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Review

Urban Green Infrastructure and Sustainable Development: A Review

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Abstract: Urban green infrastructure (UGI) can alleviate many of the problems that the growing urban population is facing. This study performed a literature review about UGI and sustainable development (SD) using the Web of Science (WoS) and the software VOSviewer. Of 195 papers selected, 89 are qualitative, focusing on theoretical approaches and design; equally, 89 are quantitative, dealing with metrics and spatial analysis and 17 combined both approaches. A high connectivity between "green infrastructure", "ecosystem services", "urban planning" and "sustainable development" was observed. Only 39 of the documents embrace environmental, social and economic aspects. Most of the papers are related to Sustainable Development Goal (SDG) 11, "to make cities inclusive, safe, resilient and sustainable" and SDG 15, "protect, restore and promote sustainable use of terrestrial ecosystems". Further research integrating the three pillars of sustainability and relating UGI to all the SDGs is recommended.

Keywords: urban green infrastructure; literature review; sustainable development goals

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1. Introduction

Urban green infrastructure (UGI) is progressively claimed as an essential structural part of cities [1], playing a key role in the sustainable development (SD) of planet Earth, because most of the human population is now living in urban zones. The UGI of a city is made up of different types of systems more or less connected with each other. The essential components of UGI are natural elements (plants, animals, water, soil and micro-organisms etc.) structured in a variety of forms (e.g., urban squares, street tree lines, parks and horticultural gardens). These are the same components structuring natural ecosystems and making them perform ecological functions, and thus provide ecosystem services (ES). However, the urban oriented design and construction of UGI and the occupation and use of natural ecosystems for urban purposes incorporate artificial components to the UGI. This causes a decrease in the provision of regulating services but an increase of recreational services, which are respectively related to the fulfillment and the limitations of natural ecological functions. In other words, UGI can contribute substantially to the SD of cities through the provision of ES and avoid disservices [2–5].

The connectivity between UGI sites is essential to provide benefits for persons in a city. In fact the network of UGI and its distribution in the urban zone is an important aspect of urban planning [6]. The growth of the cities is frequently a dilemma between the conservation and the urbanization of natural environments. As far as new natural areas are urbanized, loss of ES takes place while urban living facilities for humans increases. As a consequence of the increasing interest in SD, urban green infrastructure design, provision, maintenance, conservation and restoration are being more recognized as critical components of any holistic and realistic strategy for urban sustainability [7,8]. Urban zones acknowledged their huge contribution to global changes and increase their interest in contributing to sustainability by reducing the emission of greenhouse gases and increasing

their inhabitants' welfare [9]. Among other actions, establishing a well-structured UGI is one of the most common challenges for urban zones to contribute to these purposes.

Many different types of UGI exist and their typology has been a matter of study from different points of view [10]. Additionally, different indicators have been proposed to analyze the components and values of UGI [11]. The methodologies to study UGI vary in relation to the subject of interest. The contribution of UGI to improve people's health has been shown clearly [12,13]. Functions and services are related through a conceptual approach [14]. The spatial analysis of UGI was used by González-Duque and Panagopoulos [15], in relation to social aspects. Spatial analysis, along with surveys and interviews, was used by Meerow for land use planning [16]. The evaluation of ES was used to support the values of UGI [17]. Several research lines have been suggested to progress the understanding between urban biodiversity, ecosystem functions and services [18]. People´s preferences of UGI density were studied by Suppakittpaisarn et al. [19].

Therefore, UGI plays multiple roles in both city and global scales and is a subject of study of increasing interest. Many authors performed an intellectual exercise proposing theoretical frameworks and interpretation of the role of UGI for the ecology of cities to improve planning aspects in line with sustainability objectives [14]. Most frequently, all these aspects are approached separately while studying UGI characteristics. It is difficult to take a holistic approach because of the required specialization to study any of the mentioned aspects and because of the huge effort required for the integration of the significant number of aspects involved in UGI.

In this paper, we review how UGI research is approached in relation to SD through: (i) a literature review focusing on disentangling the methodological aspects of UGI research after an analysis of the relationships between topics and authors of the reviewed documents; (ii) an observation of the distribution of the topics of interest of the documents in relation to the three major pillars of sustainability (environmental, social, economic). Thereafter, (iii) a review on the relation between the subjects of interest of the searched documents on UGI and the United Nations Sustainable Development Goals (SDGs) was performed.

2. Materials and Methods

The steps followed for the review process and data analysis are schematized in Figure S1 in supplementary material.

2.1. Literature Search

The literature review was based on the results of a search conducted at Web of Science (WoS) on 27 April 2021 at 16:00 h using the topic keywords "Urban Green Infrastructure" AND "Sustainable development" for 1992–2020. The 663 obtained documents included journal articles and proceedings documents. Then, we excluded "book chapters" from Web of Science, in addition to documents referring to disciplines that were alien to our search interests ("energies", "lecture notes in civil engineering", "horticulture", "mathematics interdisciplinary applications", "materials science multidisciplinary", "mechanics", "transportation", "operations research management science", "engineering electrical electronic", "advanced engineering forum", "frontiers in psychology", "globalization and health" and "heliyon") and documents not written in English. Subsequently, the list of documents was reduced to 318.

Thereafter, we performed manual filtering, excluding all the articles not including the two words "green infrastructure" neither in the title nor in the abstract, and the number went down to 197. One more article was excluded because it was published in 2021 (not in the specified period of research) and another one was removed because it was a duplicate. The final number of articles used for further analysis was reduced to 195. The spatial and time trends of the research topics were obtained from the analysis of results tool of WoS.

In order to disentangle the scientific approaches used in the searched documents, they were classified as theoretical if they presented qualitative considerations or frameworks, and practical if they used quantitative data after reading the abstracts. In case of doubt,

the paper was reviewed in full. Mixed documents were those which included a qualitative approach as well as data analysis of a case study. The documents in these three blocks were then grouped according to more specific research interests and methods used. Particular attention was paid to those documents using or focusing on the evaluation of ES because of the strong relationship between ES and the topics of interest of this literature search.

2.2. Bibliometric Analysis

VOSviewer 1.6.16 was used for the bibliometric analysis. Vosviewer is a software tool for building and visualizing bibliometric networks specialized in the graphical representation of bibliometric maps. It provides different ways to display networks and allows close examination of a map via the zoom, scroll and search functions [20]. Moreover, by dealing with a large number of items, the cluster display can provide us with a clear overview of the network structure. Thus, VOSviewer was used to obtain bibliometric maps that help analyze the links between topics in order to understand how UGI and SD are linked.

The cluster display is applied in this research to have a better structural view of the networks. In a map, each unit is presented as a node. It can be a journal, a category, an author, an article or a keyword. The distance between the nodes shows their relationship. If two nodes are displayed close to each other, it can be interpreted that they are strongly related. Links between nodes represent the direct co-occurrence and co-citation. The strength of the links is proportional to the co-occurrence or co-citation frequency. Nodes related to each other with stronger links can be grouped into one cluster, and each cluster is assigned one color. It can be interpreted that the units within a cluster share a high homogeneity, while the units in different clusters are heterogeneous. With the cluster display, an identification can be made of the intellectual structure of UGI and SD research from several perspectives [21].

Firstly, after uploading a text WoS file into VOSviewer, a bibliometric analysis was conducted, which accounted for co-occurrence as analysis type and authors keywords as a unit of analysis. The software produced a superimposed view, with colors applied to the authors' keywords by year of publications. A map of 704 authors' keywords was illustrated, then an acceptable and readable result was obtained after the analysis of the authors' keywords with five being the number of a minimum occurrence of keywords (keywords that are repeated less than five times are excluded from the map), which produced a map with 24 easily identifiable keywords. Co-occurrence is when two or more keywords occur together in the same paper, thus each keyword is represented by a circle; the bigger the circle, the more the keyword occurs in the papers. Keywords that have a strong occurance together will be linked together. The link strength, which indicates the number of publications in which two keywords occur together, will be high (compared to other keywords), and the distance between these two keywords will be short. In reverse, keywords that occur together weakly will have a low link strength number and the distance between them will be high. Figure S2 shows an idealized example of this type of results from the co-occurrence analysis of keywords. K1 (Keyword 1) has the biggest circle, hence it is the keyword occurring most in the publications; the closest keyword to K1 is K2, they have a link strength of 12, meaning K1 and K2 occurred together in 12 papers indicating that there is mutual interest of research on the topics represented by K1 and K2.; K4 is the farthest from K1, so they have a link strength of 3, meaning that they appeared together as keywords only in 3 papers and that there was not much interest on joint research on these two topics, K4 and K1.

The gamma index of connectance is a measure of connectivity among nodes (subjects or topics of interest) of a network: the number of links divided by the total number of possible links [22]. It can be applied to both the full network and to a specific node of the network. The value of gamma connectance ranges between 0 and 1, where a value of 1 indicates a completely connected network/node with the rest of nodes and 0 indicates that there is not any node of the network connected to each other/a particular node is not connected to any other.

This probability index uses the combination formula (combinations of n nodes or topics taken, k, at a time without repetition) to calculate the number of possible combinations of the 24 subjects of interest selected as a network or separately for each of them; it is the maximum or potential number of links of a node or of the full set of nodes in a network [23,24]. Thus, it is the number of combinations of n nodes taken 2 at a time without repetition C = n (n − 1)/k (K − 1), and in our case n = 24 (the number of nodes/topics selected) taken by groups of k = 2. This gives 276 potential links between nodes in our network. Then, we used the actual number of links of each node (topic) divided by the potential number of links as a measure of connectivity for each node, and also for the full network as mentioned above. So, in our case, this index of connectivity for each node can range [0–0.083] ((0/276)–(23/276)) if, respectively, it is not connected to any other and if that node/topic is connected to all the other 23. For the full network, the index is useful to know the state of present connectivity among the nodes of the network (among the topics or subjects of interest of the selected network of 24 topics).

Second, a bibliometric analysis was conducted using VOSviewer which encompasses co-authorship as a type of analysis, and authors as a unit of analysis. It considers the number of occurrences of 708 authors and the links of co-authorship between them in order to know the relationships among authors and citations per author, among other aspects. Authors that cluster together are coauthors of papers, the closer the authors are to each other, and the more they published together. In Figure S2, the author 1 (A1), has the biggest circle, hence this author has published the highest number of articles on the searched subject; the closest author to A1 is A4, so these two authors have published 6 publications together; A2 is located the farthest from A1 but still connected, they have published together 1 publication connectance. A6 did not publish with anyone, that is why this author is not linked to any other author.

Third, a bibliometric analysis was performed with VOSviewer that considers citation as a type of analysis for the purpose of knowing the relationships among citations of documents and their citation ranking. A citation link is a link between two items where one item (document, publication, journal or institute) cites the other. In general, the closer two items are located to each other, the stronger their relationship. In Figure S2, D1, (2018) (Document 1, published in 2018) with the biggest circle, is the most cited document and it is also the most cited document between the authors of this idealized exercise. D2 (2019) is the closest document to D1, which means that D1 and D2 deal with related topics. D5 (2019) also has a big circle, but it is not connected to any other author. This implies that no other document in this exercise mentioned D5 (2019) but since it has a big circle, D5 is mentioned by other authors from a different subject outside the subject of interest of this idealized example.

2.3. Spatial Distribution of the Documents

Datawrapper software was used, combined with the analysis option of VOSviewer, to obtain the number of documents per country of affiliation of the first author and produce a worldwide map of the 195 documents distributed by country, which will be used to describe differences in the publication of papers between countries [25].

3. Results

3.1. Distribution of Publications through Time and Space

Before 2005, no document dealing with UGI and SD was obtained through our search. Consequently, three phases can be distinguished with respect to the number of documents published per year (Figure 1). At the beginning of phase 1 (2005–2012) the Millennium Ecosystem Assessment was published. Furthermore, the paper by Li et al. [26] was published receiving the highest number of citations (213 citations). In this period, the annual number of documents did not increase until the year 2013, when phase 2 (2013–2017) started, just one year after the United Nations Conference on Sustainable Development Rio+20 in 2012. Then, the number of published documents increased from 4 to 10 per year,

including the highly cited (94 citations) paper by Collier [27]. During this phase 2, there was a remarkable increase of published articles (57), especially in the last 2 years 2016–2017, including the second most cited paper (107 citations) by Liu et al. [28]. Then, phase 3 started in 2018 with an explosive increase in the number of papers per year (25–30), simultaneously with the publication of the forth most cited article (92 citations) by Chan et al. [29].

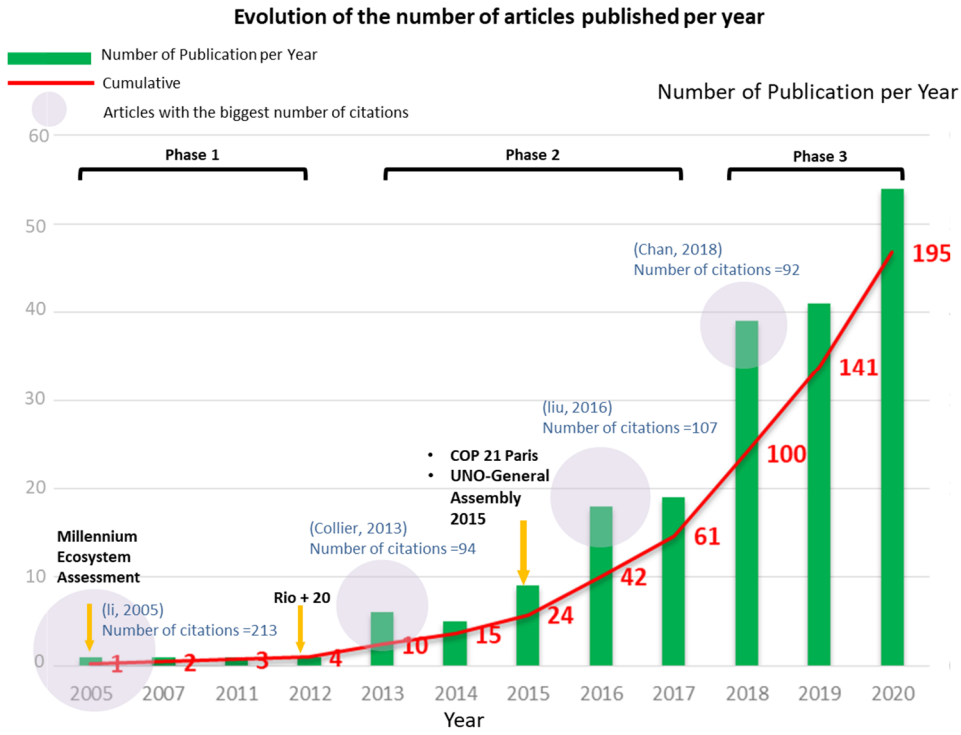

Figure 1. Yearly output of articles from 1992 to 2020, the oldest article appeared in 2005. The circles represent the articles with the biggest number of citations. The bigger the circle, the more it is cited.

The distribution of documents per country of affiliation of the first author shows the typical agglomeration of papers in scientifically powerful countries, such as the USA and China, which also accumulate problems of urban sprawl [30]. If we consider Europe as a socioeconomic unit, it contributes an outstanding number of papers, over other geographical regions (Figure S3). The number of papers from the rest of the regions/countries is much lower, except for Australia which accumulates an intermediate number, likely in relation to the scientific development of this country and the recent enlargement of its urban zones [31].

3.2. Disentangling the Methodological Aspects of UGI and SD Research

The same number of documents that were identified in the search focused on qualitative (89) and quantitative (89) aspects, while a low number (17) combined both approaches (Figure S4). Most qualitative documents (those not presenting quantitative data) present theoretical aspects, as more or less detailed descriptions of subjects of interest and conceptual frameworks, e.g., describing the role of ecosystem services in urban ecological infrastructure [32], proposing five ways of water management in arid urban zones [33]. Between the qualitative documents, 29 focused on design aspects such as landscape architecture and connectivity in relation to UGI (e.g., Cengiz and Boz [34]), urban sprawl (e.g., Zhang, L and Huang [35]) and UGI recovery (e.g., Blau et al. [36]) and 21 are literature reviews focusing on different aspects related to UGI.

Most quantitative documents (62) focused on spatial analysis. They are papers that use mapping through GIS or remote sensing to describe and analyze topics such as landscape connectivity (e.g., Niedźwiecka-Filipiak et al. [37]), urban sprawl (e.g., Gavrilidis et al. [38]),

assessing urban heat island (e.g., Marando et al. [39]), water management (e.g., Wong et al.; Kuller et al. [40,41]) and related subjects. The remaining 27 quantitative papers focused on metrics: quantitatively evaluating variables of UGI and SD such as assessment of green development (e.g., Wu et al. [42]), estimating the value of UGI or ES using cost-benefit analysis of UGI (e.g., Sutton and Anderson [43]) and analyzing the economic sustainability in storm water urban catchments (e.g., Boguniewicz-Zabłocka and Capodaglio [44]). It is also noticeable that between these 27 articles, 8 of them (the biggest number between the 27 articles) use cost-benefit analysis in their methodology (e.g., W. Liu et al. [28]). So, quantitative documents are mostly devoted to environmental and economic aspects of UGI and SD. A relatively high number, 26 of the 89 quantitative articles, directly target ES, ranging from regulating urban heat (e.g., Wu et al. [45]) and flooding (e.g., Huera Lucero et al. [46]) to citizens' recreation (e.g., Sun et al. [47]).

Of the 17 papers combining a qualitative and a quantitative approach (Figure S4), 12 performed a literature review and a spatial analysis (e.g., Liu et al. [48]), and 5 performed a literature review and a metrics analysis (e.g., Mell [49]). The papers combining both approaches are dealing with the association between the distribution of urban trees and socioeconomic status aspects (e.g., Cruz-Sandoval et al. [50]), water conservation (e.g., Monteiro and Ferreira [51]), public spaces and climate change (e.g., Vukmirovic et al. [52]) on the one hand, and people satisfaction with green infrastructure (e.g., Parker and Simpson [53]) on the other hand.

3.3. The Interest on Sustainability

Only 20%, 39 of the 195 papers, take a holistic approach combining the three pillars of sustainability (environmental, social and economic) in their studies. Between the 195 papers, 111 have any interest on just one of these aspects: 81 deal with environmental topics, 19 deal with social aspects and 9 with economic aspects. Then, 23 documents combine two aspects: 19 follow a socioenvironmental approach; 2 take a socioeconomic approach, and 2 take an environmental and economic perspective. Additionally, 39 documents deal with all three aspects. Englobing all these elements of sustainability, 24 is the number of articles that speak about policy and decision making (Figure S5).

3.4. Disentangling Subjects of Interest and Authorship Relationships

The bibliometric analysis performed with VOSviewer showed that 24 keywords were used in at least five papers (Table 1). "Green infrastructure", "ecosystem services", "sustainable development", "urban planning" and "climate change" were the most used keywords by the authors to represent the subjects of interest of their papers. These five keywords had the highest number of links with other keywords among the 24 most used (Table 1). "Green infrastructure" (GI) is represented with the biggest circle after the co-ocurrence analysis (Figure 2), it occurred in 61 papers. The closest keyword to GI is "ecosystem services" which occurred in 34 papers. GI, ES and urban planning share a relatively high connectivity (over 0, 05) (Table 1) and the strength of the link is equal to 11, meaning that GI and ES and urban planning occurred together in 11 papers. GI and "sustainable development" and "climate change" occurred 12 and 10 times, respectively, as keywords in papers and share an intermediate connectivity =(0.04). The remaining 19 keywords had a relatively low connectivity (lower than 0.04) to the other key words. All this indicates that there is still a high potential for linking topics of research related to UGI and SD.

Table 1. The 24 keywords, representing topics of interest, used at least in 5 of the 195 searched documents with the number of links (documents) to each other and their index of connectivity.

Topic	Number of Links	Number of Links/Combination Formulation
Green infrastructure	20	0.072
Ecosystem services	16	0.058
Urban planning	14	0.051
Sustainable development	13	0.047
Climate change	12	0.043
Sustainability	10	0.036
China	9	0.033
Sustainable cities	7	0.025
Multifunctionality	7	0.025
Stormwater management	6	0.022
Nature-based solutions	6	0.022
Low impact development	6	0.022
Sponge city	6	0.022
Urban	6	0.022
Urban development	6	0.022
Urban green infrastructure	5	0.018
Planning	5	0.018
Urban sustainability	5	0.018
Landscape connectivity	5	0.018
Urban ecosystem services	5	0.018
Urbanization	5	0.018
Green space	4	0.014
Urban ecology	4	0.014
Sustainable urban development	2	0.007

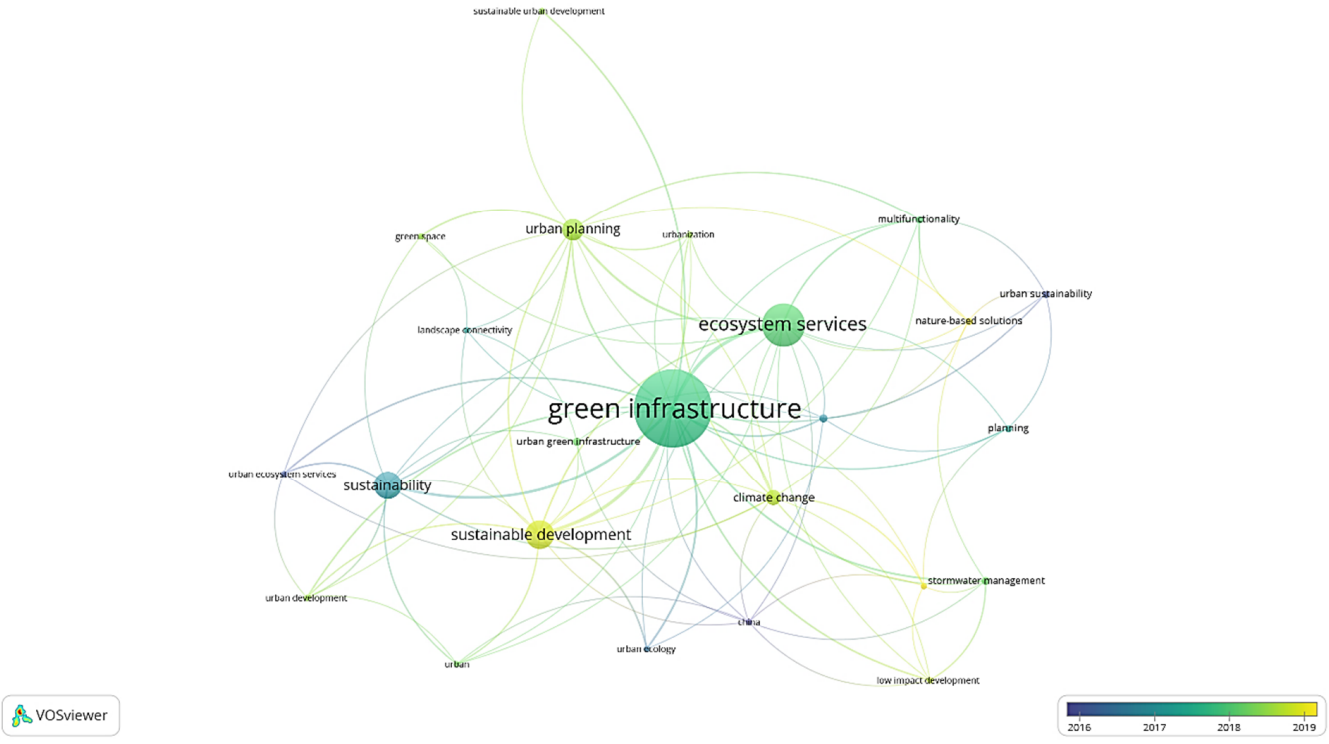

Figure 2. Keywords most frequently used in the articles reviewed. Those in colder colors appeared in the earlier years and those in warmer colors later. Bigger circles correspond to the most used keywords.

Logically, "green infrastructure" and "sustainable development" should be the keywords linked to most keywords as they were part of the words used for the literature search but this is arguable as the analysis showed different results. "Green infrastructure" must be understood as "urban green infrastructure" as it is in the context of urban zones that the search was made. "Sustainable development" is connected to many of the keywords; however, it is not connected to important topics such as urban sustainability, sustainable urban development, urban ecosystem services, storm water management or planning.

The occurrence of keywords on sustainable development (in 23 papers) and climate change (in 12 papers) are dominant in recent years (2019–2020) contrary to topics such as green infrastructure (in 61 papers) and sustainability (in 22 papers) which were dominant previously (2016–2018), nature based solutions occurred in 6 papers during 2019–2020 (Figure 2).

The index of connectivity (Ducrue and Rodrigue, [22]) for the full network of topics is 0.65, which confirms the idea that this network of topics still has a high potential for linking subjects of interest in relation to UGI and SD.

The results of the bibliometric analysis that considers the most cited papers between the 195 documents searched showed that Li et al. [26] had the highest number of citations (213) and, correspondingly, the biggest circle in Figure S6 (the above figure). The approach in this paper is qualitative, aiming to develop a comprehensive conceptual framework for urban greening of the Beijing Province in China, based on landscape ecological principles. Following the qualitative approach, the second article with the highest number of citations (94) in the VOSviewer map is Collier et al. [27], aiming to explain the sponge city concept and its development, which considers the limitation of urban sprawl through UGI planning.

Even though Li et al. [26] is the most cited document, there are only 2 other documents linked to it. This means that this paper is not highly cited among the authors of this literature review, but is cited in documents not included in this literature. The same can be said for the document by Collier et al. [27] (Figure S6).

The first most cited document with a quantitative approach (Liu et al. [28]) is the second most cited (107) between all the 195 documents searched (qualitative, quantitative and mixed). It presents a spatial–temporal assessment of urbanization impacts on ecosystem services. Badiu [54] is the second most cited article (61) between the quantitative documents; it aimed to assess urban green space (UGS) per capita. Both articles used spatial analysis in their methodology.

The same figure, but without the unconnected authors (Figure S6), illustrates that the most cited paper obtained in our review is by Newell et al. [55], which is linked to 6 other documents, meaning that this paper was cited by 6 documents of our literature review. Their paper analyzes alley greening programs in seven cities in the United States using the lens of sustainability planning. It presents a mixed methodology, including a literature review and a spatial analysis to indicate that most alley greening programs are narrowly oriented towards storm water management.

There were 708 authors of the 195 articles. However, only 88 authors (12.4%) are highly connected to each other, which is shown by 18 big clusters connected between others (Figure S7). This means that these authors worked and published together. The rest of the authors (87.6%) form clusters but they are not connected to any other of the highly connected clusters. The author Dagmar Haase has the highest number of papers (5) written on UGI and SD, followed by Artmann Artina with 4 documents.

The remarkable cluster is the red one (Figure S7). It consisted of 23 authors who worked closely together, their focus is on nature, city and sustainability. These authors do not live in the same country nor on the same continent, but the majority of them live in countries where English is the dominant language, such countries are South Africa, Canada, the USA, Sweden and Australia. One of the articles they published [56] proposes modes of operation encompassing policy, planning and management processes, that seek to transform the use of old nonsustainable practices and design new urban systems in ways that diversify their functions, anticipate new uses and enhance adaptability, to better meet

the social, economic and ecological needs of cities under conditions of deep uncertainty about the future. This paper is a qualitative one, working on the design of new urban environments in order to contribute to successful implementation of SDG11 and the New Urban Agenda (https://unhabitat.org/ accessed on 21 July 2021).

4. Discussion

4.1. Disentangling Methodological Aspects of UGI and SD Research

This work provides an overview of published papers relating UGI and SD. Linking both of them is of major interest because of the key role that urban areas with a well-structured GI can play in contributing to sustainable development [57]. An increase in the number of papers on this subject of interest was observed after the publication of the Millennium Ecosystem Assessment (2005) and, more recently, after the United Nations launched the Sustainable Development Goals (UNO-General Assembly 2015). It could seem that since 2005, international events and conferences promoting attention and action in favor of nature conservation and sustainable development stimulated research on related topics. However, the opposite also happens as many global strategies and challenges arise after scientific research on socioecological problems attracted attention to them [58]. Thus, most likely, both processes feed into each other.

The fact that half of the documents of the searched series contained a theoretical approach seems to indicate a dedicated interest by many authors to establish conceptual principles and frameworks in order to address the study of this topic. After this, it is foreseen that the number of quantitative works providing empirical information will increase more in the future and that generalizations providing advanced insights to progress the study of UGI and SD will take longer if a usual model of science progress accumulating information progressively up to synthetizing an innovative framework or theory is going to proceed [59,60].

This review shows (Figure S4) that there is a high variety of quantitative topics researching UGI and SD, but there is a lack of integrative and holistic studies, thus the need for a comprehensive approach, embracing the many aspects involved in this subject of interest. In general, a quantitative approach, providing data of measured variables is more convincing than a qualitative one. However, quantitative studies focus on few variables because of the great efforts required to measure variables and analyze data compared to theoretical approaches. Then, in the near future quantitative studies encompassing a range of aspects and many variables should be performed and should come up with holistic overviews of UGI and SD for an urban zone, a series of urban sites or globally. This will require further accumulation of data and synthesis but will contribute to balancing the uneven distribution of information with respect to the three pillars of sustainable development (Figure S5). This will also provide insights for planning and implementing UGI in such a way that improve and most efficiently contribute to the SD of urban zones.

It is also recommended to increase research relating to UGI characteristics and people´s perception (e.g., Fischer and Kowarik [61]), as the ultimate goal of studying and applying results of UGI and SD research is to provide a better quality of life for the beneficiaries, inhabitants and visitors of urban zones, and contribute to regional and global improvements of ecosystem services and SD. In fact, among the documents approaching with quantitative metrics the study of UGI and SD, 27 of them estimate the values of variables such as watercourse suitability (e.g., Simperler et al. [62]) and urban foraging impact on human health and well-being (e.g., Fischer and Kowarik [61]). Additionally, 8 of them (e.g., Hamann et al. [63]) used cost-benefit analysis in their articles to estimate the value of UGI. This indicates a relatively high interest in estimating the economic value of UGI, in spite of the fact that there are alternatives to cost-benefit analysis which can be better, or at least complementary, to quantify the benefits of UGI as providers of ecosystem services and its relation to sustainability [64] and offer an opportunity for future research.

Authorship bibliometric analysis can also provide insight into the intellectual structure of UGI and SD research. The authors that published together are located close to each other

on the map and grouped into one cluster (Figure S7). As only 12% of the authors shared a high connectance between each other, we argue that there is not yet a high experience of sharing between authors on this subject, which is also indicated by the big number of clusters unconnected. This opens a window for the possibility of greater opportunities for collaboration in the future. The light green cluster on the top left belongs to Chinese authors working and publishing together. This cluster is not connected to any other cluster even though it contains the authors of the most cited article ([26]). It seems likely that authors from different countries are not connecting enough to each other to perform research and publish together. As it was said, clusters are made of authors who published together most likely on related subjects, therefore, small clusters (less than 7 authors) in the map provide the chance for better collaboration on other topics that might be of interest in the future. Such topics could be sustainable urbanism, ecological infrastructure, green streets, for example, and all these involving social and economic aspects, as stated above.

The outstanding number of documents corresponding to three countries, the USA with 82.66% of its population living in urban areas in 2019 [65], China, where urban sprawl is now a major issue of research interest and development concern [66], and Europe with a long history of urban development, indicates the interest of researchers in these countries to contribute to improving conditions where UGI and SD presented higher deficiencies. Then, it is recommended to increase the collaboration among authors from different countries and continents in the future.

The huge difference in the number of papers between the USA, Europe, China and Australia, on the one side, and Central-South America, Africa and SE Asia, on the other side, reflects the usual difference of publications between these two groups of regions. By no means, does this indicate a difference in the capacity or interest of study in these regions, which also share common urbanizing problems with other regions of the world. In fact, a few papers by authors from countries in Africa, South America and SE Asia show excellent theoretical and practical approaches and contributions to the study of UGI and sustainable development. In addition, it is quite frequent that many authors from these regions do not publish in journals included in Web of Science and other databases (e.g., Andrade et al., Ramyar and Zarghami [67,68]).

4.2. Disentangling Relationships among Topics of Interest

The low and heterogeneous connectivity between topics (keywords) shown by the indicators used (number of links, connectivity index for both the full network of topics and for most topics) indicates that there is still a high potential for linking subjects of interest in relation to UGI and SD. So, there is an opportunity for many more topics to be researched in relation to UGI and SD and increase the links in the network of topics (Figure 2). Likely, the agglomeration (Figure S7) of authors will decrease; consequently, there will be more authors and clusters that will be more evenly distributed among authors. Additionally, it is important to note that even though this research was about UGI and SD, the results showed a high connectance between GI and ES (11 papers) and that ES and SD occurred together only in 2 papers, signaling that the path of SD needs to pass through GI providing the necessary ES to achieve the goal of sustainability, or at least that the evaluation of ES will be a major tool for research on UGI and SD studies.

Combining the three major pillars of sustainability (environmental, economic and social) in an integrated way to study UGI and SD is a desirable approach, and not only for this particular issue [69]. However, we observed few papers (20%) including the three pillars in their methods, while the majority focuses on environmental topics (81). This bias is likely due to the longer tradition of studying environmental issues in relation to UGI, which is made of natural components and also the stress put on urban zones to adapt to climate change (e.g., Wang and Pei [70]). In any case, the papers integrating the three pillars of sustainability focus on topics such as the application of green infrastructure to sustainable cities (e.g., Cengiz and Boz [34]), or just to better explain the role of UGI in urban zones (e.g., J. Wang and Banzhaf, [71]). Overall, these results indicate that there is

a need for more quantitative publications taking a holistic approach in valuing UGI and their ES in relation to SD.

As our review focuses on UGI and SD, it is supposed that published research on this subject of interest should be linked to SDGs. Reviewing the topics of the searched documents, we observed that most topics (sum of occurrence of the numbers in the boxes of the topics = 117) (Figure 3) of our search were related to SDG 15 (life on land: promote sustainable use of terrestrial ecosystems). In the second place, are the topics (sum of occurrence = 97) that are related to SDG 11 (make cities and human settlements inclusive, safe, resilient and sustainable). Followed by topics (sum of occurrence = 26) that are related to SDG 16 (promote peaceful and inclusive societies for sustainable development), and the topics (sum of occurrence = 17) that are associated to SDG 13 (take urgent action to combat climate change and its impacts). A much lower number of topics are related to SDGs dealing with social aspects, such as SDG 1 (sum of occurrence = 12), SDG 2 (sum of occurrence = 12), SDG 3 (sum of occurrence = 5) and SDG 6 (sum of occurrence = 7). However, the most outstanding number of topics (sum of occurrence = 117) is related to SDG 15, which under its general label (protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss) encompasses environmental challenges relative to providing protection for all terrestrial ecosystems, enhance sustainable management, reduce flooding impacts and land degradation, improve air quality and waste management. It is remarkable that few documents of the searched series had as a subject of interest any topic related to the SDGs that are mainly focused on social aspects, such as SDG 1 (no poverty) and SDG 2 (zero hunger) which are challenging issues as many homeless live on urban UGI in many cities and some UG sites, such as urban horticultural zones, could provide food in cities. In any case, most of the UN SDGs are not approached by any of the papers in our selected series of 195 documents (Figure 3). This offers an opportunity for researchers to perform more studies and to publish documents linking UGI and the still missing topics of SDGs, which are mostly related to social aspects.

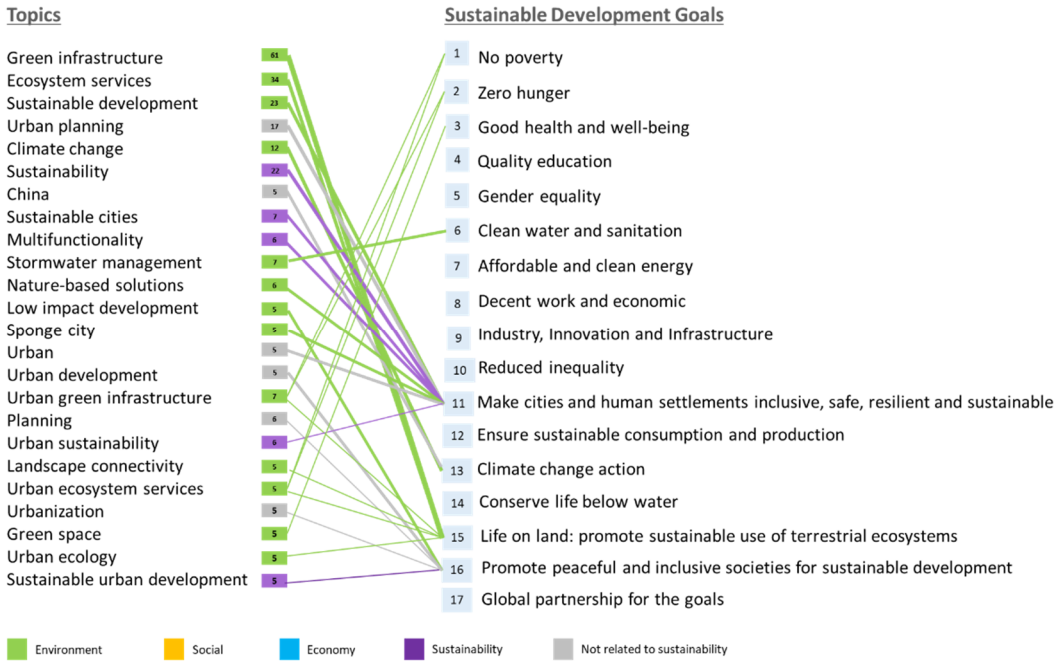

Figure 3. Correspondences between topics of the series of documents searched in this review and SDGs. The width of the line is related to the number of co-occurrences, the numbers in the boxes of the topics/keywords are the number of co-occurrence of these keywords (authors' keywords) in the 195 articles.

This review may be limited in scope as there may be works focusing on UGI and SD from different points of view (e.g., energy, mobility, engineering, transportation, hydraulics). Sustainable development is not only dependent on UGI but there are other aspects that are very important because sustainable development is also related to human and environmental health, transportation and social issues. Additionally, specific searches will be necessary for deeper analysis and reviews since the focus of this study was only reviewing the research performed on UGI and SD. More detailed reviews in other databases may provide further insights into this subject of interest. In any case, the results presented here offer an overview of the present situation of research works on UGI and SD. The increasing annual rate of publication of documents observed shows that UGI in relation to SD will be a crucial issue in multiple academic fields, especially in planning urban zones, which implies a promising future for UGI and SD research.

5. Conclusions

The study of UGI and SD is still in the early stages, as most of the published documents are offering theoretical approaches. More studies providing quantitative information on the many topics under UGI and SD will increase the fundamentals for stronger frameworks linking UGI and SD in the near future.

Most published documents on UGI and SD focus on limited environmental, economic or social aspects. Approaches integrating the three pillars of sustainability are required to further progress UGI planning and implementation and, consequently, to improve the contribution of urban areas to sustainable development. Collaborative research between researchers of advanced countries and other countries will contribute significantly to the SD of urban areas locally and globally.

Most topics of interest in the literature reviewed are related to the Sustainable Development Goals (SDGs) 11, 13, 15 and 16. However, there is very little information on the relationships between UGI and SDGs 1, 2, 4, 5, 7, 8, 9, 10, 12, 14 and 17. Further innovative research should depend on the role of UGI on these less studied SDGs. This will provide insights and key information to accomplish SDGs in urban zones through planning and implementing UGI.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su132011498/s1, Figure S1: Steps performed for the literature review following the PRISMA model and data analysis and visualization after VOSviewer, Figure S2: Above: Idealized network of 4 keywords (K) after VOSviewer. The numbers indicate the strength of the links between two keywords (the number of publications in which the two keywords linked occur). Middle: Idealized network of 6 authors (A) after VOSviewer. The numbers indicate the strength of the link between two authors (the number of papers coauthored). Below: Idealized network of citations of documents (D) after VOSviewer (D1 means Document 1), Figure S3: The distribution of the 195 articles per countries, Figure S4: Disentangling the approaches of the 195 articles, Figure S5: Venn diagram showing the number of documents approaching environmental, social or economic aspects or combinations of these three, Figure S6: The above figure shows the most-cited article (Li, 2005), indicated by the name of the first author, The below figure is the same figure as the first figure but without the unconnected/unlinked documents, (Newell 2013) is the most cited document by the authors of this research review, and (Li, 2005) is the most cited document by other authors outside this literature review, Figure S7: The highest number of articles is represented by one of the green circles, it belongs to Dagmar Haase.

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