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Crowdsourcing Technologies to Promote Citizens' Participation in Smart Cities, a Scoping Review

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Abstract

The scoping review reported by this article aimed to identify (i) the purposes of the studies using crowdsourcing technologies in the context of the smart cities' implementations, (ii) the characteristics of the crowdsourcing technologies being used, and (iii) the maturity level of the solutions being proposed. An electronic search was conducted, and 29 studies were included in the review after the selection process. The results show a current interest in crowdsourcing campaigns using participatory reporting and participatory sensing to (i) support urban infrastructures' maintenance, (ii) facilitate urban mobility, (iii) monitor the environment, (iv) manage crowds, (v) aggregate geographical information, and (vi) collect citizens' perspectives about the cities. However, the results also show low maturity level of the proposed solutions and lack of consolidated evidence about their effectiveness, which difficulties their dissemination.

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Keywords: Smart cities; Citizens' participation; Crowsourcing; Crowdsensing.

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1. Introduction

The crowdsourcing term was first mentioned by Howe [1] and due to its multidisciplinary nature, it might be considered from different perspectives [2]. Irrespective of these perspectives, crowdsourcing is an efficient process to address complex decision-making tasks [1,3], by aggregating data, information, or opinions from groups of people, which often results in better decisions than those made by a single person and promotes diversity in opinion and independence of thinking [4,5].

Smart cities aim the successful cities' management in terms of their efficiency and the quality of life of their inhabitants, while coping with environmental, social, and economic urban challenges [6]. For that, smart cities should involve the citizens by facilitating their civic engagement [7]. In this respect, since smart cities are tightly related to data collection and analysis, crowdsourcing is being seeing as an important asset [6]. Crowdsourcing might help the citizens to contribute for the identification of urban issues or even for the cities' planning [8,9] and, therefore, be a central pillar of participatory governance [6]. Moreover, by exploiting the pervasive presence of user-companioned mobile devices [6,10] crowdsourcing might complement the traditional sensing techniques based on distributed networks of sensors to acquire real-world conditions [5].

However, managing and processing the data resulting from crowdsourcing tasks poses numerous challenges, namely the huge amount of data being generated and their reliability, the security of the data collecting processes or the regulatory standardization to turn crowdsourcing mechanisms into efficient and trustworthy tools [9,11].

In this context, the scoping review reported by this article aimed to analyze the state of the art of the use of crowdsourcing mechanisms in the context of smart cities' and, therefore, to complement other reviews addressing different aspects of the implementation of smart cities, such as (i) bibliometrics [12,13], (ii) data analytics [14,15], (iii) systems architectures [16], (iv) data security [17], (v) healthcare [18], (vi) energy efficiency [19], or (vii) mobility [20], among others.

2. Methods

Three research questions (RQs) were formulated for this study:

- RQ1 - what are the purposes of the studies using crowdsourcing technologies in the context of the smart cities' implementations?
- RQ2 - what are the characteristics of the crowdsourcing technologies being used?
- RQ3 - what is the maturity level of the solutions being proposed?

After the identification of the research questions a research protocol was specified to define the selection of the studies process (i.e., data sources, the search queries, the inclusion/exclusion criteria, and the phases for the selection of studies), as well as the synthesis and reporting processes.

2.1. Selection of the Studies

Our choice of data sources included the Institute of Electrical and Electronics Engineers (IEEE) repository (i.e., IEEE Xplore), Web of Science and Scopus. IEEE Xplore was selected due to its importance in computer science related domains, a key aspect of the smart cities' developments. In turn, Web of Science and Scopus are the two major existing multidisciplinary databases and have a reputation of indexing quality peer reviewed research [21].

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', '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*)).

As inclusion criteria, the authors aimed to include peer-reviewed studies published before December 31st, 2021, that reported evidence of the participation of the citizens crowdsourcing campaigns in the context of smart cities'

implementations. The exclusion criteria were defined to exclude references that: (i) did not have abstracts or authors' identification; (ii) were not written in English; (iii) their full texts were not available; (iv) reported on reviews or surveys; (v) were books, tutorials, editorials, special issues announcements, extended abstracts, posters, panels, transcripts of lectures, workshops, and demonstration materials; (vi) reported on studies already covered by other references (i.e., when two references reported on the same study in different venues, such as scientific journal and conference, the less mature one should be excluded); and (vii) reported on studies that are not relevant for the objective of this scoping review.

The selection of the articles to be included in this scoping review was performed according to the following steps: (i) first step, the authors removed duplicates, references without abstract or authors, references not written in English, and references reporting on reviews or surveys; (ii) second step, the authors assessed all titles and abstracts for relevance and those clearly not meeting the inclusion and exclusion criteria were removed; and (iii) third step, the authors assessed the full text of the remaining articles against the outlined inclusion and exclusion criteria.

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

2.2. Synthesis and Reporting

The included studies were analyzed in terms of (i) their demographic characteristics, (ii) purposes of their technological developments, (iii) characteristics of the crowdsourcing campaigns being reported, and (iv) maturity level of the solutions being proposed.

Concerning the demographic characteristics of the included studies, a synthesis was prepared considering (i) the number of studies published in conference proceedings and in scientific journals; (ii) the distribution of the studies according to their publication years; (iii) the distribution of the studies by geographical areas, considering the affiliation of the first author; and (iv) the involvement of multinational teams.

Since crowdsourcing refers to the practice of obtaining needed services or content by soliciting contributions from a large and diverse group of individuals by mean of an open call [3,5,22,23], crowdsourcing platforms are required to act as a broker between the requester and the crowd. Therefore, the subsequent step was to analyze the purposes of the technological developments of the included studies, namely whether these developments aimed to provide (i) generic crowdsourcing platforms, (ii) crowdsourcing platforms with specific goals, or (iii) specific components of crowdsourcing platforms, as well as the objectives (e.g., urban infrastructures' maintenance or air quality monitoring) of the crowdsourcing campaigns supported by the proposed technological solutions.

In the smart city context, crowdsourcing platforms might be used to allow individuals to provide information (i.e., reports to support infrastructures' maintenance) or opinions and contribute to specific issues (i.e., participatory reporting). However, combining crowdsourcing with mobile applications resulted in new crowdsourcing services [24] that benefit from the high sensing capabilities of mobile devices, which currently incorporate different sensors such as microphones, built-in cameras, or Global Positioning System (GPS) receivers to determine location information, and might incorporate external sensors that can be easily connected via Bluetooth or wired connections [6,9,25]. Crowdsensing is a subtype of crowdsourcing and corresponds to a large-scale sensing paradigm based on the power of user-companioned devices [5,6] that offers many 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) [25]. Therefore, in the context of smart cities, in addition to the participatory reporting, crowdsourcing also allows citizens to be involved in participatory sensing, namely, to contribute with data sensed or generated from their companioned mobile devices.

The crowdsourcing campaigns require voluntary participation [10]. The individuals provide opinions and contribute to specific issues either actively (i.e., data are collected through an active stimulation of individuals' feedback on specific topics, or the individuals are requested to actively enable their companioned mobile devices to provide specific sensing data) or passively (i.e., data is collected without any stimulation of the individuals, for instance, by analyzing the opinions expressed on the social media). Individuals' participation might expose them to potential privacy risks and requires the consumption of individuals' own resources such as battery and computing power [10,25,26]. Therefore, since the impact and relevance of large-scale crowdsourcing tasks depends on adequate participation,

incentive mechanisms might be proposed for the participants of crowdsourcing campaigns [10], which can be in the form of either monetary or non-monetary (e.g., entertainment or badge) [26].

Therefore, the crowdsourcing campaigns of the included studies were further analyzed in terms (i) participatory reporting, (ii) participatory sensing, and (iii) incentive mechanisms.

Finally, the authors evaluated the maturity of the solutions being reported, by distinguishing the following development stages: (i) requirements and design, the study included the requirements' elicitation, and a general overview of the application architecture or some of the respective components; (ii) 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); (iii) 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; (iv) pilot testing, the study included a real-world evaluation by end users in their daily context during a certain period; and (v) mature, the study included an application that has been tested by end users, amended in some way and that is ready for deployment.

3. Results

3.1. Selection of the Studies

The search of the studies to be included in this scoping review was conducted in February 2022. A total of 12086 references was retrieved from the initial search: (i) 1026 references from IEEE Xplore; (ii) 7035 references from Scopus; and (iii) 4025 references from Web of Science.

Table 1 presents the results of the three steps of the articles' selection. The initial step of the screening phase yielded 7526 references by removing duplicates, references without abstracts or authors or not written in English, and references reporting on reviews or surveys. Based on titles and abstracts, 7485 articles were removed since they reported studies not relevant for the specific objective of this scoping review. Finally, the full texts of the remaining 41 articles were screened and 12 articles were excluded because they did not meet the outlined inclusion and exclusion criteria. Specifically, four of them [27-30] were excluded because they report on studies also reported by more recent articles that were considered for inclusion. Therefore, 29 articles were considered eligible for this scoping review [31-59].

Table 1. Number of articles removed during the three screening phases.

First screening phase		Number
	Duplicates	2431
	Without abstract or authors	326
	Reviews or surveys	1788
	Not written in English	15
	Number of articles excluded in the first screening phase	4560
Second screening phase		
	Out of context	7485
	Number of articles excluded in the second screening phase	7485
Third screening phase		
	Extended abstracts	2
	Reported on studies covered by other articles	4
	Out of context	2
	Number of articles excluded in the third screening phase	12
Inclusion		
	Number of articles included in the review	29

3.2. Demographics Characteristics of the Studies

In terms of publication types, 11 studies were published in scientific journals [31,32,37,38,44,51,54-59], being the remainder 18 published in conference proceedings. The included studies were published between 2013 (i.e., one studies) and 2021 (i.e., six studies), but more than 50% of the studies were published during the last four years.

In terms of geographical distribution, Europe has the highest contribution, with 15 studies (i.e., Italy, four studies [32,35,51,58], France, two studies [31,36], Germany, two studies [37,46], Greece, two studies [42,52], Latvia, one study [53], Romania, one study [43], Serbia, one study [56], Spain, one study [34], and Switzerland, one study [54]). In turn, Asia has contributed with six studies (i.e., China, one study [55], India, one study [33], Saudi Arabia, one study [39], Singapore, one study [40], South Korea, one study [48], and Thailand, one study [49]). Finally, North America and South America have contributed with four studies each (i.e., USA, three studies [38,50,57], Canada, one study [45], Brazil, two studies [41,47], Ecuador, one study [44], and Mexico, one study [59]). Regarding the wide-reaching networks between research institutions, only seven studies (i.e., 24% of the included studies) reported on the involvement of multinational teams: Germany and Switzerland [37]; Greece and Cyprus [42]; Romania and Italy [43]; Brazil and Italy [47], Switzerland and United Kingdom [54], China and United Kingdom [55], and Mexico and Brazil [59].

3.3. Purposes of the Studies

All the included studies were focused on the development of the crowdsourcing mechanisms. Some of them were focused on the development of generic crowdsourcing platforms (i.e., [32,34-36,38,40,42,49,53]), while others were focused on the development of crowdsourcing platforms with specific objectives [37,39,41,44-48,50-52,54,56-58], namely infrastructures' maintenance [57], crowds management [37,39], acoustic pollution [44,56], air pollution [51,54], air and acoustic pollution [52], online complaint management system [46], urban mobility (i.e., cyclists on their daily trips [41], accessibility [45] patterns determination [47], safety of commuters in urban areas [50], and intelligent transportation [58]). Moreover, a third group of studies were focused on the development of specific components for crowdsourcing platforms [31,33,43], including aggregation and validation of crowdsource data [31], determination of the quality of the citizens' reports [33], determination of the confidence level of citizens contributing with reports [43] and analysis of social media data [55,59].

Concerning the objectives of the crowdsourcing campaigns the following objectives were identified:

- Citizens' perspectives about the city [55].
- Urban infrastructures' maintenance [31,33-35,40,42,46,49,57].
- Not specified urban issues [53].
- Geographical information [32,48].
- Crowds' management [37,39].
- Environmental monitoring [36,38,44,51,52,54,56], namely air pollution [36,51,54], air and acoustic pollution [52], acoustic pollution [44,56] and not specified [38].
- Urban mobility [41,43,45,47,50,58,59], including traffic monitoring [58,59], recommended routes [43], accessibility [45], urban mobility patterns [47], to help cyclists on their daily trips [41], and to improve the safety of commuters in urban areas [50].

3.4. Characteristics of the Crowdsourcing Campaigns

To fulfil the objectives of the crowdsourcing campaigns, citizens were asked:

- To report on their perspectives (i.e., participatory reporting) about (i) the city [55], (ii) the maintenance of the urban infrastructures [31,33-35,40,42,46,49,57,58], (iii) the urban mobility (i.e., accessibility [45], best routes [43], safety [50], and urban traffic [59]), (iv) geographical information [48], and (v) not specified urban issues [53].

- To participate in sensing campaigns (i.e., participatory sensing) related to (i) crowd management [37], (ii) environmental monitoring [38,39,44,54,56], and (iii) urban mobility patterns [47].
- Both to report and participate in sensing campaigns (i.e., participatory reporting and participatory sensing) on (i) environmental monitoring [36,51,52], (ii) crowds management [39], (iii) geographical information [32], and (iv) urban mobility [41].

To guarantee the engagement of the citizens, a small percentage of the included articles (i.e., [32,33,42,49]) refer the encouragement of the citizens, namely using gaming mechanisms (i.e., [42,49]). The study reported by [32] adopted a simple threshold-based incentive mechanism that associates a certain score to renew the smartphone or data bundle leases, while the study reported by [33] considered different types of incentives that may include monetary rewards, civic recognition and discounts in city owned facilities such as zoos, museums, or parks. In turn, [42,49] incorporate gaming mechanisms that stimulates rivalry through scoring systems, in which the citizens are rewarded with points for the submission of valid requests or loose points when they make misleading or fake reports [42], and might be promoted to a higher level or get new badges [49].

3.5. Maturity Level

Concerning the maturity level of the included studies (Table 2), nine were classified as requirements' elicitation and design, 13 focused on the technical testing, two include prototype evaluations involving end users, three presented pilot tests, and two report the utilization of mature solutions.

Table 2. Maturity level of the proposed solutions.

Maturity Level	**References**
Requirements and design	[34,36,37,39,45,48,50,52,53]
Technical testing	[31,33,35,38,41,43,44,47,54-56,58,59]
Prototype testing	[40,41]
Pilot testing	[32,49,57]
Mature	[46,51]

Looking specifically for the more mature solutions (i.e., solutions being object of pilot testing or solutions classified as mature), different types of assessment were performed: (i) [5] reported a field trial involving 150 students to determine the percentage of successful completion of predefined tasks; (ii) [49] reported an open participation of 548 citizens during two months to determine the number of identified problems and comments; [57] reported the involvement of an unspecified number of students to analyze the effectiveness of the software design; (iv) [46] presented the results of the use of and roads maintenance application (i.e., the FixMyStreet application) since 2007 to 2018, namely in terms of number of reported problems and the number of problems that were fixed; and (v) [51] reported a long term experience with the participation of 500 students and teachers involved in citizen science activities to determine the quality of the measurements.

4. Discussion and Conclusion

Considering the demographic characteristics of the included studies, is possible to conclude that there is an increasing trend over the years (i.e., more than 50% of the articles were published during the last two years), and Europe has the highest contribution in terms of geographical distribution, since more that 50% of the included studies were published by European researchers.

Although it is always possible to point out limitations about both the chosen keywords and the databases that were used to retrieve the articles to be included in this scoping review, the authors follow rigorous methodological procedures, which allow to draw some conclusions considering the research questions that were formulated.

In what concerns the first research question (i.e., the purpose of the studies using crowdsourcing technologies in the context of the smart cities' implementations), the results point a current interest in developing crowdsourcing

platforms or crowdsourcing components to: (i) support urban infrastructures' maintenance; (ii) facilitate urban mobility; (iii) monitor the environment; (iv) manage crowds; (v) aggregate geographical information; and (vi) collect citizens' perspectives about the cities.

Concerning the characteristics of the crowdsourcing technologies being used (i.e., the second research questions) both participatory reporting and participatory sensing were reported by the included studies. Participatory reporting has mainly been used for urban infrastructures' maintenance and to facilitate urban mobility, while participatory sensing has mainly been used for environmental monitoring. In turn, incentive mechanisms to promote the participation of the citizens were only referred by few studies (i.e., four studies).

The results also show the low maturity level of the proposed solutions (i.e., the third research question) since a large percentage of the studies are related to requirements and design or technical testing. This results in a lack of consolidated evidence about the effectiveness of the proposed solutions, which is in line with other reviews related to smart cities (e.g., [60,61]), but difficulties the dissemination of these solutions. Therefore, this scoping review point to the need of future research to consolidate evidence about the effectiveness of crowdsourcing solutions to promote citizens' participation in smart cities.

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