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Review

Green Infrastructure for Urban Flood Resilience: A Review of Recent Literature on Bibliometrics, Methodologies, and Typologies

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Abstract: Urban flood resilience can critically diminish the negative effects of extreme climatic conditions. In recent decades, green infrastructure has been gaining attention among researchers and authorities in terms of its use in urban contexts to enhance urban resilience. This paper tries to provide knowledge on how urban flood resilience has been recently approached through green infrastructure. To do this, the distribution of the topics of interest, authors, and sources/regions of publication are investigated through a systematic review of recent articles. Additionally, the methodological approaches and green infrastructure typologies are examined. Findings show an agglomeration of publications in developed countries. It was also observed that there is a predominance of quantitative methodological approaches and a low connectivity for some hot topics within this field of research (e.g., biodiversity). The most common green infrastructure typologies used in urban flood resilience research are also discussed. It is noticeable that more than half of the papers used general terms (e.g., urban park/open space) to describe green infrastructure rather than using technical typologies providing more information on water flow management characteristics. The outcomes are discussed to give an overview of the latest hotspots and gaps in this field of research, which gives some future directions/expectations to be followed in forthcoming investigations.

Keywords: urban flood risk; flood mitigation; nature-based solutions; low-impact development; best management practices; sustainable drainage systems; systematic literature review

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1. Introduction

Exposure to natural hazards is continually rising as a result of increased urbanization, population concentration, and the intensity of economic activity in cities [1]. Amongst them, urban flooding is a climatic disaster that can strike anywhere and is highly intertwined with climate, human activities, urban planning, and drainage systems [2]. The problem of urban stormwater, which is not absorbed by the urban drainage system and often carries high amounts of contaminants from the sewage, streets, and roofs, is arising due to climate change [3]. Compared with rural areas, the multiplicity of land uses, the density of construction, and the diversity of urban projects all contribute to more complexity in the flood risks in urban areas [4,5].

Additionally, disasters caused by urban flooding endanger the lives of city dwellers and can also cause substantial economic damage to the urban dynamic economy. This means that economic growth and the security of life and property depend critically on the resilience of cities and the capacity to rebuild after floods [6,7]. In this regard, in urban resilience research, the adaptive capacity of the urban systems is addressed by urban resilience, whereas urban flood resilience (UFR) signifies the adaptive capacity to cope with flooding produced by climate change [8]. Flood resilience may significantly mitigate the negative consequences of harsh weather [9].

Considering urban flooding consequences, the ability of cities to deal with climate disasters must be increased. More and more severe rainfalls will be experienced as a result of global climate change. People's attention has thus been drawn to research on the resilience of cities against flood disasters in order to cope with the increasing magnitude and frequency of urban climate catastrophes associated with climate change and to maintain the capacity of urban areas to respond to risks [1].

Green infrastructure (GI) is a relatively new approach that has gained popularity as a means to lessen the destructive effects of floods and to strike a better balance between the needs of urbanization and those of nature [10–12]. In this regard, GI could be defined by its vegetated or sustainability-based techniques, such as porous pavements, green roofs, and bioretention cells, that may minimize the quantity of stormwater entering urban drainage systems [13]. In environmental engineering and within the context of stormwater management, GI is occasionally used as an alternative for gray infrastructure [14,15]. Although gray infrastructure (e.g., underground pipes, concrete structures) tends to be efficient in stormwater management, the advantage of GI is its multifunctionality, self-adaptiveness, and the co-benefits it produces in comparison to gray infrastructure's inflexibility and mono-functionality [16]. According to planners, engineers, and flood managers, GI helps reduce flood damage in a number of ways such as: (i) decreasing the amount of stormwater runoff [17]; (ii) decreasing the peak flow velocity [18–20]; and (iii) boosting the storage capacity and quality of water [10].

The resilience of urban environments can be increased by properly combining GI interventions [21,22]. A combination of GI measures, instead of single measure usage, could lead cities to gain a higher potential of GI to reach urban resilience facing flooding and other hazards [16]. Nevertheless, the adaptive character of ecosystems necessitates the management of dynamic sources of uncertainty in green infrastructure design [23]. By taking into consideration site-specific restrictions and the linked dynamics of the local environment, risk and uncertainty assessments might help to reduce such concerns during the project design [23]. Likewise, uncertainty could always be a part of the advanced predictive analysis/modeling of GI and water resource management (e.g., [24–26]), which needs to be quantified in investigations through methods such as comparisons with the field experiments (e.g., [27,28]).

GI, as a multifunctional strategy [29], offers a wide variety of social, economic, and environmental advantages in the field of sustainable urban stormwater management [30,31]. Improvements in social, educational, economic, and environmental conditions are often observed due to the transition from gray to green infrastructure in urban settings [32]. For instance, urban GI contributes to climate change mitigation by lowering greenhouse gas emissions [33], biodiversity by producing, restoring, and preserving habitats and ecological networks [34,35], economic benefits by e.g., increasing property values [36], and social/health conditions by, e.g., filtering air contamination [37], lowering noise pollution [35], and offering spaces for leisure and gatherings [38]. As a result, GI is a topic being paid increasing attention as it plays an important role on both the local and global stages [39].

The number of studies on UFR and GI has progressively grown in recent years. There are comprehensive literature reviews in the field of GI. As a recent example, Ying et al. [40] conducted a comprehensive literature review on GI, studying papers published from 1995 to 2019. Their analysis included bibliometric analyses of the documents. Although their keyword analysis indicated that a strong concentration in GI studies is on the link with stormwater management, they did not provide a deep analysis of this connection to provide more information. Likewise, there are many studies reviewing UFR and its connected aspects. For example, a scientometric review of UFR-linked papers published from 1999–2021 was recently completed by Gao et al. [1]. Although their work provided much beneficial information regarding UFR, the connection with GI was not specifically studied.

Few studies have reviewed the literature to see how GI can address urban stormwater and flooding. For instance, Green et al. [41] investigated the role of GI in urban flood risk management. They explained how GI is currently used to reduce urban flooding problems and how the solutions GI might provide would be in light of present and upcoming difficulties. Consequently, they went through a number of challenges and priorities that need to be addressed in order to include GI in the current stormwater management frameworks.

Even though researchers have undertaken studies on the connection between GI and UFR, state-of-the-art analysis is always a crucial component of literature research. To the best of our knowledge, there is no literature review explaining GI methodologies and typologies which have been recently used in this field of research. The present paper applies bibliometric and systematic methods to fill this gap and sort through the most recent research hotspots and trends in the field for using GI for UFR. We reviewed how UFR research is approached through GI by (i) an analysis of the distribution of the topics of interest of the documents, authors, and sources/regions of publication; (ii) a review of the literature that focuses on separating the methodological approaches of GI for UFR research field. Afterward, (iii) a review of the GI typologies used in recent UFR research was performed. The results showed the agglomeration of publications in scientifically and economically powerful countries with most of the authors remaining unconnected to each other. Additionally, the predominance of quantitative methodological approaches (e.g., spatial analysis, scenario planning, cost analysis) and the high potential for further connectivity between some topics of interest (e.g., biodiversity) in this field of research was observed. Additionally, more than half of the papers used general terminologies/typologies, such as green/open space, instead of more technical ones, such as bioswale or green roof, for explaining GI. Putting the "general" GI category aside, "permeable pavement", "bio-retention cell", and "rain garden/concave vegetated field" were the top GI used typologies among the total 16 specific GI classes that were extracted from the literature (without considering the general class).

The next chapters are structured as follows: Section 2 provides information about the literature search method/database and the analysis methods. Section 3 explores the results, including the distribution of the publications and citations, most cited papers and authors, most used methodological approaches, subjects of interest, and green infrastructure typologies used in this field or research. Furthermore, the discussions around the main findings of each part of the analysis are explained in Section 4, which is followed by the conclusions.

2. Materials and Methods

2.1. Literature Search

Scopus and Web of Science (WoS) are widely regarded as the two bibliographic databases with the most extensive data sources for varied topics [42]. For more than 40 years, WoS served as the primary source of bibliographic information until Elsevier debuted Scopus in 2004 [43]. Over time, Scopus has established itself as a trustworthy comprehensive database and, in some cases, even superior to WoS [42,44]. Furthermore, Scopus was seen to index a greater number of unique sources not covered by WoS [45]. As a result, Scopus was selected to perform the present state-of-the-art review.

The literature review was based on the results of a search conducted in August 2022 using keywords and Boolean operators in the documents' titles, abstracts, and author keywords (Figure 1). The string used for the search was as follows: urban AND flood* AND resilien* AND "green infrastructure" OR "nature based solution" OR "low impact development" OR "Best Management Practice". English journal articles were selected to be reviewed which resulted in a total of 148 articles.

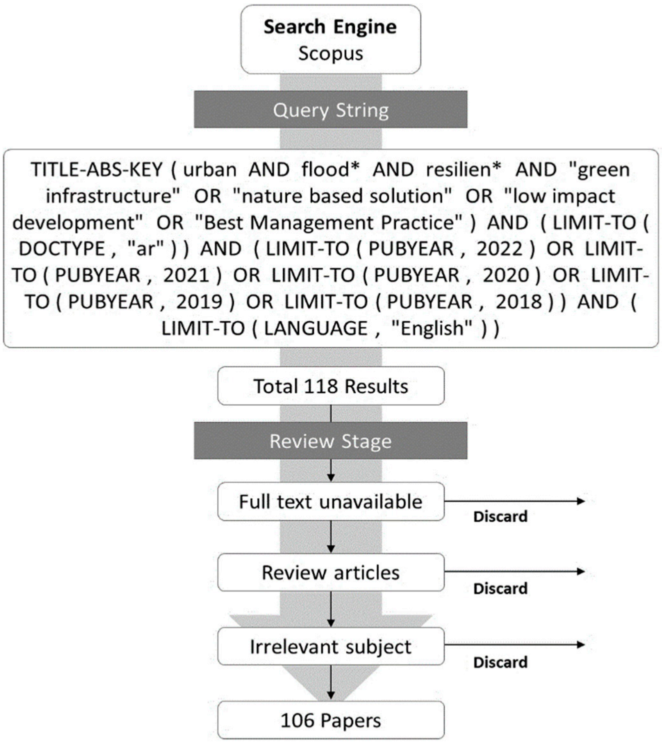


Figure 1. The literature search structure to obtain the final results for the analysis.

As is clear from the search query, we did not intend to review the articles that are solely related to GI, or the ones solely related to UFR. Each of these topics includes various dimensions which were not necessarily involved in the scope of our analysis. Consequently, we searched the articles that were directly addressing both GI and UFR in their analyses (for example, an analysis could be done on the effects of GI on human health or the associations between UFR and institutional barriers, which were not connected to our focus since both GI and UFR were not investigated simultaneously). This explains why the total results of the search query (148) were much smaller than when considering GI or URF separately.

Our search query resulted in papers published since 2013. Although both GI and UFR are not very new concepts in academia, most of the indexed investigations in these two fields are done in recent years. According to Gao et al. [1], the publications in the field of UFR have been limited to less than 10 articles per year until 2010 and only raised to more than 100 per year since 2016. A relatively similar trend is also observed for GI-related publications, with 2009 and 2014 as the years after which there are more than 10 and 100 publications per year [40]. Thus, it was quite reasonable that the publications that directly investigate both these topics were found after 2013. It was only after 2018 that more than 10 articles (addressing GI and UFR simultaneously) were published per year. Therefore, we decided to include only the publications in the last 5 years (2018–2022) in our analysis. This gave us 118 papers (around 80 percent of all articles found in the database) for the next step.

Twelve papers were discarded as either the full text was not available, the article was a review of past research, or the subject did not fit the required topic. Consequently, 106 papers were selected as our final review sample, which we believe provided sufficient materials to explore the recent trends in this field of research. We also reviewed the top ten most cited articles published before 2018 to reinforce our background and discussions and to frame our results within the findings of these highly influential papers. In this regard, six papers were found relevant and were used along with other useful materials. It should be highlighted that our sample size should not be compared to previous bibliometric reviews in the fields of GI (e.g., [40]) or UFR (e.g., [1]) as our review was not only a bibliometric analysis but also a full-text review of articles to analyze the methodologies and GI typologies used in UFR.

In order to come up with the methods of investigation, the papers were classified into three groups using qualitative, quantitative, or mixed methodologies, which include both qualitative and quantitative approaches. The documents in these three major groups were then classified based on more specific research approaches and methods. The process of these classifications and the relative analysis was done in Microsoft Excel.

The typologies of GI used in the literature were also studied. For this reason, we grouped the GI types that were indicated in the papers' analyses into multiple classes, including relatively similar GIs. A "general" class was created to include GI and/or other related terms which were used by the authors in a general form, without mentioning the specific technical terms that are used for GIs, especially when the attention is on water flow management. This general category includes the words/terms such as NBS (nature-based solutions), green/open space, park, grassed pitch, urban agriculture/afforestation, tree pits, pervious land cover, green street, etc. These are classified in the general category as they can include many specific GI/NBS/LID/BMP (LID: Low-Impact Development, BMP: Best Management Practices) techniques.

Categorizing some GI types was challenging as they are very similar to each other with slight differences. For example, bio-retention cells and rain gardens are perceived as similar in many sources; however, as the technical details differ, we decided to separate the category. Nevertheless, these differences might not be considered by the authors. Therefore, we explained, as well, the case in which these categories are assumed to be similar. Another point to consider is that one article might use one or more GI categories, therefore the total number of GIs in the results was higher than the total number of documents.

2.2. Bibliometric Analysis

VOSviewer 1.6.18 and Microsoft Excel 2019 were used for the bibliometric analysis. The VOSviewer software is designed for the graphical depiction of bibliometric maps through developing and visualizing bibliometric networks [46]. Therefore, it was employed to obtain bibliometric maps that aid analysis of the interrelationships between subject themes to understand how GI (and related concepts such as nature-based solutions) and UFR are linked.

In order to get a better structural understanding of the networks, the cluster display was used in this study. Each term appears as a node on a map. Relationships are represented by the gap size between nodes. The proximity between two nodes on the screen suggests that they are connected in a meaningful way. The connections between the nodes stand for a direct co-occurrence. In a network diagram or analysis, the strength of links between nodes is proportional to the frequency with which they appear together or are cited by one another. Each cluster of nodes shares a common color since they are all connected by a high-strength connection. The units within a cluster are seen to be highly homogeneous, but those belonging to separate clusters are viewed as being quite diverse from one another. The cluster visualization allows for the determination of the logical framework of GI (and related concepts such as NBS) and UFR [47].

Initially, after uploading a text CSV file, exported from Scopus, into VOSviewer, co-occurrence was used as the kind of analysis, and authors' keywords were used as the unit of analysis in a bibliometric study. A manually created thesaurus file was used to merge strongly similar keywords (e.g., resilience and resiliency; LID and low-impact development). As all the studied literature had urban dimensions, the keywords with "urban" words were merged with their similar keywords without the word "urban" (e.g., urban resilience and resilience). This was not done for "urban planning" as the meaning could differ when compared with "planning", which is a more general term and can include wider aspects than urban planning. Keywords that appeared five times or more were chosen for the analysis to provide a manageable and comprehensible conclusion.

A map containing 13 distinct keywords was generated by the program. Each keyword is represented by a circle; the larger the circle, the more frequently the term appears in the papers. Co-occurrence happens when two or more keywords appear in the same document. Related keywords were connected if they appeared frequently together. When two keywords are closely related to one another, the distance between them is small and the link strength is strong (relative to other keywords).

Two measures of connectivity were calculated, one for the network of topics (keywords) and one for each node (keyword) in the network. The number of observed linkages divided by the total number of potential links in the network is what makes up the gamma index, which measures the connectivity between nodes (subjects or themes of interest) in a network [48]. It takes on values between 0 and 1, with 1 indicating a fully linked network and 0 indicating that no nodes in the network are connected [39]. We used the gamma index as a measure of connectivity for our network of topics.

We defined a Keyword Connectivity Index (KCI) to evaluate the level of connectedness for each keyword in the network. For this, first, the connectivity index of the nodes which is defined as the number of nodes linkable to each vertex [49] was calculated. As there were 13 total keywords, the connectivity index for each node was equal to 12. Then, the total number of the observed links for each keyword was divided by this connectivity index, 12, giving us the KCI value for each keyword. KCI quantity could vary between 0 and 1 if, respectively, a keyword was not connected to any other node or it was connected to all other vertices. The gamma index and KCI could help gain insight into the current connections between the nodes in the network, as a whole or for each node.

Besides, the distribution of the documents per country was obtained from the Scopus analysis tool which was confirmed by VOSviewer analysis of the documents based on countries. To validate the regions with less research, a Web of Science search with a similar search query (same keyword combination and publication years) was undertaken, which showed a relatively similar outcome. The citations per country were also analyzed by VOSviewer analysis of the documents based on countries.

VOSviewer was also used to do a co-authorship assessment using authors as a unit of analysis. It takes into account the frequency with which authors appear in publications and the ties established by co-authorship between them. Co-authors of publications tend to cluster together; the closer two authors are, the more papers they have written together. The analysis of the authors and journals with the most publications and citations was done using the CSV file, exported from Scopus, in Microsoft Excel. The sorting method was used to obtain the results. VOSviewer was also used to conduct a bibliometric analysis, using co-citation as the type of analysis, to determine connections between the sources of publication and their ranking based on received citations from the references of the reviewed articles. This could be used as another factor determining the general impacts of the journals on the body of knowledge in this research field. Links between citations—appearing as a connection between two journals in the network view—occur when a reference article cites these two journals. Tables are used to present the results. Generally, the stronger the association between the sources of publication, the greater the overall strength of the link.

3. Results

3.1. Distribution of the Publications and Citations

The distribution of documents by countries demonstrates the normal aggregation of papers and connected citations in scientifically strong countries, such as the United States, the United Kingdom, and China. If we take Europe as a socioeconomic entity, it contributed a moderate number of articles in comparison to other geographical areas (Table 1). Most documents were distributed among the developed countries, except for China and Brazil, which are among the largest economies in the developing countries. Other developing countries were not listed in the countries with more than three documents. It should be noticed that high rates of publications in English-speaking countries (e.g., USA and UK) might be linked to the limitation of this review to include only English documents.

Table 1. Distribution of articles and citations in countries with more than three documents.

Country	Documents	Citations
United States	27	202
United Kingdom	19	290
China	16	212
Italy	12	128
Germany	6	57
Netherlands	6	49
Australia	6	31
Brazil	6	27
Hong Kong	5	77
New Zealand	4	35
South Korea	4	26

The distribution of documents per journal can be seen in Table 2. The top ten journals–with more than two published documents–are listed from a total of 50 sources. According to the results, "Sustainability", and "Water" journals (both published by MDPI publication) were the top journals that recently published articles in this field of research, with 14 and 11 documents respectively. They also had the highest rates of connectivity with other sources included in the literature review (257 and 333 links respectively). "Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences", published by the Royal Society, was the next journal on the list (all articles are part of the theme issue "Urban flood resilience") with seven documents. The next journals were "Science of the Total Environment" (six documents) and "Urban Forestry and Urban Greening" (five documents), which are published by ScienceDirect.

Table 2. Distribution of the documents based on sources of publication.

Source	Documents	Citations	Total Link Strength
Sustainability (Switzerland)	14	68	257
Water (Switzerland)	11	75	333
Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences	7	107	139
Science of the Total Environment	6	34	160
Urban Forestry and Urban Greening	5	24	121
Landscape and Urban Planning	3	105	78
Journal of Cleaner Production	3	42	94
Blue-Green Systems	3	36	112
Water Science and Technology	3	35	56
Land	3	28	22

The top five journals based on the number of citations received by their published papers were "Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences", "Landscape and Urban Planning", "Water (Switzerland)", "Sustainability (Switzerland)", and "Journal of Cleaner Production" with 107, 105, 75, 68, and 42 citations. The high number of citations for the "Landscape and Urban Planning" journal was noticeable as although only three published papers were from this source, the citations were almost equivalent to the highest number in the list and were higher than the citations of the other four journals which had two to 11 more published articles.

As another factor related to the citations, we also analyzed how many citations are given to each journal by the references of the 106 reviewed papers. The top ten journals (sources that are cited more than 50 times) are listed in Table 3. Accordingly, the "Journal of Environmental Management" was the top journal that received 172 citations. It also had the highest total link strength of 2416, which is an indicator illustrating the number of times each journal is cited mutually with another one (of the top ten) by the reviewed articles. Therefore, this was the journal with the highest connectivity to other top journals, as well. The next sources with the highest rate of received citations were "Landscape and Urban Planning", "Water (Switzerland)", "Science of the Total Environment", and "Journal of Hydrology", with 151, 132, 121, and 121 citations respectively. Likewise, these had the highest connectivity rates after the first rank, with, however, a different sequence.

Table 3. Journals with the highest number of received citations.

Source	Documents	Total Link Strength
Journal of Environmental Management	172	2416
Landscape and Urban Planning	151	1527
Water (Switzerland)	132	1641
Science of the Total Environment	121	1873
Journal of Hydrology	121	1493
Sustainability (Switzerland)	98	1189
Urban Forestry and Urban Greening	76	960
Urban Water Journal	66	829
Journal of Cleaner Production	53	1033
Water Research	51	885

3.2. Most Cited Papers and Authors

The 106 articles were written by 432 authors. However, just 44 authors (10.2%) are closely linked to one another, as seen by six large, connected clusters (Figure 2). This implies that the authors collaborated and published jointly. The remaining authors (89.8%) form clusters but are not connected to any additional clusters that are highly linked.

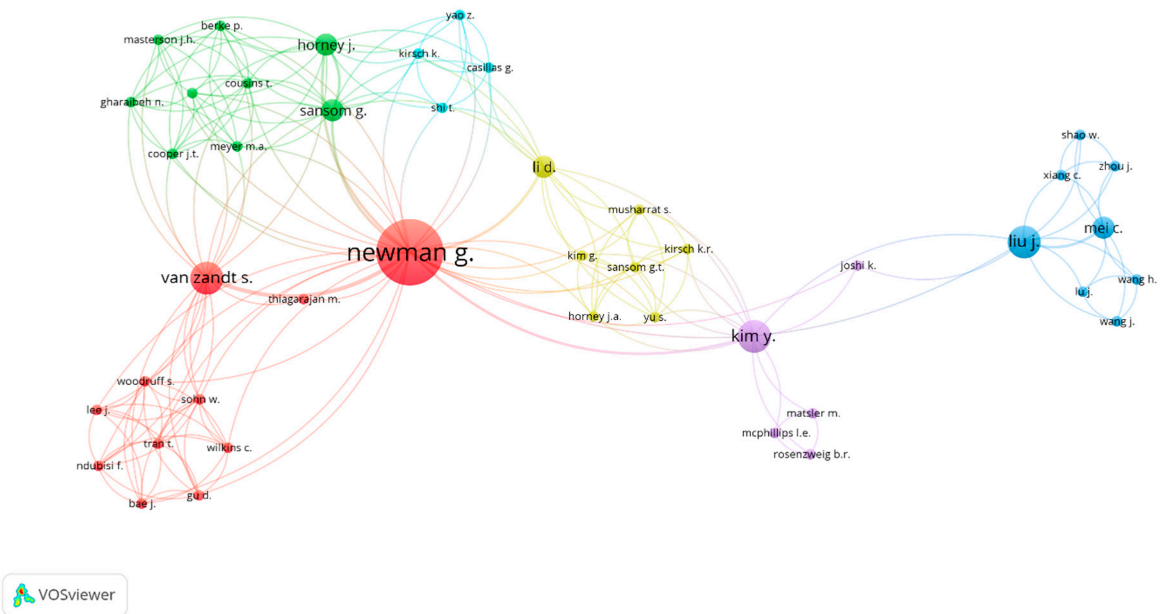


Figure 2. Clusters of authors' connections.

The red cluster is the most notable (Figure 2). It was composed of 11 authors who collaborated closely. Although it is the biggest author cluster, it is mainly caused by one publication [50] in which 10 of the 11 authors are included. It is the only paper for eight authors of this cluster, meaning that their presence in this cluster is dependent only on this paper, which is mainly an investigation of GI conditions in cities with low and high flood risk. Their results suggest that GI conditions, particularly in terms of quantity and connections, are improving in low-risk locations and deteriorating in high-risk ones.

The situation is comparable to the second big cluster (green) containing nine authors. Seven out of these nine authors have only one publication [19], in which all nine authors together with two authors from the red cluster are included. The paper describes a multidisciplinary pedagogical approach to resilience planning that encourages residents to evaluate and track the effectiveness of their community's stormwater infrastructure.

Although these are the biggest clusters, from a total of 20 authors, all are from the USA and 17 are working at Texas A&M University. Therefore, these clusters are mostly shaped by co-operations within the same institute and do not present the connectivity of authors between multiple institutions/countries. Therefore, not much cooperation between institutions or countries from different parts of the world is seen in this field of research.

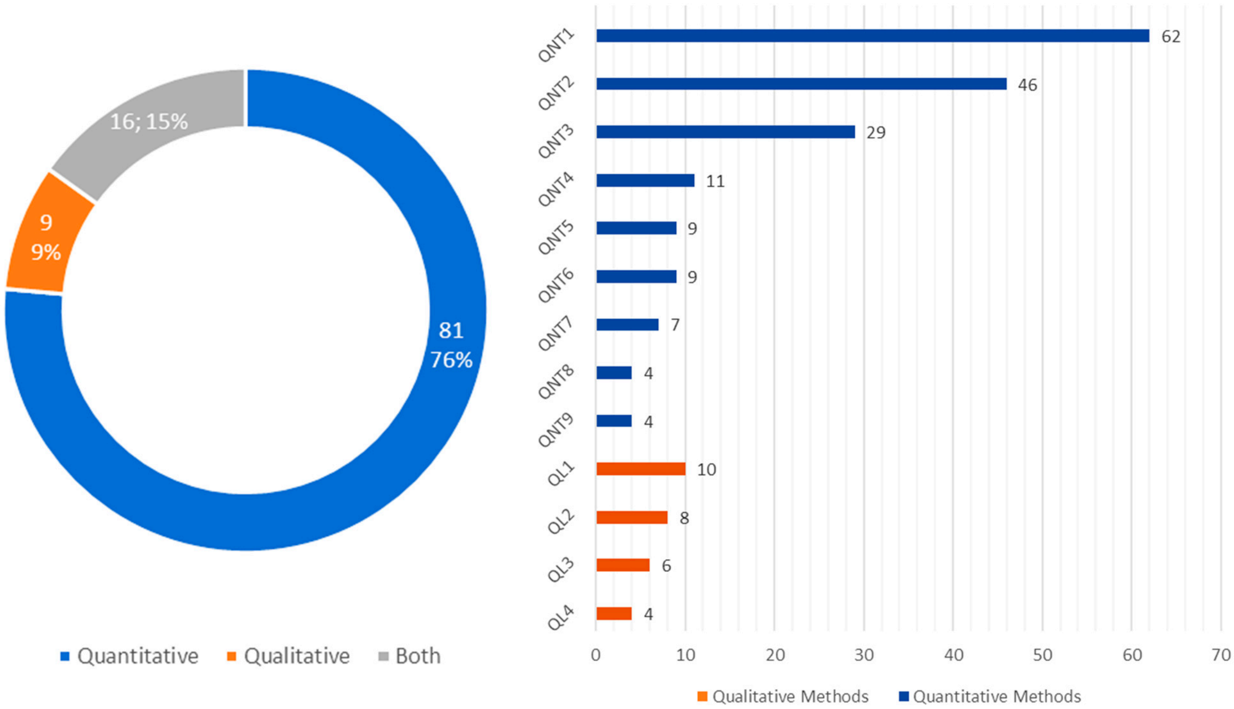
Galen Newman, from the Department of Landscape Architecture and Urban Planning at Texas A&M University, with six published articles [19,50–54], is the author with the highest number of recent publications in this field. Glyn Everett and Jessica Lamond, both from the Center for Architecture and Built Environment Research at the University of the West of England, with three mutual articles [55–57] have received 96 citations, which is the highest rate of citations for the authors of the reviewed literature. Furthermore, "Nature-based solutions: Settling the issue of sustainable urbanization" [58] is the most cited document with 57 citations. The article proposes an NBS applicative framework for local and regional policy and decision-makers. The following most cited articles are "Planning green infrastructure to mitigate urban surface water flooding risk: A methodology to identify priority areas applied in the city of Ghent" [59] and "Sustainable blue-green infrastructure: A social practice approach to understanding community preferences and stewardship" [55] with 52 and 51 citations, respectively. The first paper suggests a GIS-based multicriteria evaluation approach to pinpoint the most important locations for GI placements, while the second article investigates the possible role of Social Practice Theory (SPT) in clarifying users' needs and behaviors in relation to the sustainable functionality of BGI.

3.3. Methodological Approaches

The analysis of the methodology used in the literature shows that from the total 106 articles, 81 (76%) used quantitative methods (QNT), 9 (8%) used qualitative methods (QL), and 16 (15%) used both quantitative and qualitative approaches (Figure 3a). Accordingly, qualitative approaches were found in 25 papers (24%), while 97 articles (91%) used quantitative methods. Table 4 provides a general overview of the methodological approaches along with a brief explanation for each. Figure 3b illustrates the number of documents using specific qualitative or quantitative methods. The most used qualitative methods are QL1: desk research/document review/descriptive case study (10), QL2: interviews (8), QL3: participatory planning and multi-stakeholder engagement processes (6), and QL4: observations/field trip (4).

In terms of what topics are covered by each method, QL1 was used for topics, such as soil de-sealing concept [60], GI practices in urban poor areas to mitigate climate-related flood impacts [61], and governance structures for the wide-spread uptake of GI [62]. QL2 was used in subjects like socio-economic, cultural, and political challenges influencing Blue-Green Infrastructure (BGI) adoption [63], NBS scaling-up within greening strategies [64], and politicizing centralized water management [65]. Disaster resilience education [19], and sustainable flood-resilient urban development [66] are examples of topics for which QL3 was used. Likewise, researchers have acquired benefits from QL4 for objectives like offering an ethnographic account of flooding and stormwater management [67] and presenting the multi-objective GI contributions in climate change adaptation and resilience [68].

Furthermore, the most used quantitative method was QNT1: spatial analysis (62 papers), including hydrologic/hydraulic modeling and simulation (e.g., a spatial analysis frameworks to identify interoperable flood management interventions [69], future scenarios to evaluate the effect of LID practices on the resilience of stormwater drainage systems [70], and resilient infrastructure framework with a particular reference to adaptation [71]), and GIS/RS analysis (e.g., parking trees' potential in secondary streets in socially/environmentally vulnerable areas [72], GIS-based multicriteria evaluation method to identify GI priority areas [59], and the potential of flat rooftop and ground-level areas for agriculture, and the possible horticultural yield production [73]).



(**a**) Share of general approaches (**b**) Number of documents using each method

Figure 3. General overview of the distribution of research methods in the literature.

Scenario planning (QNT2) was applied in 46 articles for themes such as the resilience of plant species to the effects of hydrological extremes [74], a simulation-optimization framework for the spatial arrangement of LID [75], and resilience and efficiency GI under climate change [76]. Cost analysis (QNT3) was among the most implemented techniques, showing the significance of economic assessments in this field of research. There were 29 papers that developed different types of cost analyses for various targets, like calibrating a model to simulate streamflow discharge and apply it to assess the impacts of LIDs [77], assessing the cost-effectiveness of NBS scenarios through integrating hydrological impacts and life cycle costs [78], and exploring the tradeoff between the resilience enhancement and strategy transformation cost, and determining the optimal combination of the LIDs [79]. It is noticeable that four other papers [62,65,80,81] explore the significance of GI-linked costs with details but without implementing the cost analysis as a method in their articles. This means the importance of the economic dimensions was strongly acknowledged in some papers, even if they did not conduct economic analysis.

Although desk research/document review was applied in qualitative investigations, it (QNT4) was also a method to explore quantitative measures in 11 papers. Assessing the extent to which city climate adaptation plans identify the potential for co-benefits for biodiversity and quantifying the scale of those potential benefits [82] is an example of implementing QNT4. Identifying commonalities that drive and enable the implementation of NBS in different contexts [67] and reviewing design storm standards for green stormwater infrastructure across diverse cities [83] are two other examples.

Other quantitative methods could be named as follows: QNT5: statistical analysis/modeling (nine papers; e.g., [84–86]); QNT6: questionnaire survey (nine papers; e.g., online [87], postal [55], paper [56]); QNT7: MCA/MCDM (seven papers; e.g., AHP [88], Fuzzy clustering [89], TOPSIS [90]); QNT8: laboratory/prototype evaluation (four papers; e.g., [91–93]); and QNT9: environmental sampling (four papers; e.g., [19,53,94]). The dominance of quantitative approaches shows that more qualitative investigations can be done in this field of research.

Table 4. Brief descriptions of the methodologies used in the reviewed literature.

Methodology	**Description**
Qualitative	
QL1: Desk research/document review/descriptive case study	Exploring data from existing documents, research, practices, etc., where the focus is on qualitative aspects
QL2: Interviews	Verbally asking questions from individuals to gather the data (including unstructured, semi-structured, and structured)
QL3: Participatory planning and multi-stakeholder engagement processes	Participatory actions involving multiple participants to gather/process data, including focus groups, workshops, etc.
QL4: Observations/field trip	Collecting data through observing and/or visiting the objects or areas of the study
Quantitative	
QNT1: Spatial analysis	Examining and modeling geographical characteristics of data and their connections, including methods such as hydrologic/hydraulic modeling and simulation, and GIS/RS (remote sensing) analysis
QNT2: Scenario planning	Developing multiple scenarios to analyze various forms of a single issue, assessing different possibilities, outcomes, and uncertainties
QNT3: Cost analysis	Analysis of quantitative economic aspects such as costs and benefits
QNT4: Desk research/document review	Exploring data from existing documents, research, practices, etc., where the focus is on quantitative aspects
QNT5: Statistical analysis/modeling	Using statistical techniques/tools to manipulate datasets in order to find patterns, trends, and correlations
QNT6: Questionnaire survey	Employing questionnaires/polls (e.g., paper or online surveys) to gather and analyze data from a group of individuals
QNT7: MCA (Multi-Criteria Analysis)/ MCDM (Multi-Criteria Decision-Making)	Analyzing data or making decisions taking into account and prioritizing multiple distinct factors or goals, through analytical techniques such as the Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and fuzzy clustering
QNT8: Laboratory/prototype evaluation	Examining and assessing a phenomenon/object in a laboratory or using a prototype
QNT9: Environmental sampling	Gathering and testing samples from environmental sources to obtain objective information on multiple characteristics of the sources, such as environmental contamination, microorganisms, etc.

Among the 16 papers combining qualitative and quantitative methods, six used spatial analysis (e.g., [53,95,96]), five developed scenarios (e.g., [54,96,97]), and five established cost analyses (e.g., [98–100]). Besides these methods, which had the highest rates of application among papers with mixed methodology, the most used combination of qualitative and quantitative methods was using participatory planning and multi-stakeholder engagement processes and scenario planning (four papers). This approach was used by Gómez Martín et al. [97] to stress the importance of developing scientifically based and customized information on climate change impacts as a precondition for designing and implementing NBS. Outlining an interdisciplinary pedagogical strategy for resilience planning [19] and developing a community-scaled master plan utilizing land use and built environment [53] were two other instances that used this mixed approach.

3.4. Subjects of Interest

The most used keywords by authors were selected to show the subjects of interest in this field of research. The bibliometric analysis performed with VOSviewer showed that 13 keywords were used in at least five papers (Table 5). “Resilience”, “green infrastructure”, “low impact development”, “climate change”, and “nature-based solutions” were the most used keywords by the authors to represent the subjects of interest of their papers. These keywords had the highest number of links with other keywords among the 13 most used, except "low impact development" for which the total link strength was lower than "stormwater management" and equal to "flooding".

Table 5. The 13 keywords, representing topics of interest, used in at least five documents.

Keyword	Occurrences	Links	Total Link Strength	KCI
Resilience	30	12	41	1.00
Green Infrastructure	27	10	36	0.83
Low-Impact Development	19	8	19	0.67
Climate Change	17	10	19	0.83
Nature-Based Solutions	16	12	20	1.00
Flooding	13	8	21	0.67
Ecosystem Services	10	7	13	0.58
Blue-Green Infrastructure	10	6	7	0.50
Stormwater Management	7	5	12	0.42
Sustainable Drainage Systems	6	9	10	0.75
Urban Planning	6	6	9	0.50
Urbanization	5	6	10	0.50
Biodiversity	5	5	5	0.42

"Resilience" was represented with the biggest circle after the co-occurrence analysis (Figure 4). It appeared in 30 papers, with the highest possible KCI (1) which means it was connected to all other 12 subjects of interest. It also had the highest total link strength with 41 times co-appearance with other keywords. The next highest-ranked keyword was "Green Infrastructure" with 27 occurrences. This demonstrates that the term GI is recently used more in the field of UFR than other related expressions (i.e., LID with 19 occurrences, NBS with 16 occurrences, and BMP which is not included in the keywords with at least five occurrences) that are often utilized to express similar concepts. Additionally, "Blue-Green Infrastructure" was used as a keyword in ten articles, with only one link to GI. It shows that these two keywords were mostly not used together in papers. This could be because they are very commonly used to demonstrate a similar concept, and GI is usually considered to include blue components in its scope and definition.

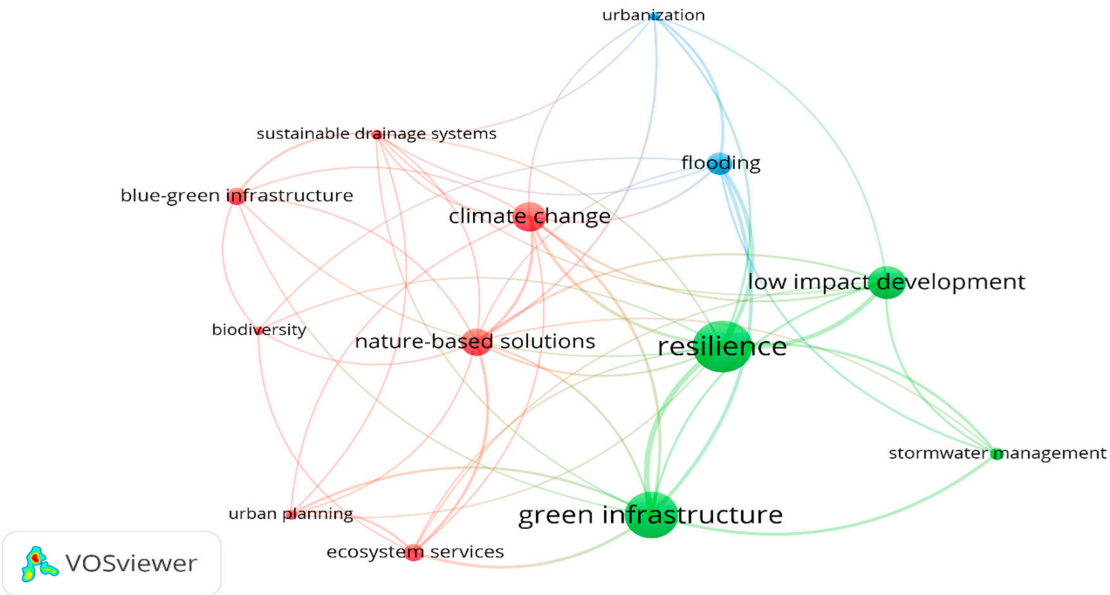


Figure 4. Keyword view and clusters in the reviewed literature from 2018 to 2022.

Resilience and NBS had the highest KCI among the keywords with a maximum amount of 1, showing that these were connected to other subjects of interest. This was followed by GI, climate change, and sustainable drainage systems (SuDS) with relatively high connectivity indices (0.75 to 1). LID, flooding, and ecosystem services (ES) had intermediate connectivity to the represented topics of interest (KCI between 0.55 and 0.75). The remaining five keywords represented relatively low connectivity (equal to or lower than 0.50) showing that there is still a high potential for linking these topics to other presented keywords within this field of research.

"Climate change", "ecosystem services", "urban planning" and "biodiversity" could be considered as the topics of research that were not directly addressed by the search query that was used for the literature review. Climate change, with the highest index of connectivity among these factors (0.83), was used as a keyword mostly together with resilience (four articles), and GI and NBS (three articles), showing the interest of researchers to analyze the mutual effects of these concepts. "Biodiversity", on the other hand, had the least connectivity among all the keywords with only five single connections (less than half of the possible links), showing that this subject was the least studied topic within this field of research.

The gamma index (γ) for the whole network also showed potential for further research in this field. It was calculated based on the following formula:

$$\gamma = \frac{e}{\frac{v(v-1)}{2}},$$

where e is the total number of observed links (52) and v is the total number of nodes (13) [48]. Accordingly, the gamma index of the network of keywords was equal to 0.67. Considering that the fully connected network has a gamma index of 1, the results showed that there are still a lot of possibilities for creating further links between the topics of interest in this network.

The cluster analysis of the keywords (three clusters) showed the difference in using the terms GI, BGI, NBS, and LID. Based on the results, GI and LID were used mostly in connection with resilience and stormwater management, while BGI and NBS were usually linked with climate change, ES, SuDS, urban planning, and biodiversity. It demonstrates that GI and LID were more used when the concentration was on the infrastructure- and resilience-linked aspects, while when using BGI and NBS terms the focus was more on climatic, natural, and sustainability dimensions.

3.5. Green Infrastructure Typologies

There are several forms of GI, and their classification has been studied from various perspectives [101]. However, how these categories might be broken down and reshaped to serve particular research needs is an area that needs to be explored further [102]. Accordingly, we analyzed the types of GI used in the recent literature to see what types were used frequently in the UFR field (Figure 5). For this, we tried not to introduce any new GI category or typology and instead to group the closely linked and similar GI types, which appeared in the literature, into classes/categories. Overall, 17 GI types/classes were extracted from the literature. It should be mentioned that one or more categories could be used by a single paper.

Based on the results, more than half of the articles (61 papers, 57%) used GI in a general form without mentioning the specific technical terms that are defined for GI highlighting water management capacities (e.g., bioswale, green roof, etc.). This general category includes the words/terms such as NBS, green/open space, park, grassed pitch, urban agriculture/afforestation, tree pits, pervious land cover, green street, etc. These are classified in the general category because they can contain many specific GI/NBS/LID/BMP techniques to manage stormwater. For example, a park or a green/open space can include many types of GI, such as permeable pavement, wetlands, or stormwater ponds, and therefore these terms do not provide clear information on specific/more technical GI typologies, especially when the attention is on UFR.

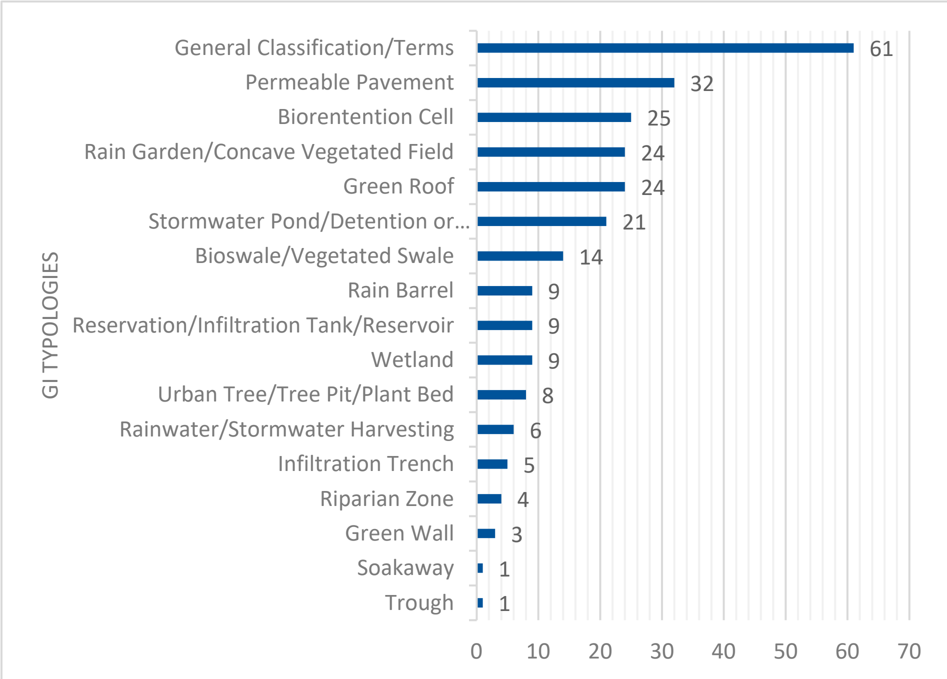


Figure 5. GI typologies used in the reviewed literature.

Putting this category aside, the most used GI types in the reviewed literature were "permeable pavement" (32 articles, 30%), "bio-retention cell" (25 articles, 23%), "rain garden/concave vegetated field" (24 articles, 22%), "green roof" (24 articles, 22%), and "stormwater pond/detention or retention basin" (21 articles, 20%). It is noticeable that four of these GIs can be used on a small/building scale, showing the great interest in this scale of solutions in the recent literature. On the other hand, "trough", "soakaway", and "green wall" were the least mentioned GI types, which were mentioned by one, one, and three documents, respectively. This could be due to the use of more novel techniques (in the case of soakaway), not linking well with the urban context (in the case of the trough), and implementation challenges/disadvantages (in the case of the green wall), such as low plant yield, high maintenance, and pest and animal attacks [103], and low benefits regarding flood mitigation [104].

As mentioned, some typologies have much in common, and differentiating among them is not simple. Among these categories are bioretention cell and rain garden/concave vegetated field. Likewise, rain barrel, reservation/infiltration tank/reservoir, and rainwater/stormwater harvesting have many mutual characteristics. Although these are not identical terms, the authors might not consider the slight differences between these terms. Therefore, these GI types (which have many similar characteristics) might be used interchangeably by various sources, and this could also be the case for the reviewed literature. In the case that we consider them identical as well, they would stand out as two major types of GI used in the recent literature in the field. Accordingly, bioretention cell and rain garden/concave vegetated field would stand higher than permeable pavement with 49 articles mentioning them. Rain barrel, reservation/infiltration tank/reservoir, and rainwater/stormwater harvesting would appear beside green roofs with 24 papers investigating these GI types.

4. Discussion

4.1. Regional/Institutional Distribution of the Literature

This work provides a general view of recently published papers relating to GI and UFR. Connecting these two is of great interest as recently GI has gained popularity as a solution for minimizing the consequences of floods and balancing the impacts of urban development with the preservation of green space [50]. Based on the results, a noticeable difference could be seen between the developed regions and the countries within the Global South, with China and Brazil (to a lesser extent) as exceptions. As mentioned earlier, this was validated by WoS results, as well. Furthermore, it is confirmed by recently published comprehensive literature reviews in the fields of GI and/or UFR.

Previous research on GI reveals that, while occupying a large area in the literature, it is mostly associated with applications in industrialized nations [105]. On the contrary, it is still an emerging topic for research in developing nations [106,107]. For example, Ying et al. [40] carried out a comprehensive literature review on GI reviewing 2194 papers published from 1995 to 2019. They reported that there is a need for more research related to GI in developing countries, except for China.

Likewise, Gao et al. [1] carried out a scientometric analysis of UFR-linked literature published in the 1999–2021 period. A total of 1416 papers were analyzed and according to the outcomes of the national-cooperative analysis, the first source country of the literature was the US, followed by the UK, China, the Netherlands, Germany, Australia, and Italy. They also reported that the first three countries accounted for more than half of the total number of published articles using "urban flood resilience" as a keyword.

These studies and comprehensive reviews, each of which covers a major core of the present study (UFR and GI), illustrate that the publications in this field are mostly done in developed regions of the world, with China as an exception as it has strong policies and research cluster interests in this field (mostly linked to the Sponge City concept) [41]. It is noticeable that the timeframes of these reviews were wider than the present study, which covers the last five years, so it could be understood that the publication gap in the Global South is not limited only to the recent years and the state-of-the-art knowledge. Therefore, studies in this area are especially important for developing regions, which are dealing with rapid urbanization, growing populations, and challenges related to environmental hazards [108].

On the other hand, the results reflected the usual difference in publications between these two groups of regions (developed regions plus China, and other countries) [39]. Brazil, as the 10th largest economy in the world and the largest in Latin America [109], and the top-ranked Latin American country in scientific performance for the period of 2000–2015 [110], was also included in the countries with the highest rate of publication for the present study, showing high local interest in studying GI for UFR. The country is also ranked as the most exposed region to flooding in Latin America considering absolute numbers [111]. It should be noticed that lower publication rates in developing countries does not indicate a lack of capacity or interest in study in these regions, which likewise share urbanization challenges with other parts of the world. It is very likely that many authors in these regions do not publish in journals indexed in Scopus or WoS. Many of the researchers from these countries are likely to use languages other than English, as well. Therefore, these limitations should be taken into consideration when implementing the results of this review.

Authorship bibliometric analysis can also provide insight into the intellectual structure of GI for the UFR research field. The authors that published together are located close to each other on the map and grouped into one cluster (Figure 2). As only 10.2% of the authors shared high connectivity with 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 large number of authors that are unconnected. This opens a window for the possibility for greater opportunities for collaboration in the future. It seems likely that authors from different countries are not connecting enough to perform research and publish together. In addition, a great number of authors placed in the first two clusters are affiliated with Texas A&M University, which is, according to Gao et al. [1], the top university in the world that has the most publications on UFR. This illustrates an opportunity for future cooperation. Consequently, it is recommended that collaborations among authors from different institutions, countries, and continents increase in the future.

4.2. Methodological Aspects

This review shows (Table 4, Figure 3) that there is a high variety of quantitative topics in the research on UFR and GI, but this is not the case for qualitative and mixed approaches. The share of methodological approaches shows that 76% of papers used quantitative methods, while only 8% and 15% used quantitative and mixed approaches. Therefore, future research could follow more qualitative and mixed approaches. It is especially recommended to apply mixed approaches in this field of research since it is focused on contributing to the solution of real-world problems. However, one potential hurdle is that mixed methods research needs more labor and requires the investigator to comprehend additional research techniques [112].

On the other hand, the prevalence of quantitative methods may be because a quantitative approach with evidence from measurable factors is viewed as more compelling than a qualitative method [39]. However, when opposed to theoretical and qualitative techniques, quantitative studies focus on fewer variables due to the significant effort necessary to measure variables and interpret data. As a result, quantitative studies involving a variety of characteristics and numerous factors should be conducted in the near future, with the goal of covering many elements of UFR and GI on different urban scales. This will need additional data collection (e.g., site-specific) and synthesis but will lead to a more integrated and thorough knowledge of this field of study. It also lowers the possible analysis uncertainty, as more performance data will be evaluated [23].

Additionally, it was seen that cost analyses shape a noticeable share of methodological approaches. There were 29 articles that used different quantitative methods to assess the costs. Four papers extensively explained the significance of costs in their results and discussions. Even though there may be alternatives that might perform better than, or at least complementary to, cost-benefit analysis to quantify the advantages of GI [113], the high use of cost analyses in the recent literature implies a noteworthy interest in assessing the economic value of GI, which offers an opening for future research. It can include not only the direct/indirect cost-benefit evaluation of various GI implementations but also other economic aspects such as big-scale economic evaluation of GI management strategies [114] and public willingness to financially support GI-related policies [115].

4.3. Relationships among the Topics/Themes of Interest

Indicators (number and strength of links, gamma index, KCI) demonstrate moderate connectivity for the whole network and low and diverse connectivity between some topics (keywords), suggesting that there is still a great deal of opportunity for linking these themes of interest in relation to GI and UFR. This is especially true for biodiversity, as the subject of interest with the lowest KCI (the only one with the observed links less than half of the possible connections) and total link strength. Including locally contextualized biodiversity in GI design in urban planning improves the city's functionality and resilience [116], which shows the significance of further research connecting biodiversity to GI and UFR from multiple aspects. There is also an opportunity for many other topics to be researched in relation to GI and UFR and to increase the links in the network of topics (Table 5). It is likely that the accumulation of authors will decline, leading to a larger total number of authors and a more uniform distribution of authorship clusters. Additionally, it is important to note that even though this research was about GI and UFR, the results showed connections to climate change, ES, urban planning, and biodiversity (with low to relatively high connectivity to the represented topics of interest). Consequently, these should be considered critical dimensions of the recent body of knowledge regarding GI and UFR, with different levels of significance.

4.4. GI Typologies

The results show that more than half of the papers use general terminologies (which do not provide much technical information) to explain different GIs. This shows that in many cases, the analysis does not go into further detail about the performance of the explained GI types. For example, referring to urban parks or green spaces as GIs would not bring many specifications about the performance details of these green systems. Although the general benefits of these GIs are well-known, using these general classifications could limit the depth of analysis and bring possible biases to the outcomes, specifically when the aim is to study the impacts of GI on urban flooding. This is confirmed by Jones et al. [104] who believe that "ideally, a [GI] typology should be . . . able to address aspects of both ecological functions and human use, and be compatible with modelling approaches to calculate ecosystem services and benefits". Using general terms to define GI limits the compatibility with modeling to find out their ES and advantages, including their abilities in stormwater management.

Possible reasons for using general terms could be the scope and scale of analyses, as they are essential factors when investigating the contribution of various GI typologies in urban contexts [102]. In general, as the scale of analysis becomes bigger, it becomes harder to distinguish individual GI elements and their spatial arrangements [102]. Consequently, more general typologies would be used to define the GI types. For example, Bae et al. [50] studied the GI conditions in low/high flood-risk cities. Their analysis included a city-scale examination of GI based on eight classes collected from the land cover database, such as developed open space, evergreen forest, and grassland/herbaceous.

In addition, the scope and purpose of GI can affect the terminologies used to define different GI types. For example, "recreational open space" or "community garden" could be used when the specific attention is on the socio-cultural functionality of the GI, rather than other possible benefits such as runoff reduction. For instance, Rayan et al. [117] proposed a sustainable indicator-based framework for urban GI using a multi-stakeholder engagement process. They considered not only ecological but also socio-cultural and economic indicators to evaluate the GI categories. "Community garden", "botanical garden", "urban park", and "horticultural" are among the GI types and green space elements they studied, showing their attention to multiple GI dimensions and not only ecological aspects or water flow management. A literature review on urban ecosystem-based adaptations also listed the frequency of ecological structures (which could be considered as GIs) in the reviewed literature, using a similar approach to our study. They categorized 11 GI types, many of which were in general terminologies (e.g., parks/gardens, grassland, green space), as the focus of their analysis was on ecosystem adaptation rather than UFR specifically [118]. Nevertheless, our results showed that these terms are also used even when more attention is on flood mitigation. As an example, Newman et al. [53] investigated the community master planning of a neighborhood prone to frequent flooding and contaminant exposure. Although one of their main aims was to reduce the runoff and they also calculated the amount of potential reduction in runoff in the designed master plan, they included general GI types such as community and neighborhood gardens in their master plan and analysis. Although this was probably carried out to clearly highlight the social value of these spaces, this has limited the level of technical knowledge regarding the water management capabilities of these spaces.

As mentioned, the use of general terms for GI could limit the ability to calculate the possible benefits and impacts of GI [104]; therefore, we suggest using more specific terms and categories to define GI in future UFR research, when possible. Although this approach can bring disadvantages in explaining well the multifunctionality of GIs (e.g., social and aesthetic expressions) [119], this could be managed using technical and explanatory terminologies. Additionally, aligned with [102], we suggest further research on offering more standardized GI defining/categorizing outlines, customized to meet the specific needs and objectives of UFR. It should be carried out with special attention to multiple contextual and spatial dimensions of this field of research and the concurrent necessity to use technically specific terms.

The permeable pavement was the second most used GI typology in recent research. A possible explanation for this vast usage is the ease of implementation, design, and analysis. Permeable pavements provide a high-level impact on water flow management [104] while being a relatively cheap option [120]; however, they could be significantly more expensive than some GIs, such as rain gardens [121]. The huge difference in using green roofs and green walls, with 24 and three papers mentioning them, is also noteworthy, as both are GI typologies that could be used in building scales and highly dense urban areas. This could be mainly because of the predominant focus of the literature review on UFR, as green roofs are more advantageous for mitigating urban flood risks. Due to their capacity for water retention, green roofs have a favorable impact on the management of surface runoff. Rainwater is captured by the plants and substrate and becomes available for evapotranspiration [29]. Average yearly retention of 60% of rainfall was found in a survey of 60 published green roof investigations that were done in tropical, dry, temperate, and continental regions [122]. In addition to retaining rainwater, green roofs help delay runoff by temporarily detaining the rainfall [123]. However, green walls are more effective in graywater treatment [124,125] with a low impact on water flow management [104]. Another explanation for the lower usage of green walls in the reviewed literature could be related to the implementation challenges of green walls, such as low plant yield, high maintenance, and pest and animal attacks [103].

It was noticed that the high rate of using available tools/software in the analysis of GI increases the use of some types/terms over others. These tools include limited types of GI in their analysis, each of which has its own special term. For example, SWMM, as a highly used tool in GI and hydrologic/hydraulic analyses (e.g., [90,126,127], can model eight GI types, such as bio-retention cells, permeable pavement, green roof, infiltration trenches, and rain barrels or cisterns [128]. Consequently, the GI types that are implemented in these tools would appear more in the papers with quantitative approaches. Thus, the way these tools/software are using GI-linked terms could also affect the general terminology of GI in the literature. For instance, rain barrels and rainwater harvesting are used interchangeably in SWMM GI categorization [128]; however, rainwater harvesting can include more complex systems to reuse the rainwater such as a complex piping system [129].

GI typologies/terminologies could also be affected by local standards, guidelines, and planning documents. For example, Bartesaghi Koc et al. [102] reviewed studies from 15 countries to see how GI is categorized and described globally. Their results showed that, in England, the recommendations of two governmental plans (PPG17 guidelines and the urban green space taskforce) have evolved into standards for the majority of subsequent studies, making it clear that government planning policies have a significant impact on the ability to identify, characterize, and deliver various GI types. Therefore, it could be considered an influential factor in using different GI typologies/terminologies in our reviewed literature as well.

5. Conclusions

Flooding is a major challenge in many urban areas around the globe, and as the climate is changing, this problem could threaten even wider regions in the future. UFR as a possible answer to this issue has been proposed, in which the use of GI could play a major role. This article provides useful information regarding the usage of GI to reach UFR, by reviewing recently published related articles.

The main outcomes demonstrate that the recent articles connecting GI and UFR are mostly published by scientifically and economically powerful countries, leaving space for further publications in other regions. In addition, most authors/institutions remain unconnected to each other, which presents an opportunity for future cooperation between institutions and regions. Besides, the majority of recent research in this field uses quantitative approaches, such as spatial analysis (hydrologic/hydraulic modeling, GIS/RS analysis, etc.), scenario planning, and cost analysis. It is, therefore, an opening especially for further development of mixed approaches (using both qualitative and quantitative methods), as this research field is focused on adding to the solution of real-world problems. As compared to theoretical and qualitative techniques, quantitative studies focus on fewer variables, we also suggest performing more comprehensive quantitative studies involving a variety of characteristics and numerous factors in the near future, with the goal of covering more elements of UFR and GI and decreasing possible performance/analysis uncertainty. The high level of attention to the economic aspects of GI in the recent literature also shows a recent hot topic of research that could be further followed by researchers.

The network/keyword connectivity indices depict that there is still a high potential for linking some topics under the umbrella of GI and UFR. This is especially true for biodiversity as the subject of interest with the lowest index of connectivity. Furthermore, the analysis of keywords showed that GI was the most used term compared to other related terms, such as LID, NBS, and BMP, in UFR-linked literature. The cluster analysis indicated that GI and LID were used more when the concentration was on the infrastructure- and resilience-linked aspects, while when using BGI and NBS terms the focus was more on climatic, natural, and sustainability dimensions. Therefore, the frequency and the way these terms (GI, NBS, LID, etc.) are used differ within this field of research.

Regarding GI typologies, more than half of the articles utilize general types/terminologies (not providing much technical information on water flow management characteristics) to explain different GIs involved in their analyses. This could limit and bias the outcomes, explicitly when the goal is to investigate the effects on urban floods. Therefore, more usage of technical terminology instead of common terms could bring benefits and clarity to understanding the results, whenever possible. However, this could bring some challenges as it might limit the ability to show GI multifunctionality in the terminology. Accordingly, we suggest doing further research on offering more standardized GI defining/categorizing outlines, customized to meet the specific needs and objectives of UFR, while maintaining the ability to explain multiple GI dimensions (e.g., sociocultural aspects).

Besides the "general" category, the most used GI typologies were "permeable pavement", "bio-retention cell", "rain garden/concave vegetated field", "green roof", and "stormwater pond/detention or retention basin". The first four classes can be used on a small/building scale, showing the great interest in this scale of solutions in UFR recent research. Despite some technical differences, bio-retention cells and rain gardens are considered identical in some sources. Accordingly, if we too consider them identical, the merged group (bio-retention cells and rain gardens) becomes the most used specific GI category, before permeable pavements. As possible influential factors on GI typologies/terminologies the role of scale, scope, and local documents/guidelines are explained. Additionally, as many reviewed articles applied tools/software in their analyses, the typologies and terminologies used in these tools were seen as effective in GI types/terms explained in the articles.

This review may be limited in scope and more detailed reviews in other databases and publication languages could provide further insights into this subject of interest. In any case, the results presented here offer an overview of the recent trends of research on GI addressing UFR, which could be useful for future work in this field.

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Data Availability Statement: The list of 106 papers analyzed in this review can be found in [130].

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