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Systematic Review

Participatory Digital Solutions for Nature-Based Solution Urban Projects: A Systematic PRISMA Literature Review

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Abstract

This paper examines the growing role of nature-based solutions (NBS) and the integration of digital technologies in participatory urban planning. It aims to assess the current state of technologies and methods for participatory approaches in NBS projects, the level of participation they can stimulate, and the drivers and barriers to their integration into planning practice. The review uses the PRISMA methodology to examine 275 records from two databases, aiming to minimize bias. Records were selected based on the following criteria: studies were conducted in urban settings; referenced NBS; incorporated participatory methods; and involved digital technologies. Both review articles and case study papers were considered. A bibliometric and content analysis was performed using VOS VIEWER software, an Excel spreadsheet, and comparison tables. The 45 reviewed studies cover citizen science, participatory mapping and co-creation using place-based or non-place-based digital tools. While these tools can improve engagement and efficiency, they also face challenges such as limited data access, demographic bias, institutional resistance, and insufficient resources. The study found that top-down methods often restrict the impact of these tools by treating public input as secondary, thereby highlighting the need for transparent, collaborative planning.

Keywords: nature-based solutions NBS; green infrastructure; digital participation; mart cities; participatory planning; citizen science; participatory GIS; co-creation; urban planning; place-based

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1. Introduction

Climate change, driven by human activities, has led to more frequent and intense extreme weather events, impacting ecosystems and economies globally [1,2]. Traditional urban planning has exacerbated these effects by compromising soil consumption, water management, and permeability, making cities more vulnerable to extreme events, such as storms, heatwaves, floods, and droughts [3]. With urbanization projected to increase, the impact of human activities on intense extreme weather events will intensify, necessitating drastic adaptation measures. Nature-based solutions (NBS) offer a sustainable alternative to conventional "grey solutions", providing economic, environmental, and social benefits [4,5]. NBS are integral to international policies, like the UN 2030 Agenda for sustainable development (SDGs 14 and 15) and the Sendai Framework [6], and have been incorporated into EU strategies, such as the EU Biodiversity Strategy for 2030, the EU

Climate Adaptation Strategy, and the proposed EU Nature Restoration Law [7]. The EU promotes NBS through research and innovation funding programs like Horizon 2020 and Horizon Europe encouraging stakeholder and community involvement [8]. Additionally, the integration of digital tools and smart sensors is transforming cities into smart cities, enhancing NBS monitoring and decision-making [9,10].

1.1. Theoretical Framework and Rationale for the Review

The terms "NBS" and "participatory approaches" are gaining traction among policymakers and practitioners, yet they often lack clarity and transparency. NBS, as a terminology, has been widely used in the literature as a synonym for complementary or overlapping approaches from different fields, such as *ecological engineering*, *natural capital* or the more recent *ecosystem services* (*ES*), since 2006, and *green infrastructure* (GI), since 2007 [11–13]. The appearance of *NBS* in 2015 has collected all these separated concepts under a common definition, as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience." [11,12]. The implementation of NBS at urban level is closely linked to the availability of urban green infrastructure (UGS), environmental equity, and social impacts [5,14]. For this review, the decision was made to concentrate on the overarching concept of NBS, encompassing a range of keywords that remain prevalent in the current literature.

NBS planning has been linked in the literature to the co-creation approach, with the emerging shift from traditional planning to more collaborative governance approaches [15]. One of the most cited definitions of participation refers to the redistribution of decision-making power to the people involved, enabling those excluded from political and economic processes to be deliberately included in the process [16,17]. Participatory processes may address declining voter turnout in developed democracies by engaging people on local and specific issues. Political actors are recognizing the advantage of these processes for rebuilding trust between voters and public administrations [18]. Advantages of participatory processes from the literature include a better understanding of local issues, integrating local knowledge in the design phase, with better public acceptance of decisions, and the promotion of social learning and awareness. However, there are also risks such as high costs, the need for stable funding, insufficient knowledge of approaches by administrations, potential stakeholder frustration, identification of new conflicts, an unrepresentative involvement of stakeholders, and the possibility of manipulation due to disparate power dynamics among stakeholder groups [19–21]. Despite the trend towards increased stakeholder participation, these processes can result in vague and contradictory outcomes, making it difficult to apply in decision-making processes [19–21]. In the literature, public participation has been analyzed through Fung's *democracy cube framework* [22] to define the quality and representativeness of a process: who participates and how they are selected, how participants communicate and make decisions together, and how discussions are linked with policy or public action. Furthermore, Arnstein's ladder of citizen's participation [16] defines different levels of citizen participation, based on power sharing dynamics, which are the essential goal to a successful process. Arnstein suggests that in some forms of participation, citizens are not heard and are therefore a means to simulate and manipulate some dynamics from the powerholders. Elaborating on Arnstein's ladder, Berman [23] places a difference between two main methods, the top-down one, such as public hearings, SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, focus groups or structured questionnaires, or, bottom-up ones, mainly promoted by no-for-profit organizations, generating a continuous and collaborative dialogue between local communities. Since 1969, the participatory planning paradigm has become increasingly popular in the US [24] and also in the UK where it is known as "collaborative planning", focusing, in the 1990s, on environmental planning issues [25]. These methods are recognized to improve the ability to extract inhabitants' local knowledge to incorporate it into planning deliverables [21,26]. In recent years, Puskàs' review [27] analyzed case study applications of participatory NBS planning, through Arnstein's framework, revealing an abundance of "partnership and consultation" methods and a general scarcity of the top levels of the scale. Regarding the different participatory techniques and practical tools, Wilker [21] reviews methods from case studies, through Luyet's framework [19]. The review proposes five levels of participation: "information, consultation, collaboration, co-decision, and empowerment", depending on the stakeholder's involvement in the decision process and highlights the "Arnstein Gap", or the difference between the desired and actual levels of stakeholder participation in a project, which are usually lower, stopping at the earliest stages, "consultation and collaboration". This review used a similar approach.

The literature suggests a mix of different approaches, tailored to the stakeholders, aiming for continuity over time, that can be reached, for example, with the use of performative participatory approaches, with a high degree and early involvement of stakeholders and the use of digital tools [21]. Internet and social media have become crucial platforms for information and communication between citizens and policymakers, significantly influencing the methodological tools of participatory processes. The terms "e-Government" and "e-Participation" reflect this growing trend [8,18]. These web-based approaches, such as social media, GIS-based methods, and visualization approaches can facilitate the engagement of hard-to-reach stakeholder groups in the planning process, along with the use of a multi-channel approach, mixing face-to-face and digital methods [21].

1.2. Research Questions and Objectives

Based on this context, this paper aims to systematically review the literature on a theoretical basis and the practical applications of the use of digital solutions in participatory approaches to NBS projects. This work organizes the current practices along with their main benefits and drivers, to guide a choice over their application, in relation to different criteria. This review is performed aiming to answer the following research questions:

(RQ1): *What is the state of the art on the use of technologies and methods for participatory approaches for NBS in urban environments?*
(RQ2): *Which kind of participation can they stimulate and which level of participation?*
(RQ3): *What are the drivers and barriers for the implementation of these solutions?*

2. Materials and Methods

A systematic literature review was conducted to provide an overview of research up to June 2024, based on the Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines (see Supplementary Materials) [28]. This process is shown in Figure 1.

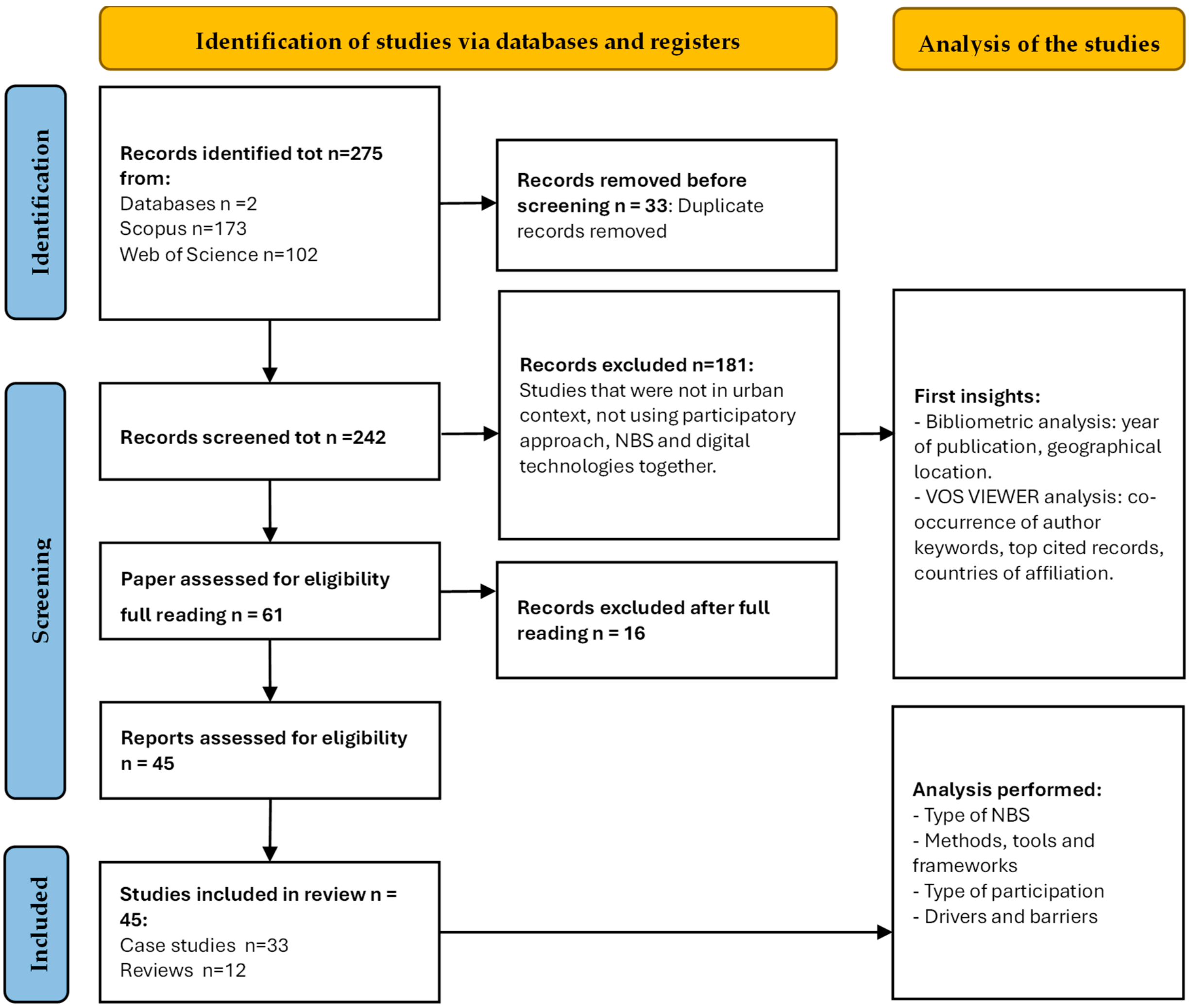


Figure 1. PRISMA reporting flow diagram for the literature review.

2.1. Identification

A preliminary investigation into publications addressing digital participatory approaches for NBS was conducted using both Scopus and Web of Science search engines. The employment of two academic search engines was conducted to maximize the scope of content and ensure an unbiased selection. The same combination of keywords was used on both the engines, using Boolean operators: TITLE-ABS-KEY ((“nature based solution” OR “green infrastructure” OR “blue infrastructure” OR “ecosystem based” OR “green space”)) AND (participat* OR “co creation” OR “justice” OR “participatory planning” OR “collaborative governance” OR “decision making” OR “social inclusion” OR “e-participation” OR “citizen”) AND (“urban”) AND (“digit*” OR “smart” OR “e-tool”)). The search yielded a total of 275 results, 173 on Scopus and 102 on Web of Science. These records were then unified and screened to eliminate 33 duplicates in an Excel worksheet, resulting in 242 results for examination by abstract reading, conducted manually by the authors. The search was not subject to any time limit, to ensure maximum inclusivity of records. A first analysis on the 242 reports was conducted with the software VOS VIEWER (version 1.6.19), to have a first overview of the results that were grouped in clusters by keywords.

2.2. Screening

The titles and abstracts of these studies were reviewed independently by the authors to determine if they met the objectives of the review. To be included, articles had to simultaneously meet all the following criteria: studies had to be conducted in urban context, they had to refer to a NBS project, and they had to involve a form of participatory approach and digital technologies in the process. Both reviews and case study papers were considered. Out of 242 papers screened, 45 were selected for detailed data extraction. Most of the papers met some criteria, but not all of them: 65 items lacked the digital aspect, 30 a specific mention to NBS, and 141 the participatory aspect.

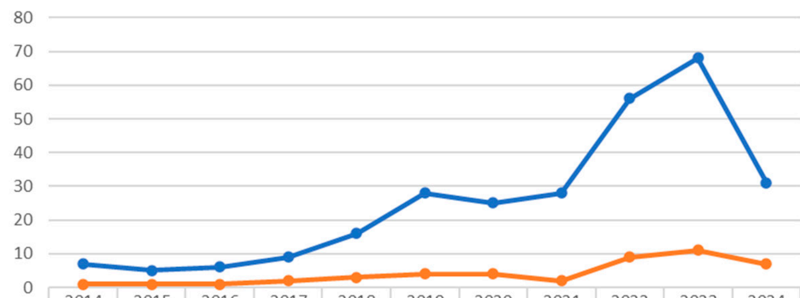
2.3. Bibliometric and Content Analysis Performed

A bibliometric and content analysis was conducted on the selected papers. The records were analyzed using VOS Viewer software to identify publication years, the most frequently cited papers, countries of affiliation, and keyword co-occurrence. Data such as geographic location, sources, affiliations, funding, and study type (including theoretical and case studies) were extracted from the consulted databases and compiled in an Excel spreadsheet. Any missing information was manually verified. Geographic data was based on the country of affiliation. The content analysis focused on the types of NBS cited, the participatory methods used, and the technologies employed, with the details organized into columns. This enabled the tracking of definitions and principles of methods, as well as types of tools and technologies. An inductive approach guided the content analysis, progressing iteratively from initial to more specific codes. This detailed analysis covered the types of stakeholders involved according to Fung's classification [22], as well as the degree of power sharing according to Luyet's classification [19]. The information was summarized in comparison tables to address the review questions. Potential sources of bias were addressed firstly by employing two separate databases, and secondly by documenting the specific reasons for each record's exclusion through coded identifiers. Excluded records were reviewed in multiple rounds on different days to ensure accuracy.

3. Results

3.1. Overview of the Reviewed Papers

The research did not limit publication year, so the database search collected reports from 2002 to 2024, but most of the results and all the selected papers pertained to the last ten years, from 2014 to 2024 (Figure 2). 2014 is recognized as a pivot year, being the starting year for the Horizon 2020 program, and the official EU definition of NBS appeared in 2015, marking the commitment from the EU Commission in this research field. Figure 2 highlights a rise in interest from 2014 on, with most publications following in the years shortly after, as result of this input. The analysis of the funding mechanism reported 13 out of 45 records were financed by EU programs like Horizon 2020, COST Action, Interreg or European Commission funds, demonstrating a strong EU commitment in the sector.



	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Abstract reading n242	6	4	5	7	13	24	21	26	47	57	24
Selected n45	1	1	1	2	3	4	4	2	9	11	7

Figure 2. Selected papers by year, trend analysis.

Along with this, Figure 3 shows that 38 out of 45 of the selected studies are from European countries. The remaining seven come from Canada, India, South Korea, Philippines, and Australia. This is also confirmed by the VOS VIEWER analysis performed on the whole sample of 242 records, regarding a network analysis based on bibliographic coupling over the countries of affiliation (minimum number of three documents) (Figure 4). Here, the top home countries were United Kingdom (17 records), Italy (16), Spain (11), Greece (10) Germany (17), and China (21), divided in four main clusters, where all the EU countries appear strictly interconnected.

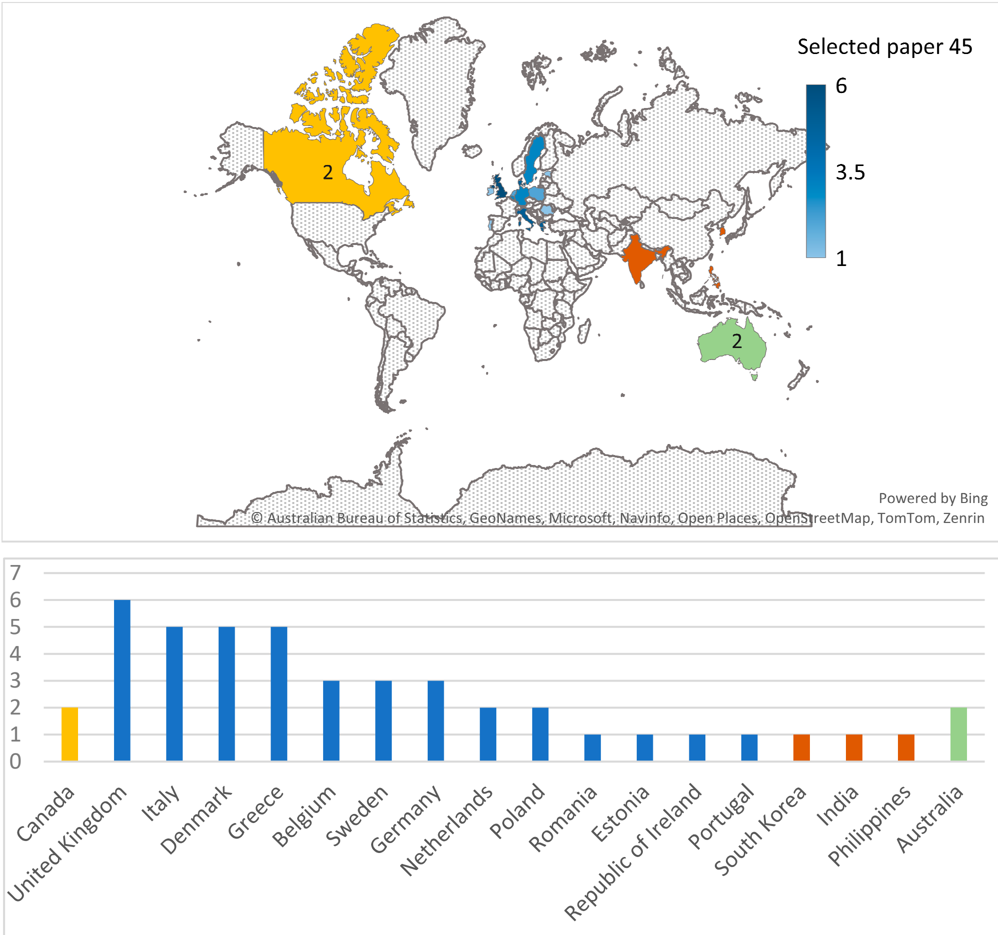


Figure 3. Graphical elaborations of the selected papers by first country of affiliation.

The VOS VIEWER analysis carried out on the 242 records for co-occurrence of author keywords (with full counting method) reported 27 keywords meeting the occurrences of four times, grouped in five clusters (Figure 5). The co-occurrence color-coded by year (Figure 5) revealed a larger use of the terms "green infrastructure", "urban planning", and "smart city/ies" in the earlies years considered, 2019 and 2020. Meanwhile, in 2022 and 2023, the terminology changes with the widest use of the terms "NBS", "ecosystem services", "environmental justice", "cities", and "resilience". This change reflects the growth in interest towards these topics in recent years, especially around the NBS umbrella concept, proposed by the European Union.

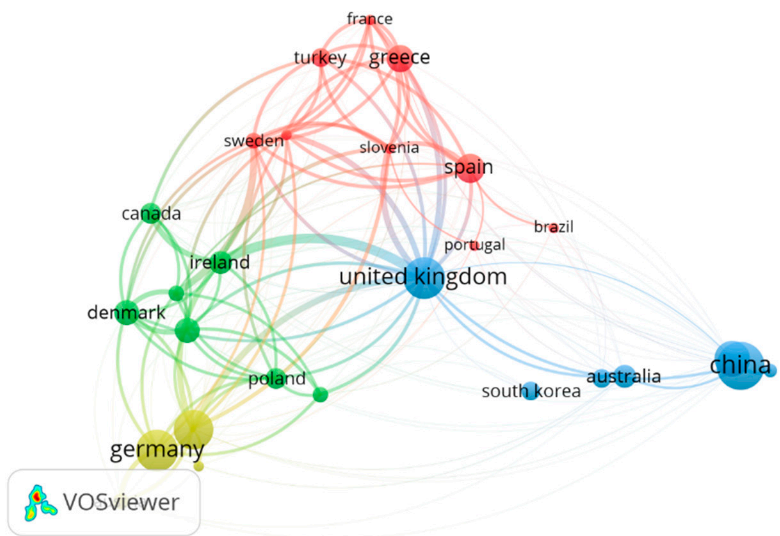


Figure 4. VOS VIEWER records by country of affiliation.

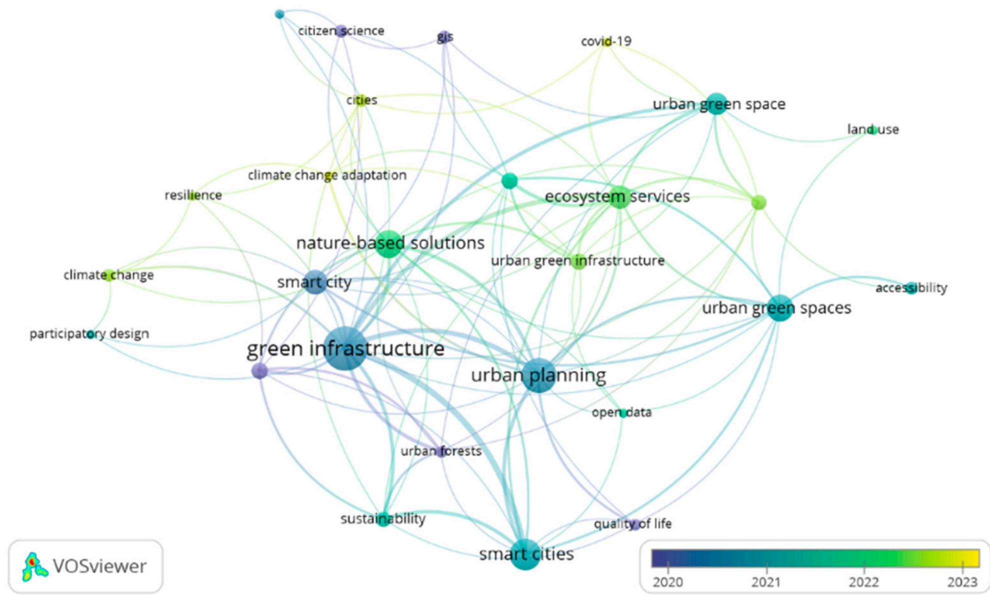


Figure 5. VOS VIEWER keywords co-occurrence by years.

The keyword analysis of 45 selected papers highlights the integration of digital technologies in city design and planning, referencing terms like "smart cities", "Public Participation Geographic Information System" (appearing nine and eight times), as well as "urban planning", "participatory design", and "IoT." After them are keywords referring to the concept of "nature-based solutions", "green space", "urban green spaces", and "green infrastructure" (nine to six times), and "urban green infrastructure" and "ecosystem services" (five and three).

The last VOS VIEWER analysis regarded the top cited records (Figure 6). Of those 242 included, 170 documents were cited at least one time and 78 were cited more than twenty times. Two top cited studies recall the topic of socio-environmental justice in cities, focusing on UGS in Berlin, with more than 470 citations [29], and in New York [30]. The urban health topic was analyzed either in relation to personal mobility [31] or to urban trees, air quality, and asthma [32], both cited more than 180 times. Digital Twins [33] are also a technological trending topic, along with Public Participation GIS (PPGIS) [34], smart urban forest trends and technologies [35], and LIDAR technologies for urban trees [36], cited more than 100 times. Among the top cited works, Zheng et al. [37] analyze how

China's low-carbon city initiatives and the implementation of sponge cities [38]. Falfan and Zambrano [39] examine urban blue spaces in New Mexico.

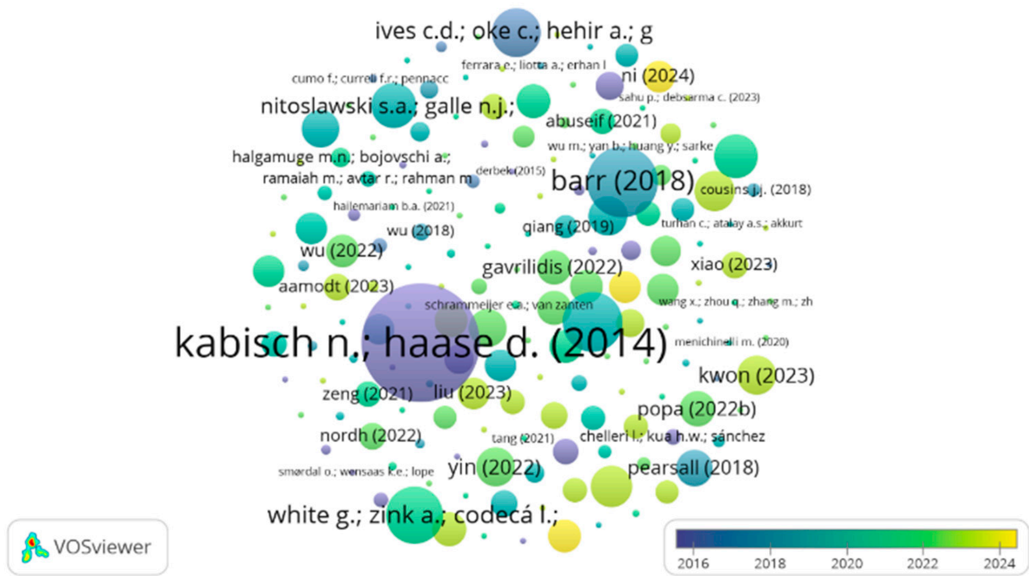


Figure 6. VOS VIEWER top cited references by year.

3.2. Type of Nature-Based Solutions

To understand the different terms under the NBS umbrella, it is proposed a map of their usage across the papers (Table 1) and its definitions. The theoretical concept of ES is applied at the city scale through green infrastructure (GI), which includes "green public spaces", "urban forests", and "water management strategies" (Figure 7).

Table 1. NBS reference along the selected papers.

	Concept		**Structural Application**	**Green Space**	**Forests**	**Water Management**	**Other Cited Approaches**
Cited terms	NBS—Nature-Based Solutions	ES—Ecosystem Services UES—Urban Ecosystem Services	GI—Green Infrastructure UGI—Urban Green Infrastructure	GS—Green Space UGS (public or) Urban Green Space (or area) "Urban greening"	UF—Urban Forest "tree or green management" "urban trees" "tree planting and maintenance"	SWSM—(Storm)Water Sustainable Management SUDS—(Sustainable) Urban Drainage System GBI—Green and Blue Infrastructure (or spaces)	SES—Social Ecological Systems PON—Politics of Nature EBA—Ecosystem-Based Approaches
Number of references	11	10	14	25	5	6	4

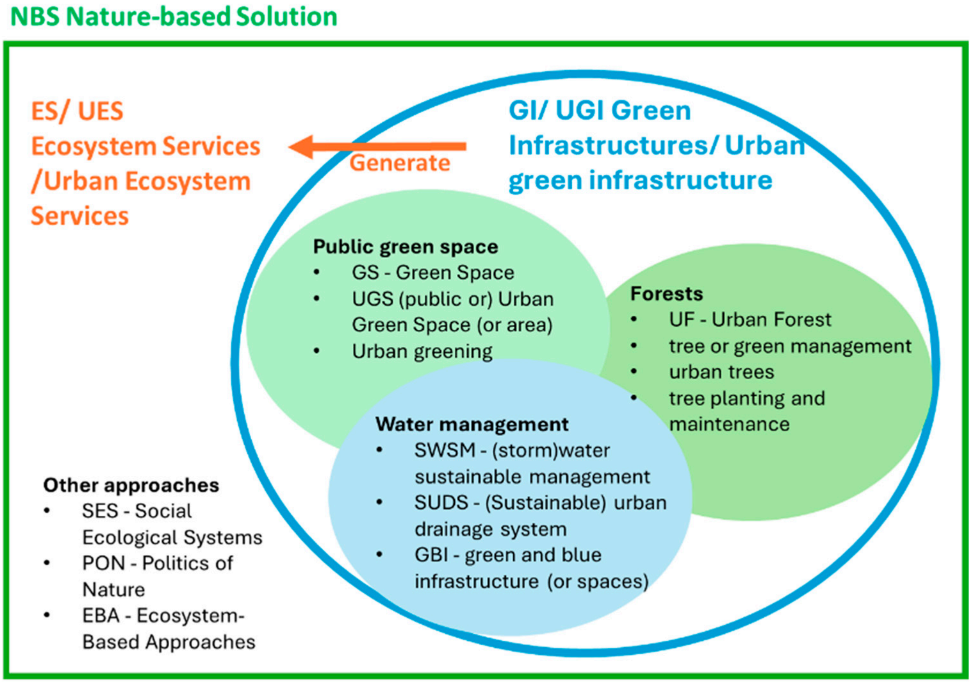


Figure 7. NBS concepts scheme.

Ecosystem services (ES) are defined as the benefits that people obtain from ecosystems. The Millennium Ecosystem Assessment (MA), classifies ES into four categories: production of goods, climate stabilization, cultural services, and supporting services [40]. The concept of ES has been translated into the urban context as **urban ecosystem services (UES)**, which include heat mitigation, energy savings, protection from air pollution and carbon sequestration, biodiversity, stormwater and flood water management, and public spaces for socialization and belonging [35].

Green infrastructures (GI) or urban green infrastructures (UGI) are natural structures that provide multifunctional ES for people [41,42]. This is underlined also by the European Commission, which defines them as "a strategically planned network (. . .) designed and managed to deliver a wide range of ES and protect biodiversity" [43–45]. Examples of UGI include permeable vegetated surfaces like green roofs, walls, public parks, urban forests, urban wetlands, etc. [41,46].

Regarding green public space, terms like "**green space GS**", "(public or) urban green space (or area) UGS" or "urban greening" all refer to areas in urban environments covered in vegetation, like city parks, gardens, and natural reserves. The concept is used with different meanings: some papers refer to GS as the concept of natural environment [47,48]; Cooper et al. [49] refers to GS as a mosaic of green patches and sealed surface covers in the urban landscape; Dickin at al. [50] talks about small recreational parks in the city; and for Barrie et al. [51], it includes any public or civic space maintained by governments or private organizations with forms of vegetation that are accessible to all members of the public, similarly to Gupta et al. [52]. Kajosaari et al. [53] define UGS as a "publicly accessible open space characterized by green elements" and others as public urban parks [54,55]. Further case studies refer to a hospital park regeneration [56], to the use of urban cemeteries as part of the residents' everyday outdoor environment [57], and urban farming projects [58].

Urban forests (UF) are a particular type of UGI that consists of the entire stock of urban trees and woody plants in urban areas, including those in parks, streets, gardens, and natural areas, that cover significant proportions of the urban land and provide ES [35,59]. The governance of UF and local information play a key role in their realization [60], as well as their monitoring. The "smart urban forest" concept integrates the use of sensors, Internet of Things (IoT) technologies, open data, and mobile-based citizen engagement, including apps and open-source mapping, that can reduce costs and improve urban forest and tree management [35,59]. One case study suggesting this approach is the "cyberpark", an urban landscape, "where nature and Information and Communication Technology (ICTs) blend together to generate hybrid experiences and enhance quality of life" [61]. This close integration of technology and nature is also referred to as "Internet of Nature", envisioning a seamless network of applications for remotely sensed monitoring of urban trees, integrated with ground surveys and measurements, the "ecosystem intelligence", that would be used, through modeling, for "ecosystem status and services assessment" [59].

Water-related GI, also known as **blue infrastructures (BI)**, include natural and engineered water systems such as rivers, lakes, wetlands, and SuDS. They manage stormwater, improve water quality, and water storage by mimicking natural hydrological processes. **Sustainable Drainage systems (SuDS)** are considered an element of GI used to reduce the pollutant load associated with stormwater [41], similarly to **water-sensitive urban design (WSUD)**, sponge cities [38], best management practices (BMPs), and low-impact development (LID). **Green and blue infrastructures (GBI) or spaces** combine green and blue elements of GS and BI, to create a multifunctional network that addresses both the benefits, like carbon removal, urban heat island reduction and at the same time flood prevention and storm damage buffering [62]. Suits et al. [63] state that current urban stormwater management is shifting toward the development of a more resilient hybrid drainage system that combines grey infrastructure (e.g., pipes, tanks, etc.) and GI, with a mix of high and low tech, continuously monitored.

Among the more theoretical approaches, **Social-ecological system (SES)** is an adaptive system where social and ecological components interact dynamically, influencing each other through feedback. Each system consists of individual agents, in competition for limited resources, which can change and learn from experience [64]. UGIs, UF, or green areas are classified as SES because people play a key role in their creation, use, and maintenance as part of nature [55]. Bruno Latour's **Politics of Nature (PoN)** is a political ecology theory that challenges existing distinctions between nature and society. Latour [65] argues for a new political framework that integrates both human and non-human actors into a collective decision-making process, the "parliament of things", where the boundaries between politics, science, and biophysical nature are blurred, promoting a more integrated approach to environmental issues. The PoN approach was applied by Raffn and Lassen [66] as a method to conduct collaborative deliberations in the planning process, rethinking the key relationships between human agency and ecosystem functionality with a board game [67]. In contrast, approaches to **Integrated Water Resource Management (IWRM)** [68] tend to classify stakeholders into standard, discrete or overlapping groupings, by employing categories of use of water resources with the introduction of normative governance [67].

3.3. Methods, Tools, and Frameworks

The review results are grouped into participatory digital place-based tools and non-place-based tools. The difference lies in the definition of **place-based e-tool**: digital approaches that gather information from specific places, following the necessity of tailoring NBS which are responsive to local context needs and community requests, including **place-based approaches** in planning [69,70]. Møller et al. [71] compare three e-tools used in UGI governance and examine how the institutional contexts influences their use. Citizen science methods put such tools in the hands of the public, generating data faster and easier, while also investing citizens in decision-making [62,72,73]. These tools can collect both quantitative and qualitative data [69], and also be used for communication purposes, allowing for direct collaboration between actors at different levels [70,71]. E-tools used in

UGI are often based on the use of GIS and **volunteered geographic information**, and they can perform on different levels such as the region, city or neighbourhood.

3.3.1. Place Based E-Tools

An **urban data platform**, also referred to as **GIS platform or Web-GIS**, is an online GIS service that allows users to manage and present georeferenced information with interactive maps about a specific area [71]. They can be used by city municipalities to ease communication, allowing citizens to report problems or damage in public areas or to participate in surveys, establishing a form of co-governance [70,74]. The Web-GIS platform developed in Bucharest allows urban residents to directly report and interact with information regarding the status of the city's GI, acting like "citizen sensors" for the public administration [75]. A similar case in Chandigarh developed a Web-based tool and mobile app that allows the user to give their feedback about the UGS-assessing factors like accessibility, maintenance, security, quality of the experience and user activities, through online surveys [52]. This facilitates the collection of surveys, which are time- and resource-consuming, and calculates a UGS functionality index. Thessaloniki's smart tool platform was developed as a citizen science platform for UF monitoring [76]. It has three interfaces: one is a web app for field data collection, accessible also by mobile devices; the second is a database management system; and the third is a Web-GIS dashboard visualizing the collected data and their statistics. Citizens can report their position, choose the reporting date, and upload images to define the identified threat. The administrator processes the reports centrally in the server infrastructure and publishes them as open data in the platform.

Citizen science apps have become increasingly popular recently, thanks to the widespread use of smartphones and reasonable development costs. Smartphone applications have the advantage of allowing, with one single easily available device, to upload images, pinpoint locations, and provide vital feedback on the state of GS. This approach allows for significant volume of data collected and, at the same time, fosters a sense of community engagement, enabling residents to take an active role in monitoring GS [77]. Examples of smartphone apps are ***Leafsnap*** [78] and ***Pl@ntNet*** [79], or ***Shmapped*** [80], that allow users to collect high-spatial-resolution ground-level botanical photographs along with geographic coordinates in a collaborative and cost-effective way [81]. *Pl@ntNet* was used in Verona's case to map the existing trees and initiate the renovation of the hospital's GS [56]. Wolf et al. [82] generated plant functional trait maps with citizen science data and species identification apps. A similar approach was used by the *Wider Countryside Butterfly Survey* [49,83] with a citizen science online survey and app, ***iRecord Butterflies*** [84]. From the natural science, these applications are moving to social sciences, like in the case of Adelaide [85], where a smartphone app was used to map older people's use of public GS, recording location, pictures, and annotations in the form of a diary. Similarly, in the UK, both subjective data—like personal feelings, type of social interactions, type of activity, and perception of space—and objective data—such as sensor data, location, time, and photos—were collected through a smartphone app [47,54]. Another application lies in UF management, like in Suwon city, where the citizens visiting the urban parks and forest on foot collect tree street-level imagery, reporting and resolving urban inefficiencies faster and cost-effectively [81]. Laumer et al. [86] detected and geocoded more than 5 million trees from street-level images. Kwon et al. [81] suggest that processing large datasets with computer vision and deep learning has enabled efficient tree species detection.

The concept of ***City Information Modelling*** is an adaptation of the urban scale of the *Building Information Modelling* (*BIM*) technologies that seek to make available to planners and stakeholders all key information about various city aspects, modeling potential impacts of existing or new urban projects and policies for a wider and integrated city planning and development [73]. CIM centralizes citywide information, including GS and personnel, enabling quick access to data, promoting stakeholder collaboration, and supporting shared decision-making. In Glasgow's case [73] five qualitative and quantitative data strands were tested: a household survey with individuals' behavior data, a travel diary to understand travel patterns of the population, GPS trails to separate walking from other ways of traveling, area deprivation, and urban greenspace access. The data was collected, merged, and integrated with external administrative datasets to produce new analytical combinations.

In the field of community mapping, the integration of **Geographic Information Systems GIS** technology has been used for the digitalization of local knowledge, like in the case of **Participatory Geographic Information Systems PGIS**. PGIS incorporates local community knowledge into GIS to address specific local geographic issues. It emerged in the 1990s and it is now increasingly being applied to involve stakeholders in delineating local boundaries and prominent landmarks, like in the case of Malaysian community mapping [50]. Here, PGIS was used to promote local mapping for dengue prevention and executed with a mixed use of mapping events with the locals using paper maps and reporting the data on a GIS map in a second moment. PGIS can also be applied in other contexts, including land use planning, risk assessment, resource management, and urban design with the aim of incorporating community knowledge.

Public Participation GIS (PPGIS) takes the PGIS a step forward, offering a way to identify **place-based** citizen knowledge and aiming to facilitate the inclusion of diverse or marginalized voices in planning processes [87]. PPGIS can be used as well as an e-tool for place-based approaches in the design and management of NBS, like in the case of NSW region in Australia [34], where it was used to understand the values people assign to GS. PPGIS data can be used to identify spatial trends, patterns, and dependencies that could be used to model and predict these trends in other locations and contexts [53,71]. PPGIS has been applied for GS community planning and governance, like in the case of Hørgården housing area, in Copenhagen. The maps-initiated group discussions with stakeholders about residents' needs and preferences. Participants assigned dots on maps to show places that were important to them and things they did not like about GS. The marker points were digitized and used for statistical analysis. PPGIS has the advantage of spatially representing community perceptions in a way that is understood by decision-makers and can be integrated into existing planning approaches [34,57,69,87,88]. Brown [87] contends that PPGIS does not necessarily increase participation, particularly when stakeholders lacking access to or unwilling to use information technology are excluded. Thus, it is up to the promoting agencies to engage the public with democratic and representative processes [19,34,69,71,87,88]. PPGIS was also used in the Helsinki Central Park [55], for the study on UGS perception in Espoo [53], for a comparison study over the use of two cemeteries as green public spaces in Denmark and Finland [57], and for the study on landscape characteristics in Sweden [89]. The **geodesign** methodology is a collaborative spatial planning GIS method, involving local inhabitants and professionals, that utilizes geospatial technologies and web-based resources. This tool enables stakeholders to visualize and develop their own proposals, which are then integrated to co-create a strategic plan for a given territory [90,91]. The methodology uses a systems-based approach to analyze human, resource, and environment interactions at multiple spatial scales, generating knowledge about the study area and providing valuable information for urban planning design and decision support [92]. The approach relies on stakeholders' feedback about the impacts and implications of proposals, using technologies in the iterative design process of scenario building, to simulate future changes [93].

Another way technology advancement can support participatory planning processes is through 3D visualization methods. **Digital twins** are digital 3D copies, up to a specific degree of accuracy, of an existing place, created with dedicated tools and on-site visits to collect the requisite information, like images, drone views, and recordings [33]. The information is processed and used in a shared digital 3D space. Planners can use digital copy to apply their solutions and share them with non-experts for co-evaluation. Kavouras et al. [94] have reported, combining digital twins with the gamification methodology, a clear benefit of this approach, which is the ability to evaluate the outcome of the interventions beforehand, minimizing the time and cost of the whole planning process.

3.3.2. Non-Place Based Tools

Decision Support Systems (DSS) is a software application, designed to assist individuals and organizations to analyze data and present it in a way that helps users evaluate options, predict outcomes, and choose the best course of action. The integration of ES research in decision-support tools is considered a mean to facilitate informed decision-making practices at the local and administrative scale facilitating the replication and upscaling of NBS [95,96]. Economic valuation practices, like societal cost–benefit analysis, are often performed at a larger scale [40], but rarely at the local level, leading to uncertainty of economic benefit and impact. When market value is unavailable, assessing and measuring UGI impacts is essential. Scholars report this is often defined in environmental terms, while economic and social valuation is seldom applied, hence the need for complete evaluation methods, addressing all its uses and co-benefits [14,41,97]. Van Oijstaeijen et al. [41] review 10 ES decision-support valuation tools, like webtool, textual guides, computer programs, and spreadsheets, that have the potential to calculate an economic value of GI elements. These methods and tools, focusing on the impact valuation as part of the return-on-investment calculation, could be the bridge to planning and financing in the implementation of UGI [41,98], if employed at the local level. Katsou et al. [74] mention several examples of **DSS**, software applications that are used in NBS implementation, like Nature4Cities, ThinkNature, and EKLIPSE that include a DSS to assess the benefits, trade-offs, and evaluation of NBS impacts. **Multi-Criteria Decision Analysis (MCDA)** is one of the methods used in the planning phase for NBS implementation. It is able to compare different scenarios and make informed decisions by considering multiple criteria and stakeholders' preferences. The review [74] reports as examples the Urban BEATS project, which uses MCDA to evaluate different water management strategies and their impacts on urban sustainability, and the E2STORMED project, which applies MCDA to assess the effectiveness of sustainable urban drainage systems. Another paper [63] discusses the application of a **decision-support matrix** to assist decision-makers in developing and implementing smart stormwater management solutions. The matrix provides a structured approach to evaluate and identify the most suitable solutions for improving existing grey and green infrastructure, considering various factors such as local conditions, environmental impacts and technological feasibility [63]. **The Nature Smart Cities Business Model (NSC-BM)** [96] was developed in close cooperation between academia and practice, trying to overcome the reported gap between the two and facilitate the translation from strategies to actual plans. The NSC-BM tool emphasizes co-creation with the involvement of local authorities and integrates a MCDA with economic cost and benefit assessment for ES assessments in qualitative, quantitative, and monetary terms.

3.4. Type of Participation

The results of the analysis were grouped in three predominant categories: citizen science, participatory mapping, and co-creation, organized in accordance with Luyen's scale of engagement [19] to understand the differences between the techniques used and the engagement (Table 2).

Table 2. Type of participatory approach.

Type of Participatory Approach	Citizen Science	Participatory Mapping	Co-Creation
Reference count	10 case studies	9 case studies	13 case studies
Degree of power [19]	Information: 4 Consultation: 3 Collaboration: 4 Co-decision: 0 Empowerment: 0	Information: 2 Consultation: 2 Collaboration: 7 Co-decision: 2 Empowerment: 0	Information: 4 Consultation: 6 Collaboration: 2 Co-decision: 5 Empowerment: 0

Citizen science involves the collaboration of citizens and scientists with a defined research objective. This form of engagement in our review was directed towards "*collaboration, information or consultation*", which are lower forms of power sharing. This is primarily because citizen science is predominantly utilized to obtain data, rather than to distribute decisional power. The citizen science approach in our review utilizes either online surveys or smartphone applications.

Participatory mapping involves researchers seeking to obtain local knowledge with mapping methods. Participatory mapping is referred to by Luyet [19] as an enabler of higher forms of participation, such as "*collaboration*, *co-decision-making*, and *empowerment*". In the context of our review, participatory mapping is predominantly associated with *collaboration* and lower forms of engagement. It manifests as co-decision in a few case studies, when linked with stakeholder and experts' opinions [55], or in the context of a social housing development [69], where all project partners, researchers, planners, social workers, and landscape architects participated in community engagement. This approach is characterized by diverse viewpoints and integration from broader policy contexts to bottom-up perspectives of practitioners and residents.

Co-creation, or participatory planning, is a collaborative process that involves the engagement of researchers, practitioners, and local stakeholders. Through this engagement, the collective knowledge and understanding of the relevant parties is enhanced, leading to the establishment of a unified vision or consensus regarding a specific planning intervention. This calls for different types of participatory techniques that are usually mixed in the use and can achieve different levels of power shared (Table 3).

Table 3. Participatory techniques.

Participatory Techniques [19]	Information	Consultation	Collaboration	Co-Decision	Records Count
Presentations, public hearings	[52]	[96,99,100]			4
Internet webpages, platforms or apps	[101,102]	[52,61,101]			4
Interviews, questionnaires,and surveys		[68,75,102]	[34,50,52,53,55–57,69,73,103,104]		14
Field visit and interactions		[52,105]	[69,73]		4
Workshops		[96,100,105]		[48,69,94,104]	7
Participatory mapping			[34,50,54,55,57,62,69,89,106]	[53]	9

Table 3. *Cont.*

Participatory Techniques [19]	Information	Consultation	Collaboration	Co-Decision	Records Count
Focus groups			[50,67]	[69,94]	4
Geospatial, Decision support system		[105]			1
Role playing				[67,104]	2
Multicriteria analysis			[99]	[55]	2
Gamification	[58]			[94]	2
Citizen science		[47,81]	[47,49,51,54,56, 62,76]		8
Co-design				[48,96,101]	3

3.4.1. Citizen Science

Citizen science, also referred to as public participation in scientific research or community-based monitoring, is a participatory method involving citizens contributing to the collection, classification, and analysis of authentic data [76]. It is widely used in natural sciences and has recently been adopted in social sciences, urban planning, and landscape planning. Helen Barrie [51] defines citizen science as a "partnership between professional researchers and volunteers in which the volunteers implement tasks which have traditionally been implemented by scientists". This collaboration aims to generate novel scientific insights, collecting large-scale or otherwise inaccessible data, beyond the capabilities of individual researchers. A secondary outcome of this collaboration is the education of the participants, enhancing their scientific knowledge and interest. There are three models of cooperation: the contributory model, where volunteers collect data; the collaborative model, where citizen scientists help analyze and interpret data; and the co-created model, in which they participate in all stages of research, from forming questions to designing studies [51]. In the present review, eight studies were found in which citizen science initiatives were employed (Table 4), primarily with the general public; although, in one instance, the initiative was directed at a specific segment of the population, the elderly [51]. Most of the studies employ digital surveys, such as those conducted by Cooper et al. [49] and those that use citizen science apps. The method was used in the context of urban biodiversity assessment [49], for urban tree and forest mapping [56,76,81] and for the qualitative assessment of public GS engagement [47,51,54,73,103], but also to report and visualize crime occurring in GS [75,106].

Table 4. Citizen science case studies analysis.

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Bucharest, Romania [75]	GI	citizen science	citizens	information, collaboration	online survey with a WebAPP	urban data web-based digital platform	Web-GIS application	GIS data, geodatabase, ortophotoplans, green cadastre, GI, and citizen requests data survey	
Urban sites in Britain; United kingdom [49]	GI; UGS	citizen science	citizens	collaboration	citizen science digital survey	online survey; smartphone app	ArcGIS; R	survey data WCBS; Ordnance Survey Master Map; Topography Layer; Land cover map	Wider Countryside Butterfly Survey (WCBS) [83]; iRecord Butterflies app [84]
South Australia, Greater Metropolitan Adelaide; Australia [51]	Green spaces	citizen science	Old people	collaboration	in-depth interviews; people's diary, pictures; workshop for participation in decision-making around data collection interpretation and analysis	Outdoor Space Audit Tool, online tool for smartphone	smartphones and digital cameras; ESRI platform to host the tool; Survey123™ platform for the statistical data, SPSS Statistics Version 26. NVivo	spatial data; preliminary demographic survey and Survey 123™ audit data; recorded and transcribed interview data	
Urban forest of Seich Sou, Thessaloniki, Kalamaria, Panorama, and Kalochori, Greece [76]	UGI; ES	citizen science	citizens	collaboration	field data collection platform for citizen science	web-based citizen science digital platform;	in situ sensors; database management subsystem, Web-GIS graphical user interfaces subsystem; the data fusion geoprocessing subsystem	indicators for earth observation data; satellite data; mobile sensors and citizen science data; DSM	

Table 4. *Cont.*

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Sheffield (UK) [47,54]	Green areas, NBS	citizen science	citizens	collaboration	citizen science, participatory mapping via phone app	phone app to monitor citizen data regarding health and wellbeing in green areas	smart sensing; the Internet of Things; data science; smartphone app Shmapped	subjective data: personal feelings, type of social interactions, type of activity, and perception of space; objective data: sensor data, location, time, photos, GPS	IWUN [107]; Shmapped [80,108]
Suwon city, South Korea [81]	ES; tree mapping	citizen science	citizens	consultation	smartphone application for citizen science tree mapping	CADA smartphone application for tree mapping	smartphones sensors; web-based airborne images, vehicle-mounted sensors	airborne-sensed imagery, 2020, citizen science data	
Verona, Italy [56]	Urban green area	citizen science	university students	information, consultation	citizen science events and qualitative interviews with target groups: university students; hospital staff, patients, visitors	digital identification of trees using Smartphone application Pl@ntNet	cloud-based web application	quantitative: citizen mapping data, 'Open StreetMap' + qualitative: focus groups and interviews	Pl@ntNet [79,109]
Belgrade, Lodz, Piraeus, and Gladsaxe [103]	NBS	citizen science	citizens	information	monitor citizen wellbeing with phone and smartwatch or a smart band; Questionnaire	smartphone app, euPOLIS by BioAssist application	smartphone app	citizens' parameters	[110]
Glasgow, UK [73]	Urban green spaces	citizen science	citizens	consultation	household survey, individuals' travel diaries	Multimedia City Data, a multi-stranded collection of urban datasets	GPS trails around the city, urban administrative datasets on area deprivation and greenspace	analyses of data from the iMCD project, person-level and sensed information; five linked data strands and external administrative datasets: household survey; travel diary; and GPS trails, data on deprivation and greenspace	Lifewide learning in the city [111] Integrated Multimedia City Data (iMCD) [112]

3.4.2. Participatory Mapping

Participatory mapping is a process in which community members contribute with their own experiences, information, and ideas about a place, through cartography. Participatory and community mapping have become effective methodologies that enable inclusive expression, incorporating both physical and sociocultural dimensions to identify and communicate with collective perceptions and needs. These approaches support social change by facilitating visualization of the connections between locations and their respective local communities. It has frequently been used as a catalyst for group dialogue and to promote deep engagement with the planning process, employing both physical and sociocultural aspects [34]. Participatory mapping employs a range of tools, from sketch mapping to three-dimensional modeling, and more recently, digital technologies, including GPS, aerial photographs, and remote-sensed images from satellites, GIS, and the geospatial web [113]. This review uses participatory mapping to refer to any digital or physical mapping conducted with citizens or users. This category encompasses a range of approaches, including the hybrid use of sketch mapping and digital reporting, as well as the utilization of PPGIS tools. The review yielded nine case studies that exemplify participatory mapping (Table 5).

Table 5. Participatory mapping case studies analysis.

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Central Park, Helsinki, Finland [55]	UGI, UF, ES, SES	participatory mapping	experts, stakeholders, citizens	citizen(collaboration); stakeholders, experts (co-decision)	interviews, multicriteria decision-making, survey, web-based PPGIS study	public participation GIS(PPGIS)	web-based PPGIS tool "MyDinamic-Forest", ArcGIS	hot/cold spot mapping, questionnaire, and route data GPS tracked	https://app.dynamic-forest.com (accessed on 22 July 2025);
Putrajava and Serembran municipalities, Malaysia [50]	GS	participatory mapping	local community; semi-structured interviews with key informants including community leaders and public health staff.	community mapping (collaboration)	semi-structured interviews; focus groups; physical community mapping transferred online; PGIS	maps digitized into GIS to create a georeferenced map of community knowledge	ArcGIS	community mapping data; GIS satellite images google	
Poland [106]	Urban green areas;	citizen mapping	citizens	information; collaboration	reports geographically mapped	GIS-based tool	GIS	citizen data reports	
Lower Hunter region of NSW, Australia [34]	GS, GI	participatory mapping	citizens	collaboration	socio-demographic survey, physical community mapping	PPGIS, community mapping transferred online with ArcGIS	ArcGIS	spatial data layers from local councils and governments, Google maps, Google street view imagery, and Gregory's Newcastle Street Directory (2012)	
Edinburgh, UK [62]	UGS, UGI, ES	participatory mapping	citizens (citizen science) and residents (emotional mapping survey); university partners (app development)	collaboration	participatory mapping with the app and survey; green space participatory mapping, emotional mapping; citizen science	Natural Capital Standard for GI digital mapping tool. "How Green is Your Campus" app	GIS, ESRI	the scoring system based on the Natural Capital Standard for GI developed by the Scottish Wildlife Trust, survey	https://www.thrivinggreenspaces.scot/news/article/5/green-infrastructure-mapping-pilot-project (accessed on 22 July 2025)

Table 5. *Cont.*

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Green cemeteries in Copenhagen (Denmark) and Helsinki (Finland) [57]	GS, Green and blue spaces, Urban ecosystem services	participatory mapping	citizens	collaboration	socio-demographic survey and digital PPGIS survey	PPGIS digital survey	online tool	Urban Atlas 2018, spatial population data at a 100 m grid resolution by Statistics Denmark. Building-level population data	
(Hørgården) in Copenhagen, Denmark [69]	NBS	participatory mapping	citizens	information; co-decision, collaboration;	digital PPGIS, community and resident engagement street interviews	PPGIS tool	digital tool	Social–ecological–technological systems; data from the PPGIS	
Espoo, Finland [53]	UGS	participatory mapping/ participatory planning	citizens	consultation	PPGIS online survey on visiting frequency and citizen perception	PPGIS	IBM Statistics SPSS v28 and spatial analyses with ESRI ArcGIS	Urban Atlas land cover data; land use data	
Umeå, Sweden [89]	Green spaces GS	participatory mapping	citizens	consultation	PPGIS digital survey	online survey tool Maptionnaire	machine learning modeling, LiDAR data, Open-StreetMap	Open Street Map	Maptionnaire [114]

3.4.3. Participatory Planning or Co-Creation

Co-creation is defined as the process of participation, interaction, collaboration or co-production of NBS with organized or non-organized citizens, experts and urban planners, local politicians and representatives, and public officers and private stakeholders [8]. The process can take different applications in practice, but it is closely related to the co-governance concept, because of its institutional path [72]. Policy frameworks, part of the European Green Deal, rely on citizen participation and activation, such as the New European Bauhaus [115] initiative, aimed to be a best practice competition for municipal citizen-led initiatives. **Co-governance** refers to processes and structures of public decision-making and management that continuously engage people across the levels of government, in a multi-phased, iterative, inclusive, adaptable process [116]. A **Living Lab (LL)** is a local place-based intermediary among stakeholders, used to involve citizens, academia, government, and private and non-profit organizations, based on the quadruple helix model [104,117].

The Horizon project CLEVER Cities evaluated a complete co-creation pathway with implementation tools and actions through Urban Living Labs in three European cities. The cooperation with the local stakeholder was maintained through the whole process, from the co-design, co-implementation, co-monitoring and co-development of NBS [118]. The Horizon project VARCITIES [119] uses a similar four-phase strategy: co-identification, co-design, co-implementation, and co-evaluation, using questionnaires and interviews, focus groups, a digital platform, and a gamification app in the diverse phases. The use of IoT, mixed reality and digital technology tried to involve in different ways the population, experimenting, for example, with citizen science sensors on e-bikes and open real-time data coming from each one of the seven cities involved with the Health and Wellbeing digital platform [102]. Similarly, the project SCORE [120] introduced the Coastal City Living Labs (CCLLs), to minimize the damage for climate-related hazards using simulations of future scenarios [104]. The project experiments a four-step engagement process: first, stakeholder mapping and prioritization, and then, user identification, followed by a discussion and scope of the design situation, to reach a persona–scenario construction [104,117]. The engagement process used a mixed form of consultation, involving both online surveys and specific workshops with project partners, citizens, scientists, and decision-makers, to reach a form of co-decision. In this case, the mixed use of data-driven and citizen-centered approaches was permitted by the development of a web app data platform (SCORE ICT Platform SIP [120]) that uses digital technologies (e.g., digital twins, advanced climate and hydraulic/hydrological modelling, DTM), climate modeling, low-cost sensing technologies, and citizen science to support decision-making [104].

A part of the co-creation strategy is the **co-design** process, where people actively participate in the project design with ideas and suggestions. Co-design is reported in three reviewed papers: in a workshop with children, to decide how to design nature-related digital tools [48], with academic and local authority partners [96], or to design a digital platform and mobile app with the youngsters of the "Union Youth Chania" local association [101].

Kavouras et al. [94] present a case of co-creation applied to architectural planning, involving both local experts (architects, engineers, and team members) and non-experts (citizens, city council members, etc.), cooperating with feedback and proposals. The methodology exploits game engine software (UE5) and a 3D digital twin model to simulate different scenarios in the planning process. **E-Participation** is a form of hybrid participation, that emphasizes citizens' roles as equal partners in political decision-making [94]. It includes online techniques like petitions, debates on proposed laws, and forums for expressing opinions on local projects, local websites, and social media [70,121]. E-participation is a crucial component of e-governance initiatives.

E-government involves using digital technologies to make public administration services accessible online, enhancing proximity to citizens, transparency, and service orientation [18]. Møller and Olafsson [70] categorize the stages of e-governance based on the differences in the use of e-tools as knowledge mediators: from those who are one-directional in their communication, to those who are enabling it, allowing space for collaboration and empowerment. The Cyberparks digital tool [61] is one example of this aim and consists of a smart phone application, cloud, and web services to create a public open space designed for and with people. Similarly, the case of UnionYouth in Chania enabled the consultation and collaboration of citizens that, with the digital platform and mobile app, contributed to the transformation of the city public space [101]. These tools allowed for continuous interactions between the digital community, the city's decision-makers, and city actors. Citizens' involvement, focused on solving social issues, can be effective and useful in real case studies [101,122]. Scholars [59,70] envision forms of **e-governance**, to enhance participation and reach forms of co-creation and collaborative management. The New Urban Agenda (UN 10 October 2016) and the European eGovernment Action Plan 2016–2020 [45] both suggest e-governance and the use of open data platforms [70]. Fegert et al. [123] and Wolf et al. [124] studied the use of augmented reality technology for civil participation processes in public construction projects and how these mixed forms can inspire citizens to participate in the early stages of co-design, reaching better results. Global-Detector [105] is a knowledge-based GIS method, promoting co-creation of fit-for-purpose indicators for a shared acceptance of the outcomes by the stakeholders involved. In Amsterdam, it was used to identify promising locations to create new pocket parks and neighborhood gardens. Experts gathered spatial data, like land use, vegetation cover, infrastructure, etc., from various sources, such as satellite imagery, GIS, and local surveys. The collected data was used to develop indicators that are relevant to the specific project. A model was built using the developed indicators to analyze the spatial data and the results were validated through on-site visits and feedback from local experts and stakeholders [105,125]. The gamification of the planning process enhanced the decision-making process, and the interactivity allowed a greater participation of non-experts.

The gamification method involves using game design elements in non-game contexts to stimulate citizen engagement, like in the case of the Agrihood application, that was developed to make the citizens more aware about their consumption and ecological footprint [58]. This approach enhances the user's motivation to collaborate. It is increasingly applied in fields such as participatory modeling, urban planning, and user-centric design, ensuring that the game elements align with user needs and preferences, usually through co-design workshops. Two other cases using gamification are Yin's co-design workshops [48] with children and Chania's app, where the users have to fight against pollution in mixed reality for the VARCITIES game [102]. **Serious games** are frequently used for co-creation and co-design in both digital and non-digital formats. The urban planning literature reports that they can ease the involvement of local stakeholders into city management and planning [126–129]. They can serve as an initial approach to facilitate discussions on various scenarios and allow for the examination of different factors and potential solutions. Below is a summary of the co-creation approaches reviewed (Table 6).

Table 6. Co-creation case studies analysis.

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Rotterdam, Netherlands [48]	UGI, GS	co-design	secondary school children	co-decision	two days of activities: co-design, participatory design workshop	nature-related digital tools			
Costal cities from Ireland, Italy, Portugal, Spain, Poland, Slovenia, Turkey [104]	NBS; costal water related solutions; ecosystem-based approaches	co-creation	citizens and decision makers	consultation, collaboration (citizens); co-decision (decision-makers)	online surveys and workshops with project partners, citizens, scientists, and decision-makers	ICT digital data platform SCORE ICT Platform SIP	web GIS application; digital technologies like digital twins, advanced climate and hydraulic/hydrogeological modelling, ICT, low-cost sensing technologies and citizen science kits; DTM	reliable climate information: wave data, sea-level data, hydrological data, meteorological data, Copernicus data	SCORE tform SIP https://platform.score-eu-project.eu/#/ (accessed on 22 July 2025)
Trento; Italy (proposal) [58]	GS; vertical farming	co-creation with gamification	citizens	information	active participatory process and gamification	Agrihood digital system, gamified app to monitor urban garden cultures	mobile app; IoT-based monitoring sensors	open data platform, Opendatatrentino	
Chania, Greece [102]	NBS	co-creation	citizens	information	co-creation; questionnaires and surveys, interviews. use of the platform, use of the app	game application: GoNature game, Health and wellbeing platform	digital techniques (IoT, mixed reality, ICT), digital data platform, and smartphone app game	open data platform with real time data provided by smart devices regrading climate monitoring, air pollution, noise pollution, citizen science, KPIs	VARCITIES Health and wellbeing platform https://varcities.eu/resources/hwb-platform/ (accessed on 22 July 2025)
Kapelle, Netherlands [96]	GI, NBS, ES	co-design	academic and local authority partners	co-decision	co-creation and co-design, stakeholder engagement, design thinking; capacity building workshops	Nature Smart Cities Business Model NSC-MB tool	Nature Smart Cities Business Model NSC-MB tool	MCDA, cost benefit	

Table 6. *Cont.*

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Piraeus, Greece and Gladsaxe, Denmark [94]	NBS	co-creation	experts (architects, engineers, team members) + non-experts (citizens, city council, etc.),	cooperation, co-decision	co-creation, co-evaluation, gamification of the planning process, citizen collaboration with feedback and proposals	digital twin for planning with 3D visualization and game engine	3D reconstruction (digital twin): 3D Digital Terrain Model + ArcGIS satellite/Blender or Blender OSM, Open street map; game engine software: Unreal Engine 5	online GIS Data: cadaster data, digital terrain models, digital elevation models, satellite data; user-generated data. various geospatial data: digital elevation models or digital terrain models; raster images Open Topography, ArcGIS Satellite, Google Earth, OpenStreetMap, Cesium, Mapbox	
Barcelona, Lisbon and Ljubljana [61]	GS	participatory planning, citizen science	citizens	consultation	app for citizen science; opinions and proposals from the citizens	ICT, digital tool WAY Cyberparks	The Cyberparks smart phone application, server/cloud and web services	information on participant profile, position, answers, and suggestions (weather conditions, real-time positions and paths)	https://cyberparks-project.eu/ (accessed on 22 July 2025)
Chania, Greece [101]	GS, GI	co-design	citizen, youths	consultation, collaboration	co-design with an app	digital platform and a mobile app consisting of engagement tools	UnionYouth Chania, digital platform and mobile app	citizen real-time data that is generated using community procedures	https://dmlab.tuc.gr/project/union-youth/ (accessed on 22 July 2025)

Table 6. *Cont.*

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Chandigarh, India [52]	UGS	ICT tools to obtain citizen centric services	citizens	information, consultation	participatory surveys, web-based tools, mobile apps, and collaborative planning groups, field visits, public meetings, and household surveys	citizen-centric smart web-based tools for monitoring and management of urban green spaces	open source tools such as PHP, JavaScript, CSS, HTML, Leaflet for Front End Design and PostgreSQL, Post GIS in backend. ArcMap, Geoserver, OpenGeoSuit; mobile application	citizen science data	
Dresden and Heidelberg in Germany [99]	UGS, urban ecosystem services	users' preferences	citizens	consultation	surveys, multi-criteria evaluation approach, local events co-promoted by the pilot cities with users	web app meinGrün web-based dashboard user interface that provides a simple way to see and manage implicit and explicit feedback	the web/mobile app meinGrün and browser-based dashboard for the OpenRouteService, OpenStreetMap, Java	data to calculate green or shaded routes derived from 3D point cloud data, municipal tree cadastre data or openly available OSM and Sentinel-2 satellite imagery	https://meingruen.org/ (accessed on 22 July 2025)
Manila, Philippines [100]	GS	participatory planning	citizens	consultation	participatory design, active participatory process, participants in online and face-to-face interactions, workshops	participants in online and face-to-face interactions	virtual online platform, mobile phones, and desktop computers	participants' information	

Table 6. *Cont.*

Case Study	NBS Used	Participatory Approach	People Involved	Degree of Power Shared [19]	Method of Engagement	Kind of Tool Used	Kind of Technology Used for the Tool	Information Database or Framework Used	Tool Extra Info
Amsterdam, the Netherlands [105]	GS	participatory planning	citizens	consultation	participatory GIS-approach to define indicators and locations for greening; site visits, stakeholder engagement	Global-Detector, a knowledge-based GIS-method, in which experts and stakeholders are involved to jointly convert spatial data into relevant indicators	integrated GIS	GIS-based spatial data, stakeholder knowledge	Global-Detector [125]
Eerste River catchment in South Africa [67]	water sustainable management, Politics of Nature, ES	participatory planning; role playing	stakeholders	collaboration, co-decision	role playing stakeholder engagement and discussion	data documenting these processes were collected digitally	digital sessions on Skype; virtual seminar; digital platform; web development application Jam.py	SQLite data structure	

3.5. Drivers and Barriers on the Implementation

Through the records analysis, the key drivers reported for the application of digital participatory solutions in urban NBS planning can be summarized as follows:

1. Increased resilience and co-benefits: NBS planning addresses climate risks and enhances resilience in urban contexts [62,130]. At the same time, along with their co-creation, they offer multiple co-benefits: environmental, social and economic [69,74,96,103].
2. Stakeholder acceptance and better design: Incorporating co-design, participatory approaches, and feedback loops increases acceptance and usability of the solutions. Participatory mapping and community input enhance data quality, capture local knowledge, and promote inclusive planning. Addressing equity and social justice through participatory methods allows for marginalized voices to be represented in decision-making [69,71]. Mattijssen et al. [105] points out that transparency should be the key for co-creation processes, because it allows trust to be built between stakeholders and contributes to the acceptance of outcomes. Public participation is effective if citizens are not only consulted, but if there is an actual exchange of opinions, leading to shared decisions.
3. Environmental awareness: E-tools, along with co-creation activities, citizen science, and participatory mapping, promote knowledge exchange and users' education, in terms of awareness on the environmental topic, public health, sustainable mobility, etc. [52,58,96,101,102,131].
4. Transdisciplinary collaboration: the use of these tools and methods promotes collaboration across different fields and the integration of both data-driven and place-based information, improving decisional processes [69,72,94,105,131].
5. E-participation and e-governance: E-tools can promote e-participation and e-governance practices, linking to forms of place-based governance or mosaic governance. However, these e-tools should not be seen as a standalone participatory practice but rather complement and enlarge traditional ways of data collection and participation with qualitative methods, and offline meetings and activities [69,70].
6. Long-term engagement: Digital technologies have been used to keep long-term citizen engagement in co-creation activities, providing information on project advancements and updates. This is often reported as one of the most recurring problems [35,61,70,77,96,101,132].
7. Technology integration for broader participation: The use of digital engagement solutions can enhance broader participation [52,61,101], allowing us to compensate through volume and engagement, for citizen-sourced data inaccuracies, taken with traditional methods. Digital tools like smartphone apps and visualization platforms could be an effective way of adapting scientific traditional approaches to practical urban planning tools that are relevant and usable. Balancing intuitive interfaces with scientifically robust models ensures accessibility without compromising accuracy [54,62,105].
8. Cost and time efficiency: The use of digital resources, like digital twins, digital platforms, and smartphone apps can significantly reduce the time and cost of the planning and management process. Efficient and accessible tools are essential, particularly for smaller cities with limited resources [52,54,94,96,101].
9. Adaptability and scalability: The digital tools, like the Nature Smart Cities Business Model [96] or citizen mapping apps [52] and digital integrated methods [34,94,105], have the advantage of being easier to adapt to diverse local contexts and scalable for place-based knowledge across various urban planning applications.

Conversely, here is a summary of barriers that hinder the integration of these solutions in cities:

1. Complexity and accessibility of data: Data integration challenges, uncertainties about data quality, limited availability of high-quality datasets, and difficulty in interpreting complex data could hinder effective deployment of these solutions. Data collected from sensors and other digital tools may present uncertainties or may not be so representative of the entire community or area concerned, leading in the end to ineffective decisions. [47,63,70,71,94,130,133]
2. Governmental barriers: On the other hand, governmental barriers have been described, like insufficient personal capacity, limited financial, political, and management support, and specific legal issues. Scholars report citizen issues as well, like social exclusion [62,71].
3. Technical and legal challenges: The implementation of digital tools and GIS faces technical complexity and legal constraints, including privacy, GDPR compliance, and delayed planning processes [130]. Concerns about data security, privacy, and accuracy of citizen-sourced data hinder the widespread use of participatory tools [59,71–73]. Barriers include compliance with ethics and legal frameworks, delays due to legislative processes, and balancing open data access with privacy requirements [133].
4. Institutional barriers: Lack of institutional support, and lack of training and organization in local authorities are reported among the main obstacles in UGI planning. Silo-based thinking in public administrations and poor integration of tools with other systems make comprehensive planning difficult [96,133]. The lack of unified standards and practical guidelines is also reported as a barrier along with uncertainties over costs and current policies and administrative procedures [63,74,96].
5. Participatory inclusion issues: Digital divide, demographic biases, and lack of inclusion of older adults and underrepresented groups in participatory platforms may create barriers to equitable citizen engagement [62,70,71,73]. Digital divide is described as one of the main threats, because it is rooted in the societal conditions and could become a higher risk for participant exclusion. Education, age, and gender, along with individual motivations, are the strongest factors influencing differences in internet usage, whereas internet experience, income, and residency seem to hold less importance. Tool and app usability plays a crucial role [74,96,130].
6. Participation transparency: Communication barriers include lack of transparency from local governments on the steps and aims of the participatory process, which could resolve the loss of trust in the administrations [49,96].
7. Resource constraints: Financial limitations, staffing shortages, and insufficient maintenance resources pose challenges, particularly for smaller municipalities [63,74,81,94,96]. The difficulty in solid economic evaluation and in the use of existing valuation toolkits is also considered a barrier to the implementation [96].

4. Discussion

The analysis of the reviewed papers highlights a significant trend in the use of technologies and methods for participatory approaches in NBS projects, particularly within the last decade. The rise in publications from 2014 onwards, coinciding with the beginning of the Horizon 2020 program and the EU's official definition of NBS, underscores the European Union's strong commitment to this research field (Figure 2). The funding mechanisms and the geographical distribution of the selected papers further demonstrate this commitment, with a substantial portion of the studies being financed by EU programs in European countries or countries collaborating with EU (Figure 3). EU-funded projects such as VARCITIES, CleverCities, and SCORE have demonstrated the practical application of NBS and their positive outcomes, further solidifying the EU's commitment to this research field [6,8]. As a recent research topic, this raises questions about the gap between the theoretical and normative approaches described and their practical implementation by local municipalities. Capacity building at the local level, along with dedicated programs for implementation, may facilitate progress in this area.

Additionally, the VOS VIEWER analysis reveals evolving trends in author keywords, indicating a shift in focus towards terms like "NBS", "ecosystem services", and "environmental justice" in recent years (Figure 5). This shift mirrors the growing interest in these topics, driven by the EU's promotion of the NBS umbrella concept and the interest in research for an equal spatial and social distribution of NBS benefits [29,69]. Kabisch and Haase [29] cite the distribution of urban green spaces in Berlin as an example, noting significant variation based on both immigrant status and age. Maurer et al. [69] note that NBS research seldom focuses on disadvantaged groups or adapts to local contexts. To address this, broader approaches are needed, considering different range of actors, including the "more-than-human" ones, such as the ethics of care approach [134] or the Politics of Nature one [65], which include natural elements as stakeholders. With leaving no one behind being central to the green transition, scholars and policymakers urge context-specific analysis to generate scalable evidence [135].

In this regard, technologies can support inclusive placemaking in the digital era, as highlighted by applying Lefebvre's right to the city [136] theory [72,137]. Place-based e-tools collect location-specific data to meet community needs, while non-place-based tools like DSS assist in analyzing data for decision-making. The Smart City concept aims to benefit citizens' life, including technology ICTs and Internet of Things IoT in the urban environment [72,138]. Case study reviews like Fuentes et al. [72] and Oikonomaki et al. [77] show the potential of digital placemaking practices, outlining main trajectories for the incorporation of smart technologies in the process. Citizen engagement in data collection can be enhanced through mobile apps, digital surveys, and online feedback forms. Social media platforms facilitate community event organization and input gathering, supported by data visualization tools. IoT and 3D geographic modeling enable deeper participation and sustainable planning, while VR/AR and gamification provide immersive project visualization. GIS mapping supports workshops and data analysis. Finally, AI, machine learning, and big data deliver valuable insights into ecosystem dynamics and services. Technologies can facilitate GIS integration into UGI planning but often lack social and normative perspectives and tend to reinforce top-down planning strategies. Top-down approaches may result in a lack of public support. The use of e-tools does not automatically enlarge the number of people involved or the quality of the process but acts as a facilitation tool in the hands of the organizers. There is a need for more democratic processes sensitive to different axes of inequality and injustice [19,34,69,71,87,88]. Co-creation of UGI requires a shift towards a collaboration between practitioners and stakeholders. However, bottom-up approaches that rely on practical knowledge may not be sufficient to secure local support or ensure fair and inclusive implementation. Their combined integration with data-driven ones is not often applied and the debates on environmental justice highlight the difficulties of empowering local citizens and representing their interests in GS planning and governance [69,105]. Some scholars [15,113] suggest a more participatory use in planning practices. Mattijssen et al. [105] summarize three main suggestions: first, to link the efforts of local stakeholders to strategic planning approaches and GS policies; second, to link local knowledge with data-driven approaches; and third, to have a meaningful collaboration, where the actors trust each other and empower local stakeholders, so that the outcomes are not rejected as top-down. Co-creation processes have been accepted; however, challenges, like the difficulty of engaging with people, the methods to organize effective participation, and the quality of the information produced, remain. In this regard, a different use of participatory techniques, mixed with digital technologies, could help enlarge the user's number and composition [94].

The analysis of publications allowed us to identify three main areas of participatory approaches where digital tools could be integrated into, with different levels of engagement (Table 2). First is citizen science, which generally involves collaboration between citizens and scientists with a defined research objective, typically characterized by lower forms of power sharing, where researchers gather local knowledge using mapping methods, potentially enabling higher forms of participation such as collaboration, co-decision, and empowerment. Then, there is participatory planning or co-creation, where researchers, practitioners, and locals work together to gain knowledge and build consensus regarding planning interventions or developments, involving higher forms of power sharing. The analysis of the level of decisional power shared revealed an abundance of lower levels of power on the ladder, such as information, consultation, and collaboration, with few cases classified as co-decision and none as empowerment (Table 3). While this analysis may be mediated by the authors' interpretation, the findings align with those of similar analyses, such as Puskás's study [27] of NBS participatory approaches. Most of the reviewed papers focused on either theoretical debates or technical aspects, with little consideration given to key questions such as citizen inclusion, climate justice, and power sharing in case study applications. The normative approach is often adopted without considering integrating instances directly from citizen communities. Most case studies were guided by government or research entities and were top-down in nature. While these processes were intended to open a dialogue with citizens and users, in some cases this appeared to be more of a justification for certain decisions than a genuine desire to integrate citizens into the decision-making process [18].

The use of technology in tools and practices does not address most critiques of participatory approaches, such as difficulty in power sharing and representativeness in participation. While technology can ease and enlarge the share of participants, it does not change the fundamental way these processes are carried out. The tools and methods evolve, but the aims and settings of these processes remain the same as in-person processes. Citizen science and participatory mapping data should be used first to assess climate justice in cities and influence decision-making, updating the methods as well. As pointed out by Mattijssen et al. [105], transparency in the process and trust are important factors for successful co-creation processes; therefore, attention should be paid to establishing and maintaining this relationship. Public participation is considered effective when citizens are engaged in an exchange of opinions that contributes to collaborative decision-making, rather than being limited to consultation only. It should be otherwise noted that the proposed case studies were always quite limited in scope and in terms of the number of people involved. This raises the question of whether it is possible to achieve high levels of involvement in decisions at the city level, not just strictly local.

These conclusions may be subject to limitations and biases in both the abstract selection process and the paper analysis. Future research should aim to transform the current government system, in terms of both methods and intent, by enhancing citizen involvement in processes and encouraging co-government over local decisions while maintaining an open and transparent dialogue. If they are not correctly addressed, participatory digital approaches are their own worst enemy. An administration that promotes an unclear and non-transparent participatory approach is more susceptible to criticism and could eventually discourage citizens from participating in the future. Further research is required into the close integration of shared governance and justice in case studies. A key issue is that most of the reviewed studies are from European countries (Figure 3), which may limit the generalizability of the findings to regions with different socioeconomic and environmental contexts. The systematic literature review relies on publications from Scopus and Web of Science, which could introduce selection bias, excluding other databases or grey literature. Future studies could also examine grey literature and technical reports to better reflect discussions from sectors such as policy. Another important consideration is the long-term impact and effectiveness of participatory approaches and digital solutions, which have not been widely evaluated.

5. Conclusions

In conclusion, NBS have been the focus of worldwide study, and some existing reviews have addressed these solutions in general terms, relating to their environmental and social benefits, opportunities, and challenges. Participatory and co-creation methods boost citizen engagement and support solutions. Digital tools can boost participation and reduce time and resource limits, as long as processes are effective, representation is sufficient, transparency is ensured, and consistency is maintained.

The primary applications identified were categorized into three distinct groups: citizen science, participatory mapping, and co-creation methods. It was observed that these methods predominantly facilitated low or medium forms of power sharing. The main barriers identified by local administrations were the silo mentality, resistance to new technologies, and resource constraints. These issues could be addressed through targeted capacity-building sessions. Another important point is the way these participatory channels are made accessible to citizens. Often, they are developed for a specific purpose or project and then closed at the end of the initiative. However, a transparent and continuous process, perhaps involving a dedicated office and personnel, could be more effective in building trust and maintaining high levels of engagement for future initiatives.

Further research is required into the methods by which these barriers can be overcome and climate justice can be integrated into planning. A pivotal element in this regard is the evaluation of participatory processes and the establishment of criteria to ascertain their efficacy and success. Technological solutions have considerable potential to enhance NBS planning. However, it is crucial to emphasize the need for greater transdisciplinary collaboration involving research, government, and citizens.

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Abbreviations

The following abbreviations are used in this manuscript:

NBS	Nature-based solutions
EU	European Union
IoT	Internet of Things
ICT	Information and Communication Technology
ES/UES	Ecosystem Services/Urban Ecosystem Services
GI/UGI	Green Infrastructure/ Urban Green Infrastructure
SWOT	Strengths, Weaknesses, Opportunities and Threats
GIS	Geographic Information System
PRISMA	Preferred Reporting Items for Systematic Reviews
PGIS/PPGIS	Public/ Participation Geographic Information System
UGI	Urban Green Infrastructure
GS/UGS	Green Spaces /Urban Green Spaces
UF	Urban Forest
SWSM	Storm Water Sustainable Management
SUDS	Sustainable Urban Drainage System
GBI	Green and Blue Infrastructure
SES	Social Ecological Systems
PON	Politics of Nature
EBA	Ecosystem-Based Approaches
BMPs	Best Management Practices
LID	Low-Impact Development
DSS	Decision Support Systems
MCDA	Multi-Criteria Decision Analysis

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