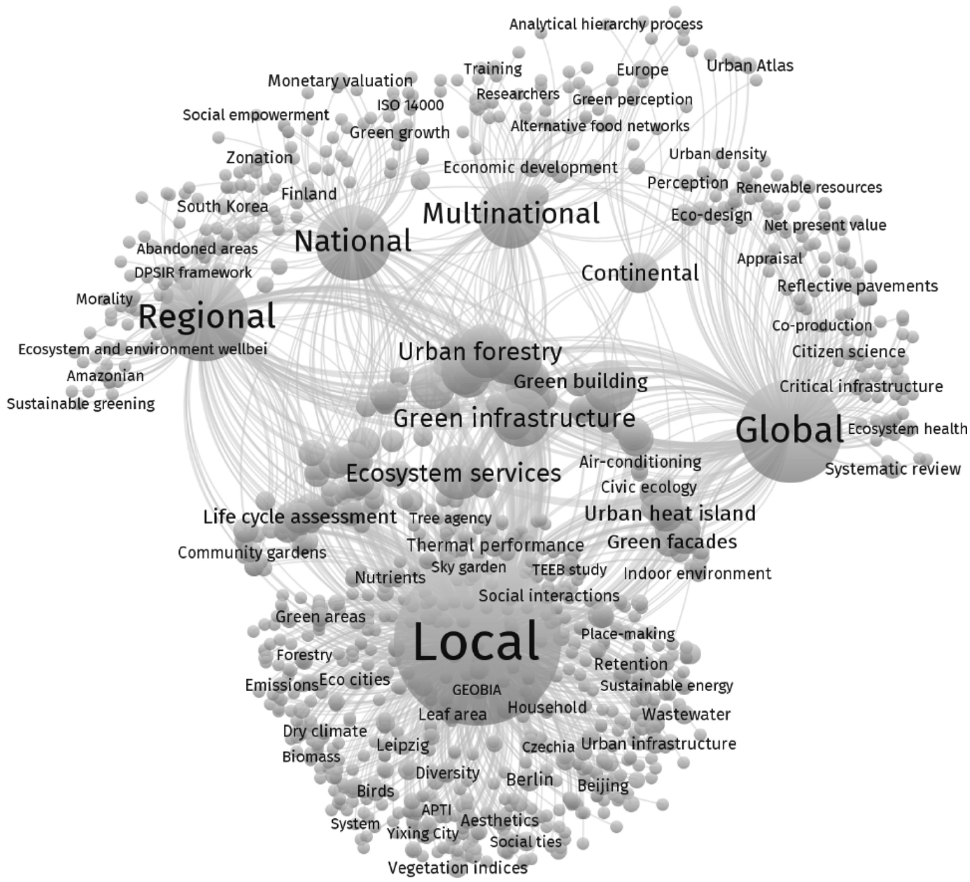

Fig. 5. Global keywords network affiliated to the type of UGI approaches by scale (size of nodes is given by total link strength).

Table 4
Frequent typologies of UGI found in the articles with over 5 recordings.

Type of UGI	No. of articles
Urban forests	94
Urban parks	92
Green roofs	68
Trees	20
Living walls	17
Street trees	17
Gardens	14
Rain gardens	14
Allotment gardens	13
Green walls	13
Community gardens	11
Urban gardens	11
Vertical greenery	11
Urban woodland	10
Green facades	9
Private gardens	9
Wetlands	7
Green spaces	6
Greenways	6
Permeable pavements	5
Vertical gardens	5

Regarding UGI benefits, we found information on how ecological, economic and social benefits (Table 5) are evaluated in both primary and review studies. There was a large prevalence of ecological benefits over economic and social ones, with notable differences also in the assessment approaches: for social and economic benefits, authors mainly used theoretical approaches, while for ecological benefits, quantitative methods prevailed.

Table 5
Presence of benefits in analysed papers (number of papers).

	Ecological benefits	Economic benefits	Social benefits
Absent	112	321	241
Presented at theoretical level	128	97	131
Presented with qualitative assessment	24	11	52
Presented with quantification	226	61	66

The largest number of articles had more than one method for benefits analysis, but the most frequently used are statistical methods (n = 169), literature reviews (n = 132), spatial analyses (n = 104), experimental methods (n = 101), social surveys (questionnaire) (n = 95), field research (n = 89) or participatory processes (n = 15).

4. Discussion

Our paper evaluated, based on the keywords and major findings of 490 articles, the approaches used to investigate UGI, how are the studies connected to each other and how are the benefits perceived and analysed. Our major findings show that, in terms of evaluating the concept, studies are directed towards few important keywords, such as green infrastructure, ecosystem services and urban forestry, regardless of scale of analysis, where some specific differences occur. There is a tendency in the scientific world and also in urban planning for including the more and more prominent concept of *ecosystem services* in the analysis of green infrastructure, where emphasis is put on the capacity of UGI to provide various benefits in cities (Niemelä et al., 2010; Gómez-Baggethun and Barton, 2013; Hansen and Pauleit, 2014).

4.1. The place of urban green infrastructure in research articles

Landscape and Urban Planning was found to be an important journal for publishing on the subject of UGI, in our study and in the study of Ferrer et al. (2018). Both studies show that UGI is a concept related to and relevant for an array of subject areas: social sciences, urban planning, climate change, water management and ecological engineering or energy policies.

We found a large body of articles published after 2012, when the subject gained popularity and relevance for research, policy development and urban planning. This came as a consequence and in parallel with the work developed by the European Commission, in terms of strategies and policies on green infrastructure (European Commission, 2012, 2013, 2014), in order to improve nature conservation, ecosystem services provisioning and human health and well-being. The lower number of articles found for 2017 (14) is explained by the fact that we stopped our search in the first trimester of the aforementioned year.

Usually, authors publishing on the subject are affiliated in public research institutions rather than private or administrative fields which is the case for the majority of studies involving urban ecology. Our results were also consistent with those of Ferrer et al. (2018) which found universities to be dominating the range of authors. One can also notice the absence of African and South American countries, from the highest positions of number of articles published, where we can also add Eastern Europe countries as being underrepresented in the literature. This could be explained both by the late penetration of the UGI concept in these countries (Badiu et al., 2016) and also by the lack or reduced connections established by authors with Western research institutions. Fig. 1 shows that the concept of UGI was mainly addressed and analysed in the United States, United Kingdom and Germany (Weber et al., 2006; Radford and James, 2013; Haase et al., 2014; Cvejić et al., 2015; Kabisch et al., 2016b; Artmann et al., 2017b) and it was further implemented in China and Australia in experimental studies in order to establish the potential of several UGI categories, such as living walls or green roofs, to contribute to energy efficiency use (Chen et al., 2013; Jim, 2014).

4.2. Connections between articles on urban green infrastructure

Our keyword network analysis results distinguish the European network as an important and connected body of research. Despite the fact that the concept of green infrastructure was first introduced in the United States, as a way to improve well-being and nature conservation (Benedict and McMahon, 2002), the subject was quickly picked up in Europe, in planning, science and policy interfaces (Sandström, 2002; James et al., 2009). Other studies have also found Europe to be a frontrunner in studies related with UGI (Hegetschweiler et al., 2017), even if they are based mainly on papers from northern and western countries.

As a result of its great relevance for human health and well-being, UGI was also included or associated with other concepts, such as *ecosystem services*, which is another important keyword in the network. In research articles or planning documents, UGI is often considered a main tool for providing regulating, provisioning and cultural urban ecosystem services (Gómez-Baggethun and Barton, 2013). Likewise, the research on urban forests has increased and it is an influential subject for Europe but most importantly for the rest of the world, such as United States, where the concept first appeared (Konijnendijk et al., 2006). The reason why *urban forestry* was a central keyword for the rest of the world network but less important for the European one can reside in the fact that the concept was later introduced here, in 1990 and the terminology was not very clear from the beginning (Konijnendijk, 2003).

Green roof was also found as a frequent used keyword and this aspect reflects the trend of studies to also address UGI in an experimental way, with technological support (Harper et al., 2015; Razzaghmanesh et al., 2016).

We also found differences in the way UGI is analysed at various scales. Most often, UGI was evaluated and discussed for local case studies and less frequently at a continental level. At a local level the most important typologies for evaluation were urban forests and green roofs, which were suitable for local social surveys or experimental studies (Tyrväinen et al., 2005; Santamouris et al., 2007; Tyrväinen et al., 2007). At a national level, we found keywords such as *ecosystem services* and *monetary valuation* to play important roles in the network and this can be explained by the target set by European Commission in the EU Biodiversity Strategy (European Commission, 2011). Therefore, member states are supposed to map and assess the state of ecosystems and their services, including with monetary valuation instruments.

When talking about multinational scale, researchers develop comparative studies to analyse the similarities and differences between various types of UGI and we found parks as being the most used typology in this regard. Many of these studies compared urban parks in terms of use, activities and accessibility or cultural ecosystem services provided (Bertram and Rehdanz, 2015; Speak et al., 2015; Zwierzchowska et al., 2018).

Another interesting aspect occurred for studies developed at global scale, mostly review articles that often address the concept of *resilience*, a keyword that is well connected with other powerful keywords. There are great efforts made in the scientific and political areas to redevelop cities in a more sustainable and resilient way (United Nations, 2016) for a lower ecological footprint and a better life quality for residents (Normile, 2016). The reason why resilience is on the mind and in the studies of many researchers is that UGI contributes to the process of ecosystems' resilience by improving their capacity to adapt to natural disasters (McPhearson et al., 2015, 2016).

4.3. Benefits and elements of urban green infrastructure

Our study showed that ecological benefits are assessed with quantitative methods, social benefits are either just mentioned or evaluated in a qualitative manner, while economic benefits are evaluated with a lower frequency. This shows the fact that benefits of UGI are evaluated in a complementary way, considering all three types of values (ecological, social and economic). Our results are in line with the general trend that recommends an integrative approach when evaluating ecosystem services and considering biophysical, socio-cultural and monetary values (Barton et al., 2018; Jacobs et al., 2018). Also, the need to assess and value benefits and ecosystem services is fundamental for achieving sustainability objectives (Raymond et al., 2017). Other review papers found that benefits of UGI are represented mainly by health or well-being rather than socio-economic ones (Tzoulas et al., 2007; Hegetschweiler et al., 2017). Benefits associates with UGI came also from the regulating ecosystem services sphere (Wang and Banzhaf, 2018).

On the types of studies, the literature still requires more functional studies, on the way UGI addresses specific global challenges and we consider that the trend is increasing for this type of studies, as a result of the nature-based solutions concept (Kabisch et al., 2016a). There is a mounting body of research on climate change adaptation by UGI and ecosystem services provisioning in general (Larondelle and Haase, 2013; Demuzere et al., 2014; Elmqvist et al., 2015) and with the concept of nature-based solutions there is the expectation for a better science-policy integration of the UGI approach (Nesshöver et al., 2017).

As the keywords network analysis showed, urban forests represent one of the most important types of UGI in scientific studies, followed by urban parks and green roofs. Our results were similar with the ones of Gavrilidis et al. (2017) and O'Brien et al. (2017) who found urban forests and urban parks to be the most used UGI for a city. Moreover, the majority of articles focus on complex urban green areas such as parks or urban forests while neglecting the role and contribution of smaller elements that can also provide ecosystem services (Gómez-

Baggethun et al., 2013; Iojă et al., 2014).

Our study showed a comprehensive analysis of articles addressing UGI but there are still some limitations that we acknowledge, such as the exclusion of articles written in a language other than English, the use of one, though extensive, database (Science Direct) and the fact that the number of analysed articles is not exhaustive. For example, the journal Arboriculture & Urban Forestry could potentially have numerous relevant papers but it is not indexed in the Science Direct database. Furthermore, because some journals recommend that keywords should not repeat words from the title of the paper, there could be several relevant omitted articles, when the search is based only on keywords. Also, our search on papers stopped in the first trimester of 2017 but there is still a growing number of articles after that point.

Regarding the fact that we particularly separated the European network from the rest of the world, we considered that the number of papers for each continent, to do separate network analyses, was not sufficient. Specifically, we analysed a similar number of papers for the European network that we did for the rest of the continents and regions. This is the reason why we considered separate network analyses for each continent to be unsuitable at this moment. Still, we consider that separate network analyses on other continents, not just Europe, with a sufficient number of papers, would consist in an important future direction and emphasize interesting trends on urban green infrastructure.

The body of literature on UGI is extensive but not necessarily comprehensive and there are still some major aspects that can be further developed and for which the knowledge can be improved, for example with studies on the use of UGI by different social groups, on the complementary benefits of UGI or on the enhancement of science-policy interface. Our results showed that the science-policy interface should be further strengthened to promote and establish UGI that are more accessible and just, not only spatially but also cultural, for different social groups, such as elders, children or people with disabilities (Artmann et al., 2017a; Haase et al., 2017; Łaszkiewicz et al., 2018). UGI knowledge regarding new indicators to better assess urban ecosystem services needs to be further improved (Lakes and Kim, 2012) as well as the current needs of users and their preferences towards different activities of nature experience (Scopelliti et al., 2016). Our results also showed a gap in the know-how of the role and connections of different institutions in UGI planning (Connolly et al., 2013).

Moreover, UGI as part of the nature-based solutions concept, should focus on addressing specific challenges that affect nature conservation and the quality of life and it should be developed accordingly, both spatially and functional. Urban green space should not be planned just as a recreation tool but it should be developed in order to simultaneously address different problems, such as climate change, storm water management, air pollution or the relation between human and nature (Church, 2015; Lafortezza et al., 2017). And while improving multi-functionality is essential, several trade-offs or issues emerging from the existence of UGI should be acknowledged. Trade-off analysis, alongside co-benefits and ecosystem services evaluation is crucial for decision-making (Haase et al., 2014; Bodnaruk et al., 2017) and it should be further investigated in future urban green infrastructure studies (Maes et al., 2019).

5. Conclusions

Our study highlighted the fact that UGI is differently evaluated between continents or scale, with a more extensive body of research in Europe and at a local scale. The variability in approaches is also explained by different schools that evolved around different concepts, such as urban planning, urban forestry, ecosystem services or nature-based solutions (Sandström, 2002; Konijnendijk et al., 2006; De Groot et al., 2010; Hansen and Pauleit, 2014; Faivre et al., 2017; Escobedo et al., 2018).

As such, studies evolved around certain subjects, characterized with keywords such as: ecosystem services, urban forestry or urban planning and are connected with each other by authors, countries or methods of analysis.

Despite many and diverse approaches, the general understanding is that UGI is a powerful and demonstrated solution to global challenges and it can help cities become more resilient and sustainable.

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