A close look at Citizen Science through the HCI lens: a systematic literature review

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Abstract. In this paper, we present a systematic literature review of Citizen Science (CS) research projects with a focus on Human-Computer Interaction (HCI) and on the modalities in which CS is employed in this field. The query was conducted in March 2022 and provided us with 929 items, of which 646 were research articles. Through the usage of the PRISMA flow diagram, we included 27 papers in our survey. We aim to depict the state of the art regarding CS projects that are directly supported and explicitly defined by the HCI community. We compared the studies on variables like the field of interest and the impact area. We present the mutual interests of CS and HCI, the tools, and the methods that are employed to address these projects. Eventually, we conclude by pointing out some reflections on the value that can sprout from properly employed CS in HCI research.

Keywords: Citizen Science · HCI · Systematic literature review · ECSA.

1 Introduction

Citizen Science (CS) is an old practice. Some researchers claim that it goes back at least a couple of millennia, when, in ancient China, migratory locusts frequently destroyed harvests, and residents have helped to track outbreaks for some 2,000 years [1]. In more recent times, a relevant project is the Christmas Bird Count. In 1900, Frank Chapman, an ornithologist at the American Museum of Natural History, proposed an alternative to the "side hunt", a popular activity in New England towns on Christmas Day. He encouraged citizens to go out and count the birds they saw instead of shooting them. Chapman pioneered a methodology for having citizens record the abundance and distribution of birds for particular areas, and his tradition is still alive today [41].

To see the term citizen science used for similar projects, we needed to wait until January 1989, when it appeared in an issue of the MIT Technology Review. The article, titled 'Lab for the Environment', covers - as an example - Audubon's recruitment of volunteers in a 'citizen science' [23]. After this first appearance, CS started gaining a lot of attention from different research fields, and several definitions were coined. Some of them are focused on the method, such as the one of Rick Bonney, an ornithologist, who proposed CS as a method to collect scientific data through public effort in collaboration with professional scientists [3]. An alternative definition was proposed in 1995 by Alan Irwin, a sociologist. He focuses on the expertise retained by those who were canonically considered 'ignorant' (Irwin, 1995 in [3]). In this sense, CS is considered a skill or a quality that is intrinsic to the individual. Looking closely, we can see that both these definitions are limited if considering the value that CS adds to scientific research and to those who participate in these projects [18]. On the one hand, such added value is found in the expertise and collaboration with non-academic citizens, whose different backgrounds and interests can spark innovation or shed light in previously ignored directions. On the other hand, participants can find in CS an opportunity for self-development by learning about scientific methods and techniques [2][34], deepening their interest in the topic of the project [18], and by taking part in a community and creating social relations [6]. Given its multifaceted nature, a common, precise definition is missing. This issue can be linked to the widely different natures and objectives that the single projects have between them. Hence, it is not easy to find a one-size-fit description.

In light of this, in 2015, the European Citizen Science Association (ECSA) working group on 'Sharing best practice and building capacity for citizen science' proposed a broader definition of the CS paradigm. The result is a document outlining the "10 principles of Citizen Science" [11] that, for the first time, tried to define CS from a variety of perspectives, nuancing for the best the different aspects of the paradigm, going beyond the methodological elements and including its educational, scientific and social features. This is aligned with the HCI interest in better understanding how to approach CS, and it does so by addressing different challenges [35]. First, community relations and participants' engagement in the project [38]. Second, scientists ask for data, in both quantity and quality. Hence, data management is an important topic that spans from teaching the volunteers to gather and handle data, to understanding how to make sense of data, for example, through data visualization [49]. In this regard, a further objective is to promote Open Science. This means granting access to both science-in-the-making as much as its results [40]. Moreover, technological innovation is the avenue through which Citizen Science is thriving, providing tools (i.g. smartphones, sensors, CS platforms, social media, blogs, and more) both to conduct CS activities and to share the resulting knowledge [29]. Keeping in mind the HCI lens and CS principles, it is possible to preserve open science qualities such as education, self-development, democratic policymaking, and scientific research. In such a heterogeneous scenario, design can occur through different processes, enabling user-centered design, participatory design, and research through design [35]. By addressing cultural issues and social characteristics of the case/group of interest, it is possible to develop successful tools that can meet the participants' explicit needs as well as the hidden ones that recall upon their habitus [4], which is the set of behaviors, preferences, and ways of thinking that shapes who we are and how we navigate the world, often without us even realizing it. HCI, as we will discuss in this paper, seems to be following this lead with its studies in regard to CS projects. For these reasons, these 10 principles can be used as "a framework against which to assess new and existing citizen science initiatives with the aim of fostering excellence in all aspects of citizen science", as stated by Robinson et al. [37].

Driven by the interest that the CS paradigm is gaining from the HCI community, in this paper, we intend to provide a critical review of how HCI is embracing CS as a new paradigm for collaborative and voluntary participation of people in scientific research. In this regard, digitalization and the use of innovative technologies have a relevant impact when considering modern CS projects, opening new interesting research challenges in HCI [35].

2 Related work

In this section, we present the current landscape of CS literature surveys and their specific topics of interest. We report surveys with interest in CS per se and also in the shape it takes within the HCI field.

Methods for Design. HCI literature often revolves around the design of technologies and software programs to support different CS communities. Specifically interested in the user-centered design of technology within the context of environmental digital CS, [43] develops a set of guidelines to ask citizen scientists about their desire for new technologies or useful features that may help them in their research. They suggest that this field is still a novelty, and many included studies report direct feedback from the participants of their own projects. Another study surveys the literature about methods to properly tackle user-centered design for CS whilst creating a list of already existing tools used in CS and evaluating their mode of use in the different types of projects [42]. In this scenario, HCI expertise coupled with "the widespread availability of smartphones and other Internet and communications technologies (ICT) used for collecting and sharing data" [35], constitute a fertile environment for collaboration with citizen scientists and great opportunities to design innovative tools for Open Science, scientific research and bottom-up policymaking processes.

Data validity and scientific communication. A topic of interest in the literature is the perception of CS as an established and valid scientific framework by the wider academic and scientific world. In their literature review, Wang et al. [50] draw a picture of the projects interested in urban biodiversity that makes use (or not) of CS-gathered data. This study contributes to the CS and HCI literature by highlighting the dynamics of contemporary engagement between citizen science and urban ecology. They focus on the necessity for design in terms of optimization of CS programs to facilitate communication and collaboration with the broader scientific community.

Impact. The educational aspect is also addressed by studies like [34] and [2]. In the first study, information about the effects of biodiversity sensitization is collected from different sources. As a result, the authors reported that people actively involved in CS are subject to a growing sensitization toward biodiversity and sustainability, furthermore, they are also improving their personal knowledge regarding scientific methodologies [34]. The second study confirms that even when citizen scientists take part in online projects, they are subject to the same positive effects regarding scientific knowledge [2].

Our systematic review positions itself in what - to the best of our knowledge - we consider an unexplored issue, that is, how effectively HCI studies make use of concepts and practices of CS.

3 Methodology

In this section, we first define the research questions (RQs) that drove our literature review. In doing that, we better explain why we decided to exploit the ECSA 10 principles as a framework to assess CS projects. Finally, we describe the process we employed to select and analyze the papers.

3.1 The research questions and the ECSA CS principles

The objective of this survey is to address the interests of HCI in CS. In particular, we intend to address the following broad research question (RQ):

RQ0 How are CS projects addressed within the HCI field of research?

To answer this RQ, we first needed to define what a CS project is. For this reason, we decided to exploit the ECSA 10 principles of citizen science [11] as our main framework to assess the validity of the eligible papers. The ECSA 10 CS principles are the most widely recognized guidelines for defining CS projects [37]. The 10 principles are reported in Table 1. This framework enabled us to keep a focus on what can be considered CS and what not, strengthening our selection process by giving both consistency and adaptability. This may seem a strict assessment method if applied to a broad field like HCI. However, as argued in the paper, nowadays, the ECSA principles seem to be the more comprehensive framework to assess a CS project, overcoming the lack of a clear and shared definition of what CS is.

In light of this, we refined the RQ0 as follows.

RQ1 Are CS projects addressed within HCI respecting the ECSA principles?

Then, we narrowed our analysis to two sub-research questions, as follows:

RQ1.1 In which field of interest do CS projects addressed by HCI studies operate?
RQ1.2 In which impact area do CS projects addressed by HCI studies operate?

To answer these questions, we focus our discussion on three main themes: CS score, field of interest, and impact area. Namely, i) CS score is an indicative scoring system that is achieved by adding the number of ECSA principles that are tackled in a given paper that describes a CS project; ii) the field of interest represents the main topic of the project presented by the paper; iii) the impact area indicates the geographical level at which the project is operating.

The 10 principles of Citizen Science
1. Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding.
2. Citizen science projects have a genuine science outcome.
3. Both the professional scientists and the citizen scientists benefit from taking part.
4. Citizen scientists may, if they wish, participate in multiple stages of the scientific process.
5. Citizen scientists receive feedback from the project.
6. Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for.
7. Citizen science project data and metadata are made publicly available and where possible, results are published in an open-access format.
8. Citizen scientists are acknowledged in project results and publications.
9. Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.
10. The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data-sharing agreements, confidentiality, attribution and the environmental impact of any activities.

Table 1. The ECSA 10 principles of Citizen Science

3.2 Query specifics

We performed a systematic review of the CS literature by searching the Association for Computing Machinery (ACM) Guide to Computing Literature. According to ACM, the ACM Digital Library is the most comprehensive bibliographic database in existence today focused exclusively on the field of computing[3]. Hence, we used the advanced research tool to conduct the query. Here, we report the specifics of our query:

> 'Search Within' >Anywhere: "citizen science" OR "citizen scientists"; 'Publication Dates' >Custom Range: From January 2012 - To January 2022.

This query resulted in 929 items. By keeping research articles only (peer-reviewed conference and journal articles), we reduced this number to 646. In the following paragraphs, we discuss how the selection, classification, and analysis of the data have been conducted.

3.3 Data analysis: from screening to included articles

The screening process followed the PRISMA 2020 guidelines [31]. The 646 papers went through a skimming process to assess their relevance, where the minimum requirement was to include the phrase 'citizen science', 'citizen scientist' or 'citizen scientists' within their title, abstract or keywords. The process was not automated; all the abstracts have been read to ensure the inclusion of works that may

[3] https://libraries.acm.org/digital-library/acm-guide-to-computing-literature

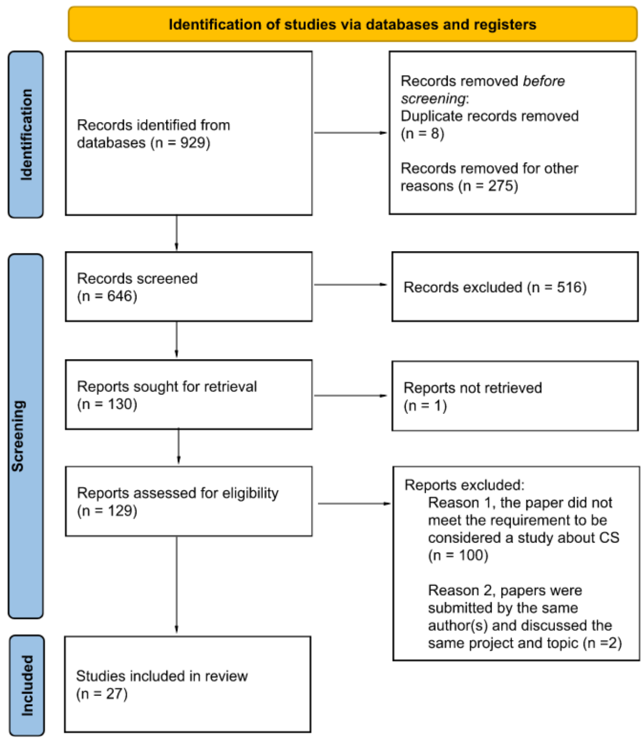

Fig. 1. PRISMA chart and details of exclusion

have differently phrased CS-related concepts. Furthermore, to assess the validity, in case of uncertainty, the process was extended to the discussion and conclusion paragraphs. The skimming process resulted in a selection of 129 papers. These papers then underwent the categorization process. The 129 selected papers have been fully read and classified in a spreadsheet for the following characteristics: CS score, field of interest, and impact area.

In order to be included in this study, the articles had to i) refer directly to a CS experience, ii) describe software and tools that have been tested in the CS project (or for future implementation), and/or iii) present methodologies for future and innovative CS work.

It is important to note that the whole process considered what was stated in the papers rather than the CS project to which they referred. For instance, if a study reported that the participants collected data, we assume that they only took part in that research phase, therefore excluding further involvement in other phases of the process. This choice was made in the interest of an objective survey; in this way, we can avoid making assumptions about non-reported items.

After the screening, 27 papers remained for the last phase of analysis. In this phase, all the papers were processed once more by reading them and comparing them with their entries in the spreadsheets to ensure the correctness of the analysis. No major changes were made. Two papers were excluded because they were from the same authors and they discussed the same issues or simply because they were the same papers found in two different editions.

The final selection includes 27 papers, distributed evenly between 2016 to 2021, with 3 publications per year (4 in 2017), while only one paper per year during 2015 and 2014, the remaining 6 papers were published in 2013.

4 Findings

This survey is structured around dimensions that have been used to categorize the papers included in the review: field of interest, CS score, and impact area. In this section, in order to answer our RQs, we discuss the classification of the papers and draw a picture that describes the overall set of included studies.

4.1 Field of interest

The field of interest is a relevant dimension as it depicts an image of the interests of HCI for CS. We identified seven fields of interest: education, biodiversity, environment, sustainability, health, policy, and equality. A single project may fall into different fields of interest, nonetheless, we opted to indicate the main area of contribution of the project. In Figure 2, we can look at the distribution of studies based on their main field of interest. The topics of major interest are education, environment and biodiversity. CS has great literature on projects about biodiversity and environmental topics, and it is renowned for its achievements in such areas. Meanwhile, education studies seem to be rooted in the interest in the innovation of technologies for communication (HCI). Furthermore, six out of seven papers interested in education have been published between 2017 and 2021, hence making this thematic a novelty in the field of HCI studies that make use of CS as their main research paradigm.

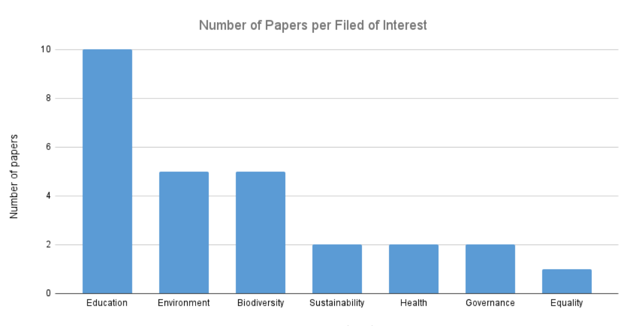

Fig. 2. Distribution of paper for main field of interest

All the considered papers share a degree of interest in multiple areas of impact like the study presented in [19], which edges between environment and policy. Therefore, the aim of this subsection is to provide a representation of interests' distribution of the included studies, whilst keeping in mind that the interest of a project is rather nuanced than fixed. We will discuss in-depth the three fields of interest which are covered by the highest number of studies, and later we will discuss the remaining ones.

Education All the projects within the realm of education drift toward Open Science, looking into granting access to citizens in the development of the scientific community. The included studies tackle open research from three major standpoints: (i) innovative research questions, (ii) open science and knowledge creation, and (iii) self-development and growth opportunities.

(i) Projects that are looking to generate new ideas for interesting research questions are collaborating with citizens because they find value in the great variety of perspectives, expertise, knowledge levels, and cultural and social backgrounds of the participants. In project experiences like Gut Instinct [32] and Docent [33], the volunteers cover a central role, and the participation is open to everyone without any expertise ceiling. In fact, their objective is to let innovation and creative ideas stem from profane contributions around scientific research topics. The heterogeneity is the element that brings value and validity to these methods; this way the unpredictability of the discourse can facilitate out-of-the-box thinking processes.

(ii) Open science is one of the main objectives that citizen science tries to achieve with its research ethic. The projects falling in this area create opportunities for the citizen to access culture and knowledge, while through their active involvement, they can also help in preserving and sharing [47]. In these projects, citizen scientists' role is particularly variegated and foresees their engagement in an array of different tasks. For example, in the ExploreAT! project, the citizen is involved from the very beginning of the design and throughout the multiple stages of the research process, contributing to participatory experiments, common idea-collection, and testing and evaluation of existing prototypes and research tools [16]. The ExploreAT! platform links cultural knowledge to folklore artifacts present in museums, enabling citizens to access culture through digital experiences. Therefore, the platform functions as a tool to give everyone open access to culture and knowledge. In the same fashion, Interlinking Pictura [47] is digitalizing a piece of cultural heritage in the form of a wiki-style platform. The opera is by F. J. Bertuch (1790-1830), and it is called Bilderbuch für Kinder (illustrated book for children). With this project, retired teachers, researchers, and autonomous associations are trying to create an interlinked corpus about Bertuch‘s illustrated book by connecting the distributed knowledge about its creation, reception, and usage in pedagogical practices [47]. These projects are dedicated to preserving folklore and cultural heritage, whilst in the meantime creating opportunities to further promote open science, also beyond active participation in the projects themselves.

(iii) The production of knowledge, open science, and research skill development can bind together and foster self-development and growth opportunities, as in the Wikipedia Classroom Experiment [5]. Within this experience, classrooms of students conducted research and wrote Wikipedia articles. After experts' reviews and polishing, they have been published on the famous website. Following this example, there are other projects that enable citizen scientists to be authors other than researchers, like the Crowd Research project [46]. Through a system of peer credit allocation, participants are recognized for their merit as citizen scientists in direct proportion to the quantity and quality of their efforts and production. Through this system, citizen scientists can improve their skills in article writing and reviewing and can gain credibility through the acknowledgment of their contributions in publications. A similar approach was investigated In Trento (Italy), where researchers involved schools, students, and the general public in practical experiments to learn firsthand about ICT, with the aim of reducing the digital divide and furnishing basic knowledge for the use of digital tools, both for personal use and scientific research [12]. Lastly, Interactive cloud experimentation for biology [20] present a cloud experimentation architecture to share and execute many experiments for chemotactic experiments in parallel, remotely, and interactively at all time. Its versatility allows for integration with various biological specimens and tools to facilitate scalable interactive online education, collaborations, research, and citizen science [20]. This paper addresses education at an advanced level, and it aims at reducing the skill gap that citizens have to face when approaching biology projects for citizen science, therefore pursuing education for a specific target and reason.

Generally, projects that are addressing education as their first area of interest tend to focus on the volunteers' direct and lived experience to flourish. The very nature of educational projects stands within the fulfillment of the participants and of the general public that they address, rather than on external factors (e.g., natural science projects).

Biodiversity and Environment Biodiversity preservation (5 papers) and Environment (5 papers) are the second most addressed issues within the considered studies. Citizen Science is renowned for its efforts in natural sciences and attention to local fauna and flora. "The National Audubon Society's Christmas Bird Count had begun in 1900" [3] and it is canonically attested as the first experience of citizen science, while also starting a strong tradition of biodiversity preservation and research within the paradigm.

HCI is interested in these areas mainly to test technology that can support the data-gathering process. With a focus on the cultural embedment of new technologies in social practices, [48] within their study Making local knowledge matter, propose a smartphone application suited for non-literate people. Their application enables Mbendjele hunter-gatherers to "share their environmental knowledge in scientifically valid and strategically targeted ways that can lead to improvement in environmental governance, environmental justice, and management practices" [48]. Furthermore, poaching poses a great danger to biodiversity in the first place, but even to the population living in the territory, especially to children. The application supports the community in different ways and provides valid motivation for keeping it in use, rather than being a mere measurement tool.

Even in less extreme scenarios, cultural embedment of technology covers a key role, as affirmed by the authors of Listening to the Forest and its Curators [28] "findings from interviews with members of the biodiversity community revealed a tension between the technology and their established working practices". In fact, the activity within the biodiversity community is not reducible to data collection, especially considering that participation is on a voluntary basis and that many people take part to stay in nature. Hence, the interviewees lamented that the excessive presence and use of technology disrupted their workflow and general appreciation of their work in the field, as an integral part of it was annotating sightings in a diary or using paper guides. Finally, technology and tools that simplify tasks raised concerns among the Cicada Hunt community. It appears that such simplification of the processes can be potentially harmful to the research and to the cicadas themselves. The high number of non-properly-trained participants, attracted to the project by these tools, end up posing Cicada and their environment at risk, rather than supporting their preservation.

On the other hand, POSEIDON [36] brings a positive experience in terms of merging tourism with citizen science. This project will be later further presented, but here is worth noting that technology enhances the experience of tourists that are practicing whale watching by enabling them to hear live whale sounds, whilst in the meantime collaborating to create a database for scientific purposes. Biodiversity can be addressed by different groups of people and through different modalities, but its fragile nature demands attention from a design standpoint. In scenarios as the POSEIDON project shows, proper technological implementation can enhance both research and recreational activities.

Tool evaluations remain a key interest within the HCI field when discussing citizen science, the next studies present design evaluations about their software and platforms advancing suggestions and advice for future work. First, Planting for Pollinators [51] is a tool embedded in the BeeWatch platform. It provides precise information regarding the favorite flowers of the different species of bumblebees. Hence, citizens can make an informed decision about which plants and flowers to plant in their gardens and balconies to favor bumblebees during the pollinating season in their area. Second, Exploration of Aural & Visual Media About Birds Informs Lessons for Citizen Science Design [30] tested a tool to educate birdwatchers (with different levels of expertise) in recognizing aural and visual media. The tool revealed great enthusiasm together with some challenges for future work, nonetheless, the participants' feedback was positive, and over time engagement in bird recognition and education about their lives increased.

Overall, biodiversity preservation can happen in any environment. Forests, woods, oceans, urban neighborhoods, and more, such a variety poses infinite possibilities and challenges for tools and software developments in support of this kind of project. Nonetheless, a topic of interest remains how to create a sense of engagement and interest in the participants of a project. Within this paragraph emerged that cultural variables are key when designing tools for citizen science, but it is not the only element. It is in fact essential to devise tools based on the period and level of engagement of the volunteers, as it is possible to create long-lasting communities like in the case of Mbendjele hunter-gatherers or just one-time contributors as in the POSEIDON experience.

The environment is equally represented in the CS paper within HCI, and the topics span between extreme weather events [19], high-tide floodings [14], local environmental data monitoring [15], urban noise-pollution [7], and air pollution [21]. Within our publications pool, we find projects that are using apps and GPS to report extraordinary events [19][14] to keep records of such events and the relatively long time consequences. Apps are also used to monitor common variables such as noise [7] and smell [21] in the air, these projects' employment shows us two completely different approaches to a similar problem. One is to delegate detection to external and dedicated sensors [7] to gather data that can be used for policy making regarding urban noise pollution; the other one [21] gets rid of dedicated sensors and even further, doesn't use any sensors, but only the sense of smell of the people to address air quality in specific areas of the city. Different approaches are needed for different cultural realities, and with the work of [15] we see that the social embeddedness of technology can be also achieved by integrating the user in the process of design of the tools that will be used to gather and communicate data. The last three projects are approaching similar issues on a different scale of participation and with very different tools at their disposal, while the final objective is always data gathering for informed policy-making for the environment and the quality of life of those living in it.

Sustainability, health, governance, and equality The remaining fields of interest are scarcely discussed within the HCI community invested in citizen science.

Concerning health, Sharing heartbeats [10] describes the ambitious project that many countries tried to accomplish during the covid-19 pandemic: limiting covid-19 outbreaks by registering contacts with infected people through an application. Meanwhile, [27] study describes a mobile game that "harnesses the human computing capability to align multiple sequences of genomes and use the results to help geneticists to understand the genetic code".

Sustainability is mostly addressed by means of bottom-up processes. The first study reports homemade food science experience in local communities [26], arguing that the expertise generated by self-education and the use of everyday artifacts can shape the way in which science is perceived, explored, and made. The social value of technology can therefore spark innovation and generate useful approaches to more complex problems at a higher level of research, meanwhile enhancing citizen expertise and know-how toward scientific matters.

Similarly, technology can gain social value as demonstrated in another study where two communities engaged in a project with living sensing organisms [25].

The citizen scientists adopted the solution of using microorganisms as long-term technology to record pollution in their area.

Governance follows a bottom-up process within the citizen science community. BudgetMap [24] is a platform where citizens can tag government policies and categorize them according to the social area that they affect. This process allows for a better frame of the Budgeting plans and gives the opportunity to the citizen to learn about budgeting while in the meantime helping to reshape it depending on their necessities. Public transport is the focus of Data4UrbanMobility [45], a platform that collects data about urban pathways suggesting versatile routes and agile urban planning.

Finally, [39] proposes the concept of impromptu crowd science taking inspiration from the Bechdel-Wallace movement which seeks through a scoring system the level of gender equality in movies. The study theorizes the opportunity for "hybridizations between such impromptu crowd science and academic inquiries [to] stimulate crowd theorizing" [39]. Equality is rather difficult to address through citizen science, and although this paper is only theorizing a possible approach rather than describing an active project experience, we argue that it is important to give highlight the presence of such work in the collection of ACM Digital Library.

4.2 Citizen science score

In order to answer RQ1, we computed a citizen science score. This score does not represent the value of a specific CS project but represents the level of information that the authors of a given publication reported within their work, enabling the reader to understand how many of the ECSA guidelines have been addressed. After analyzing each paper, we assigned a score by checking the list of the 10 principles (one point per addressed principle). The sum of the points constitutes the final CS score, ranging from 0 (no principle addressed) to 10 (all the principles addressed).

As shown in Figure 3, 22 papers are above 8 in the CS score scale and each Field of interest has at least two or more papers above this threshold, except for Equality (which only has one paper). Three are the papers scoring 7 points based on the ECSA guidelines, interested in equality, biodiversity, and environment. The remaining two articles scored 6 and 5 points, respectively papers from the field of environment and education.

In the following subsections, we will present a detailed analysis of all the papers, in order to answer our sub-RQs in terms of (i) field of interest and (ii) impact area.

4.3 Impact area

Every project is characterized by its impact area, meaning the territorial level at which the project is working and the area it is expected to affect. This aspect highly impacts the socialization, communication, and approach to the research [8] [9] [17], therefore we decided to analyze and discuss differences in this regard

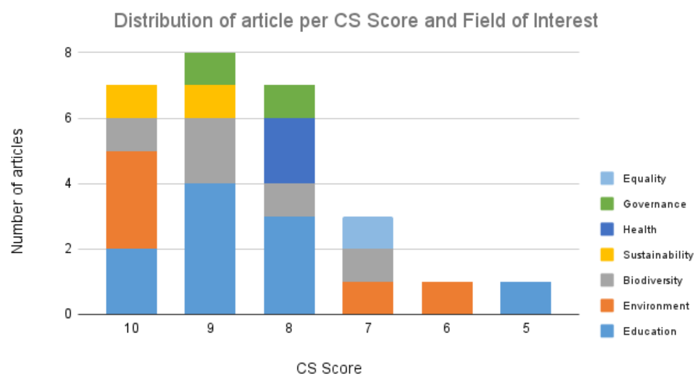

Fig. 3. Papers distributed per CS score and colour coded per field of interest.

within the literature. We identified four levels: i) local, ii) urban, iii) national, and iv) global. We also added a fifth level, tailor-made for a paper that has a theoretical focus and discusses a method for the 'scalability' of the project, starting from the local and expanding its reach with time and when other variables allow it. This fifth impact area was identified with v) scalable. Figure 4 presents the distributions of papers per impact area.

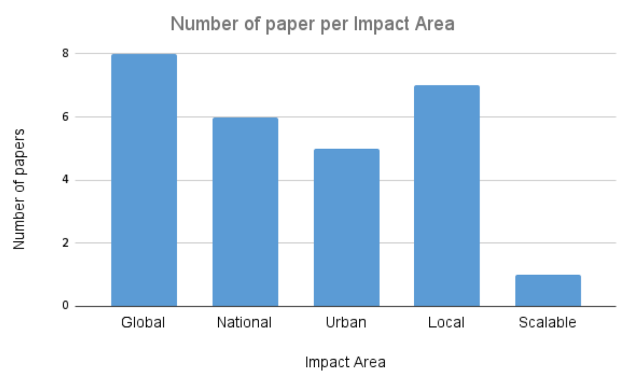

Fig. 4. Number of papers per Impact Area.

Local At this level, projects tend to work with the local population, where cultural heritage [15] [44] [26], local knowledge [48], the ability to work in small groups [28], are key to the development of the project and great booster for the community's cohesion itself. Furthermore, the local projects give immediate feedback to the participants, maintaining a high degree of both personal and communitarian investment. Volunteers that participate in these projects tend to get in direct contact and meet regularly, therefore, creating opportunities for the community to strengthen. The immediate feedback provided by these projects helps citizen scientists build a sense of accomplishment through their work. For example, during public workshops, as described in [15], the process of "Building a personal device leaves participants with the satisfaction of completing a project and building a craft. [. . .] This in turn can spark activism in communities". Finally, the pre-existent social relations may favor a deeper collaboration leading to greater social cohesion, therefore, helping to perpetuate the projects which often become independent institutions [13]

Urban The urban projects have a reasonable impact area, where projects' effects are perceptible by the individual, but the community tends to be lesser dense and its members don't always meet each other. The main moment of community bonding will happen during events rather than periodic meetings. Volunteers are likely to participate and contribute to individual work rather than organized groups. This picture is well-represented by the Smell Pittsburgh project where citizen scientists contribute singularly to the creation of the public database. Moreover, "there are typically two types of community data, which are generated from either sensors or proactive human reports" that contribute to the dataset of smells, but the focus of the two communities of data is different. As proactive human reports are mainly contributing to a representation of the lived experiences of the citizens affected by the different smells in the different parts of the city, therefore, qualitatively speaking, providing more detailed information about a given specific odor and area.

Proactive human reports are in fact mainly concerning projects that want to investigate social issues. Data4UrbanMobility project [45] makes use of the MiC app "to complement available datasets with intermodal mobility data (i.e., data about journeys that involve more than one mode of mobility)". The resulting database can be employed by the public administration for efficient city planning, given that D4UM focuses on data otherwise rarely available, for example, information regarding bike routes and others. This data can narrate the lived experience of citizens that navigate the urban environment in the most disparate ways. Similarly, with Smell Pittsburg project [22] participants contribute individually without participating in an active social community. Therefore, the effect of scientific research is perceived by the citizens, but the citizen scientists' community remains hidden.

On the other hand, there are experiences that keep a discrete degree of communitarian participation even in the urban environment. A great example would be A Maker Approach For The Future Of Learning [12], which through the maker philosophy and two FabLabs is actively involving schools and the general public to address and learn ICT.

National What characterizes these projects is the direct impact on the lives of citizens on a national levelUsually, ministries, governments, or other major national institutions fund or partially fund these initiatives. National institutions manage to address problems at a capillary level through the contribution of individual volunteers. By gathering information through crowdsensing or active reporting of specific pieces of information, these projects are used to dispatch a clearer image of a specific scenario to interested stakeholders, thereby enabling them to make informed decisions and favor more efficient policymaking. The case of 'Sharing Heartbeats' [10] is a current topic: covid-19 prevention. Such a project provides "citizens with the opportunity to share their health data from fitness trackers and smartwatches, with the aim to better record and understand the spread of COVID-19, detecting local fever outbreaks potentially associated with COVID-19" [10]. Within this project, the participants have a passive role, leaning towards the crowd-sensing paradigm; nonetheless, their participation was not limited to the data gathering, enabling them to take part in different parts of the project. Another example is BudgetMap [24]. This project enables taxpayers to tag government programs in order to classify them based on the social issues that they tackle. Furthermore, citizens can query these programs using the tag system enabling the government organization to follow the changes in public interests regarding policymaking. The authors show how "participants' awareness and understanding of budgetary issues increased after using BudgetMap, while they collaboratively identified issue-budget links with quality comparable to expert-generated links" [24]. Finally, another large-territory project is Damage Tracker [19] constitutes a database for research on tornados meanwhile it does also create a catalog of the damages caused in Alabama state. Hence, geo-tagging makes use of the expertise of the volunteers, facilitating location recognition given that they are often unrecognizable after such catastrophic phenomena.

Global This category, together with the local category, collects the highest number of citizen science-related papers in our survey. Usually, projects at this level are hosted within some major platforms like Zooniverse, iNaturalist, CitizenGrid, hackAIR, CAPTOR (and more). These platforms bring together millions of users around the world, contributing hugely to academic and scientific research. In this context, platforms, and software play a key role in citizen science projects. In fact, they constitute both the main instrument for data gathering and the mean through which the communities thrive. These communities are mostly 'virtual' communities, similar to projects at national levels the individuals do not know each other personally, and public events for meetings are not common within these kinds of communities.

Furthermore, the effects of the research have no direct impact on the lives of the participants. In fact, the aim of the projects that work at this level is to create large databases (e.g., Galaxy Zoo, Foldit, iNaturalist) rather than improving the living situations of citizens in a specific territory as local, urban, and national projects tend to do. Even though there are exceptions to this scenario, POSEIDON [36] is a project that takes place in Madeira. The isle is one the principal location in Europe for whale watching. Here tourists can become citizen scientists during their excursions using the specific and appositely designed app. POSEIDON "goes beyond merely capturing acoustic data, deploying a novel on-board mobile application for augmenting the user experiences with real-time sound detection and classification of cetaceans" [36]. The result is a detailed dataset visualization openly available to environmental conservation authorities and the scientific community. This project manages to unfold at a local level while delivering results, and therefore impacting, on a global level.

In this category, we can find projects which focus on finding new ways to think about research rather than on data collection, classification, or analysis. Gut Instinct [33] provides an environment where 'profane' questions and answers are the center of attention, and through them, innovation and new ideas can be considered. Gut Instinct values the heterogeneity of the contributions that it can collect through the different backgrounds and perspectives of its participants. On a similar note, Docent [33] seeks to create scientific hypotheses starting from the lived experience of the participants, who, through an online learning architecture, provide system principles for people to brainstorm causal scientific theories [33]. The lens shifts even more towards the participants' expertise and research acknowledgment with Crowd Research [46]. All these experiences lead to innovation in the scientific and academic field, therefore impacting a worldwide community and engaging participants from all over the world.

Scalable This is the last impact area individuated even though it does comprehend only one study, we think it sets a valid discussion point about approaches to the citizen science methodology. In fact, the paper addresses a methodological discussion introducing "PLACE, an iterative, mixed-fidelity approach to Prototyping Location, Activities, Collective experience, and Experience over time in LBAGs" [5]. PLACE offers a protocol for projects that want to start at a local level and slowly expand their impact with the growth of the community and of the project's resources. One further strength of this protocol is that it does not rely on any kind of tool, software, or platform, and it is, therefore, applicable to any project.

5 Discussion

In this section, we present our reflections based both on the HCI perspective on CS and the findings of our systematic literature review.

As argued by Preece in her seminal work about HCI and CS, "HCI researchers can empower citizen scientists to dramatically increase what they do and how they do it" [35]. Even though she focused on biodiversity citizen science, she puts light on two main fields of interest where HCI specialists and citizen scientists can leverage each other's skills for positive change: (i) supporting the development of (sustainable) technologies to foster sustainability and (ii) contributing to educational efforts [that serve the environmental cause] through citizen science. This is actually aligned with our output, where, besides the clear interest of researchers in applying CS to projects about the environment, biodiversity, and sustainability, education through CS resulted in being a hot topic in HCI.

Preece envisioned four main topics (and the related challenges) where a research agenda on stimulating action across HCI and CS should focus: (i) community (participation and motivation), (ii) data (quality and issues about sharing, aggregating, and archiving), (iii) technology (deciding which technology to use, active data collection citizen science projects such as iNaturalist VS passive data collection with sensors, tracking devices, cameras, and drones, etc.), (iv) design (including privacy issues in terms of respect for persons, beneficence, and justice) [35]. In analyzing the literature about CS in HCI, we realized that most of the papers focus on at least one of these four macro areas. Nonetheless, our screening activity emphasized the fact that, even though all the studies mentioned CS, it was not possible to grasp the whole CS experience. In other words, it is not possible to assess if the community's engagement/the design method/the developed technology/the data model will actually succeed in a real word CS action. This claim is motivated by the fact that CS is a complex concept; several researchers and practitioners tried to define it without finding an agreement [35]. One of all, the fact that a strong discussion is still existing about whether crowdsourcing is or isn't a CS practice. We were able to overcome this issue by considering the ECSA 10 principles of Citizen Science as the framework to assess the studies. In fact, the ECSA principles provide guidelines to assess community, data, and design as integral parts of the CS action. On top of that, we added the technological aspect, which is crucial in HCI research [35]. Based on that framework, 100 papers were excluded, reinforcing the need for HCI researchers to better situate their study in the CS complex scenario.

Moving now to the 27 papers included in our systematic review, in general, we noticed a lack of clarity in defining if and how the participants can take part in multiple phases of the project (correlated to the community and design Preece's topics [35]). Nonetheless, from the majority, it is deductible by the research design and the general description of the results. A step toward affinity with CS definition by ECSA would be the implementation of participant demographic. Unfortunately, 14 out of 27 papers did not provide such information about their participants. Clarity about CS case studies would improve if authors included specific details about the number of involved volunteers and their demographic information. Furthermore, the considered papers lack a description of the involved communities and their nature (formal, informal, sporadic, or regular meetings). As it's been discussed throughout this systematic review, the relevance of the subcultural dimension is key for technology to be fruitfully employed in a group. Therefore, HCI studies would benefit from providing additional information regarding the social settings in which the projects unfold.

Finally, one of the strengths of CS is its capability to educate and help develop specific skills in its participants. Usually, this process is mediated by expert researchers that can overwatch the project. However, most of the papers did not address this issue in detail. For this reason, we suggest that research articles, especially those interested in studying and enhancing the level of engagement of citizen scientists, should pay more attention to the effects that their tools and methodologies can have in this regard.

6 Conclusions and limitations

This paper presents and discusses the results of a systematic literature review about CS in HCI studies within the ACM Digital Library, over the last ten years. A peculiar element of this review is the adoption of the ECSA 10 principles of Citizen Science as a framework to assess the pertinence of the studies to the concept of CS. The aim was to assess, through the use of such guidelines, the understanding and employment of CS practices within the HCI field. Applying the PRISMA method, we selected 27 papers that were categorized, analyzed, and compared through the HCI lens, which seeks to grasp the core features of the projects based on what we call 'CS score' (scoring system based on the number of the 10 ECSA principle addressed in a research article), 'field of interest' (the main topic of the project), and 'impact area' (geographical level of projects' activities). This framework highlighted the main qualities and interests of these studies while granting the integrity of the CS concept. Through our analysis, we pointed out the risk of inflation of the term citizen science, which is often used loosely, causing it to lose its significance instead of empowering the relationship between HCI and CS. This seems one of the consequences of the lack of a common definition of CS, that the ECSA guidelines can help to overcome. As a final consideration, CS has proved to be a great proving ground for breaking ground technologies and methodologies while promoting open research and bottom-up innovation processes. Our systematic review consolidates this view, suggesting taking a step toward better defining what CS is, granting the integrity of the core principles of this paradigm.

The findings of this study have to be seen in light of some limitations. (1) The major limitation of this systematic review is that the query was conducted on the sole ACM Digital Library. Therefore, even though it was our interest to consider only this part of the literature (considering the fact that most of the more relevant and well-established conferences and journals about HCI are published there), it is important to underline that, with this decision, we excluded potential HCI papers about CS published elsewhere. (2) Given the focus of this particular literature review, we preferred maintaining a stricter query, including in our study the article that actively and consciously referred to CS. In particular, we searched the ACM Digital Library by querying the terms 'citizen science' and 'citizen scientists'. This decision improved, on one side, the accuracy of our search, whilst, on the other side, it could make us miss some relevant contributions. (3) We are aware of the strict variables we adopted to select the papers in our final step, resulting in a limited sample of works. On the other hand, this should underline the importance of finding a proper and fitting definition for citizen science, given that applying the ECSA guidelines was the main reason for papers to be discarded.

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