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Original Article

Citizen Science Web for Asynchronous Urban Waste Reporting in North Lima

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Abstract *- The accumulation of solid waste in urban spaces in Lima Norte, Peru, represents a persistent environmental, health, and social problem, aggravated by the limited coverage of traditional citizen reporting channels. This article presents the design and preliminary evaluation of an asynchronous citizen science web model for the georeferenced reporting of urban waste hotspots, based on the Design Thinking approach and oriented to the methodological adaptation of an existing digital platform. The exploratory phase, based on a form applied to more than one hundred and eighty people, collected perceptions on knowledge of tools, platform preferences, assessment of citizen participation and attribution of responsibilities. Subsequently, technological alternatives were comparatively evaluated through a decision matrix and a georeferenced prototype was implemented with photographic capture, GPS coordinates and citizen comments, compatible with heterogeneous devices and operational under intermittent connectivity. Preliminary validation verified the functionality of the prototype and supported the relevance of adapting existing tools versus developing from scratch. The PDF reports addressed to municipalities are presented as a future line, conditioned by the maturation of the volume of data, the standardization of indicators and institutional articulation. The study provides a replicable model of urban environmental citizen science based on functional simplicity.*

Keywords *- Citizen science, Urban waste, KoBoToolbox, Georeferenced report, Design thinking, Urban environmental participation.*

1. Introduction

Urban solid waste management is one of the environmental challenges that still persist on a global scale, which is related to population growth, the expansion of consumption and the pressure of municipal collection and disposal systems [1, 2]. It has been evident in some countries that there are neglected areas with accumulation of waste, but they do not take the necessary actions to solve it since they do not realize that it not only deteriorates environmental quality, but also increases health risks, also affects social cohesion and reduces the perceived quality of the urban environment.

Likewise, findings in the recent literature have been able to agree that technocratic approaches are insufficient to address this problem, due to the need for complementary models that can integrate the citizen dimension [3].

Latin American cities present specifically complex conditions, which are associated with accelerated urbanization, territorial heterogeneity and budgetary constraints of local governments [4, 5]. In this context, waste has been shown to be in various parts of the country, often scattered in areas with less focus of attention or security, which makes it difficult to constantly monitor through the static institutional mechanisms that they may use. As a consequence of this, it generates a persistent gap, although the authorities record or keep information on the state of the cities, but this data does not always show the reality of the streets, which limits the ability to take action to act in time.

For example, in Peru, specifically in North Lima, which is a dense area which is constantly growing and with a very varied socioeconomic reality, illustrates that various urban points of garbage accumulation are frequent, but do not always reach the official records of the corresponding authorities.

However, when citizens want to report this type of problem, it is difficult for them to receive an immediate response since traditional channels, such as telephone numbers, face-to-face offices, or requests that are sent through emails, are cumbersome, impractical processes that rarely allow them to indicate precisely where the problem is [6, 7].

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That is where citizen science comes into play, since this approach presents a simple but very useful proposal, which does not even require technical knowledge to use it and can contribute to generating useful information to take care of its environment. This means that, with the support of accessible digital tools, any citizen can report a waste of garbage from their cell phone, with a photo and location, thus allowing them to provide concrete data that complement official records and strengthen environmental management [8, 9].

On the other hand, the problem of some existing applications has been shown to put unnecessary obstacles, such as having to download them, create an account, have a good signal and a cell phone with enough memory [10, 11]. In contexts such as Lima Norte, where connectivity is sometimes not always stable and devices are very varied, so these barriers could leave many people out. Also, developing your own platform from scratch is not viable for most projects either, due to the high costs involved.

Therefore, this type of gap is what this paper presents a proposal that seeks to address this type of problem. In addition, the scientific literature shows that there are few studies that have managed to combine simplicity of use, reporting from the browser without the need to install anything, as well as allowing you to capture photos, obtain geolocation and be low cost.

However, despite the growing use of digital tools for citizen monitoring and reporting on urban environmental problems, there is still a significant research gap. In addition, most existing technological solutions, such as mobile applications, require installation, registration and a stable internet connection, or some even rely on more complex geographic information platforms, access to which may be limited by high cost factors, technical requirements and the need for prior user training.

On the other hand, these limitations are relatively problematic in heterogeneous urban contexts such as the north of Lima, because the quality of internet connection, the characteristics of mobile devices, and the level of digital literacy of the inhabitants can vary significantly. Likewise, the scientific literature still presents few proposals that simultaneously integrate access through a web browser without requiring the installation of an application, geolocation of messages, upload or direct capture of photos, the ability to transfer data asynchronously, through unstable connections and low implementation costs. Therefore, the research gap lies not only in the lack of citizen reporting tools, but also in the lack of simple, adaptable and replicable models, particularly designed for the real conditions of Latin American urban areas. The novelty of the proposed study lies not in the development of a new digital platform per se, but in the methodological adaptation of existing technological solutions to adapt to the conditions of the ecological cycle of northern Lima.

Unlike approaches focused on specialized mobile applications, complex geographic information platforms or infrastructure-dependent, the proposed model of the study offers a single-process web access solution that does not require the installation, photographic documentation, georeferencing, storage and asynchronous transmission of data; It is also compatible with various devices and has low resource requirements.

In addition, this approach considers technological simplicity not as a limitation, but as a design advantage, which favors the reduction of barriers to participation and the increase of the applicability of citizen science in competitive environments.

Therefore, based on the gap found, the study aims to design and preliminarily evaluate a web model that allows citizens of northern Lima to report sources of garbage through a photograph and obtain the location of the waste, without the need to install any application or have limitations to access from any device. The idea or strategy is to offer an economical and adaptable tool that serves as a starting point to improve communication between residents and municipalities around urban waste management.

2. Related Works

2.1. Environmental Citizen Science and Participatory Monitoring

Citizen science is a topic that has been consolidated as a serious focus within environmental research, since it has been used with good results for the monitoring of biodiversity, air quality, water and waste, so there is more and more evidence that the data provided by citizens is really valuable [6, 7]. When neighbors report what they see in their environment, it is possible to cover areas and situations that the traditional systems used by municipal governments often fail to detect, and thus allow for a more complete and real picture of what is happening in the city [7]. But beyond the figures or numbers, this approach has another important effect, because people feel part of the solution, which would promote a kind of shared responsibility for the territory where they live [12].

In Latin America, it has been shown that the experience of international citizen science platforms demonstrates a clear lesson: that citizens continue to participate does not depend only on having good technology [13].

When technological tools are easy to use, people adapt quickly, use it in their context and connect with organizations in their areas, in this way, participation is sustained. When tools are simply developed and published without listening to the territory, citizens abandon it or stop using it quickly.

2.2. Digital Tools for Citizen Reporting

The various digital tools that exist for citizens to report urban problems are varied, but not all the options that are available to the public to use work the same in all contexts. For example, mobile applications always have to be downloaded, created an account and kept updated, which means a significant barrier in areas where the signal does not reach, or cell phones have little capacity [10, 14]. On the other hand, web platforms are more accessible because they are opened directly from any browser, but they do not always geolocate as well. In addition, specialized mapping tools are useful, but they also often require the user to have knowledge to use them [9].

A recent review of smart city applications found that most of the documented experiences are particularly related to citizen reports to identify urban problems [15]. And studies on global platforms such as CrowdWater in Latin America showed something not so new or out of the traditional, in which the user has to register but that takes up a lot of space on the cell phone and depends on a good connection, so these are the most common reasons why people stop using these tools [13]. All this suggests that the simplest is often the most effective.

2.3. Urban Waste Management and Georeferenced Data

In the field of solid waste, technology has advanced a lot, for example, there are sensors in containers, networks of connected devices, artificial intelligence models that can predict accumulations and even satellite images that can detect informal waste [1, 2, 16]. However, although they are powerful tools, many of them are expensive, and some municipalities simply do not have the budget to be able to buy or implement them, since some of them would cost to maintain. In addition, these solutions based on fixed infrastructure do not work well to detect sources of garbage that appear and disappear quickly, which is exactly what happens in many Latin American neighborhoods.

For this reason, georeferenced citizen reports appear as a very valid complementary alternative. When someone can report a garbage point with a photo, location and a brief description, that generates concrete and useful information for the authorities to act [12, 17].

The pending challenge is to ensure that this information reaches the municipalities well, with clear standards and established communication channels, something that is still under construction in many places.

2.4. Gap Identified

Despite all the in-depth research that has been done, there is something that is still missing, and that is the literature remains limited regarding in a single proposal the design designed for the user, where no installation is required, provides the option of capturing photos or taking a capture in real time, geolocation, low cost and the possibility of scaling towards real communication with municipalities.

Particularly in Latin American cities, most experiences have only focused on complex mobile applications or high-cost technologies, without exploring the potential of being able to adapt them to simple existing tools. That is the gap that motivates this study, since it is committed to simplicity, accessibility and practicality as its main strength.

Table 1. Comparison of related citizen science and urban reporting approaches

Study	Approach	Main contribution	Gap / difference
Cardoso-Andrade et al. [10]	Citizen science mobile apps	Identifies technological and behavioral factors influencing adoption	Focuses on adoption and engagement rather than asynchronous urban waste reporting
Hognogi et al. [11]	Mobile citizen science apps	Reviews mobile apps as tools for citizen participation and data collection	Broad mobile-app perspective; not focused on low-cost georeferenced waste reporting
Breitenmoser et al. [12]	Citizen science waste diary	Uses citizen-generated household waste data for monitoring	Focuses on household waste diaries rather than real-time georeferenced urban hotspots
Blanco-Ramírez et al. [13]	CrowdWater mobile app	Demonstrates community-based environmental monitoring in Latin America	Focuses on water monitoring and app-based participation
Bastos et al. [15]	Smart-city citizen applications	Reviews digital tools for reporting urban problems and supporting governance	Broad smart-city framework; limited focus on asynchronous reporting under unstable connectivity
Proposed study	Asynchronous web citizen science	Combines photo capture, GPS, cross-device access and asynchronous reporting for urban waste	Designed for low-cost deployment and heterogeneous connectivity in North Lima

Therefore, the proposed model differs from existing technological solutions in several interrelated aspects. While mobile applications for citizens to make their complaint often require installation, registration and stable connection, and specialized geo-information tools may require greater technical and economic knowledge, the focus is on reducing barriers for the end user.

In addition, the characteristic that distinguishes it is the combination of geolocated photographic reports, asynchronous operation, operability on various devices and the adaptation of the existing infrastructure to the local context. Consequently, the contribution of this study does not focus so much on the development of new software, but on the development of a replicable model for the implementation of accessible digital technology in urban citizen surveillance processes.

In order to provide a better understanding of the proposed approach with respect to existing research, a comparative analysis of the most relevant studies in the fields of digital citizen science, urban monitoring and citizen participation was carried out. As can be seen in Table 3, previous studies confirm the great potential of mobile applications, digital platforms and citizen monitoring; But its goals are specifically focused on user engagement, data collection, or supporting governance processes.

On the other hand, the study of the proposed application is distinguished by its combination of geolocated photographic messaging, asynchronous operation, access in different devices and adaptation to heterogeneous urban environments with low infrastructure requirements.

3. Methods

3.1. Study Design

This present work is an applied and exploratory study, aimed at the construction and evaluation of a web tool so that citizens can provide their report of garbage outbreaks in their home environment. To organize it, the Design Thinking approach was used, a methodology that allows a clear understanding of user needs, define the problem precisely, explores possible solutions, build a prototype to see if it really works [18, 19]. Therefore, this approach was chosen because in projects where technology has to serve people in the real environment, it is not enough for something to work technically; It has to fit in with the way people live and use digital tools in their day-to-day lives.

3.2. Study Area and Target Population

The study was carried out in North Lima, an urban area of Lima, Peru, with an average population density, but with constant growth and a very diverse socioeconomic reality. More than 180 residents of northern Lima participated in the research phase. Likewise, the people selected were neighbors and citizens in general interested in reporting garbage accumulation points near their places of residence or work. For this exploratory phase, a statistically representative sample was not sought; Participants were selected based on their accessibility, prioritizing that they could provide useful perspectives to understand the problem from within.

3.3. Methodological Phases based on Design Thinking

The study was organized into the five phases of Design Thinking, presented in Figure 1, where each phase produced inputs for the next, in a process of continuous and progressive learning.

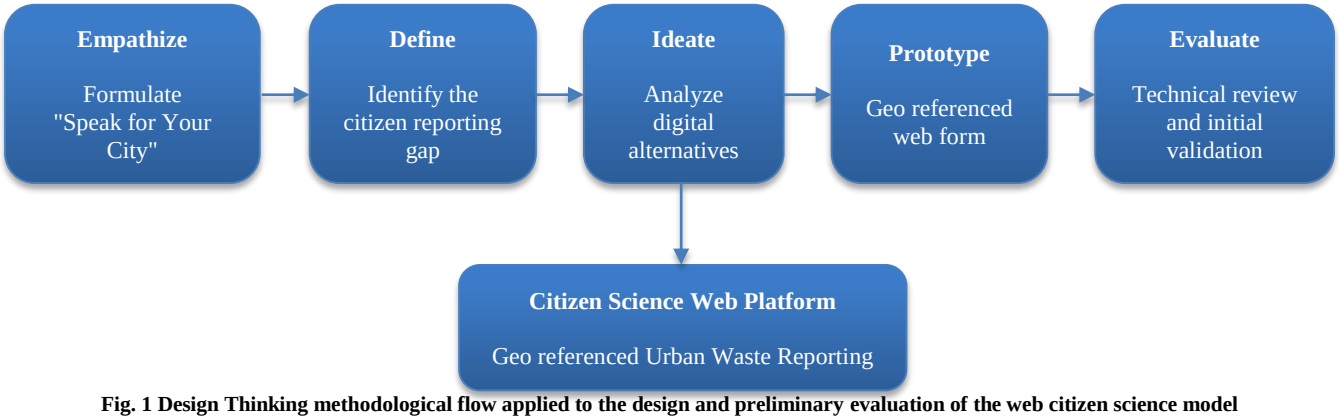

Fig. 1 Design Thinking methodological flow applied to the design and preliminary evaluation of the web citizen science model

1) Empathize: In order to understand the reality that each citizen is experiencing, a form was designed and applied in Google Forms entitled "Speak for your City", which was aimed at citizens and residents of North Lima. The instrument collected information on whether they know of tools for reporting urban pollution, what they would like to use by type of platform, the perception of the importance of citizen participation, how aware they considered themselves of the environmental issue and who they believed should be responsible for managing garbage. The details of the instrument are summarized in Table 1.
2) Define: Based on the information collected from the survey, functional needs and design constraints were

identified. Among the requirements that were considered included accessibility, ease of use, operation from mobile devices, the possibility of uploading an image or capturing it in real time, obtaining geographical location, that it did not depend on a stable connection all the time and that it did not put too many obstacles for people to be encouraged to participate.

3) Ideate: Different technological options were compared, such as web forms, mobile applications or even low-cost web platforms. To evaluate them, criteria such as ease of administration, whether it worked on different devices, whether it captured coordinates and photos, as well as whether it could operate without a continuous connection, how much it would cost to maintain, whether it was easy to scalable, and how easy it would be for the end user.
4) Prototype: For this phase, a functional form was built to record the photo of the landfill waste, the geographical location, a free comment and basic data of the report of the area. In addition, it was designed to send the information as soon as a connection was available, without losing what had already been completed. Also, the details of how it was implemented are explained in the results section.
5) Evaluate: Finally, a preliminary evaluation was carried out that included a technical review of the options analyzed, testing of the form on different devices, operational feasibility was analyzed, and a basic review of ethical and privacy aspects. For this, the technical review was carried out by an independent expert who had experience in environmental information systems.

Table 2. Variables of the citizen exploratory form "Speak for your City"

Dimension	Guiding question	Response Type	Purpose
Prior knowledge	Do you know applications to report urban pollution?	Closed (yes/no)	Estimate digital familiarity
Technology preference	What type of platform would you prefer to use for reporting?	Multiple Choice	Guiding channel choice
Participation	What importance do you attach to citizen participation in waste?	Ordinal scale	Estimate Disposition
Environmental awareness	How would you describe your level of environmental awareness?	Ordinal scale	Contextualizing perceptions
Attribution of responsibility	Who do you consider to be primarily responsible for waste management?	Multiple Choice	Mapping perceived governance

3.4. Ethical Considerations

Although this research did not collect medical data or involve any type of direct intervention on people, ethical aspects were considered from the beginning.

In addition, it was ensured that people participate in a voluntary and informed manner, special care was taken that the photographs uploaded did not allow any person to be identified, the location information of the participants was protected, the personal data was anonymized, and all the information collected was used only for academic and environmental purposes [20]. All the criteria follow what the specialized literature recommends using for digital citizen science projects and georeferenced participation.

3.5. Data Analysis

The responses to the exploratory survey were analyzed in a simple way: frequencies and proportions were calculated for each question. To compare the technological options, a decision matrix was used in which each alternative was evaluated according to the criteria defined in the ideation phase, assigning values according to its performance in each one. Finally, the preliminary validation of the prototype was based on documented functional tests and the opinion of the expert who reviewed the system.

In order to formalize the process of comparing technological options, each criterion was assigned with an ordinal score according to the degree of compliance with the requirements of the study. In addition, technologies that had favorable conditions received a higher score, while less favorable ones scored lower. The overall suitability of each technology option was determined as the sum of the scores of all the criteria that were considered.

$$s_j = \sum_{i=1}^{n} x_{ij}$$

The equation presented was used with the sole purpose of systematizing the comparative analysis, so it does not constitute a predictive mathematical model. Where (s_j) represents the global evaluation of the technological alternatives ($_j$), (x_{ij}) would be the evaluation of the alternative according to criterion ($_i$), and ($_n$) which would be the total number of criteria. Likewise, for the comparison, the need for

installation, the ability to obtain GPS coordinates and photographs, asynchronous operation, cost and scalability were taken into account.

4. Results

4.1. Results of the Citizen Exploratory Form

The survey "Speak for your City" received more than 80% responses, the results of which are summarized in Figure 2. First, the focus of attention was that most people had never used or known of any digital tool or application to report urban pollution, which means that most of them are not well marketed or disseminated about this type of tool among common citizens. When asked about what type of platform they would prefer to use, the web option was the one that won out over the traditional mobile app. In addition, citizen participation was valued as very important by the majority, although the level of knowledge about environmental awareness of the participants was mostly average, an interesting figure that indicates that there is a willingness to participate, but a more solid environmental culture still needs to be built. Finally, when asked who should be primarily responsible for managing garbage, the answer was municipalities, with very little mention of other actors.

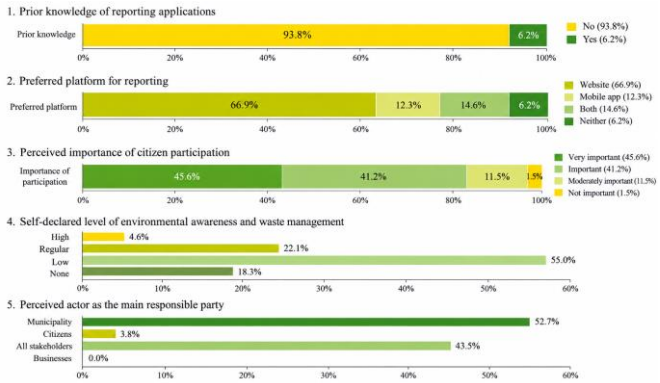

Fig. 2 Synthesis of the results of the exploratory form "Speak for your City" (n > 180 interactions)

Therefore, these results should be taken as a basis for making design decisions, not as definitive conclusions about the city of North Lima, because the sample was exploratory and not statistically representative. Therefore, the fact that the preference for web platforms, the high valuation of citizen participation and the attribution of responsibility to municipalities coincide gives a clear and coherent direction for the next stages of the project.

On the other hand, Figure 3 shows a heat map with the distribution of the various garbage accumulation points that were reported in North Lima. The darkest areas of the map are where the reports are most concentrated, which allows you to identify at a glance where the most frequent problems are. This shows that combining geolocation with citizen reports can be a very useful tool to understand how pollution is distributed in the city and to complement urban environmental monitoring.

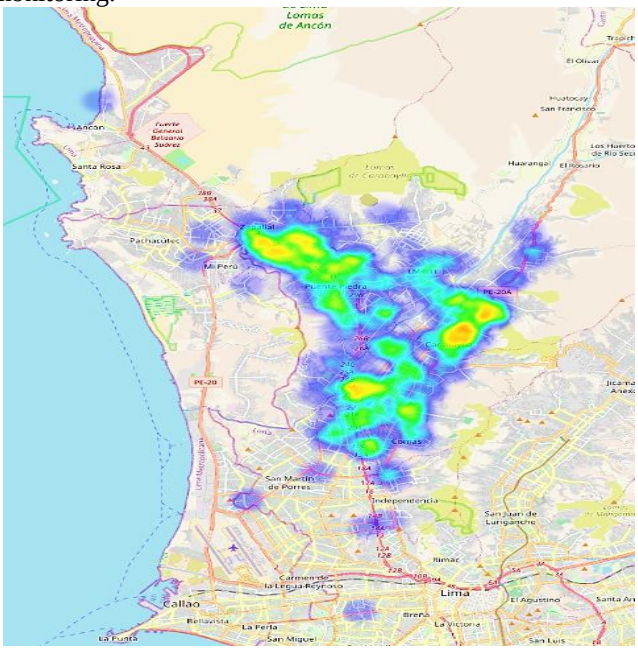

Fig. 3 Visualization by heat map of georeferenced reports of urban waste in North Lima

4.2. Comparison of Technological Alternatives

To select a viable technological option, the different alternatives were compared in a decision matrix whose results are summarized in Table 2. The comparative analysis showed, developing your own mobile application was quickly discarded: the cost is high, you have to install it, and that is already a major barrier for people to use it. Traditional web forms are more accessible because they open directly from the browser, but they have limitations when it comes to capturing GPS coordinates and do not work well when the connection is intermittent. Existing citizen platforms met several criteria, but their ability to scale or adapt to the local context was limited. And geographic information tools designed for fieldwork proved too expensive and complex for an average user without technical training.

Table 3. Comparison of technological alternatives according to design criteria

Alternative	Installation	GPS/photo	Asynchrony	Cost	Scale
Own mobile app	Mandatory	Yes	Possible	High	Media
Survey123	None	Partial	Limited	Low	Media
iNaturalist	Variable	Yes	Partial	Medium	Media
Field GIS tool	Media	Yes	Partial	High	Media
KoBoToolbox /KoBoCollect	None	Yes	Total	Low	High

After this analysis, KoBoToolbox was selected together with its KoBoCollect client component as the most viable and suitable option. This platform achieved the best balance between all the features that were required. It also already has a proven track record in environmental, health and humanitarian projects, which gives confidence in its technical soundness [21].

4.3. Prototype Implementation

The prototype was implemented as a georeferenced web form within KoBoToolbox, which can be accessed both from the KoBoCollect application and directly from the browser of any device (Figure 4). The form is simple and straightforward, and allows the user to take or upload a photo of the waste, capture GPS coordinates, write a comment and send everything to the server. It works on cell phones, tablets and computers, and is designed for when the signal is not so stable, in case there is no connection at the moment, the report is saved on the device and sent automatically when connectivity returns. The entire procedure is completed in 4 steps, making it quick and hassle-free.

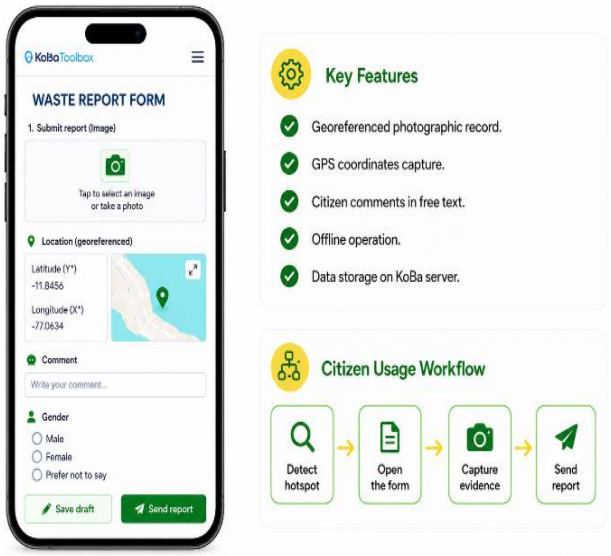

Fig. 4 Prototype of the georeferenced web form implemented on KoBoToolbox/KoBoCollect

Figure 5 shows some of the photos captured through the tool, and the truth is that they speak for themselves. Different cases of garbage accumulation can be seen in neighborhoods of North Lima, with notable differences between areas: some areas appear much more affected than others, especially those near roads and public spaces.

Beyond the data, these images provide a concrete and visual representation of the environmental situation that many residents face in their day-to-day lives, and make it clear why citizen participation is so important: without someone taking the time to report and photograph these points, many of them would simply go unnoticed.

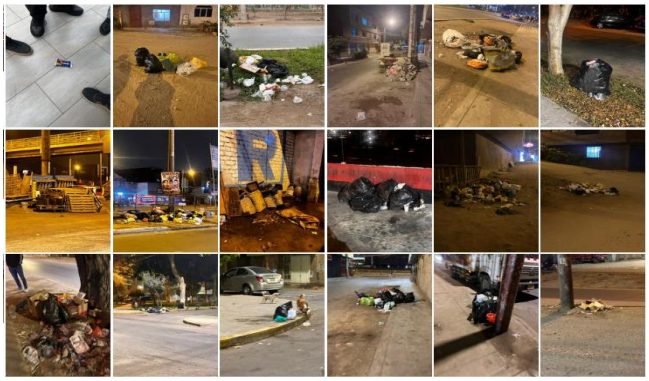

Fig. 5 Evidence of photographs uploaded through the app

4.4. Preliminary Validation

For the validation of the prototype, functional tests and a review by an external expert were carried out. In addition, the tests verified that the form captured photos correctly on different devices, that it recorded GPS coordinates with the accuracy that each urban environment allows, that the data was synchronized well, and that the offline mode worked as expected. It was also verified that the data could be managed without complications from the platform's dashboard.

The expert, a specialist in environmental information systems, compared this solution to the option of developing one's own platform from scratch and clearly recommended the adaptation of an existing tool, considering costs, maintenance, scalability and implementation time. That recommendation ended up confirming that the decision taken was going in the right direction.

Because the system proposed in the present study does not employ a proprietary predictive model, a specialized sensor, or an evaluation algorithm, no independent algorithmic calibration procedure was used. Since the acquisition of images and GPS coordinates was carried out through the standard functions of mobile devices and the KoBoToolbox/KoBoCollect platform. Therefore, the technical testing phase focused on correct photo captures, recording geographic coordinates, local data storage and subsequent synchronization after re-establishing the internet connection.

In order to evaluate the operation of the platform, functional tests were carried out under normal conditions of use, so that, in this way, the basic operations of the prototype can be validated. In addition, the procedure integrated access to the form from different devices, the upload or capture of a photograph, the obtaining of GPS coordinates, the saving of the information entered, the operation during temporary interruptions of the network and the subsequent synchronization of the data once the internet signal is restored. Also, the accessibility of the information registered was verified through the platform's control panel. To ensure that

the results are not replicable, all tests followed the same sequence of actions described in the prototype workflow. On the other hand, since the study worked in a preliminary and investigative way, the functional validation was specifically focused on confirming the functionality of the main components of the prototype, rather than a statistical comparison of performance. Therefore, the quantitative analysis was limited to descriptive survey metrics and a comparative matrix of technological alternatives, while functional validation was used to confirm the correct functioning of image capture, geolocation, asynchronous storage and subsequent data synchronization.

4.5. PDF Reports as Future Scaling

The automatic generation of PDF reports to send to municipalities is not something that this study has developed, and that was a conscious decision. For this type of report to be really useful, it is first necessary to have a sufficient volume of data, validate it, define how to classify types of waste, standardize territorial indicators, refine coordinates and establish formal channels of communication with municipalities. Rushing to automate reports without all that could produce unreliable documents or ones that generate expectations that the data can't yet sustain. That is why it is proposed as a future stage, not as a weakness of the model.

5. Discussion

5.1. Citizen Science and Urban Environmental Participation

The results of the study confirm something important: people do want to participate in identifying environmental problems, as long as the tool is accessible and easy to use. The high valuation of citizen participation, combined with the preference for simple digital channels, shows that there is a real willingness that only needs the right channel to be activated. This coincides with what recent literature has been pointing out about environmental citizen science: tools are not just a means, they are what make it possible for people's motivation to be converted into concrete data [6, 7, 12]. And the value of this model goes beyond reporting garbage points: it also allows for the construction of distributed territorial evidence that complements, without replacing, official records.

5.2. Technological Barriers and Preference for Web Solutions

That most prefer a web platform over a mobile app is not a surprise, and the evidence backs it up. Traditional apps bring with them a chain of obstacles: they have to be downloaded, they take up space, they ask for long registrations, they are constantly updated, and they are often not compatible with older cell phones [10, 11, 13]. In urban contexts as heterogeneous as Lima Norte, all this accumulates and ends up alienating people. The web solution, on the other hand, is available from any browser without installing anything, which allows reporting at the right moment when someone comes across a source of garbage, without unnecessary friction.

5.3. Asynchrony as an Advantage in Heterogeneous Urban Contexts

One of the most concrete strengths of this model is that it works, even if the signal is bad. In areas where connectivity varies by neighborhood, time, or carrier, being able to capture the report, save it to your device, and send it when the connection returns makes a big difference. This reduces information loss and makes the system more reliable in practice. In addition, it separates the time of reporting from the time of transmission, which opens the possibility of using it even in areas with very limited coverage.

5.4. Using Existing Tools vs. Developing from Scratch

Choosing an existing platform instead of building one from scratch deserves to be well explained. Developing your own software in pilot projects usually involves high costs, long times, dependence on technical equipment and permanent maintenance that often cannot be sustained. Adopting a robust and open-source tool, such as the one chosen here, allows us to concentrate efforts on what really matters: methodological design, data quality, and articulation with institutions [21]. In this sense, the innovation of this study is not in the platform, but in how it is integrated into a process designed from and for citizens. And that, in participatory monitoring and smart city experiences, has proven to be as important as any technological sophistication [15, 22].

Comparison with approaches from already published studies facilitates a better interpretation of the results obtained. Unlike solutions that are particularly based on specialized mobile applications, the proposed model does not require installation to access the web and generate photographic documentation, acquisition of GPS coordinates, and asynchronously store the data in a single process. In addition, functional tests confirmed the correct registration of photos and coordinates on various devices, as well as the storage and subsequent synchronization of messages when the network connection was restored. This is particularly important for the heterogeneous urban conditions of northern Lima, where the stability of the internet connection and the specifications of users' devices can vary significantly. Therefore, the advantage of the proposed approach lies not in its superior computational performance compared to existing systems, but in the reduction of technological and infrastructure barriers to citizen participation, while maintaining the essential functions of geolocated environmental monitoring.

5.5. Relationship with Municipalities and Future PDF Reports

Projecting automated PDF reports for municipalities as a future stage is not to recognize a limitation, but to make a methodologically responsible decision. For these reports to be truly useful, sufficient and validated data are needed, a coherent classification of waste, stable indicators, good traceability and real coordination with municipalities [12, 22]. Generating documents before you have all that ready could

produce unreliable information or create expectations that data can't meet. Considering this as a next step takes care of the credibility of the model and avoids premature institutional commitments.

5.6. Limitations and Future Lines

Like any pilot, this study has limits that are worth naming clearly. The sample was exploratory and not representative, which may introduce territorial biases. The quality of the photos depends on the device and who takes them. GPS accuracy varies depending on the equipment and environment. A formal validation with the municipalities has not been completed, and it is still necessary to measure whether citizen participation is maintained over time.

Future steps include scaling up implementation, validating the model with local governments, generating standardized PDF reports, creating a public visualization panel, automatically classifying types of waste, spatially analyzing the most recurrent sources, integrating environmental management indicators, and evaluating long-term citizen participation.

In short, the central contribution of this study is to demonstrate that a simple, web, asynchronous and low-cost solution can be more effective in activating environmental citizen science than a complex application, especially in Latin American cities where what matters most is that the tool is easy to use and sustainable over time. Simplicity, far from being a limitation, is a strategic advantage.

6. Conclusion

This study managed to design and preliminarily evaluate an asynchronous web model so that the citizens of North Lima could report sources of garbage in their environment. The Design Thinking approach was key to consistently connecting people's perceptions to concrete design criteria, and then to the implementation and validation of the prototype.

Opting for an existing platform instead of developing your own allowed you to save time, reduce costs and avoid the complexity of maintaining your own system. The solution combines photo capture, geolocation, continuous offline operation, cross-device compatibility and low cost, making it a replicable model for similar initiatives in other urban contexts. The pilot phase confirmed that it works technically and that it adapts well to what citizens need.

The automatic generation of PDF reports for municipalities is left as a future stage, once more data, standardized indicators and formal channels of communication with local governments are available. Putting it this way is not a weakness, but a way of taking care of the credibility of the model and of managing institutional expectations responsibly.

In summary, this work provides a replicable model of environmental citizen science: simple, economical, accessible from any device and designed to strengthen citizen participation in urban waste management, with a view to building more structured communication with municipalities. Technological simplicity, once again, proves to be a strategic resource to activate participation in Latin American cities.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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