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The Integration of Green Infrastructure in Urban Planning for Sustainable Development

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Abstract: *As cities develop, urban green infrastructure (UGI) may solve several issues. This research reviewed UGI and sustainable development (SD) literature using WoS and VOSviewer. Out of 195 studies, 89 are qualitative, focused on theoretical methods and design, 89 are quantitative, on metrics and geographical analysis, and 17 combine both. High linkage was found between "green infrastructure", "ecosystem services", "urban planning" and "sustainable development". Only 39 papers address environmental, social, and economic issues. Most studies focus on SDG 11 "to make cities inclusive, safe, resilient and sustainable" and SDG 15 "protect, restore and promote sustainable use of terrestrial ecosystems". Research combining the three sustainability pillars and linking UGI to all SDGs is advised.*

Keywords: Urban Green Infrastructure, Sustainable Development Goals

I. INTRODUCTION

Since most people live in cities, urban green infrastructure (UGI) is becoming a significant structural component and a key participant in Earth's sustainable development (SD). A city's UGI is networked. Urban squares, street tree lines, parks, and horticulture gardens have plants, animals, water, soil, and microbes. These constituents build natural ecosystems and allow ecological activity and benefits. UGI's urban design and construction and natural ecosystem occupancy and exploitation contain artificial components. Recreational services, which depend on natural ecological activities, grow as regulatory services decrease. Thus, UGI ES may improve city SD and reduce disservices.

Residents gain from UGI site connectivity in cities. UGI network and distribution are key urban planning elements. City growth frequently conflicts with environmental conservation. As more wild regions are urbanized, ES drops and urban amenities increase. Any complete and effective urban sustainability strategy must include urban green infrastructure design, supply, management, conservation, and restoration due to SD's rising popularity. Urban areas realized their global effect and prioritized sustainability by reducing greenhouse gas emissions and enhancing resident wellbeing. A well-structured UGI is one of urban zones' main challenges in achieving these aims.

Several approaches have examined UGI typology. UGI components and values are examined using different indicators. UGI research methodologies vary by subject. UGI improves health. Conceptually, functions and services relate. Panagopoulos and González-Duque used UGI spatial analysis for social challenges. Meerow used surveys, interviews, and spatial analysis to plan land use. UGI values were supported by ES. Many research areas aim to comprehend urban biodiversity, ecological functions, and services. Suppakittpaisarn et al. evaluated UGI density preferences.

UGI is a burgeoning study subject with several city and worldwide purposes. To improve sustainability-focused design, several authors presented theoretical frameworks and interpretations of UGI's city ecology work. These UGI traits are normally examined separately. A holistic approach is difficult since it takes specialist knowledge to investigate any of the components and a lot of work to combine the numerous UGI elements.

A literature analysis, topic-author linkages, and subject distribution in respect to the three sustainability pillars (environmental, social, economic) are used to assess UGI research on SD. UGI papers' topics were matched to UN Sustainable Development Goals.

II. MATERIALS AND METHODS

Figure S1 shows the review and data analysis process in supplementary material.

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Literature Search

A search at Web of Science (WoS) on 27 April 2021 at 16:00 h using "Urban Green Infrastructure" and "Sustainable development" for 1992–2020 guided the literature review. The 663 resources included journal articles and proceedings. We then excluded "book chapters" from Web of Science and documents from unrelated disciplines ("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" The document list dropped to 318.

We carefully removed publications lacking "green infrastructure" in the title or abstract, leaving 197. Another article was removed since it was published in 2021, beyond the research period, and another was duplicated. Additional analysis was restricted to 195 publications. WoS analysis of findings showed study subject geographical and temporal tendencies.

The searched papers were classified as theoretical if they utilized qualitative frameworks and practical if they used quantitative data to identify their scientific techniques after reading the abstracts. The paper was extensively reviewed if needed. Case study and qualitative data were analyzed in mixed papers. The publications from these three blocks were categorized by research interests and methods. Because ES is relevant to the research fields, our literature search focuses on studies using or assessing it.

Bibliometric Analysis

Bibliometric analysis using VOS viewer 1.6.16. Vosviewer is a bibliometric map-based network builder and visualizer. It displays networks in multiple ways and lets you zoom, browse, and search maps. The cluster display may also show the network structure by handling several objects. VOS viewer was used to create bibliometric maps to examine subject linkages to understand UGI and SD.

This study uses cluster display to see network structure. Nodes represent units on maps. A journal, category, author, article, or keyword. The nodes' distance reveals their connection. Two nodes near together indicate strong relationship. Node links indicate direct co-occurrence and co-citation. Link strength is related to co-occurrence or co-citation frequency. One color is allocated to each cluster of nodes with stronger connectivity. While units in separate clusters are varied, those within a cluster are very homogeneous. The cluster display shows UGI and SD research's intellectual structure from several angles.

After uploading a text WoS file to VOSviewer, a bibliometric analysis was performed using co-occurrence and author keywords. The program overlaid authors' keywords by year of publication in colors. After analyzing 704 authors' keywords, a map with 24 easily identifiable keywords was produced with five being the minimum occurrence of keywords (keywords repeated less than five times are excluded from the map). Each term is represented as a circle; the larger the circle, the more often the keyword appears in the document. Strongly occurring keywords will be connected. The connection strength, or number of articles with two keywords, will be strong and the distance between them small. Weakly linked keywords have a low link strength value and a large distance. Figure S2 displays an idealized keyword co-occurrence analysis result. K1 (Keyword 1) has the largest circle, so it is the keyword appearing most in publications; K2 is the closest keyword to K1, with a link strength of 12, meaning K1 and K2 occurred together in 12 papers, indicating mutual interest in research on the topics represented by K1 and K2. K4 is the farthest from K1, with a link strength of 3.

The number of linkages divided by the total number of potential links is the gamma index of connectance, which measures network node connectedness. It may be used on the whole network or a particular node. Gamma connectance spans from 0 to 1, with 1 indicating a fully linked network/node and 0 indicating no connection.

This probability index uses the combination formula (combinations of n nodes or topics taken, k, at a time without repetition) to calculate the maximum or potential number of links of the 24 subjects of interest selected as a network or separately for each of them. $C = n\,(n-1)/k\,(K-1)$, where n = 24 (number of nodes/topics picked) is taken by groups of k = 2. This provides our network 276 plausible node linkages. As noted above, we measured connectedness for each node (topic) and the overall network by dividing the actual number of linkages by the prospective number of links. Our node connection index ranges from 0 to 0.083. ((0/276)–(23/276)) if it is unconnected and if it is linked to all 23. The index helps determine the connectedness of the whole network's nodes (the 24 topics of interest).

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Second, VOSviewer was used to do a bibliometric analysis that included co-authorship and authors. It examines 708 authors' occurrences and co-authorship linkages to determine author affiliations, citations per author, and more. Paper coauthors cluster closer together and publish more together. In Figure S2, author 1 (A1) has the largest circle, so he has published the most articles on the searched subject. A4 is the closest author to A1, so they have published 6 publications together. A2 is the farthest from A1, but still connected, so they have published 1 publication together. A6 has no connections since he never published with anybody.

Third, VOSviewer was used to do a bibliometric study to determine document citation associations and citation rankings. Citation links are links between documents, publications, journals, or institutes that cite one other. The closer two objects are, the stronger their bond. The largest circle in Figure S2 shows Document 1, (2018), the most referenced document and the most cited document among the writers of this hypothetical exercise. The nearest document to D1 is D2 (2019), therefore they cover relevant issues. The large circle in D5 (2019) is unrelated to any other author. This suggests that no other document in this exercise addressed D5 (2019), but because it has a large circle, other writers from a different field cited it.

Spatial Distribution of the Documents

Datawrapper software and VOSviewer's analysis option were used to determine the number of documents per first author's country of affiliation and create a global map of the 195 documents distributed by country to compare paper publication rates.

III. RESULTS

Distribution of Publications through Time and Space

Our search yielded no UGI/SD documents before 2005. Thus, three periods of annual document publication may be identified (Figure 1). Starting phase 1 (2005–2012), the Millennium Ecosystem Assessment was published. The most cited work was Li et al.'s. The yearly quantity of papers did not grow until 2013, when phase 2 (2013–2017) began, one year after Rio+20. Then, from 4 to 10 papers per year were published, including Collier's 94-citation piece. A notable rise of 57 publications was published during phase 2, notably in 2016–2017, including Liu et al.'s second most cited work. Phase 3 began in 2018 with a rapid rise in articles each year (25–30) and Chan et al.'s fourth most referenced article.

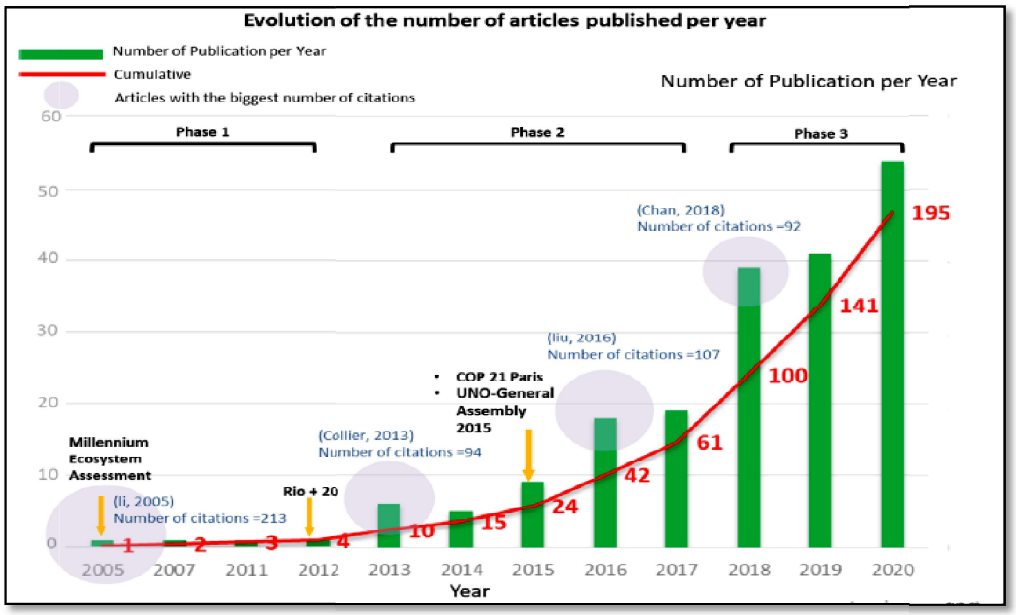

Figure 1. Yearly output of articles from 1992 to 2020, the oldest article appeared in 2005. The circles represent the articles with the biggest number of citations. The bigger the circle, the more it is cited.

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Documents by original author country tend to agglomerate in scientifically prominent nations like the US and China, which have urban sprawl difficulties. Europe publishes more than other socioeconomic regions. Australia has a medium number of papers, presumably owing to scientific growth and urbanization.

Disentangling the Methodological Aspects of UGI and SD Research

89 qualitative and 89 quantitative studies were found, with 17 combining both (Figure S4). Most qualitative publications explain theoretical ideas and frameworks, such as ecosystem services in urban ecological infrastructure and five strategies to manage water in dry urban zones. 29 qualitative papers explored UGI landscape design and connectedness (Cengiz and Boz), urban sprawl (Zhang, L and Huang), and recovery. 21 literature reviews discuss UGI. Most quantitative research (62) examined space. Landscape connection, urban sprawl, urban heat island assessment, water management, and similar themes are covered in GIS or remote sensing publications. The remaining 27 quantitative publications studied urban catchment indicators including green development, cost-benefit analysis, and economic sustainability. At least 8 of these 27 studies use cost-benefit analysis (W. Liu et al.). Quantitative materials examine UGI and SD's economic and environmental implications. ES is addressed in 26 of 89 quantitative articles, from urban heat control (Wu et al.) to floods (Huera Lucero) to citizen entertainment.

Figure S4 shows 17 qualitative-quantitative publications: 12 literature reviews and geographical analysis (Liu et al.) and 5 metrics analyses (Mell). Both methodologies are used to study urban tree distribution, socioeconomic position, water conservation, public spaces and climate change, and green infrastructure satisfaction.

The Interest on Sustainability

Only 20%, 39 of 195 publications, combine environmental, social, and economic sustainability in their investigations. Only 111 of the 195 publications are interested in one of these: 81 include environmental, 19 social, and 9 economic subjects. Then, 23 papers integrate two aspects: 19 are socioenvironmental, 2 socioeconomic, and 2 environmental and economic. Additionally, 39 papers cover all three elements. Including all these sustainability factors, 24 papers discuss policy and decision making.

Disentangling Subjects of Interest and Authorship Relationships

VOSviewer bibliometric analysis discovered 24 keywords in five papers. Article authors most commonly used “green infrastructure”, “ecosystem services”, “sustainable development”, “urban planning” and “climate change”. Five of the 24 most used terms have the most relationships. Following co-occurrence analysis, "green infrastructure" (GI) occurred in 61 articles and was the biggest circle. The closest GI phrase is “ecosystem services” in 34 papers. With a connection strength of 11, GI, ES, and urban planning are significantly related over 0.05. In 11 productions, they appeared together. With intermediate connection = (0.04), publications mentioned GI, “sustainable development” and “climate change” 12 and 10 times, respectively. The remaining 19 words were less linked (-0.04). UGI-SD study participants may still be connected.

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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

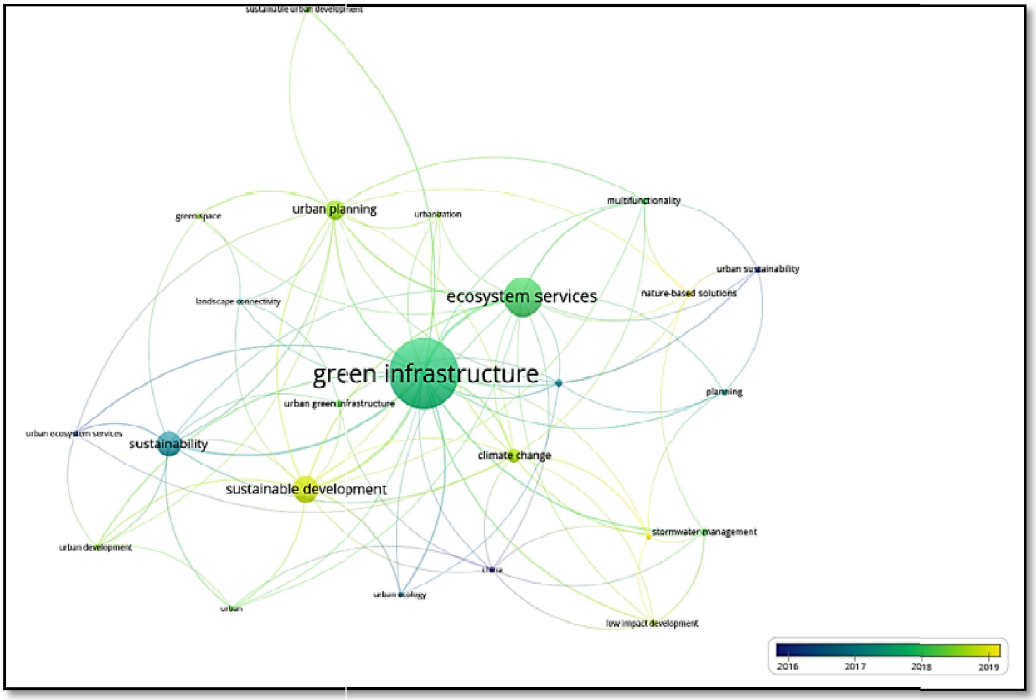

Figure 2. Keywords most frequently used in the articles reviewed. Those in colder colors appeared in the earlier years and those in warmer colors later. Bigger circles correspond to the most used keywords.

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The literature search includes "green infrastructure" and "sustainable development," which should be the most prevalent phrases. The search was urban, therefore green infrastructure is "urban green infrastructure". Many notions are related to "sustainable development," but not urban sustainability, sustainable urban development, ecosystem services, storm water management, or planning.

23 and 12 articles on sustainable development and climate change were published in 2019–2020. Green infrastructure and sustainability publications have 6 nature-based solutions in 2019–2020, down from 61 and 22 in 2016–2018.

The network of subjects' index of connection is 0.65, showing UGI and SD concerns are linked.

In bibliometric analysis of 195 publications, Li et al. had 213 citations, forming the biggest circle in Figure S6. In Beijing Province, China, qualitative study gives a landscape ecological conceptual framework for urban greening. Sponge city development study by Collier et al. uses UGI design to control urban growth and has 94 VOSviewer citations, second only to qualitative approaches. Only two publications cite most-cited Li et al. This literature review does not mention this research, but others do. See Collier et al.

Liu et al. is the second-most-cited quantitative paper out of 195. The geographical and temporal consequences of urbanization on ecological services are explored. Urban green space (UGS) per capita was calculated by Badiu, the second most cited quantitative article. Both research analyzed space.

Without the unconnected authors, Newell et al.'s work was cited by 6 publications, the most in our literature study. They explore alley greening in seven US cities using sustainable planning. A literature and geographical analysis indicated that most alley greening methods reduce stormwater.

708 authors wrote 195 articles. Only 88 authors (12.4%) are significantly connected in the 18 main clusters. Writers published. Authors in the remaining 87.6% group loosely. Dagmar Haase has 5 UGI/SD publications, Artmann 4.

The red cluster sticks out. The 23 authors discussed nature, city, and sustainability. Most of these authors live in English-speaking South Africa, Canada, the US, Sweden, and Australia. In one article, they propose policy, planning, and management strategies to transform nonsustainable practices into new urban systems that diversify functions, anticipate new applications, and adapt to cities' social, economic, and ecological needs under extreme uncertainty. To satisfy SDG11 and the New Urban Agenda, qualitative research builds new cities.

IV. DISCUSSION

Disentangling Methodological Aspects of UGI and SD Research

This review covers UGI-SD articles. Linking them is important because metropolitan areas with well-structured GIs may contribute to sustainable development. After the Millennium Ecosystem Assessment (2005) and the Sustainable Development Goals (UNO-General Assembly 2015), additional publications on this topic were published. It seems that worldwide conferences and activities supporting environment conservation and sustainable development have spurred study on relevant themes since 2005. Many worldwide strategies and challenges develop once scientific study on socioecological issues draws attention to them. Both processes presumably feed each other.

The fact that half of the searched series' publications used a theoretical approach suggests that many writers want to build conceptual concepts and frameworks to investigate this issue. After this, the number of quantitative works providing empirical information will increase and generalizations providing advanced insights to advance 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 to proceed.

This review demonstrates that there are numerous quantitative subjects addressing UGI and SD, but few integrative and holistic studies, highlighting the necessity for a complete strategy that covers all elements of this issue. In general, quantitative data from measurable factors is more persuasive than qualitative data. Because quantitative studies involve more work to gather and evaluate data than theoretical techniques, they concentrate on fewer variables. In the near future, quantitative studies should take into account various factors and provide comprehensive overviews of UGI and SD for an urban zone, a series of urban locations, or internationally. This requires more data and synthesis but will balance information dissemination across the three sustainable development pillars. This will also help design and execute UGI to enhance urban SD most effectively. Increase research on UGI characteristics and perceptions aims to improve quality of life for urban beneficiaries, residents, and visitors, and contribute to regional and global ecosystem service and SD improvements. In reality, 27 of the publications studying UGI and SD quantitatively quantify

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characteristics such watercourse appropriateness (Simperler et al.) and urban foraging influence on human health and well-being. In their publications, 8 (including Hamann et al.) estimated UGI value using cost-benefit analysis. This shows a high interest in estimating UGI's economic value, even though cost-benefit analysis may not be the best or most complementary way to quantify UGI's ecosystem service benefits and sustainability impact and offer an opportunity for future research.

Authorship bibliometric analysis may reveal UGI and SD research's intellectual structure. The writers who published together are clustered on the map (Figure S7). As just 12% of writers shared a high connectance, we claim that there is not currently a lot of experience sharing on this topic, as seen by the large number of disconnected clusters. This opens the door to future cooperation. Chinese writers publishing together are in the top left light green cluster. This cluster comprises the authors of the most referenced article but is unconnected. It seems that writers from other nations are not networking sufficiently to study and publish together. Since clusters are comprised of writers who wrote together on similar themes, tiny clusters (less than 7 authors) on the map provide the potential for improved collaboration on future topics of interest. As mentioned above, sustainable urbanism, ecological infrastructure, and green streets include social and economic issues.

The high number of documents from three countries the USA, where 82.66% of its population lived in urban areas in 2019, China, where urban sprawl is a major research and development issue, and Europe, which has a long history of urban development indicates researchers' desire to improve UGI and SD conditions. Future cooperation amongst writers from various nations and continents is advised.

The enormous discrepancy in articles between the USA, Europe, China, and Australia and Central-South America, Africa, and SE Asia reflects the regular variance in publishing. This does not imply these areas, which share urbanizing difficulties with other regions, are less capable or interested in research. In reality, a few studies by African, South American, and SE Asian scholars provide good theoretical and practical approaches to UGI and sustainable development. Many writers from these locations do not publish in Web of Science or other databases.

Separating Interest Topics

The measures utilized demonstrate low and diverse connectivity between topics, indicating that UGI and SD may still link subjects of relevance. Thus, many more UGI and SD issues might be explored to expand the network. Author agglomeration will likely reduce, resulting in more authors and more equally dispersed clusters. 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 SD must pass through GI to achieve sustainability, or at least that ES evaluation will be a major tool for UGI and SD research.

Integrating the three sustainability pillars environmental, economic, and social to investigate UGI and SD is beneficial, and not only for this topic. Few studies (20%) used the three pillars, whereas most (81) focused on environmental issues. This bias may be owing to the longer history of investigating environmental concerns in connection to UGI, which is formed of natural components, and the burden on urban zones to adapt to climate change (Wang and Pei). In any event, publications incorporating the three pillars of sustainability discuss green infrastructure in sustainable cities (Cengiz and Boz) or UGI in urban zones (J. Wang and Banzhaf). These findings suggest that additional quantitative publications should value UGI and their ES in respect to SD holistically.

Our evaluation covers UGI and SD, hence published research should be related to SDGs. Most subjects of the searched texts were connected to SDG 15. SDG 11-related subjects (97 occurrences) rank second. Following SDG 16 and SDG 13, there are 26 and 17 issues, respectively. SDG 1 (12), SDG 2 (12), SDG 3 (5), and SDG 6 (7), which deal with social issues, have fewer themes. SDG 15 (protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss) addresses environmental issues related to protecting all terrestrial ecosystems, improving sustainable management, and reducing flooding impacts. It is surprising that few documents in the searched series addressed social SDGs like SDG 1 (no poverty) and SDG 2 (zero hunger), which are difficult to achieve because many homeless live on urban UGI in many cities and some UG sites, such as urban horticultural zones, can provide food in cities. In any event, none of our 195 publications address most UN SDGs. Researchers may do additional studies and publish materials tying UGI to the SDGs' missing social concerns.

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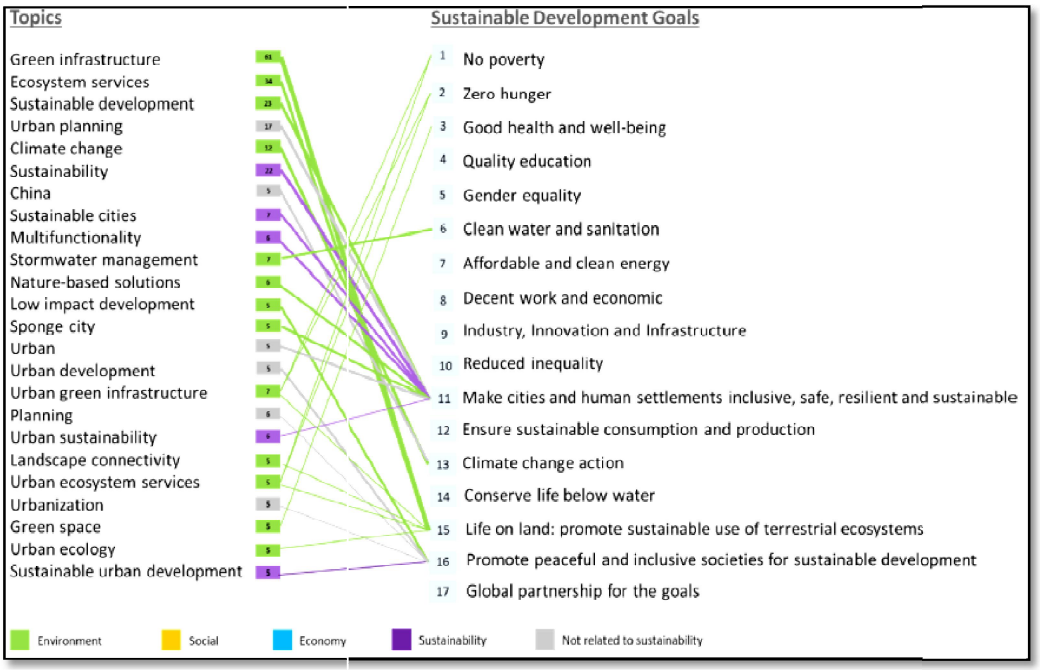

Figure 3. Correspondences between topics of the series of documents searched in this review and SDGs. The width of the line is related to the number of co-occurrences, the numbers in the boxes of the topics/keywords are the number of co-occurrence of these keywords (authors' keywords) in the 195 articles.

This evaluation may be limited by UGI and SD research from energy, mobility, engineering, transportation, and hydraulics. UGI is not the only component in sustainable development's health, transportation, and social impacts. This research only analyzed UGI and SD papers, therefore additional analysis and assessments will need specialized searches. Other databases' comprehensive assessments may elucidate this subject. However, these statistics summarize UGI and SD investigations. The increased annual rate of document publication shows that UGI and SD will be a serious concern in many academic fields, including urban zone planning, suggesting a promising future for UGI and SD research.

V. CONCLUSION

This evaluation may be limited by UGI and SD research from energy, mobility, engineering, transportation, and hydraulics. UGI is not the only component in sustainable development's health, transportation, and social impacts. This research only analyzed UGI and SD papers, therefore additional analysis and assessments will need specialized searches. Other databases' comprehensive assessments may elucidate this subject. However, these statistics summarize UGI and SD investigations. The increased annual rate of document publication shows that UGI and SD will be a serious concern in many academic fields, including urban zone planning, suggesting a promising future for UGI and SD research.

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