Review

Smart City Applications to Promote Citizen Participation in City Management and Governance: A Systematic Review

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Abstract: This systematic review aimed to provide a comprehensive view of (1) the purposes of research studies using smart city infrastructures to promote citizen participation in the cities' management and governance, (2) the characteristics of the proposed solutions in terms of data sources, data quality, and data security and privacy mechanisms, as well, as strategies to incentivize citizen participation, and (3) the development stages of the applications being reported. An electronic search was conducted combining relevant databases and keywords, and 76 studies were included after a selection process. The results show a current interest in developing applications to promote citizen participation to identify urban problems and contribute to decision-making processes. Most of the included studies considered citizens as agents able to report issues (e.g., issues related to the maintenance of urban infrastructures or the mobility in urban spaces), monitor certain environmental parameters (e.g., air or acoustic pollution), and share opinions (e.g., opinions about the performance of local authorities) to support city management. Moreover, a minority of the included studies developed collaborative applications to involve citizens in decision-making processes in urban planning, the selection of development projects, and deepening democratic values. It is possible to conclude about the existence of significant research related to the topic of this systematic review, but also about the need to deepen mechanisms to guarantee data quality and data security and privacy, to develop strategies to incentivize citizen participation, and to implement robust experimental set-ups to evaluate the impact of the developed applications in daily contexts.

Keywords: smart cities; citizen participation; crowdsourcing; crowdsensing; systematic review

1. Introduction

Citizens represent the lifeblood of a city and are inextricably linked to its continued existence and prosperity. Therefore, it is imperative for the government of a city to care for its citizens and to pay careful attention to their needs [1]. Moreover, citizens must be active in their cities' management and governance, since they are aware of the problems of the communities where they live and work and can evaluate the actions of city authorities [2,3].

However, despite its importance, citizen participation in the management and governance of their cities is not a simple process, even when city authorities value citizen opinions [4]. To optimize this process and face diminishing public trust due to scandals, corruption, worsening of the economic situation and inequalities [5,6], city authorities are changing and updating government mechanisms to increase citizen participation [7–9]. This has naturally led to the formulation of concepts such as e-government and e-governance, where information technologies are used to deliver services and facilitate communication

between different entities [10–12]. These concepts are also considered in smart city implementations since smart governance is a relevant smart-city domain [13,14] aiming to develop and disseminate new forms to engage citizens in city management and governance.

Smart cities presuppose intensive data collection and analysis to improve the available services [15]. However, a precise definition of what makes a smart city is a much more difficult proposition, where many definitions have been proposed, but none has achieved universal consensus [16]. Even so, it is possible to identify common elements in these diverse definitions: economic development, sustainability, environmental responsibility, citizen quality of life and focus on citizens and their needs [17–21].

Citizens can report pertinent data about their environments [22–26] and might use or allow the usage of the sensors of their mobile devices to collect heterogenous types of data [27–29]. Moreover, authorities might analyze public data generated by citizens during their daily lives (e.g., social networks, comment boards, or online forums) to gather ideas and opinions [30–33].

Additionally, citizens should be integrated into the decision-making processes as active participants instead of just being passive participants in providing different types of data [34–41]. This might not only increase the trust of citizens in their respective city authorities by promoting transparency and minimizing corruption [42,43] but also promote the implementation of new forms of democratic governance, such as e-democracy, which can be defined as "the practice of democracy with the support of digital media in political communication and participation" [44] and demands the communication and sharing of ideas between citizens, relevant stakeholders and authorities [45–48].

This systematic review aimed to analyze and synthesize state-of-the-art smart city applications to promote citizen participation in city management and governance. In this regard, the authors aimed to systematize the purposes of the studies using smart city infrastructures to promote citizen participation in city management and governance (e.g., identification of urban issues), as well as the approaches and respective technologies (e.g., crowdsourcing or algorithms to analyze social media data) followed by these studies to implement the proposed applications. These applications might be supported in different data sources (e.g., reports from the citizens or social media data), which justify the need to identify the data source types (e.g., data generated by human observation, data gathered by personal sensors, or data available from smarty city open data repositories, such as public transports data) and how data quality is verified and assured.

Citizen participation can potentially put their privacy at risk [49,50] and requires the consumption of their own resources, such as battery and computing power [51–53]. Therefore, applications aiming to promote citizen participation in city management and governance need to handle data security and privacy concerns and should consider strategies to incentivize the participation of citizens. Therefore, these specific topics were also considered important for this systematic review.

Since the dissemination of the smart city applications depends on their maturity level, this systematic review also aimed to synthesize the development stages of the proposed applications.

This study might contribute to (1) the systematization of the main recently published research on the topic; (2) the identification, typification, classification and discussion of relevant smart city applications to promote citizen participation in city management and governance; (3) the identification of current approaches to developing these applications; (4) the analysis of the maturity level of the reported applications; (5) the discussion of the main results of the current research; and (6) the identification of aspects that need further research.

2. Materials and Methods

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [54]. A review protocol was defined with explicit descriptions of the methods to be used and the steps to be taken [55]: (1) research

questions; (2) search strategies; (3) inclusion and exclusion criteria; (4) screening procedures; (5) data extraction; and (6) synthesis and reporting.

2.1. Research Questions

The objective of this systematic review (i.e., to review and analyze the state-of-the-art of smart cities 'applications to promote citizen participation in city management and governance) was decomposed into the following research questions:

- RQ1—What are the purposes of the studies using smart city infrastructures to promote citizen participation in city management and governance?
- RQ2—What are the characteristics of the proposed applications in terms of data sources, data quality, data security and privacy, and strategies to incentivize citizen participation?
- RQ3—What are the development stages of the applications being reported?

2.2. Search Strategies

Google Scholar was not considered in terms of resources to be searched since the objective was to retrieve peer-reviewed research studies. Instead, IEEE Xplore was selected since it indexes peer-reviewed research studies and is important among researchers in computer science-related domains, an essential aspect of smart city developments. Moreover, Web of Science and Scopus were also considered since they are the two major existing multidisciplinary databases, have a reputation for indexing quality peer-reviewed research [56], and contain a significant number of references indexed by other databases, such as ACM Digital Library, ScienceDirect, SpringerLink or even IEEE Xplore. The three selected databases (i.e., IEEE Xplore, Web of Science and Scopus) were also considered, either alone or in conjunction with other databases, to support several reviews related to smart cities [57–67].

Boolean queries were prepared to include all the articles that have in their titles, abstract or keywords variations of the expression 'smart city' (e.g., 'smart city', 'smart cities', 'smartcity', 'smartcities') together with a reference to at least one of the following terms: 'governance', 'democracy', 'participation', 'engagement', 'empowerment', 'collaboration', 'codesign', 'co-design', 'crowdsourcing' or 'crowdsensing'. As an example, the instance used for the Scopus repository was the following: TITLE-ABS-KEY ("smart?cit*" AND (govern* OR democra* OR participat* OR engagement OR empower* OR collaborat* OR co?design OR crowd?sourc* OR crowd?sens*)).

2.3. Inclusion and Exclusion Criteria

The inclusion criteria were: (1) full English articles; (2) articles published in peer-reviewed scientific journals or conference proceedings; (3) articles published before 31 December 2021; and (4) articles reporting evidence of citizen participation in smart city management and governance. The exclusion criteria were articles that, (1) although addressed smart city topics, did not report evidence of citizen participation in smart city management and governance or (2) did not address issues related to the defined research questions, (3) did not have abstracts or authors' identification, (4) their full texts were not available, (5) were not primary studies, since they reported on reviews or surveys, or were books, tutorials, editorials, and special issues announcements, and (6) were posters or extended abstracts. Moreover, articles reporting on studies already covered by other included references were also excluded: when two references reported on the same study in different venues, such as a scientific journal and a conference proceeding, the less mature one was excluded. Table 1 provides details of the inclusion and exclusion criteria.

Table 1. Inclusion and exclusion criteria.

Inclusion	Exclusion
Articles published in peer-reviewed scientific journals or conference proceedings.	Articles not published in peer-reviewed scientific journals or conference proceedings.
Articles published in English.	Articles published in languages other than English.
Full articles.	Non-full articles, such as posters or extended abstracts
Articles published before 31 December 2021.	Articles published after 31 December 2021.
Articles that reported evidence of citizen participation in smart city management and governance.	Articles that did not report evidence of citizen participation in smart cities management and governance or did not address issues related to the defined research questions.
Articles reporting primary studies.	Articles reporting non-primary studies, including literature reviews or surveys, books, tutorials, editorials, or special issues announcements.
Articles with access to the full text.	Articles without access to the full text or without abstracts or authors' identification.
Articles reporting on studies not covered by other included references.	Articles reporting on studies already covered by other included references.

2.4. Screening Procedures

The selection of the articles to include in this systematic review was performed according to the following steps:

- First step—The authors removed the duplicates, the references without an abstract or authors and not published in English.
- Second step—The authors assessed all titles and abstracts for relevance and those not meeting the inclusion and exclusion criteria were removed.
- Third step—The authors assessed the full text of the remaining articles against the outlined inclusion and exclusion criteria.
- Fourth step—The authors performed a secondary analysis of the references of all the included articles to identify additional articles to be included.

Throughout this entire process, all articles were analyzed by at least two authors and any disagreements between them were discussed and resolved by consensus.

2.5. Data Extraction

Concerning data extraction, the following data for each one of the included studies were registered by the authors: (1) the demographic of the study (i.e., authors and respective affiliations, year and source of publication); (2) the objectives and outcomes of the study; (3) the purpose of the smart city application being reported; (4) the adequacy of the context of the study; (5) the study research methods; (6) the findings of the study; (7) the limitations of the study; (8) details of the implementation of the study, namely data sources, data quality assessment, data security and privacy concerns, and the strategies to incentivize citizen participation, and (9) the development stage of the application being reported.

2.6. Synthesis and Reporting

Once the data extraction procedures concluded, a table was prepared to synthesize the outcomes reported by the included studies.

Considering the demographic data, the authors prepared a synthesis of the characteristics of the included studies, considering (1) the number of studies published in scientific journals and conference proceedings; (2) the distribution of the studies by publication year; (3) the distribution of the studies by geographical areas, considering the affiliation of the first author, and (4) the involvement of multinational research teams, considering the affiliations of the authors.

In addition to general inclusion and exclusion criteria, the included studies were assessed against the following quality questions, which were adopted and adjusted from other studies [68,69]:

- Q1—Are the objectives of the study clearly identified?
- Q2—Is the context of the study clearly stated?
- Q3—Do the research methods support the aims of the study?
- Q4—Does the study adequately describe the technologies being used?
- Q5—Is there a clear statement of the findings?
- Q6—Are the study's limitations explicitly discussed?

Each question was answered according to a binary scale (i.e., 1 for Yes or 0 for No).

To categorize the purposes of the applications being reported, the authors applied the method proposed by Ghapanchi and Aurum [70] (i.e., terms and definitions used in the included articles were identified to create a primary list of categories and subcategories, which were later refined by further analyses). This categorization was later checked and discussed as a group. A narrative synthesis of the included studies was prepared based on the identified purposes.

Moreover, several analyses were performed in terms of data sources, data quality, and data security and privacy, as well as strategies to incentivize citizen participation. Therefore, several syntheses were prepared to (1) identify the data sources types, including data generated by human observation, data gathered by personal sensors, or data acquired from smart city open data repositories; (2) assess how data are verified for validity and are cleaned to eliminate outliers, corrupt or missing values; (3) assess how data security and privacy are addressed; and (4) identify the strategies used by the included studies to incentivize citizen participation.

Finally, the authors categorized the development stages of the applications reported by the included studies by distinguishing the following stages: (1) requirements—the study included the requirements' elicitation, which could involve, in some cases, forms of co-design with potential end-users; (2) design—the focus of the study was a general overview of the application architecture or some of the respective components; (3) technical testing—the study included results of a performance evaluation of the application or some of its components (e.g., the performance of a specific algorithm); (4) prototype testing—the study included a laboratory evaluation involving end users (e.g., a usability evaluation) of a minimally working version of the application being proposed; (5) pilot testing—the study included a real-world evaluation by end users in their daily context during a certain period; and (6) mature—the study included an application that has been tested by end users, amended in some way and that was in deployment.

3. Results

3.1. Selection of the Studies

Figure 1 presents the PRISMA flowchart of the systematic review. The electronic literature search was performed in February 2022. A total of 12,086 articles were retrieved: (1) 1026 from IEEE Xplore; (2) 4025 from Web of Science; and (3) 7035 from Scopus.

The first step of the screening procedures yielded 7543 articles since 4543 were removed because they (1) were duplicated (i.e., 2431), (2) were reviews or surveys (i.e., 1786), or (3) did not have authors or abstracts (i.e., 326).
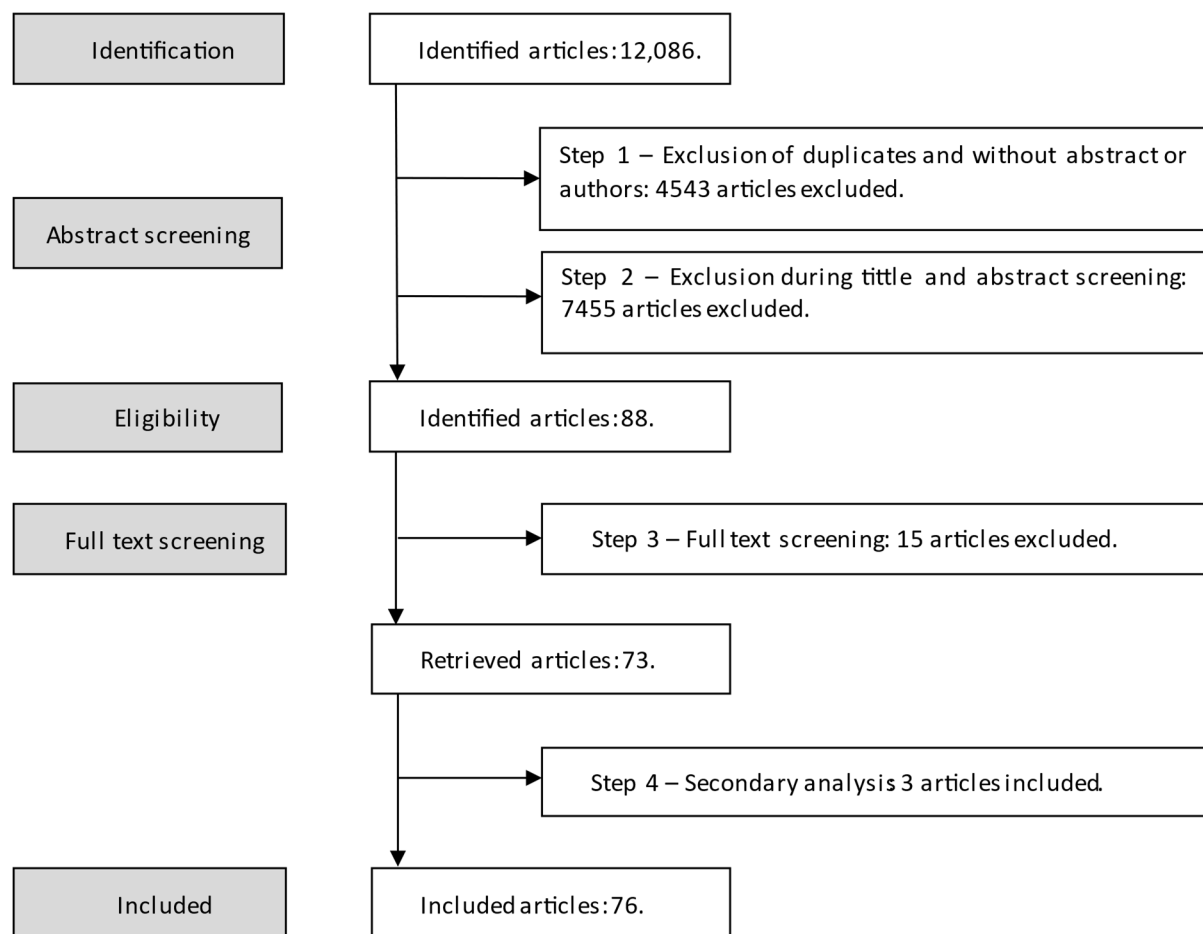
Figure 1. PRISMA flowchart of the systematic review.

During the second step, 7455 articles were excluded according to the inclusion and exclusion criteria. Most of them were excluded because they did not report evidence of citizen participation in smart city management and governance, although they focused on other topics of smart cities such as, for instance, smart vehicles (e.g., [71,72]), energy efficiency (e.g., [73,74]), approaches of smart city planning (e.g., [75–77]), smart city indexes (e.g., [78]), smart city logistics (e.g., [79]), or specific systems to be integrated into smart cities (e.g., [80–87]).

After the full-text analysis (i.e., the third step), 15 articles were removed. Four of them reported on studies already reported by other included studies [88–91]. The remainder 11 articles were removed because (1) their full texts were not in English (i.e., two articles), (2) their aims were presenting arguments on the advantages of citizen participation (i.e., four articles), and (3) they focused on specific aspects that can support citizen participation, such as a voting system [92], but not on applications with a specific purpose (i.e., five articles).

During the fourth step (i.e., a secondary analysis of the references of all the previously included articles), three more articles were identified.

Therefore, the final list of the retrieved articles contained 76 studies [93–168] that were included in this systematic review. The outcomes reported by the included studies are presented in Table 2.

Table 2. Outcomes reported by the included studies.

Reference	Outcome	Year
[93]	An application to share and evaluate photos of points of interest.	2013
[94]	A method to increase the quality of data collected from an interactive voice response system used by citizens to report safety incidents.	2013
[95]	A participatory sensing application allowing the assignment of sensing tasks to be performed by the citizens.	2013
[96]	An application to report city problems.	2014
[97]	An application to report city problems.	2014
[98]	An application to suggest tailored paths for people with mobility impairments.	2014
[99]	An application to report city problems that includes a data analysis engine.	2015
[100]	An application to report borough issues.	2015
[101]	A questionnaire-based participatory reporting application.	2015
[102]	An application to collect the location of events' participants for better management.	2015
[103]	A middleware to collect data using both sensors and social networks with incentive mechanisms.	2015
[104]	An application to collect data and provide services to pilgrims during the Hajj.	2016
[105]	A method to collect citizen information that can be used to understand citizen needs and prioritize new projects.	2016
[106]	A reference architecture for mobile sensing to help cyclists on their daily trips.	2016
[107]	An application to unify city government services and to give citizens a direct communication line with the authorities.	2016
[108]	An application to collect and collate data from various social media to infer alerts, insights, and recommendations.	2016
[109]	An application to review and share locations based on how accessible they are for people with mobility impairments.	2016
[110]	A serious game to introduce the concept of electric mobility and collect data on mobility needs.	2016
[111]	An application to allow citizens to present and vote on ideas for the benefit of the city.	2016
[112]	An application to report city problems.	2016
[113]	An application with incentives to create participatory sensing campaigns.	2016
[114]	An application to provide the tools and knowledge to create and orchestrate participatory reporting and sensing campaigns.	2017
[115]	An application to monitor urban accessibility.	2017
[116]	A generic participatory sensing application.	2017
[117]	An application to report city problems.	2017
[118]	A method to support the use of social media data by governments to better understand their citizenry's opinion.	2017
[119]	An application to allow citizens to participate in collaborative decision-making processes.	2017
[120]	Challenges and needs of different stakeholders in creating new digital participatory tools.	2017
[121]	An application to share information between citizens and government.	2017
[122]	An application to support data visualization and feedback.	2017
[123]	An application to support the maintenance of city infrastructures.	2017
[124]	An application to promote the transparency of public administration.	2017
[125]	An application to infer sentiments from social media data.	2017
[126]	An application to assess trip quality when riding a vehicle.	2017
[127]	An application to gather location data to generate mobility patterns and the city's points of interest.	2018
[128]	An application to enable citizens to monitor urban services.	2018
[129]	An application to support the creation of crowd-based smart maps for disabled people.	2018
[130]	An application to gather ideas from citizens and to choose and fund projects based on those ideas.	2018
[131]	An application to support the design of urban spaces by citizens.	2018
[132]	An application to report city problems.	2018
[133]	An application to report city infrastructure issues.	2018
[134]	A unified framework using different data sources to identify urban problems.	2018
[135]	An application to report city problems supported in natural language processing.	2018
[136]	An architecture to allow mobile devices to serve as noise sensors for urban environments.	2018
[137]	An application to report and share the accessibility level of city locations.	2018
[138]	An application to allow citizens to make suggestions from select categories directly to city governance.	2018
[139]	An application to predict next-day events in an area from citizen reports and Twitter data.	2018

Table 2. *Cont.*

Reference	Outcome	Year
[140]	An application to support two-way communication between citizens, governments, and other city stakeholders.	2018
[141]	An application to gather information for urban planning from social media data.	2018
[142]	An application to infer sentiments and detect citizen concerns from social media data.	2018
[143]	An application to identify trending views and influential citizens from social media data.	2019
[144]	An application to report city problems that include gamification.	2019
[145]	An application integrating participatory reporting mechanisms and access to public services.	2019
[146]	An application using natural language processing to infer sentiments for urban planning from social media data.	2019
[147]	An application using a machine learning algorithm to perform sentiment analysis to gauge public opinion from social media data.	2019
[148]	An application to report illegal waste dumping.	2019
[149]	An application to report city problems.	2019
[150]	An application to report safety incidents.	2019
[151]	An application to monitor air and noise pollution levels in a city.	2020
[152]	An application to support the use of social media data for the implementation of smart cities.	2020
[153]	An application to support the information shared and the reporting of city issues.	2020
[154]	An application to support the co-creation of neighborhoods.	2020
[155]	An application to recognize needs according to human needs theory from Tweet data.	2020
[156]	An application to identify the opinion of the citizens about the local authorities from social media data.	2020
[157]	An application to support the use of social media data for the implementation of smart cities.	2020
[158]	A machine learning algorithm to gather insights for urban planning from data of a civic participation application.	2021
[159]	An application to promote the transparency of public administration.	2021
[160]	An analysis of the applications for urban democracy that were implemented in Madrid and Barcelona.	2021
[161]	An application to report city problems.	2021
[162]	An application to report city problems.	2021
[163]	An application to provide various tools to help citizens to participate in the decision-making processes.	2021
[164]	An application to allow different stakeholders to collect data about a city from various sources.	2021
[165]	A government-backed petition application for the citizens of Taiwan.	2021
[166]	An application to report potholes for the city of Malang.	2021
[167]	A serious game to teach citizens how to design a smart city collaboratively.	2021
[168]	An application to capture soundscapes to be used for urban planning and design.	2021

3.2. Demographic Characteristics of the Studies

In terms of publication types, 33 studies were published in scientific journals [93–95,102,107, 108,111,115,119–123,126,130,131,134–136,139–141,143–145,147,155–158,160,161,167] and 43 studies were published in conference proceedings [96–101,103–106,109,110,112–114,116–118,124,125, 127–129,132,133,137,138,142,146,148–154,159,162–166,168].

Concerning the publication years, as presented in Figure 2, the included studies were published between 2013 (i.e., three studies [93–95]) and 2021 (i.e., eleven studies [158–168]). Moreover, 73% of the studies (i.e., 55 studies) were published since 2017.

Figure 3 presents the distribution of the included studies by country. Europe had the highest contribution (i.e., 35 studies). Asia contributed 21 studies, North America with 10 studies and South America with 6 studies. Finally, Africa and Oceania contributed two studies each.
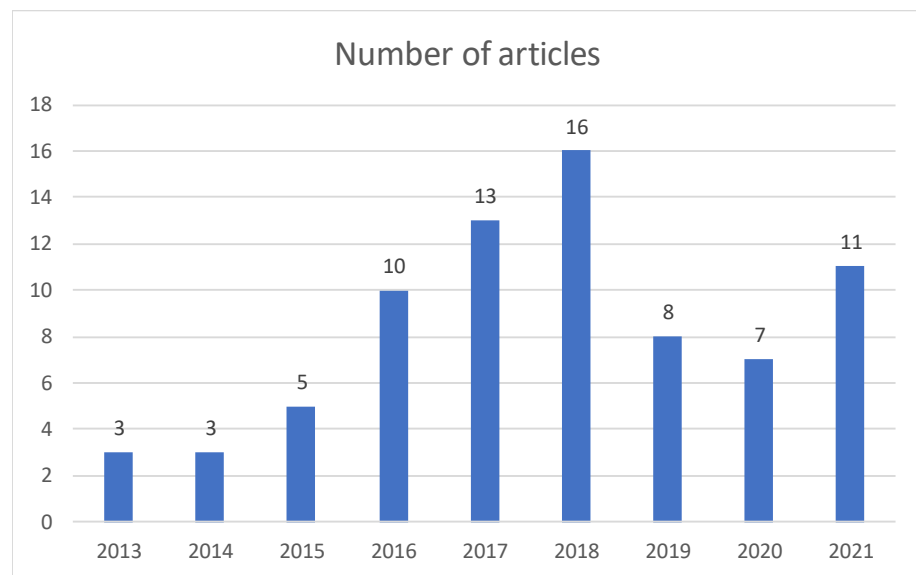
Figure 2. Distribution of the articles by publishing year.
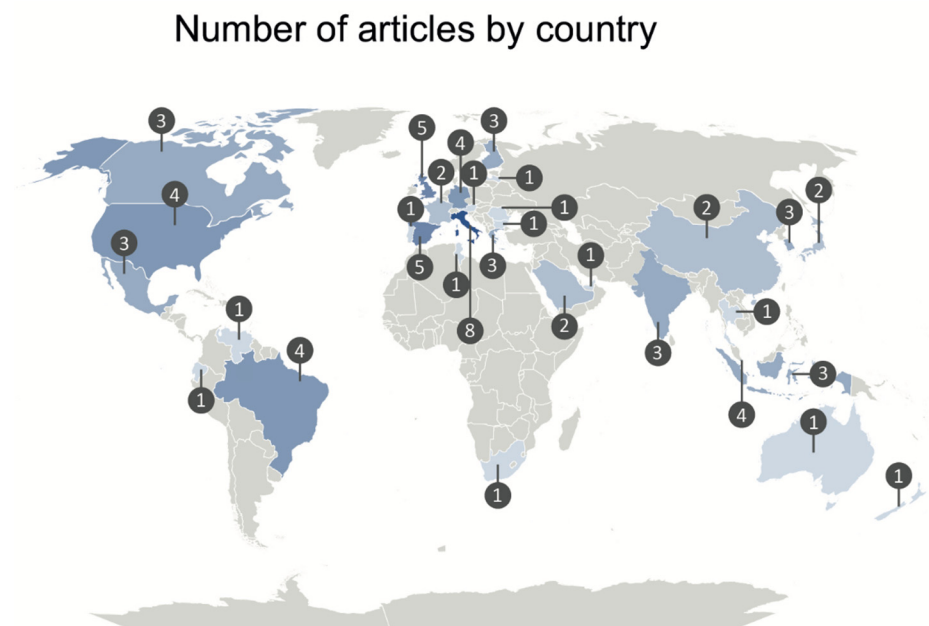

Figure 3. Distribution of the selected studies by country.

Moreover, almost one-third of the included studies (i.e., 25 studies) [96,97,104,105, 109,111,116,119,121,124,125,127,129,132,133,136–138,141,142,152,157,158,161,167] reported on the involvement of multinational research teams.

3.3. Methodological Quality Assessment

The results of the methodological quality assessment of the included studies are presented in Figure 4.
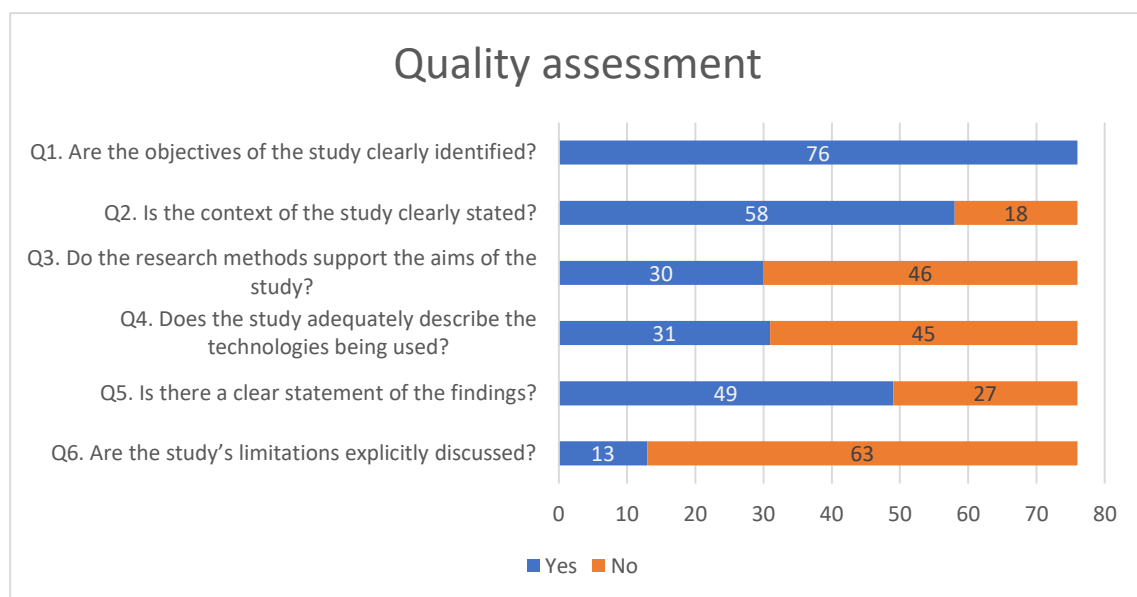
Figure 4. Methodological quality assessment of the included studies.

All studies stated the aims and objectives of the conducted research (Q1. are the objectives of the study clearly identified?). In turn, only 13 studies explicitly discuss the limitation of their results (Q6. are the study's limitations explicitly discussed?). The results of the remaining four questions of the methodological quality assessment varied from 58 (Q2. is the context of the study clearly stated?) and 30 (Q3. do the research methods support the aims of the study?)

3.4. Studies' Purposes

In terms of the purposes of the included studies, two major categories were identified:

- Citizen participation in the identification of urban problems, 59 studies.
- Citizen participation in the decision-making processes (i.e., citizens do not just report problems, but are somehow involved in the decision-making process), 17 studies.

3.4.1. Citizen Participation in the Identification of Urban Problems

The category citizen participation in the identification of urban problems was further divided into the following subcategories (Figure 5): (1) participatory reporting (i.e., use of technologies such as crowdsourcing to allow citizens to report on urban problems), 25 studies; (2) participatory sensing (i.e., crowdsensing applications supported on the use of sensors from citizens' personal devices to acquire diverse parameters), seven studies; (3) citizen-centered data analysis (e.g., social media data mining aiming to identify urban problems), 14 studies; and (4) multiple approaches (i.e., integration of various approaches such as participatory reporting in conjunction with citizen-centered data analysis), 13 studies.
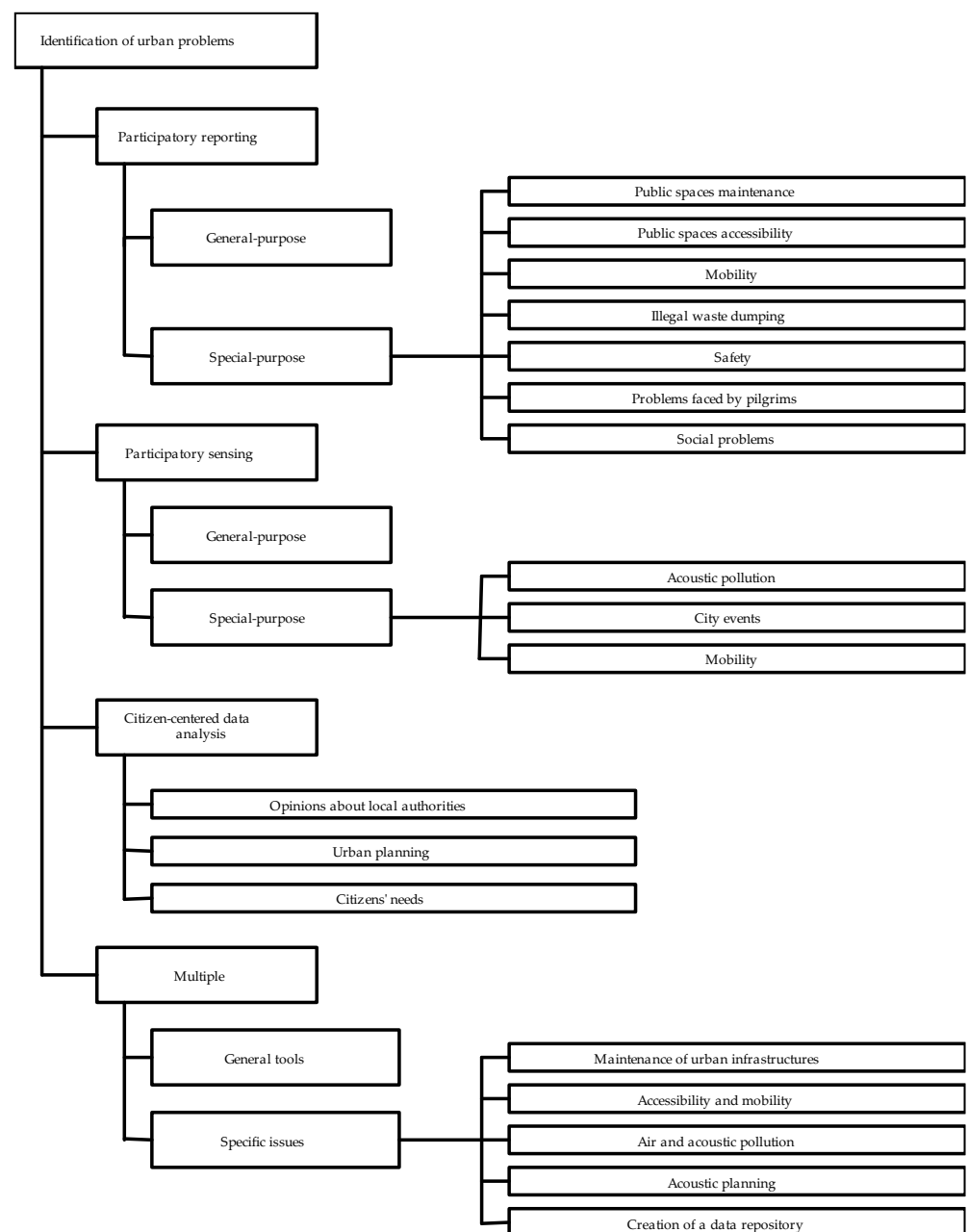
Figure 5. The different aims and approaches of the studies classified as citizen participation in the identification of urban problems.

Participatory Reporting

Participatory reporting aims to provide city authorities with a better understanding of problems faced by the citizens. Ten studies [96,97,99,101,107,132,144,145,149,153] related to participatory reporting did not focus on specific issues, but instead described general purpose participatory reporting applications. These applications allow citizens to report on various types of issues (e.g., roads conditions, waste, traffic conditions, accidents, or crime, among others) and have various specific features: ref. [101] presented MinaQn, a web-based system that allows city officials to create questionnaires about different topics citizens can then answer; the application provided by [132] requires authentication so that the citizens can receive feedback about the status of the issues they reported; in the application described by [97], citizens must be authenticated so that their reports can be checked for quality and timeliness; the study reported by [144] was focused on the engagement of the citizens by using gamification concepts (e.g., user levels, avatars or leaderboards); ref. [99]

presented an analysis engine to aggregate and consolidate the collected data; and the studies reported by [107,145,153] integrated comprehensive mechanisms to allow citizens to access services provided by the authorities (e.g., administration, education, healthcare, paying taxes or filling applications) and receive updates about city issues and the status of the reports they made.

Fifteen studies [93,94,100,104,109,110,112,117,129,133,137,138,148,150,162] developed participatory reporting applications focused on specific issues: maintenance and accessibility of public spaces, mobility in the urban space, illegal waste dumping, safety, problems faced by pilgrims, and social problems (Figure 5).

The maintenance of public spaces was addressed by seven studies [93,100,112,117,133, 138,162]. The applications developed by these studies allow citizens to report problems they find for proactive management of public spaces [162]. Although the participatory reporting mechanisms are similar among these studies, it is possible to distinguish specific features: ref. [93] proposed an application to allow citizens to share photos of points of interest; ref. [138] presented an application developed for the city of Tangerang, Indonesia, to allow the citizens to make suggestions from ten different categories of city development; in addition to participatory reporting, the prototype described by [112] also serves as a digital library so that citizens can have better information about their surroundings; the application presented by [100] allows the citizen to check the status of any reported issue; the application described by [117] makes use of gamification to incentivize citizens to participate; and the application reported by [133], FixMyStreet, according to official data, has been accepted by 98% of the British Councils.

In terms of the accessibility of public spaces, ref. [109,137] presented applications that allow citizens to comment and review city locations according to their accessibility to people with mobility impairments.

The study reported by [110] was focused on mobility in the urban space and presented a serious game aiming to introduce people to the concept of electric mobility and convince them of its utility. The gaming approach was chosen in lieu of more traditional surveys to investigate how gamification can improve the receptiveness of the public.

Considering that illegal waste dumping can cause social and health problems, the application proposed by [148] aimed at the quick identification of illegal waste dumping based on citizen reports. The application uses the Ethereum blockchain to create a currency that can be gained by performing certain actions on the system (e.g., reporting or voting), which can then be exchanged for goods and services from sponsors.

Since quick and efficient reporting of incidents that threaten the safety of citizens is of paramount importance, ref. [94] presented a method to increase the quality of data collected from an interactive voice response system for the city of East London, South Africa, that allows citizens to call and report safety incidents. Moreover, ref. [150] presented an application that allows two types of reports, an emergency one, where citizens only need to press a button to send pre-defined messages with their locations, or if the citizens are not in danger, four categories' reports (i.e., criminal activity, perceived danger, suspicious activities and other) can be written and sent.

Based on the various problems pilgrims can encounter during the Hajj (Muslim holy pilgrimage), ref. [104] presented an application to share data with the city's government and services, both from sensors and from citizen inputs, which might be used in conjunction with existing city services to support the management of the pilgrims as well as city residents.

Finally, one study [129] aimed at identifying the problems that affect minorities. In this regard, a basic foundational and theoretical framework for crowd mapping was developed to be used to create a crowd-based smart map for disabled people.

Participatory Sensing

Looking specifically at the second subcategory related to citizen participation in the identification of urban problems (i.e., participatory sensing [95,102,106,113,116,127,136]), a subset

of studies [102,106,127,136] had specific aims, while another subset of studies [95,113,116] was focused on general-purpose applications to allow the creation of participatory sensing campaigns to obtain different types of data (Figure 5).

Three aims were identified in terms of special-purpose applications: acoustic pollution, city events, and urban mobility. Concerning acoustic pollution, ref. [136] presented a participatory sensing architecture that allows smart devices to become noise sensors for urban environments, while ref. [102] described an application that might be used to provide several services to support city events (e.g., festivals or concerts) since it collects precise location information that can be used by city officials for better management during normal operations or during emergencies. Finally, two studies focused on understanding how citizens move around the cities for a better planning of the available transportation: ref. [106] presented a reference architecture for an application that collects data from mobile sources, analyzes the collected data and then gives feedback to the citizens, namely alerts of dangerous spots. The study reported by [127] used the ParticipAct platform (also used by the study reported by [109]) to store location data collected from the citizen mobile devices, which were then analyzed to infer the citizen mobility patterns (i.e., what paths they take from location to location) and identify points of interest in the cities.

Citizen-Centered Data Analysis

Fourteen studies [108,118,125,135,141–143,146,147,152,155–158] proposed applications that analyze citizen-centered data from social media (e.g., Facebook or Twitter) to identify needs or problems faced by the citizens to support urban planning and to determine the citizens' opinions about the performance of local authorities (Figure 5).

Seven studies [108,125,135,142,146,147,155] were related to the identification of needs and problems faced by the citizens. The study reported by [155] used NeedFull, a tweet analysis framework, to investigate the reactions of the people of New York State during the COVID-19 pandemic, while the remaining six studies [108,125,135,142,146,147] aimed to analyze large volumes of data to understand the sentiments of the citizens about certain topics [108,125,142,146,147] or to infer alerts, insights, or recommendations [108].

Concerning urban planning, one study [141] used freely available data on citizen activities to identify common points of interest and urban areas where sports are played. In contrast, another study [158] used a machine-learning algorithm to identify citizen trends in terms of urban planning by analyzing data from a civic participation application.

Moreover, five studies [118,143,152,156,157] aimed to identify the opinion of the citizens about the local authorities. Article [156] presented an analytical framework to retrieve citizen-centered data from an online comment board to be used by local governments to assess political reforms and implementations. In turn, refs. [152,157] presented how social media can be used to generate data that municipalities can use to implement smart cities. Furthermore, ref. [118] presented how governments can use social media to analyze specific services and better understand their citizenry's opinion (i.e., positive, negative, or neutral) of those services. Additionally, ref. [143] presented a system that uses social media data to identify trending views and influential citizens.

Multiple

Finally, looking specifically at the thirteen studies [98,103,115,123,126,128,134,139,151, 161,164,166,168] that focused on the use of multiple approaches to identify urban problems (i.e., the fourth subcategory related to citizen participation in the identification of urban problems), two articles [103,161] presented generic tools (Figure 5): ref. [103] presented a middleware that allows the collection of data from multiple sources, be they static sensors, participatory sensing by citizens or data mined from social media, while ref. [161] presented an application that allows citizens to report city problems and collect data through smartphone sensors. The remainder eleven studies [98,115,123,126,128,134,139,151,164,166,168] focused on specific issues: maintenance of the urban infrastructures [123,128,134,166], ac-

cessibility and mobility in the urban spaces [98,115,126,139], air and acoustic pollution [151], acoustic planning [168], and creation of a data repository [164] (Figure 5).

In what concerns the maintenance of urban infrastructures, namely the maintenance of roads potholes, ref. [166] presented an application that uses data mining of public data on Twitter together with data provided by a mobile application to allow citizens to report any potholes they find, including data about the hole (e.g., depth, diameter, or damage) along with its geolocation. In turn, ref. [123] presented an application that supported an urban data challenge to allow young citizens to document and reflect on their city problems through photos, videos, interviews, and posts from Facebook and Twitter. Moreover, the application presented by [128] aims to allow citizens to perform tasks to monitor urban services using participatory reporting and participatory sensing. Additionally, ref. [134] presented a unified framework to use different data sources, including data from social media and reports or measurements provided by the citizens.

Regarding accessibility and mobility in urban spaces, two studies [98,115] focused on the mobility of impaired people. Article [98] presented an application that uses participatory reporting, participatory sensing, and city open data to create tailored routes for citizens with mobility impairments, considering a routing algorithm that takes accessibility barriers as constraints. In turn, ref. [115] presented an application to promote urban accessibility by having citizens, both with and without disabilities, using wearable sensors to collect their movement patterns, which are processed to identify the routes that are not used by citizens with disabilities.

Still, in terms of mobility in the urban spaces, ref. [139] presented an application that aims to use both crowdsourced geodata from citizen reports and data gathered from Twitter to predict events that are likely to happen the next day in the same geographical area, while ref. [126] presented a participatory sensing application to assess trip quality when riding in a vehicle. This application collects data from sensors and allows the citizens to report specific situations, and the aggregate data are analyzed to determine road or traffic quality [126].

Knowing that smart cities might reduce pollution levels if pollution sources are identified, ref. [151] presented an application to measure air pollution and noise levels in a city using multiple inputs: a network of high-precision static nodes, lower-precision mobile nodes, microphones of mobile devices to gather random noise samples, open access data sources, and citizen participation by answering questionnaires about air quality and noise levels. In turn, considering that the sounds of an area and how they impact people's lives can be unintentionally neglected when designing urban environments, ref. [168] presented an application composed of multiple software tools to allow citizens to collect soundscapes and to provide reports to be used as part of the process of planning and designing urban environments, which is more commonly focused on the visual elements.

Concerning the creation of data repositories, ref. [164] proposed an application that allows various types of stakeholders (e.g., citizens, government, or companies) to collect data about a city from various sources (e.g., citizen reporting, dedicated sensors, or social networks), to be shared and visualized in several ways (e.g., 3D renders, heatmaps or lists).

3.4.2. Citizen Participation in Decision-Making Processes

When planning and designing urban environments, the citizens living and working in those environments are the most affected. Therefore, it is an objective for smart cities to have citizens involved in the governance processes. In this respect, different types of collaborative applications were identified (Figure 6) to (1) support citizen participation in urban planning and design; (2) provide visualization tools for urban planning; (3) allow participatory budgets; (4) allow the dissemination of the citizen ideas and prioritization of city projects considering citizen satisfaction; and (5) promote democratic values including the transparency of public administration.
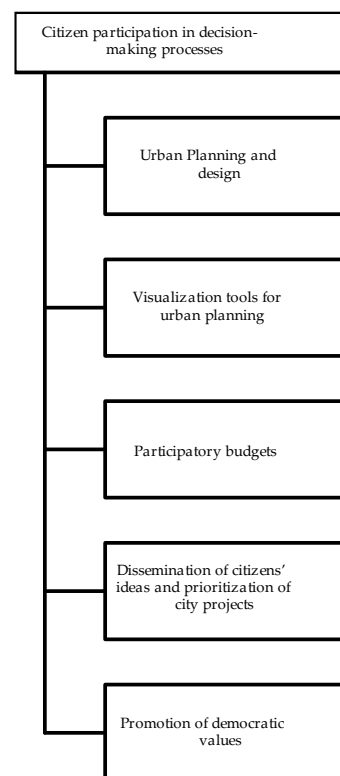
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        └───│ Promotion of democratic │
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Figure 6. Types of collaborative approaches related to citizen participation in decision-making processes.

Six studies [114,119,121,140,154,163] focused on collaborative applications for citizen participation in urban planning. Article [114] presented an application designed to give the common person the tools and knowledge necessary to create and orchestrate citizen participatory reporting and sensing campaigns based on a six phases process: identification of issues, framing those issues in the existing context, design, deployment, orchestration of the finished product, and outcome review. In turn, collaborative applications to support city decision-making were presented by [119,163]. Moreover, refs. [121,140] presented applications to allow citizens and government officials to share information between themselves, and ref. [154] proposed an application for the co-creation of neighborhoods by allowing the collaboration between citizens, and between citizens and the municipalities for the design and approval of houses, public spaces, renting spaces or other situations where government officials would also need the collaboration of the citizens.

Since it can be hard to extract information from large volumes of data, four studies [120,122,131,167] focused on applications providing visualization tools to allow citizens, both experts and non-experts, to better understand the repositories containing data related to urban planning: ref. [122] presented a tool to facilitate the visualization of data collected by city governments on several topics (e.g., pollution, attractiveness of surroundings, or resource management), and to allow citizens to give feedback on the data presented and services available; ref. [131] presented the Quick Urban Analysis Kit, which aims at the design of urban spaces by the citizens; ref. [167] presented a serious game to allow citizens to collaborate in constructing a smart city; and ref. [120] presented a mixing panoramic imaging and architectural drawing tool for future urban plans.

Regarding participatory budgets, ref. [130] presented an application to allow citizens to propose projects to be funded and implemented. In turn, ref. [105] described an application to prioritize city projects considering citizen satisfaction according to various metrics. Finally, ref. [111] presented an application to allow citizens to present ideas for the benefit of the cities and comment and vote on ideas already posted. To incentivize citizen participation, competitions might be considered to distribute prizes such as gift certificates [111].

Four studies [124,159,160,165] focused on applications to promote democratic values and scrutinize public authorities' decisions. Article [124] described the Visor Urbano application, which aims to lower city governments' corruption by allowing citizens to request permits for building, opening businesses and other licenses. In turn, ref. [159] described an application to help identify misuse of resources and corruption in public works, allowing citizens to view the details of public works and report any inaccuracies or suspicious details they found to the government. Moreover, two articles [160,165] presented applications to provide the discussion and review of governmental policies: the applications for urban democracy that were implemented in Madrid and Barcelona were presented by [160]. In contrast, ref. [165] presented a government petition application of Taiwan that allows citizens to propose petitions if they reach the threshold of 5000 signatures in 60 days. Since the application has been in service since 2015, several proposed petitions have been implemented into policy.

3.5. Data Sources, Data Quality, Data Security and Privacy, and Strategies to Incentivize Citizen Participation

In terms of data sources, 25 studies focused on participatory reporting [93,94,96,97,99–101, 104,107,109,110,112,117,129,132,133,137,138,144,145,148–150,153,162] and in other 12 studies [98, 115,123,126,128,134,139,152,161,164,166,168] participatory reporting was used together with other approaches, such as participatory sensing or citizen-centered data analysis.

In turn, 19 studies (Table 3) implemented participatory sensing applications that use the sensors from personal mobile devices to collect data related to location, activity, and environment.

Table 3. Types of data acquired by personal sensors.

Types of Sensors	Location	Activity	Environment	Not Specified
Smartphones' sensors				
Unspecified	[95,97,101,102,106,168]	[95,98]	[136,168]	[96,102,103,106,113,116,126,128,138]
Microphones			[151]	
Gyroscopes and accelerometers		[95]		
Global Positioning System (GPS)	[101,115,117,127,136]			
Wearables Body Area Network				[104]

Furthermore, fourteen studies [108,118,125,135,141–143,146,147,152,155–158] were exclusively focused on the analysis of social media data (e.g., Facebook or Twitter), while seven other studies [103,123,128,134,139,164,166] combined the analysis of social media data with participatory reporting and participatory sensing.

In terms of data sources, one article [98] referred to the use of open data about real-time public transportation means (i.e., available equipment and respective accessibility barriers and facilitators), while another article [151] referred the use of open access data sources and a network composed by high precision static nodes and lower precision mobile nodes in addition to the microphones of the citizen mobile devices and answers to questionnaires about air quality and noise levels.

Since different heterogeneous data sources were considered, there is the possibility of contradictory data or data with low quality (e.g., missing values or outliers). Therefore, analyzing data quality and minimizing the consequences of low-quality data are relevant processes to be considered. However, just four articles reported how low-quality data are managed: the low-quality or incomplete data are filtered out by a classifier [97]; the open data collected from various sources were cleaned to eliminate corrupt and duplicate data, and standardized into a homogenous format, with the sources themselves checked for consistency [122]; the most extreme five percent of data records (best and worst) were ignored during evaluations, and the same ride trips were compared to each other to identify

and correct abnormal readings [126]; data collected from multiple sources were verified for validity, outlier detection and missing values [151].

The applications reported by the included studies can potentially put the participants' privacy at risk, namely in terms of the communication of personal data. Therefore, secure data transmission and storage must be guaranteed. However, only 10 articles [94,102,107,115,116,126,128,139,150,151] referred data security and privacy mechanisms or the usage of security frameworks: in the study presented by [94] auditing mechanisms were used to reinforce access control mechanisms; ref. [102] reported the implementation of a privacy module to allow the citizens to manage the data collection and to prevent unauthorized accesses; the study reported by [107] used OpenStack services and Spring Security framework; ref. [115] presented a method to preserve anonymity with Radio Frequency Identification (RFID); in the study reported by [116] the data transmitted was encrypted using the Advanced Encryption Standard (AES); ref. [126] summarized several methods to handle privacy issues in participatory sensing applications; the study reported by [128] implemented a location obfuscation mechanism; in ref. [139] is mentioned as a future work the mitigation of denial of service attacks; in the study reported by [150] the Secure Sockets Layer (SSL) protocol is used to encrypt data to be transmitted or stored; and ref. [151] presented a method that allows recognizing environmental sounds while speech intelligibility is masked.

In addition to potential privacy risks, citizen participation requires consuming their resources, such as battery and computing power. Therefore, since the impact and relevance of participation campaigns depend on the engagement of the citizens, incentive mechanisms might be proposed, which can be either monetary or non-monetary (e.g., entertainment). To guarantee the engagement of the citizens, 19 of the included articles [95,97,101,103,110–113,116,117,126,128,132,144,145,148,151,160,167] reported the need to implement incentive mechanisms. However, only four of them [110,117,144,167] reported the use of gaming mechanisms and the other four [97,126,145,148] implemented incentive mechanisms considering different approaches: in [97], incentives were evaluated empirically to ascertain which one is better in which conditions to promote citizen participation; in [126], the various stakeholders gained benefits from the data collected; in [145], every performed action gained points for a ranking system, and in [148], the participants were awarded with a civic currency that can be traded by assets provided by sponsors.

3.6. Development Stages

Concerning the development stages of the included studies (Table 4), three studies were classified as requirements and 22 as design. The remainder studies were classified as technical testing (i.e., 22 studies), prototype testing (i.e., 17 studies), pilot testing (i.e., nine studies), and mature (i.e., three studies).

Table 4. Development stages the proposed applications.

Development Stages	References
Requirements	[129,154,159]
Design	[94,96,103,104,107,116,119,120,122,124,128,131,138,141,146,148,150,151,153,157,158,164]
Technical testing	[93,97,98,106,109–113,118,125,126,135,136,139,142–144,147,155,156,166]
Prototype testing	[105,114,115,117,127,130,132,134,137,145,149,152,161–163,167,168]
Pilot testing	[95,99–102,108,121,123,140]
Mature	[133,160,165]

As can be seen in Figure 7, which presents the number of studies by development stages over the years, the most mature solutions are not associated with more recent years. All the articles focused on the applications' requirements were published after 2018, and most of the articles focused on the design of the proposed solutions were published between 2018 and 2020. In turn, a high percentage of the articles reporting on technical testing and

pilot testing were published between 2016 and 2018, while most of the articles that reported the assessment of prototypes involving real users (i.e., prototype testing) were published after 2016. Finally, two-thirds of the articles reporting on mature solutions were published in 2021.
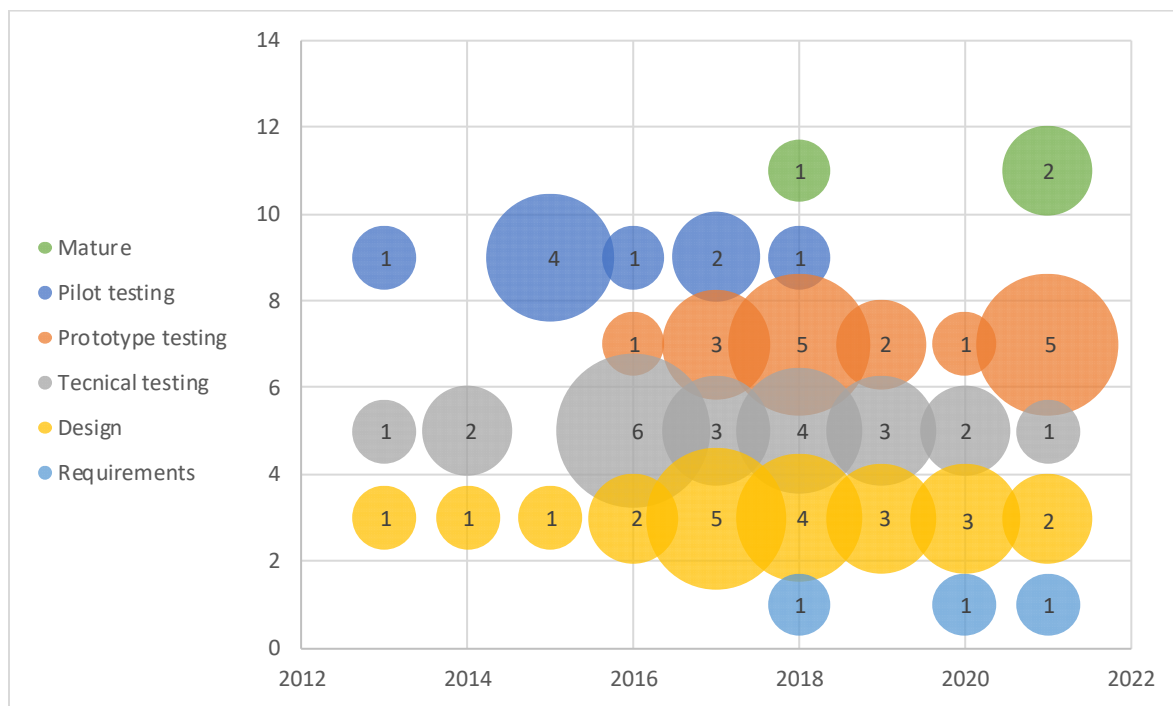

Figure 7. Number of studies by development stages over the years.

4. Discussion

The demographic characteristics of the included studies, as presented in Figure 2, indicate they were published between 2013 and 2021. However, 73% of them were published after 2016, which shows a current interest in the topic of this systematic review.

Moreover, regarding the geographical distribution of the studies, Europe had the highest contribution (i.e., 46% of the included studies). It is not surprising to have the highest contribution from Europe since it stands out regarding scientific productivity related to smart cities [57,169]. However, not expected was the low contribution of countries such as the USA, the People's Republic of China and India, as they are important contributors in terms of scientific publications related to smart cities [57,169]. A possible explanation for this result might be the existence of studies focused on citizen participation and governance developed in the context of other research topics, such as open government, collaborative government, or smart government, but not in the context of smart cities and, therefore, not included in this review.

Concerning the first research question (i.e., the purposes of the studies using smart city infrastructures to promote citizen participation in city management and governance), 78% of the studies focused on allowing citizens to identify urban problems, while 22% of the studies focused on promoting the involvement of citizens in city governance processes. Moreover, considering the studies focused on citizen participation in the identification of urban problems (e.g., to report urban issues, share opinions about city management or monitor certain environmental parameters), 42% were classified as participatory reporting, 12% as participatory sensing, 24% as citizens-centered data analysis, and 22% as using multiple approaches.

In terms of data provision by citizens, the respective studies considered both active participation and passive participation. Through active participation, citizens provide feedback on city issues (i.e., participatory reporting) or provide specific sensing data through

their mobile devices (i.e., participatory sensing). In turn, through passive participation, data are collected without any stimulation of the individuals, for instance, by analyzing the opinions expressed on social media to infer information that city authorities might use (i.e., citizens-centered data analysis). Moreover, several studies considered multiple approaches, such as participatory sensing and data mined from social media.

Participatory reporting aims to provide city authorities with a better understanding of the problems citizens are facing. For that, some studies related to participatory reporting described general-purpose participatory applications while others proposed special-purpose applications focused on maintenance and accessibility of public spaces, mobility, illegal waste dumping, safety, problems faced by pilgrims, and social problems.

In turn, by analyzing the studies focused on participatory sensing, it is possible to identify general-purpose applications to allow the creation of participatory sensing campaigns to obtain different types of data, as well as applications focused on acoustic pollution, city events, and city mobility. Acoustic pollution and air pollution were also a concern of studies using multiple approaches to identify urban problems. Other concerns of these studies include the maintenance of urban infrastructures, accessibility and mobility in urban spaces, acoustic planning, and the creation of data repositories.

Moreover, considering the studies that proposed applications to analyze citizen-centered data from social media, their aims include identifying needs or problems faced by the citizens, gathering data to support urban planning and determining citizen opinions about the performance of local authorities.

A large percentage (i.e., 59%) of the included studies focused on participatory reporting, participatory sensing, or multiple approaches applications and, therefore, aimed to take advantage of crowdsourcing technologies. Since crowdsourcing refers to obtaining needed services or content by soliciting contributions from a large and diverse group of individuals through an open call [170–173], these studies aimed to implement crowdsourcing applications to act as brokers between citizens and city authorities. Moreover, combining crowdsourcing with mobile applications resulted in crowdsensing services [174] that benefit from the high sensing capabilities of mobile devices [24,51,171]. These devices offer several advantages over traditional sensor networks, which require many static wireless sensor devices, particularly in urban areas (e.g., limited costs in terms of implementation or the inherent mobility of the devices that provide large spatial and temporal coverage) [51].

With respect to the second research question (i.e., the characteristics of the proposed solutions in terms of data sources, data quality, data security and privacy, and strategies to incentivize citizen participation), 37% of the studies processed citizen reports, 25% of the studies processed sensing data provided by citizens, 28% of the studies analyzed social media data. Only 3% considered open data from the cities.

Moreover, despite the importance of data quality when aggregating data from different sources, and the relevance of data security and privacy, namely in research (e.g., [64,175]), the results indicate that these issues were not conveniently addressed. Few articles (i.e., 5% of the articles) reported how data are verified for validity and cleaned to eliminate outliers, corrupt or missing values. In turn, the studies also failed to present evidence about how data security and privacy are guaranteed: 13% of the articles referred to data security and privacy mechanisms or the usage of security frameworks, but only 5% of the articles reported the implementation of these mechanisms. Therefore, future developments of applications using smart city infrastructures to promote citizen participation in city management and governance need to implement adequate data security and privacy mechanisms.

Furthermore, a minority of the included studies (i.e., 5%) considered incentive mechanisms using gaming or other strategies to motivate citizen participation and, in general, their technical details were poorly described. Specifically, none of the articles reporting on solutions classified as mature according to their development stages [133,160,165] referred to the implementation of incentive mechanisms or the need to implement these types of mechanisms.

Potential reasons for the limitations related to data quality, data security and privacy, and incentive mechanisms might be the complexity of the development of smart city applications with significant variability in terms of design, implementation and required technologies. However, these limitations, irrespective of their causes, represent significant gaps in the smart city applications that aim to promote citizen participation in city management and governance and, therefore, demand further research.

Concerning the development stages of the applications being reported (i.e., the third research question), 62% of the studies did not perform assessments involving potential end-users: 4% of the articles reported the requirements' elicitation of the proposed applications, 29% of the articles present a general overview of the applications' architectures or some of the respective components, and 29% of the articles reported performance evaluations of the proposed applications or some of their components. In turn, considering the assessments involving end-users, 22% of the articles described a laboratory evaluation of a minimally working version of the application being proposed, 12% of the articles reported a real-world evaluation by end users in their daily context during a certain period, and 4% of the articles presented mature solutions that have been tested by end users, amended, and deployed.

Only 16% of the studies implemented real-world evaluations by end users in their daily context during a certain period or considered mature solutions already deployed. This result indicates difficulties in evaluating the proposed applications' impact on their potential users, which is in line with the results of other systematic reviews focused on other aspects of the smart city implementation [176,177]. Moreover, an evolution of the maturity level of the proposed solutions over the years would be expected. However, considering Figure 6, it is possible to infer that the most mature solutions are not the most recent ones. For instance, all the articles focused on the applications' requirements were published after 2018, while all the articles reporting on pilot testing were published until 2018, which might indicate poor incorporation of the knowledge and solutions generated by previous research studies.

The difficulties in evaluating the proposed applications might be explained by the fact that the development and effective evaluation of smart city applications requires various types of resources and a diversity of stakeholders. Despite the existence of models aiming to optimize smart city implementations (e.g., [178]), the coordination of these resources and stakeholders requires experience and a large amount of effort.

Building a smart city demands the combination of different domains where information technologies might be an enabler of new favorable behaviors and environments. Although it is a challenge to define a comprehensive taxonomy, different studies proposed frameworks to define the dimensions of smart cities [13,14,52,57,58,179–183]. Among these frameworks, the one proposed by Giffinger et al. [13,14] was widely quoted [169,184] and considered the following six dimensions: smart economy, smart people, smart governance, smart mobility (transport), smart environment (natural resources) and smart living (quality of life) [13,14].

These dimensions are presented in the included studies. First, the included studies aimed to promote citizen participation in city management and governance (i.e., smart governance), which presupposes citizens who are well-informed and willing to contribute to the common interest (i.e., smart people). Secondly, the purposes of the included applications intend to contribute to the competitiveness of the cities (i.e., smart economy) and are related to smart mobility (e.g., transports), smart environment (e.g., natural resources), and smart living (e.g., quality of life): maintenance of urban infrastructures, mobility in urban spaces, accessibility of public spaces, air and acoustic pollution, illegal waste dumping, citizen safety, problems faced by pilgrims, and social problems.

Smart governance has the heritage of e-government literature, which studies how information technologies can be used to deploy better policies [169]. According to diverse frameworks supporting the development of smart cities, smart governance is an important pillar of this development: smart governance [13,14], urban proactiveness and smart city governance [57,179], institutions (governance and policy) [52], governance, policy context [180],

governance [58,181], collaboration [182], and smart citizen and smart government [183]. Twenty-two percent of the included studies are in line with this interest in smart governance since they focused on citizen participation in the decision-making processes by providing collaborative applications to support urban planning, select development projects and promote democratic values, including the transparency of public administration.

Two of these studies focused on mature applications already deployed, the applications for urban democracy implemented in Madrid and Barcelona [160] and the government petition application implemented in Taiwan [165]. This petition application allows citizens to propose petitions that are presented to the authorities if they reach the threshold of 5000 signatures in 60 days. According to the authors [165], several proposed petitions have been implemented into policy.

Moreover, to complete the set of three mature applications identified by this systematic review, one should refer FixMyStreet, a mature solution already deployed and accepted by 98% of the British Councils [105] to support roads' maintenance.

5. Limitations

Although the authors tried, in methodological terms, to follow rigorous procedures in the selection of the studies and the extraction of data, it is always possible to point out limitations about both the chosen keywords and the databases that were used in the research and even the judgement of the authors when screening the articles. Grey literature (e.g., technical reports or industrial solutions) was not considered in this review, and this can be seen as a gap of some significance since it is assumed that there are many local field projects that are not published in scientific articles.

Additionally, since this review was specifically focused on smart city applications, one should consider the existence of other applications related to citizen participation and governance whose development was not performed in the context of smart cities (e.g., their authors did not consider the concept of the smart city), but according to the perspectives of other research areas, such as crowdsourcing or crowdsensing technologies [51], smart contracts [185], or the implementation of government services based on information technologies (e.g., to fight corruption [186], to promote deliberative participation [187] or to support environmental policies [188]). This is a consequence of the difficulties in consolidating common and accepted taxonomies in emergent research areas that are transdisciplinary by nature, such as in the cases of citizen participation, smart city, or governance.

Therefore, this systematic review provides an overview of studies published in indexed scientific journals and conferences related to the use of smart city infrastructures to promote citizen participation in city management and governance but does not include all the existing smart city applications with these purposes nor all the applications with similar purposes but developed in the context of research topics other than smart cities, such as open government, collaborative government or smart government [189]. This limitation can be seen as an opportunity for further research in terms of systematic reviews.

6. Conclusions

The systematic review aimed to analyze the state-of-the-art of smart city applications to promote citizen participation in city management and governance, and 76 studies were identified after the selection process. It is foreseen that the number of studies related to the topic will increase in the future since the research effort has increased over the years, and 73% of the studies have been published since 2017.

In turn, concerning the geographical distribution, Europe was the geographic area with the highest number of contributions (i.e., 46% of the included studies).

Relevant contributions were identified that aimed to provide applications to promote citizen participation in city management and governance. Different approaches (i.e., participatory reporting, participatory sensing, or citizen-centered data analysis) were used for the identification of urban problems related to the maintenance of the urban infrastructures, mobility in the urban spaces, accessibility of public spaces, air and acoustic

pollution, illegal waste dumping, citizen safety, problems faced by pilgrims, and social problems. Moreover, the analysis of citizen-centered data (i.e., social media data) was also used to support urban planning and determine citizen opinions about the performance of the local authorities. Finally, collaborative applications were proposed to promote citizen participation in the decision-making processes in urban planning, selection of development projects and deepening democratic values.

Although the included studies make use of technological developments that are important for smart city development (e.g., crowdsourcing and crowdsensing technologies), this systematic review also evidences the poor incorporation of knowledge and solutions generated by the research related to other smart city topics, such as data quality, data security and privacy, whose integration need to be optimized. In addition, the strategies to incentivize citizen participation require further research.

Additionally, since a considerable investment is being made to bring together smart city stakeholders, including industry, for creating market-ready solutions, a major gap in the current research related to smart city applications to promote citizen participation in city management and governance is the assessment in real conditions for a certain period of the proposed applications. Robust experimental set-ups to evaluate the impact of the applications being developed are required to facilitate and sustain their dissemination.

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