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Into the Unown: Improving location-based gamified crowdsourcing solutions for geo data gathering

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ABSTRACT

Crowdsourcing has been recently successfully used to gather rich geo data in location-based games such as Pokémon GO. However, the academic literature has demonstrated that the selected crowdsourcing practices have led to the reinforcement of existing geographic biases, favouring rich areas and urban neighbourhoods over poor and rural areas. In this work, we investigate through two studies whether these biases could be mitigated by improving the crowdsourcing platform (Study 1) and supporting the crowdsourcing tasks with open map resources (Study 2). As an outcome of the first study, we derived 15 recommendations across six thematic areas for optimising the crowdsourcing processes. In the follow-up study, we demonstrated with a proof-of-concept work the potential to computationally improve the point of interest coverage particularly in developing countries and rural areas, and highlighted the potential of utilising open map services to build decision support systems for assisting in the evaluation of the crowdsourced content.

1. Introduction

Spatial crowdsourcing, sometimes also discussed as location-based crowdsourcing [1], is an umbrella term for describing the approach of harnessing laypeople to collect geographic information at scale [43]. As a specific form of crowdsourcing, it can consist of various tasks such as taking photos of real-world objects, reviewing spatial data, recording the movements of wildlife or documenting where paths in the wild lead to. Popular examples of applications that have been built via spatial crowdsourcing include OpenStreetMap (OSM), the live traffic service Waze [37] and the point of interest (PoI) database of Niantic that is used as a backbone for location-based augmented reality (AR) games such as Pokémon GO, Pikmin Bloom, Ingress Prime and NBA All World [7,20,38].

What makes spatial crowdsourcing approaches particularly applicable in today's socio-digital landscape are the ubiquitous availability of internet connectivity and the high quality of end users' mobile devices. Accordingly, laypeople can be harnessed to assist in collecting data of the real world, which can then be further processed and organised to provide value for various stakeholders [11]. According to a recent review on spatial crowdsourcing by Tong et al. [37] spatial crowdsourcing platform creators face four categories of technical challenges: (1) quality control; (2) task assignment; (3) privacy protection; and (4) incentive mechanisms. Each of the four categories have various details and nuances that need to be considered. The relative importance and the specific problems within these dimensions differ based on the specific crowdsourcing tasks that are being solved [37]. Regarding the incentive mechanisms, gamification has received a lot of traction in academic research and commercial applications recently [12,29,42]. One of the reasons for this is that while games and gamified systems are expensive to produce, they are relatively cheap to copy and distribute globally [18], making gamification a scalable solution for motivating participation in crowdsourcing.

Prior studies on gamified spatial crowdsourcing have investigated various application purposes such as detecting and documenting free parking spots [30], collecting land cover data [23,27] mapping participants' emotions in the temporal and spatial dimensions [5] and fetching prices from offline grocery retailers to support existing similar services operating in the online space [26]. These examples underscore how manifold the opportunities in the space of spatial crowdsourcing are, but also indicate that there are task-specific elements that need to be considered when designing gamified crowdsourcing systems. Due to the

Abbreviations: PoI, Point of interest; AR, Augmented reality; OSM, OpenStreetMap.

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complexity of some spatial crowdsourcing tasks, it may be feasible to sometimes create entire location-based AR games even around the crowdsourcing problems to motivate participation [28], or leveraging these games as platforms for spatial crowdsourcing [20]. While the academic corpus of literature on spatial crowdsourcing [37,43] and gamified crowdsourcing [29] are both growing fast, the early studies on the Niantic Wayfarer platform which serves as the backbone for games such as Pokémon GO highlight that the system has produced data unequally, favouring rich and urban areas over disadvantaged and rural areas [7,16,20,38]. While some of this is the direct consequence of the chosen the PoI criteria [38], the rest of the influence comes from the crowdsourcing platform and those contributing to it. Furthermore, since there are increasingly many high-quality open-source databases of spatial information (such as OSM), academic research could explore how feasible the use of these databases is in assisting or supporting the crowdsourcing tasks. Accordingly, we focus on the following two research questions (RQs) in this study.

RQ1: What are the challenges arising from the end user perspective that current market leaders face in their spatial crowdsourcing solutions?

RQ2: Can we address these challenges with the help of existing open-source sources?

To address RQ1, we conducted an in-depth case study on the Niantic Wayfarer gamified spatial crowdsourcing system that contains both a submission (data generation) and review stages. We mapped the identified issues into thematic areas, and formulated recommendations on how to address them. Based on these recommendations, we identified opportunities for automation via computation building on existing open-source data. Thus, to address RQ2, we explored the use of OSM data to alleviate some of the identified key challenges. With this approach we contribute to the literature on spatial crowdsourcing [37,43] and gamified crowdsourcing [29] by identifying the challenges that current commercial market leaders face, and by proposing solutions as well as directions for future research.

2. Theoretical background and related work

2.1. Gamification of crowdsourcing

Gamification directly addresses two of the key challenges of spatial crowdsourcing [43], namely scalability and the incentive mechanism. Regarding scalability, gamification motivates participation without the need to pay contributors, and can lead to higher quality data in some instances as opposed to money-based incentive mechanisms [9], since the gamification activities can be used to guide and direct the crowdsourcing process [29]. In relation to the incentive mechanism, there are various types of gamification approaches that can be used to motivate desired behaviours, from simple points, badges and leaderboards all the way to complex game mechanics and complete games [20]. A popular example of spatial crowdsourcing being integrated into complete games is the Niantic Wayfarer system, previously known as Operation Portal Reckon, which externalises both the submission and review process of playful real-world objects to a crowd of laypeople consisting primarily of location-based AR game players [20]. The Wayfarer system and its predecessors have been successful as they have generated the backbone of the global megahit Pokémon GO, and other popular location-based AR games such as Pikmin Bloom, Ingress Prime and Harry Potter: Wizards Unite.

On a broad level, the motivators, also discussed as incentive mechanisms, can be divided into two categories: extrinsic and intrinsic [42]. Extrinsic motivators include things such as monetary compensation and integrating crowdsourcing as part of mandatory schoolwork, whereas intrinsic motivators include aspects such as gratification derived from contributing to citizen science and gamification [29]. While in this work we focus on gamified crowdsourcing systems, it is worth noting that multiple incentive mechanisms can operate simultaneously, and the motivation to participate can be multi-layered. For example, players may be motivated by altruistic desires to help others [30] but also simultaneously by collecting statistics of how many crowdsourcing tasks they have successfully completed.

In Fig. 1 we display a snapshot of the current literature on spatial and location-based crowdsourcing (based on 1439 peer-reviewed studies). The coloured circles represent author-listed keywords in the studies, and the bigger the circle, the more prominent the keyword is in the literature. The line between the keywords represents how often two keywords occurred together in the studies (minimum n of times occurred was set to 10). Looking at Fig. 1, we notice that gamification appears as a minor keyword in the top left corner, being connected to the following six keywords: incentive mechanism, mobile crowdsourcing, blockchain, indoor localization, location-based service and citizen science.

Overall, gamification appears to be a prominent yet rather small part of the overall body of literature on spatial crowdsourcing. Except for the keyword “citizen science”, it is the only specific keyword relating to participant motivation. Due to gamification showing promising results in improving participant motivation across various information systems [19] and gamification being applied successfully to also motivate participation in crowdsourcing (e.g., [10,30,42], there is a need to further understand how gamification works when utilised at a global scale. For this, we need to study commercially successful gamified crowdsourcing systems, how they are operated, and what challenges they face.

2.2. Location-based games as a vehicle for crowdsourcing

Location-based AR games superimpose a digital layer on top of the real world, connecting the virtual game world to the physical environment [24]. Previous research has explored various ways to improve the fidelity of this connection, among which one key approach is to connect in-game geolocated PoIs to real world objects [2]. The market leader in location-based AR games, Niantic, has so far utilised spatial crowdsourcing, both in PoI submission and their review [20,21], but more recently in also asking players to take videos of real-world objects to collect point cloud data [2].

While location-based AR games such as Pokémon GO rely on the crowdsourced database of PoIs for the playing locations of PokéStops and Gyms [38], they can also utilise a wide range of other services to boost the connection between the game and the real world. In the case of Pokémon GO, these include AccuWeather for weather services, OSM for the background map, and possibly other sources such as player activity to detect places for Pokémon creature spawns [2]. This coupling between the game and open data (e.g., OSM) has reportedly led to as high as a 17-fold increase in OSM contributions in some areas following the launch of Pokémon GO [15], but also directed how players contribute to the crowdsourcing tasks. For example, contributors driven by gamified elements (Pokémon GO) did more edits with tags “water body” and “park” than other contributors to influence Pokémon spawns [15]. While these contributions may still be valuable, there have also been reports of cartographic vandalism, where players have done malicious edits to open-source map databases in hopes of making the associated game more fun for them [14,17].

At the start of the COVID-19 pandemic in early 2020, several location-based AR games including Pokémon GO introduced new remote playing opportunities for players, and therefore, the game’s linkage to the physical PoIs and outdoor movement was reduced [8]. This offered interesting insights in how the locative elements of the games had influenced inter-player relationships and underscored the role of social play in motivating the playing of location-based AR games [4,8]. Riar et al. [36] demonstrated that cooperative mechanics in location-based AR gamess can give rise to altruistic tendencies, which consequently, could also lead to increased desire to participate in contributing to the common good through crowdsourcing. Social play is important in crowdsourcing motivation also since there are various

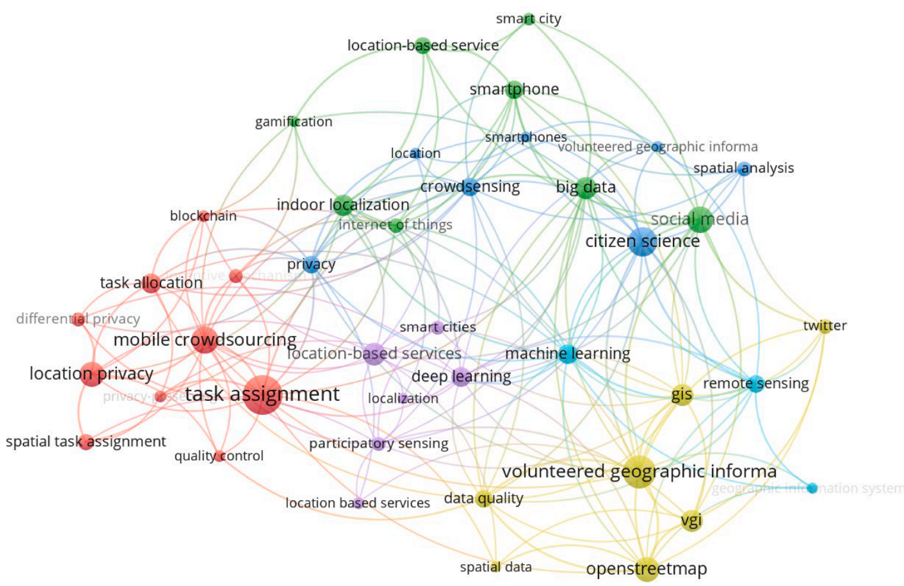

Fig. 1. A Scopus search done on gamified crowdsourcing (“TITLE-ABS-KEY (crowdsourcing AND (spatial OR location-based OR “location based”)) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cp”))”) in November 2022 resulted in 1439 entries. We used VOSViewer to visualise the co-occurrence of the relevant keywords and chose to display only keywords that occurred in at least 10 studies in this literature. We removed the search words (e.g., crowdsourcing) from the Figure for clarity.

online groups and forums where players collectively discuss, debate, and agree on how the given crowdsourcing tasks should be completed in the game context. This calls for further investigation into the socially influenced motivators of crowdsourcing participation, and on how the social hierarchies and connections between players end up impacting the result of the locative crowdsourcing solutions. Hence, this was one of the aspects we focused on in this work as we sought to provide answers to the two proposed RQs.

3. Research design

To investigate the RQs presented in the Introduction section, we committed to a four-step design which we outline in Fig. 2. These steps were divided into two parts, where steps 1–3 were carried out in Study 1, and Step 4 was carried out in study 2. This mixed-methods study design guided us to first investigate in-depth the Niantic Wayfarer system, and then, based on the findings, explore the opportunities in putting the recommendations into practice via harnessing open-source data to optimise and support the studied spatial crowdsourcing processes.

Next, we present the materials, methods, and findings for the two studies so that first, we present Study 1 (steps 1–3), and then Study 2 (step 4).

4. Study 1: Identifying issues in the Niantic Wayfarer process

4.1. Methodology

We drew from the researchers’ a priori experience with the Niantic Wayfarer as reviewers and submitters, but also collected ad hoc new data for this research. The analysis was made possible by Niantic Wayfarer (https://wayfarer.nianticlabs.com/, accessed April 12, 2023) documenting and storing all submissions that players had made, including the review outcomes for these submissions. The Niantic Wayfarer is a web application and the current crowdsourcing platform for PoIs in Niantic games. When players submit PoIs through either Ingress Prime or Pokémon GO, they may become available for evaluation at the Wayfarer platform. Players who have reached a certain level in the games can log in to Niantic Wayfarer and evaluate PoI submissions around their geographical area based on a set of given criteria such as accuracy of location, and historical and cultural significance. These reviews are then used to determine whether the submitted PoI can become part of Niantic games or not. Next we discuss the data collection and analysis processes for this study.

4.1.1. Data collection

A researcher began submitting PoIs through the Niantic Ingress game application in November 2017 when it was allowed again by the developer. Simultaneously, the researcher reviewed PoI candidates in a web application called Operation Portal Reckon (which was later rebranded as the Niantic Wayfarer). The researcher also participated in two Wayfarer-focused private Telegram channels, and two researchers regularly read the /r/NianticWayfarer subreddit and the Wayfarer official forums. These data sources are summarised in Table 1.

The data for this study were a mixture of objective quantifiable data (Niantic criteria, Wayfarer statistics) and subjective (the researcher’s experience of the system, the players’ posts regarding the system on Wayfarer forums, Telegram and Reddit). We estimate that these sources offer a balanced view to the system.

4.1.2. Data analysis

The data collection approach can be loosely considered an autoethnography since a researcher actively partook in the Wayfarer processes

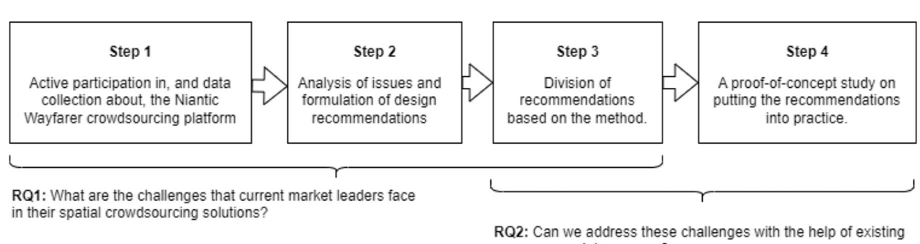

Fig. 2. The research design.

Table 1
Data sources for the autoethnography study.

Data sources	Description	Research material
OPR/Wayfarer review experience	Overall, 998 reviews done over the time period of 2017–2022.	Non-structured notes of the researchers experience as a reviewer. Screenshots of the review screen and what it entails.
PoI submissions	Altogether 443 PoIs submitted of which 185 were accepted.	A full list of all submissions made by the researcher including a date of submission and decision (accept/reject/duplicate).
Public and private discussion forums	Regularly reading the https://www.reddit.com/r/NianticWayfarer subreddit, the Wayfarer forums https://community.wayfarer.nianticlabs.com/ and participating in two Wayfarer-focused Telegram channels.	A Table of links to relevant threads in the /r/NianticWayfarer subreddit.
Niantic Wayfarer criteria	Read the Niantic Wayfarer Criteria in detail to understand what kinds of PoIs the researcher should submit and which kinds of PoIs the researcher should accept.	The criteria have changed only slightly over the years, and for this reason we refer to the latest criteria (November 3, 2022) which are listed in Appendix A.

and documented their experience for further analysis. However, as opposed to observing people as is typical in (auto)ethnographies [6], the focus was on the analysis of the information system (Wayfarer), how it works, what problems arise and how to improve it. Due to the nature of the data, interpretation was needed, and the researchers relied on their experience about the system to make informed interpretations. Overall, the analysis can be seen to have three steps [32]: (1) familiarisation with the data; (2) formulation of a thematic framework; and (3) refining the framework with the help of supporting data sources. As is typical with qualitative analyses, we revisited previous steps and kept on refining the framework until we were satisfied that it accurately represented the data.

The analysis proceeeded as follows. First, the authors read through the collected materials and listed the 443 PoI submissions including outcomes in an excel sheet. The submissions were first classified based on the target object (e.g., playground, statue, trail marker) and organised into clusters. A researcher then looked at variance within each cluster, as well as variance within submissions of the same object. Subsequently, two researchers identified categories of objects that were frequently accepted, and objects that were frequently rejected. The researchers reflected upon these observations in light of the community discussion that we followed and linked to relevant reddit posts and Telegram conversations for bringing clarity to the identified issues, such as why a specific category of PoI matching the Niantic criteria was systematically rejected.

Second, the reviewers formulated a thematic framework to discuss the identified issues. This framework initially consisted of five themes, but upon revisits to the data and comments from another researcher, one theme was further split into two. Ultimately, this led us to conceptualise the issues under six themes. Third and lastly, the researchers returned to the data and took screenshots of PoI submission to support the identified issues. The researchers then got together and discussed potential remedies for the issues, which lead to the formulation of design recommendations for addressing the issues. While some recommendations were straightforward, others required further proof and investigation (see Study 2). Next, we present the six discovered themes from the inductive qualitative analysis of the Wayfarer data.

4.2. Findings

4.2.1. Inconsistency in evaluation outcomes

There were multiple examples within the 443 Waypoint submissions where a target that seemingly matched the PoI criteria was rejected. On a few occasions in the data after re-submitting the same exact PoI with a new image, it was then accepted. An example of this is displayed in Fig. 3. The factors influencing this outcome included but were not limited to: (1) who happened to be selected as reviewers; (2) the submission title; (3) submission photo; (4) submission description; (5) additional information included in the submission; and (6) the acceptance thresholds set on the server side. However, none of these reasons were obvious to the PoI submitters. From the user's perspective, the evaluation outcomes simply appeared inconsistent.

The issue of inconsistency seemed more pronounced with some PoI categories than others. For example, for places of public worship such as churches the majority (22/24) were accepted on the first try in our data, while indoor sports facilities (See Fig. 4) were more controversially rated (7/16) with inconsistent results. This observation (that objects belonging to certain PoI categories are almost always accepted, while in others there is more ambiguity and uncertainty) suggests that some PoI submissions could be automatically reviewed to reduce user burden. However, other PoI categories such as indoor sport facilities, trail markers, non-public playgrounds and local hotspots require further guidance and assistance by the developer. Accordingly, we suggest the following two recommendations:

Recommendation 1: *Automate the discovery of new PoIs for certain straightforward and objective categories, such as places of public worship,* e.g., *by obtaining the PoIs directly from existing open-source map databases such as OSM.*

Recommendation 2: *Clarify the PoI criteria to reviewers, and constantly give reviewers clear feedback on what fulfils the PoI acceptance criteria and what does not, to avoid inconsistent reviews in certain categories.*

4.2.2. Inability to provide comprehensive rejection criteria

At some point around 2018–2019 the Wayfarer system began including reasoning to PoI submitters on why their submission was rejected. However, these rejection criteria were typically generic and vague, and oftentimes unhelpful. In Fig. 5 (left) we see an example where the criteria are useful, as it indicates that the photo was blurry. However, in Fig. 5 (right) the submitter was only shown the following message: "other rejection criteria" which offers no guidance as to what went wrong and how to proceed. Based on this information, the submitter cannot know whether they should try to resubmit the PoI or concede.

While providing more information may prima facie be an easy solution for this issue, there exists a trade-off between providing transparency in explanations, and curbing system manipulation. For example, in case the developer provided a completely clear explanation on why a submission was rejected, a malicious party would also benefit from this information, making it easier for them to improve their shortcomings in system manipulation, and consequently, they could learn to abuse the system more effectively. For this reason, resolving the issue of unclear feedback is not a straightforward task. We argue that instead of telling users exactly which player segments gave which score to the PoI, there would be precise verbal feedback on the rejections. One opportunity here would be to collect this verbal feedback from the reviewers. This could also allow system admins a way to triangulate whether the reviewers are following the system rules or not. Thus, we recommend the following:

Recommendation 3: *Collect verbal feedback from reviewers when they give a bad score and provide this feedback to the submitters. Also use this feedback to check whether there are unintended reviewer biases in certain PoI categories.*

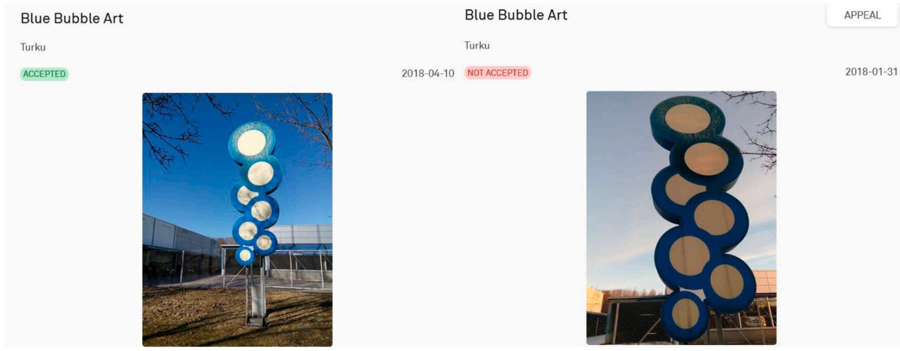

Fig. 3. A statue first being rejected, and later accepted.

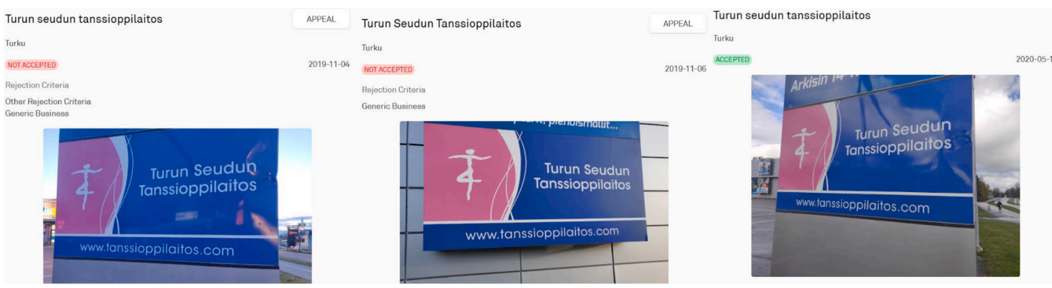

Fig. 4. A dance facility being rejected twice before being accepted.

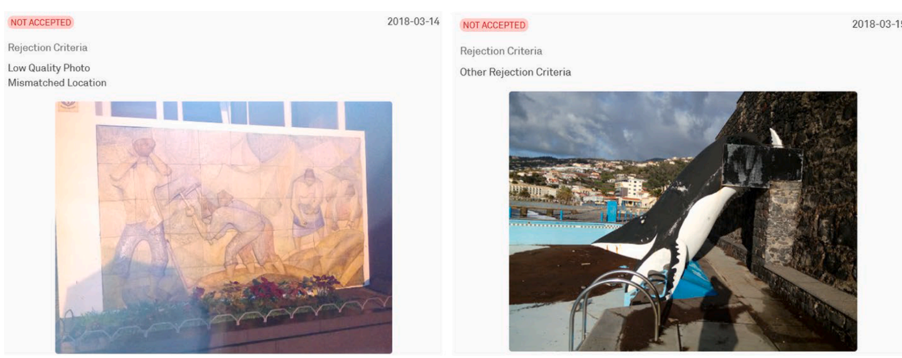

Fig. 5. At some point the system began giving reasons for rejections. However, sometimes these criteria were not helpful at all (right).

4.2.3. Reviewers sometimes make up their own rules

An issue connected to both of the previous two themes is that Wayfarer reviewers seemed to make up their own rules. There was evidence of this particularly in some categories, including (1) community gardens; (2) nature signs; (3) unusual or unique local shops; (4) hiking trails; (5) biking trails; (6) parks and plazas; (7) popular

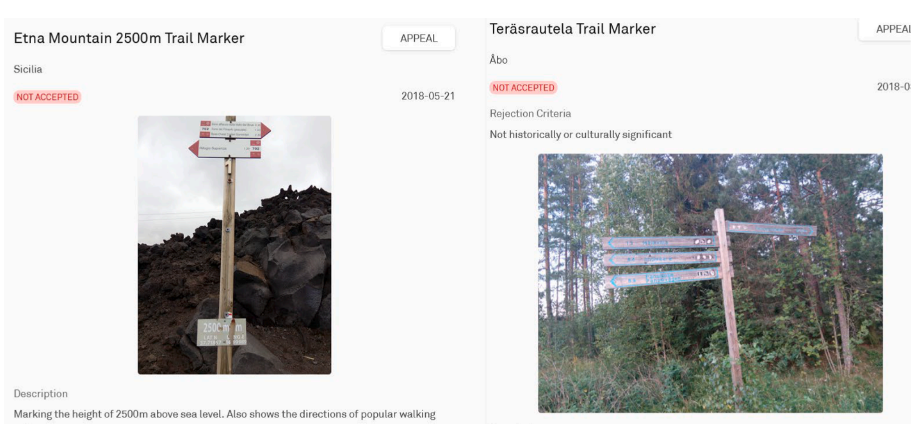

Fig. 6. Trail markers are often rejected in the Wayfarer despite being good candidates according to the official criteria.

restaurants; (8) forests; and (9) favourite coffee shops. In Fig. 6 we give an example of trail markers getting rejected, which appeared frequently in our sample of Waypoints nominations despite the official Niantic guidelines (see Appendix A) stating they are a great place for exercise and an exemplar Waypoint category.

In our investigation of the Wayfarer system, we also joined several private, semi-public and public groups of Wayfarer contributors. In these groups it was not uncommon for the community members to agree on not accepting certain kinds of locations or give advice on what kinds of locations to submit instead. Interestingly, sometimes this advice was in opposition to the Niantic guidelines (Appendix A), which partially explains why preferred Waypoint candidates in some categories were regularly rejected. However, in some rare cases there was also evidence of clear collusion. As an example, in the public discussion forum Reddit, there was a recent thread on the topic of players colluding to manipulate the Wayfarer system [34]. The original poster made bold claims such as:

"Everyone of these were rejected, then I got a message from some ingress players who play locally to stop, how they were downvoting everything because it affects the lines they make and how they are in charge of new poi. They claimed to be trying to report bomb me on wayfarer to get me banned from making new stops and everything." (Content-Pension-607).

This sparked a vivid discussion, where multiple other users shared similar experiences and gave advice on how to act in such situations. Overall, these observations highlight that the player communities have enormous influence on how contributors view the Waypoint criteria and review candidates, and that the player communities in many cases may provide a different vision for the system than what Niantic, the developer, provides. For these reasons it is critical that the system provider regularly checks on whether some categories are systematically misjudged by the community and keeps an open channel for players to appeal submissions or report abuse. We summarise these conclusions in the following two recommendations.

Recommendation 4: *Conduct manual checks on rejected reviews and seek patterns if certain kinds of PoIs are constantly rejected. Explain these unclear categories to both reviewers and submitters.*

Recommendation 5: *Identify users who repeatedly vote against the official guidelines and provide them targeted information on why their reviews* were *against the guidelines.*

4.2.4. Subjectivity in reviews is fuelled by complexity of the real world and subjective measures

In criteria-based crowdsourcing of real-world locations there are inevitably situations where it is unclear whether a particular location matches the criteria or not. The Wayfarer system asks contributors to rate submissions with a numerical value (1–5) on various categories (e.g., "should this be a Wayspot?" and "historical and cultural significance"), which are inherently subjective measures. For this reason, reviewers may gravitate towards giving visually appealing locations better scores than ugly ones, even if both would fill the PoI acceptance criteria (for a list of the criteria, see Appendix A). In Fig. 7 we provide two examples of nature location signs, both which should be acceptable candidates, but the more detailed sign has been accepted while the "uglier" sign has been rejected with the reasoning that it is not "visually unique". In fact, later the rejected PoI candidate on the right got also added to the Wayfarer system, but through being submitted by another contributor. This also showcases how having highly subjective measures as part of an objective review process can lead to a suboptimal user experience for submitters, as PoIs matching the acceptance criteria may still be regularly rejected.

Another related issue was that some PoIs such as playgrounds or ruins are in fact a compilation of multiple objects. In these cases, there were examples where it was by no means self-evident whether the location (e.g., "ruins" or "playground") should be one PoI or consist of several PoIs. For example, in our data we had an old anti-air battery ruin that used to be a single PoI, but which after several rounds of submissions grew to become a compilation of PoIs where individual bunkers received their own PoIs. This example case caused some worry to both submitters and review contributors, and the evaluation outcomes in these situations were varied and unpredictable. While this issue of granularity of PoIs can be clearly stated, the way to address it requires the approach in recommendation #2. But even still, some subjectivity remains, and the submitters have responsibility but also artistic freedom to decide how exactly they wish to present the real world complexity through their crowdsourcing contributions. However, in terms of addressing the issues of variance in PoI quality and format, we suggest the following two recommendations.

Recommendation 6: *Acknowledge the variance in PoIs within a specific category and clarify if only certain candidates within that category will be accepted, or all of them.*

Recommendation 7: *Collecting subjective measures is good for evaluating PoI quality but should not influence the PoI acceptance outcome. Otherwise, submitters will be discouraged.*

4.2.5. A slow review processes lead to multiple issues

During the data collection period (2017–2022) there were multiple instances where the Waypoint review times extended over 12 months. These occurred for many reasons. At one-point, certain S2 [33] cells were "blocked" so that PoIs submitted there would be reviewed, but the final decision would never come. Currently as of November 2022, there are review lines as long as 15 months in some S2 cells unless a review is "boosted" via an upgrade button. In addition to the obvious unfortunate part of long waits, the map not being up-to-date leads to players accidentally submitting duplicates. For example, if a contributor submits a playground and must wait for over a year for the review to be completed, it is possible that during this time another contributor submits the same location, unknowing that it has already been submitted. Examples of duplicate outcomes due to this reason are given in Fig. 8. This leads to extra work for both the reviewers and submitters.

The primary way to address these issues is to come up with solutions to reduce the time that PoI submissions are in review. This can be done by, for example, increasing reviewers' rewards, improving the UX of the review process, advertising the review process to a broader pool of

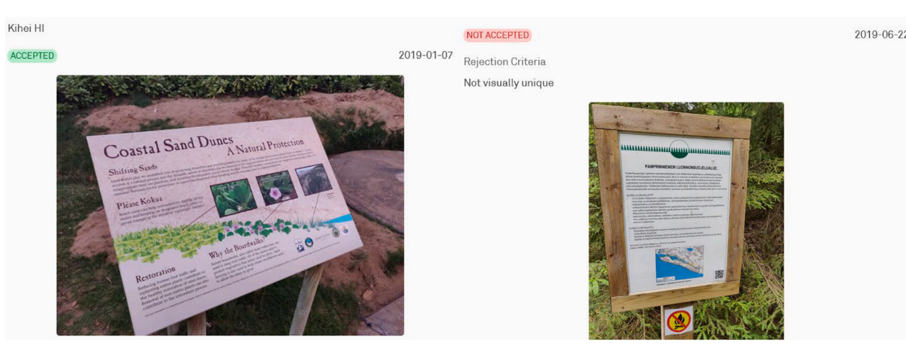

Fig. 7. More beautiful and unique nature signs seem to be more frequently accepted than ugly and generic ones, even if both fill the acceptance criteria.

Fig. 8. The longer the review process takes, the higher the chance that other contributors will submit the same location leading to unplanned duplicates.

potential crowdsources and by lowering the number of required reviews per PoI submission. Alternatively, it can be done by improving the automation by e.g., automatically rejecting submissions with blurred photos or by automatically detecting duplicates (similar photo, name, and description). As a third possibility the contributors could be better educated on which candidates are acceptable and preferred, and they could be asked to provide useful metadata to support their submission such as according to which Waypoint criteria (see Appendix A) their submission is acceptable. Also fourthly, open-source data (e.g. OSM) could be used as a decision support system to help reviewers make informed decisions faster. Currently Wayfarer already supports images from Google Maps, meaning this step would conceptually not be a big leap. If despite all these measures there are long review queues, we suggest that submitters who create accidental duplicates are not punished with a hard red duplicate notification, but would instead receive some accolade for their contribution, nonetheless. We summarise these recommendations below.

Recommendation 8: *Accelerate the review queue by improving user's motivation to contribute (*e.g.*, better rewards, improved UX), by increasing the number of reviewers or by lowering the number of required reviewers per PoI candidate.*

Recommendation 9: *Accelerate the review queue by automating parts of the process such as automatic detection of duplicates and automatic rejection of blurred photos.*

Recommendation 10: *Help reviewers make faster decisions by utilising open data as a decision support system.*

Recommendation 11: *Ask submitters to mark down the specific criteria based on which their submission is acceptable and display this criteria to the reviewers.*

Recommendation 12: *Acknowledge contributors who submit PoIs even if multiple users submit the same PoI and it ends up being a duplicate.*

4.2.6. Gaming the system

During the 5-year data collection period the researchers witnessed various forms of dubious and borderline nefarious behaviour in both the review and submission processes. Regarding PoI reviewers, the authors followed player coalitions in chats who collectively agreed to accept certain PoIs and reject others, as discussed also in the third theme. These coalitions would also agree on specific times of day they would go online and review candidates, increasing the likelihood of them encountering the same PoIs. Regarding PoI submissions, the researchers encountered PoIs that were purposefully named incorrectly, PoIs purposefully submitted in incorrect locations, and moving PoIs around to impact their inclusion in Pokémon GO, and to impact which PoIs turn into gyms (see [35]). Arguably all these behaviours were motivated by in-game elements, meaning the participants were using the Wayfarer system as a vehicle to gain advantage in the game they enjoyed playing (whether that was Pokémon GO, Ingress Prime, both or other Niantic games). This underscores that while gamification may be an effective incentive mechanism for spatial crowdsourcing participation, it can also backfire if it motivates unwanted forms of contribution.

In some forum posts on both Reddit and the Wayfarer forum, contributors expressed frustration as these abuse scenarios were not quickly dealt with, and these contributors claimed to have subsequently lost their motivation to participate in the crowdsourcing processes. Important to note is that it is in some situations unclear which types of behaviours should be considered abuse and which should not. To mitigate these issues, we encourage rapid responses from the system maintenance on abuse scenarios, clear and transparent communication to the community regarding which behaviours are not acceptable and why, and also speculate whether open data (e.g. OSM) could help in detecting potential cases for abuse (e.g. there being a public place of worship in the Niantic database which does not appear in OSM, which could trigger further investigation on the topic). In the latter case, an example would be to try and see if a submitted PoI name matches a name in OSM nearby, and if it does, there could be a location check to see if they are in the same place. We summarise these recommendations as follows.

Recommendation 13: *React to abuse cases quickly and effectively to discourage future abuse.*

Recommendation 14: *Explain to the community which behaviours are not allowed and why.*

Recommendation 15: *Triangulate PoIs using open sources to flag cases for further investigation on abuse.*

4.3. Connecting the recommendations to actionable insights

Altogether, we proposed 15 design recommendations for improving the Wayfarer crowdsourcing system of real-world spatial data. To make the recommendations actionable, we sort them into areas based on what part of the overall product they concern. The resulting three actionable areas are: (1) UX improvements; (2) system oversight; and (3) leveraging open-source data. These areas are displayed in Table 2.

Out of these areas the first, UX improvements, is related to the implementation of the specific system, which in our study context was the Niantic Wayfarer. The second area, system oversight, is related to the hiring and utilisation of human workforce to improve the way the system functions. The third area relates to the use of open sources either as a direct source or as a decision support system. The first two categories require no further elaboration, as they are issues that need to be solved at the level of individual solutions and companies. However, the third category requires further investigation. For this reason, and to address the second RQ of this study, we decided to investigate the use of open-source data to improve the Wayfarer system.

Table 2
Summarising the recommendations in three actionable areas: UX improvements, system oversight and leveraging open-source data for addressing existing shortcomings.

Actionable area	Recommendations (#)
UX improvements	3,6,7,8,11,12,14
System oversight	2,4,5,13
Leveraging open-source data	1,9,10,15

5. Study 2: Approaches to automatically support the Wayfarer system

While there are PoI candidates within the Niantic criteria that absolutely require crowdsourcing (see e.g., murals and urban artwork), previous research suggests that most of the crowdsourced information (such as the locations of parks and public places of worship) is already readily available at open map services such as OSM [38]. For this reason, we conducted a follow-up study to explore a computational approach for automatically generating PoIs for location-based AR games that are connected to real world objects. Currently, Niantic is already using crwodsourced data in area classification (e.g., whether a place is a park or not) [38,41]. We expand this state of the art by looking at automation of PoIs from OSM data. In addition to addressing the issues identified in Study 1, this proof-of-concept research explores the feasibility of the computational approach for addressing the following issues: (1) reducing the crowdsourcing load of both submitters and reviewers by automating the complete process of PoI generation; (2) reducing queues and wait times in the crowdsourcing process; (3) offering a way to obtain PoIs to locations where there are no submitters; and (4) being used potentially as a decision support system to help reviewers work faster and more efficiently.

5.1. Materials and methodology

5.1.1. Data collection

In this follow-up study, we explored the use of available open geo data to support the Wayfarer crowdsourcing system. To this end, chose to study the use of OSM, since it contains manageable tags for locations and using it for supporting location-based AR games has already been suggested in prior research [38]. From the two databases (Wayfarer and OSM), we systematically selected distinct areas around the globe. To differentiate between various land use characteristics, we referred to the National Center for Health Statistics area classification scheme that divides areas into rural, suburban, and different sizes of metropolitan areas [13] based on their population size, as shown in Table 3. Continuing with this scheme, for each continent, excluding Antarctica due to its low population size, we select five metropolises belonging to distinct countries or at least two distinct regions to achieve a proficient coverage for the continent. For each of the remaining three population categories and for each metropolis, we select one location with the appropriate population size according to census data in the metropolis's broad vicinity. A complete list of evaluated regions can be found in Appendix C.

5.1.2. Analysis

After gathering the data, we proceeded to evaluate both the global applicability of using OSM data to generate PoIs with the Wayfarer criteria, as well as the area dependent content availability. The developers of the Wayfarer system provide global data on the availability of content with the Ingress Intel Map [31], that is immediately accessible to everyone who creates a Niantic account. Since the Ingress database builds the foundation of the Wayfarer content database it is applicable as a benchmark for content availability in the regions specified in Appendix C. For other Niantic games not all data is used, due to additional constraints limiting the appearance of content locations in direct vicinity, leading to a slightly reduced number of content locations available for gameplay. Thus, the number of Ingress portals in each area gives an upper bound estimate for the available content location in other Niantic games.

Table 3
Urban category area classification according to [13].

Urban category	Population size
Medium & Large Metropolitan	> 250,000
Urban / Small Metropolitan	50,000–250,000
Suburban / Micropolitan	10,000–50,000
Rural	< 10,000

For each location in Appendix C, we selected 16 cells arranged in a four times four grid, with an S2 [33] level of 14 to cover a quadratic section having the size of an S2 level 12 cell. On average, these cells have an area of 5.12 km^2, depending on their latitude, with each decreasing level increasing its size by a factor of four. We deemed this appropriate to still be able to cover rural areas and small towns, without most of the area being purely environmental.

After identifying the game areas, we extract relevant OSM data for each cell based on tags provided in previous academic studies [38,39]. Here, the system enforces a set of safety and security restrictions like omitting areas on private property, company grounds, or even military areas as well as locations with "no foot" access like highways. For the identified relevant tags, many combinations is possible, which is why we constructed three groups. The first group includes all tags (*strict*, group 1) that mostly correspond to Niantic's guidelines (See Appendix A) for high-quality content in their games. The second group additionally includes the tags (*relevant*) representing locations with shops, relevant societal buildings, or leisure areas. The final, third group (*notable*) now also incorporates tags intended for better coverage in suburban and rural areas.

5.2. Results

5.2.1. Comparing Wayfarer data with processed OpenStreetMap data

To explore content available through OSM filtering we divided our data according to each location's continent and urban category, shown in Fig. 9. Thereby, each plot contains five individual locations, totalling to 120 investigated locations. To compare each set of OSM tags to the currently active locations for Niantic games, we reported values as the total number of eligible OSM-based locations divided by the amount of active Ingress portals. The upper bound cut-off is set to 500% to visualise the results more clearly. Since Ingress only allows one portal for each level 18 S2 cell this constraint is integrated in the extraction process for better comparison. Thus, the dotted line in Fig. 9 resembles the break-even point where equal amounts of playable locations are identified by OSM filtering compared to the manual collection of locations over time through the Wayfarer system. The visualisation of total numbers for each category is found in Appendix D.

During our analysis we identified multiple patterns:

First, content quantity provided through the Wayfarer system for metropolitan areas is already high across almost all areas. This indicates that PoIs that strictly adhere to Niantic's Wayfarer criteria have been successfully submitted and converted into approved content locations. The surplus of approved locations in this area can be explained by additional accepted criteria not directly related to specific OSM tags, such as urban artwork. However, the OSM *strict* tag group is only intended to provide a minimum estimate of high-likelihood locations.

Second, the results for this tag group get closer to the amount of content locations in Ingress with a decrease in population size for the other urban categories. This also shows the general applicability of this tag group for new location-based games not utilising or not having access to the Wayfarer content system.

Third, for the *relevant* OSM tag group the difference becomes most evident. This group mainly adds other amenities not covered by the Wayfarer criteria and locations related to public transportation. These are commonly designed for goods accessible for people, thus being a potentially meaningful addition for location-based games increasing content density. The substantial increase in eligible locations is evident in the data for all continents but Africa. For Asia the location in Eastern Asia (in or around Seoul, Shanghai and Tokyo) stands out, having comparable content representation as locations in Europe and North America.

Fourth and finally, when including more OSM tags as shown in the

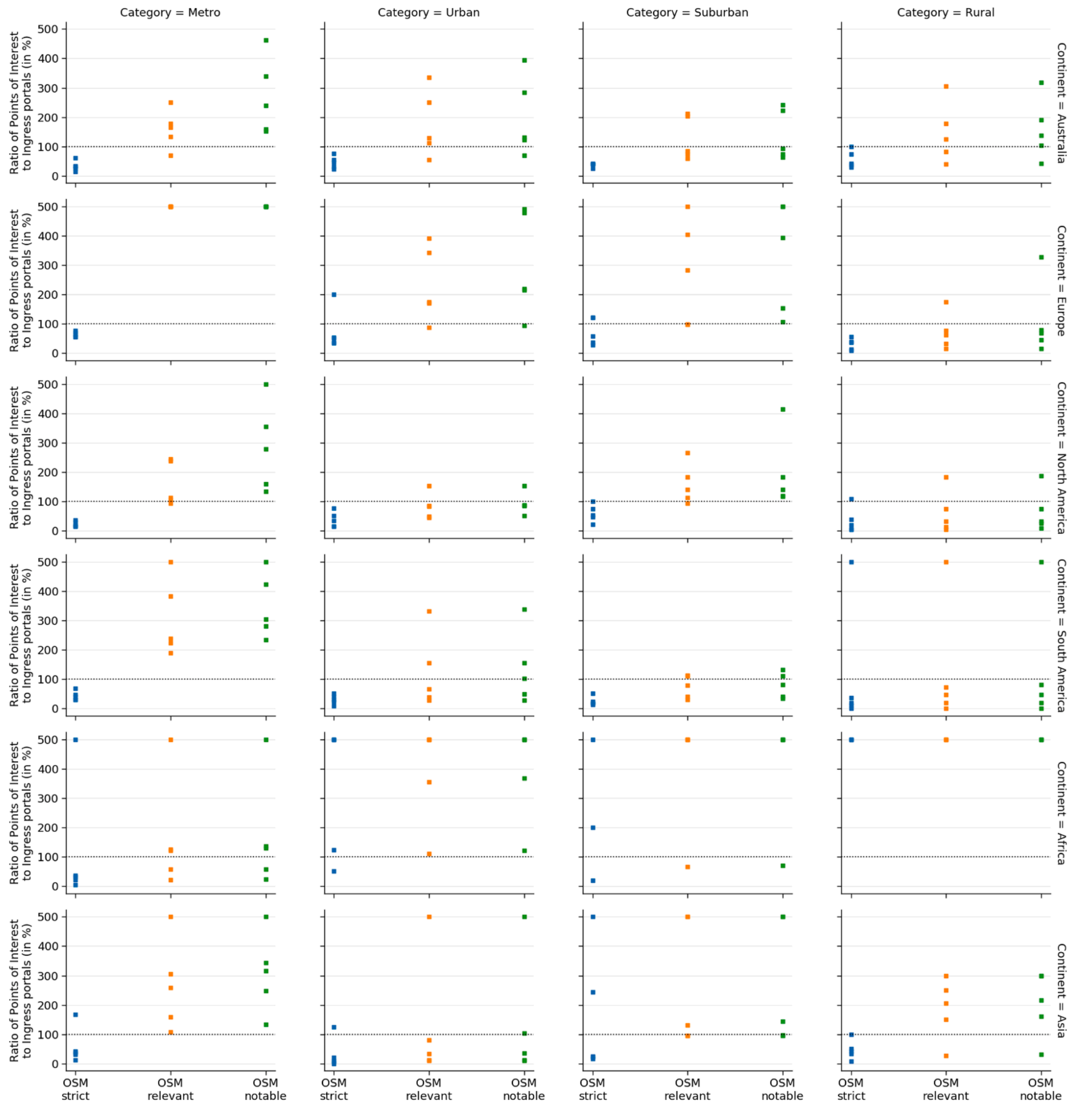

Fig. 9. OSM-based point of interest extraction for 120 locations divided by continent and urban category.

notable tag group, the results hardly differ and only show a small increase in content locations. The largest changes are seen for Australia and Europe. One possible explanation for this is the underlying OSM data. Since the OSM tags exclusively used in the *notable* tag group rely on smaller, more common items found in the area like benches, post boxes, public toilets, springs or individual trees, those locations are not tagged for most areas. For the explored European and Australian locations, we observed a high level of detail in OSM tags leading to such smaller locations being tagged and thus being available for automatic extraction.

6. Discussion

6.1. Revisiting the recommendations: How OSM data can improve the Wayfarer system

Building on the findings of Study 2, we now discuss how open geo data can be used to improve the Wayfarer system by discussing the recommendations (See Appendix E) derived in Study 1.

6.1.1. Reducing the crowdsourcing load by leveraging existing open data repositories

Related to recommendations #1 and #9, we showed that automating PoI submissions using existing open-source map databases like OSM can reach results comparable to the existing Wayfarer database for relevant playable locations at planet-scale. This suggests that OSM and other similar services can indeed be used to automate the discovery of playful PoIs for location-based games *(recommendation #1)*. Further, content selection based on the extracted data is a fitting follow-up step to increase presented content quality by selecting high-quality locations. This selection process can be tailored towards the application scenario, e.g., targeting a specific distribution of content locations (increasing or decreasing location clustering), or prioritising certain locations based on their OSM tags (as also discussed in [39]. Integrating these automation steps into the system inevitably impacts the review process. Establishing a direct linkage between suggested PoIs and the underlying OSM data is a straightforward approach to detect duplicate submissions *(recommendation #9)* and to increase Wayfarer location accuracy, due to OSM data likely being more precise than the hand-selected location by the submitter.

6.1.2. Open geo data as a decision support system and a tool to detect abuse

Currently reviewers at Niantic Wayfarer are already offered some support for decision making. For example, for determining the PoI location, the reviewers are shown it on a map (they can select road or satellite map) and a Google Street view of the PoI location. We propose that these decision support systems could be significantly improved via the help of OSM. In Study 2, we demonstrated that OSM contains many of the same exact tags (e.g., parks, places of public worship, historically important locations…) that are preferred candidates in Wayfarer. Even if not sourced directly from OSM to Wayfarer, as suggested in the previous step, this data could be given to reviewers to quickly check if the PoI exists in another map service. This could assist reviewers in reaching the standards given for reviews, and free up reviewers' resources, enabling them to effectively complete more tasks and more reliably. This could accelerate the review process *(recommendations #8 and #9)* and make the outcomes of the reviews more reliable (*recommendation #2*).

OSM tags can be used for even further purposes. First, open-source geo information can be used to support the identification of rejection patterns, which can then be used to provide valuable feedback for both the submitter (why the submission was rejected) and the reviewer (whether the rejection was justified) *(recommendation #4)*. Second, this process is further improved when submitters are required to mark each submission with the criteria based on which their submission should be accepted. Marking these with the respective OSM tags, allows for easier or even automatic validation on the soundness of each submission, potentially resulting in more consistent reviews *(recommendation #10)*. This also holds true for the investigation of potential system abuse by verifying submissions using OSM tags for further investigation in case of a mismatch *(recommendation #15)*.

6.1.3. Avoiding eligibility criteria that are in fact not PoIs.

In Study 1 we demonstrated that due to the variance in PoIs within a specific category (e.g., entire playgrounds compared to individual play equipment; or alternatively, a beautiful nature trail sign vs an ugly nature trail sign) there is inherent subjectivity in the reviews, and for objective crowdsourcing goals, efforts should be made to minimise this and instead, enforce objectivity. While OSM manages areas via tags, it is difficult to reduce area criteria in Wayfarer like "gardens" or "forests" to singular points within an S2 level 18 or even level 20 cell. Instead, they could be what they are, areas. Based on Study 2, we suggest that perhaps these areas could be obtained in their entirety from OSM, and then reviewers could be given the option to select relevant PoIs within these areas. This would be an actionable approach and to some degree an alternative for recommendation #6.

6.2. Theoretical and practical contributions

Our study extends the scientific knowledge on spatial and location-based crowdsourcing [1,37,43] in two major ways. First, we outlined the crowdsourcing system challenges that the current market leader of playful spatial geodata crowdsourcing (Niantic) faces (RQ1). Second, we illustrated how open data sources can be combined to create new information and knowledge via our second study on the use of OSM to support the Wayfarer system (RQ2). Next, we discuss the implications of these two contributions.

Past research has proposed gamification as a solution to crowdsourcing problems where participants want to maximise their profits and end up turning in sloppy or abusive responses [9]. Prima facie our research contradicts this postulation since in our empirical investigation of the Wayfarer system, we noticed various abusive behaviours even though there is no monetary incentive mechanism. However, a closer inspection reveals that while there was abuse, the forms of abuse were predominantly motivated by specific aspects of the gamification / game mechanics. For example, individuals submitting non-existing PoIs near their home had the incentive to create more playable content for themselves in the Niantic games. Meanwhile communities colluding to manipulate the PoI review processes were, as evidenced by their own testimonies, motivated by creating more playable content to the whole community in central areas. This finding has important implications on the gamified crowdsourcing literature [29]. It underscores the need to holistically understand participant motivations and then adjust the gamification motivation mechanisms to serve the needs of the crowdsourcing tasks.

Our research supports prior surveys on spatial crowdsourcing which have taken a more technical stance (e.g., [37]), since we studied the end users' UX and related challenges, and then devising solutions to address the identified issues. Our work is also focused on a commercially successful system, supporting the myriad of academic research done on field experiments and ad hoc systems [37]. Enriching a location-based content system with open data as postulated in Study 2 also enables its flexible use in other application scenarios like tourism [3], advertisement, or awareness. For location-based gaming, open data can enable more content options like player guidance systems [40] or content contextualisation by selecting fitting game locations on an individual player basis. Prior work on the influence of location-based gaming on the open-source data repositories have brought onward some concerns related to cartographic vandalism [14;15;17]. Therefore, while our results showedpromise in improving the Wayfarer system via the use of OSM, such approaches need to be applied with care, as they may have undesired side effects in the map data quality. For location-based AR game designers, this means that they must be considerate on what types of game mechanics they create, as these may have unwanted motivational effects related to adverse OSM contributions. This is particularly important since recent work (e.g., [21,22,36]) have demonstrated various social emergent behaviours among location-based game players, showcasing the complexities resulting from the mixing of gaming as an integral part of players' daily social lives.

6.3 Limitations and future work

As with all research, the empirical research presented in this work has limitations. First, we carried observations in a specific context, Niantic Wayfarer, and inductively derived design recommendations for spatial crowdsourcing systems. The interpretive nature of the research leaves room for alternative conceptualizations, and there remains the question regarding to what extent our findings are relevant for other similar crowdsourcing systems. We argue that more empirical work is needed on other commercial spatial crowdsourcing applications, as new opportunities are constantly emerging. For example, recently Apple has started adding lidar sensors to their newest iPhones, which allow laypeople to perform accurate scans of real-world locations [25]. Furthermore, while based on this research design we can identify issues in the Wayfarer system, we could not determine the frequency of how often they appeared and whether there are geographical differences also in the appearance of the identified issues.

Second, in Study 2 we explored whether OSM data could be used to automatically generate PoIs using the Wayfarer criteria and additional criteria. Future research could look at other data sources besides OSM, such as the data provided by OSGeo or other similar organisations. Furthermore, while Niantic has specified a set of criteria for playful geographically located PoIs (see Appendix A) for Wayfarer, past work has produced alternative criteria (e.g., [38]), and we argue that future research should continue experimenting with available open resources to uncover which aspects of the real world would result in the most fun and playful experiences when incorporated into location-based AR games.

Regarding the Wayfarer system, past academic research has viewed it as a platform where players are involved in decision making [4]. This highlights that Niantic Wayfarer is not only about doing objective submission and review work, but there are multiple elements of creativity and decision making involved, as also evidenced by our empirical work. Regarding PoI submissions, players need to make decisions on what to submit, what to name the PoI, what kind of a description to write, where exactly to place the PoI and what kind of a photo to take for it. Regarding PoI reviewing, players also have some impact as they rate the PoIs and can collectively decide to accept or reject it, but also to move the PoI from its original location. Since there clearly is decision making involved in Wayfarer [4], future work should investigate the balance between objectivity and subjectivity in spatial crowdsourcing participation, especially as it relates to the sourcing of playful geodata.

7. Conclusion

Spatial crowdsourcing as a data sourcing approach is still in its infancy, but as both academic studies and commercial applications are constantly being developed, we are also seeing rapid maturing within the field. Gamification has emerged as a promising means for motivating participation, as opposed to providing monetary compensation or other extrinsic rewards, it offers a scalable and sustainable solution. In this study we elucidated 15 design recommendations on how to improve the existing state-of-the-art solutions (See Appendix E) and conducted a follow-up study to further demonstrate the applicability of these suggestions. Our work highlight in particular three areas where the Niantic Wayfarer system had room for improvement: (1) the user experience of the system; (2) system and process oversight; and (3) the leveraging of open data to support the system. In addition to the considerations described in this study, new opportunities arising from the proliferation of high bandwidth internet connectivity, more capable smart devices and the availability of better sensors continue to offer new opportunities for spatial crowdsourcing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

We wish to thank the anonymous reviewers, the handling editor and Dr Manuel Bär for providing us helpful feedback on this manuscript.

The title of this study refers to four things. First, it is a wordplay referencing the song “Into the Unknown” from the Disney movie Frozen 2. Second, “Unown” is an elusive Pokémon creature in Pokémon GO, and one which players have hunted using spawn maps. Third, it refers to the explorative aspect of location-based games: players travel to unknown places while playing. Fourth and finally, it links to the unknown outcomes of those kinds of crowdsourcing processes that deal with complex topics, such as the classification task of real-world objects into acceptable and non-acceptable PoIs for location-based games.

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Appendix A. Wayspots guidelines according to Niantic Wayfarer: https://wayfarer.nianticlabs.com/new/criteria/eligibility, accessed April 29, 2023)

A great place for exploration	A great place for exercise	Great places to be social with others
Historic plaques	Parks and plazas	Pavilions
Unique Art or Architecture	Gardens	Post Offices
Public Libraries	Forests	Gaming/Comic stores
Public places of worship	Hiking trails	Libraries (including free little libraries on public spaces)
Zoos	Biking trails	Parks and plazas
Museums and galleries	Exercise equipment in public spaces	Fountains and water features
Community gardens	Sport arenas	Famous transit stations
Historical gravestones	Sport fields	Popular restaurants
Nature signs		Favourite coffee shops
Unusual or unique local shops		

Appendix B. OSM tags related to Niantic’s content criteria. Tag groups extracted from [38], [39].

Strict *OSM tag group (group 1):*

Historic places: building = ruins; man_made = obelisk; historic = *.

Places of worship: amenity = place_of_worship; building = cathedral, chapel, church, religious, shrine, synagogue, temple; man_made = cross, torii.

Places of entertainment, arts, culture and tourism: amenity = fountain; man_made = windmill; tourism = museum, information, attraction, viewpoint, artwork, gallery, thema_park, zoo; amenity = arts_center, planetariums, studio, theatre.

Town halls: amenity = townhall.

Libraries and public bookcases: amenity = library, public_bookcase.

Places for picnic or barbecue: amenity = bbq; leisure = firepit, picnic_table; shelter_type = picnic_shelter; tourism = picnic_site.

Huts and other shelters: leisure = bird_hide; amenity = hunting_stand, shelter; building = hut; tourism = alpine_hut.

Mountain peaks: natural = peak.

Parks and Playgrounds: leisure = park, playground.

Places for doing sport: leisure = beach_resort, bowling_alley, fitness_centre, fitness_station, pitch, sauna, stadium, swimming_pool, water_park; amenity = dojo, public_bath; sport = *.

Relevant *OSM tag group (group 2):*

Educational establishments: amenity = college, dancing_school, kindergarten, language_school, music_school, school, university; building = college, kindergarten, school, university.

Places for food or drink: amenity = drinking_water, fast_food, cafe, food_court, ice_cream, restaurant, pub, bar, biergarten.

Healthcare and social facilities: amenity = animal_shelter, clinics, community_center, dentist, doctors, kneipp_water_cure, pharmacy, social_facility, veterinary; healthcare = *; social_facility = *.

Product shops and services: amenity = atm, bank, bureau_de_change, internet_cafe, marketplaces, vending_machine; building = kiosk, retail, supermarket; craft = *; shop = *; vending = *.

Stations and stops for means of transport: amenity = bicycle_parking, bicycle_rental, bus_station, charging_station, fuel; building = train_station, transportation; highway = bus_stop, rest_area, services; public_transport = station, stop_position; railway = halt, station, tram_stop.

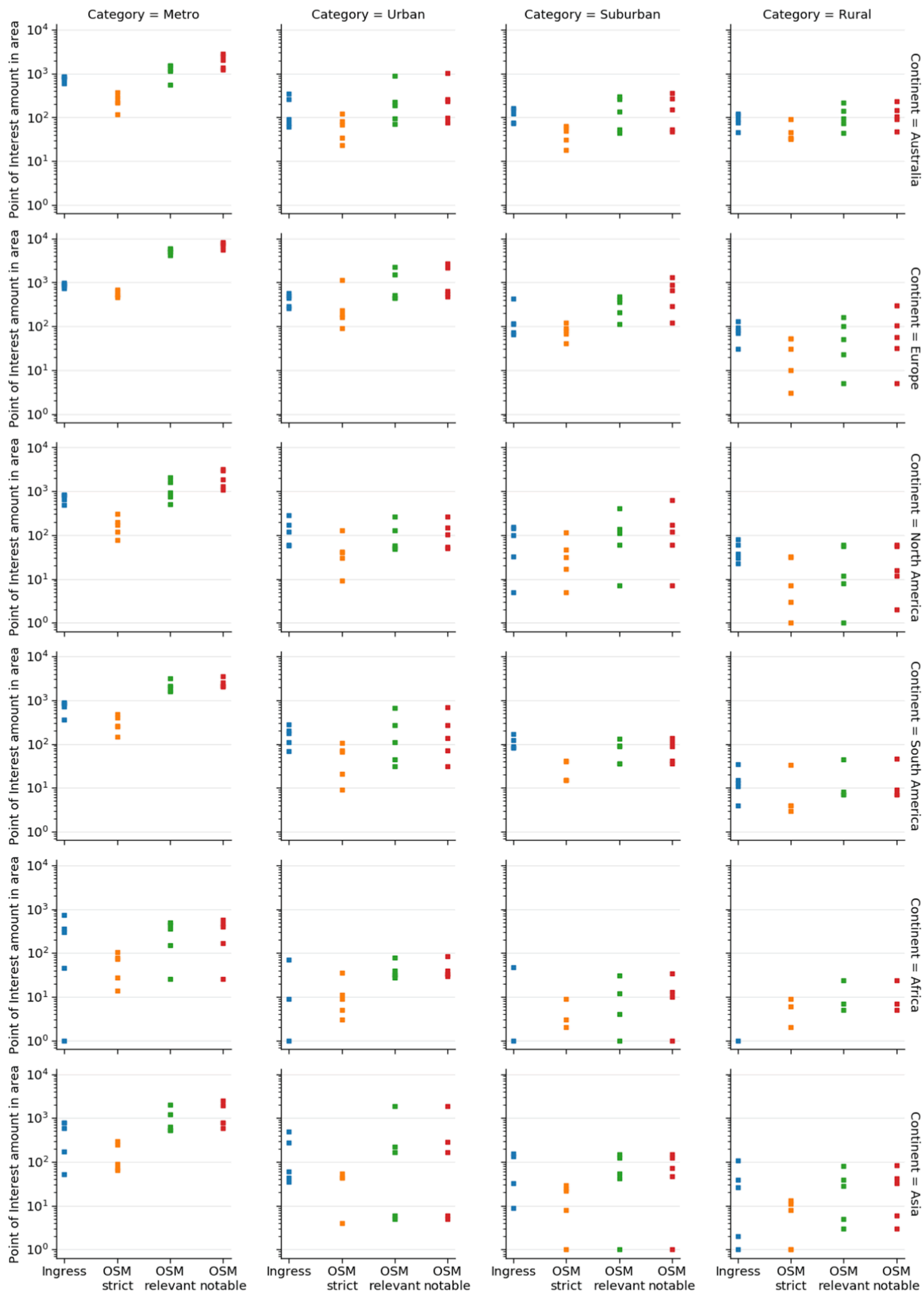
***Notable** OSM tag group (group 3):*

Benches: amenity = bench.
Public communication: amenity = post_box, post_office, telephone.
Waste disposal and toilets: amenity = recycling, toilets, waste_basket, waste_disposal; building = toilets.
Wells, towers and survey points: man_made = communication_tower, survey_point, tower, water_tower, water_well.
Trees, stones and springs: natural = rock, spring, stone, tree.

Appendix C. Full list of selected locations for evaluation.

Metropolitan area / region		Selected area in metropolitan area's vicinity		
		Urban	**Suburban**	**Rural**
Africa	Johannesburg	Vanderbijlpark	Heidelberg	Mooinooi
	Kairo	Beni Suef	Al Ayyat	Damallij
	Lagos	Ikorodu	Igbo Ora	Lemode
	Abidjan	Anyama	Akoupé	Lopou
	Nairobi	Naivasha	Kenol	Isinya
Asia	Tokyo	Chigasaka	Samukawa	Manazuru
	Shanghai	Chongming	Zhangyan Zhen	Tongjiang Jiedao
	Delhi	Bulandshahr	Tigri	Khera Khurd
	Seoul	Guri	Sohol-eup	Yeoncheon
	Abu Dhabi	Ajman	Al Dhaid	Al Madam
Australia	Brisbane	Sunshine Coast	Southport	Byron Bay
	Sydney	Wollongong City	Nowra-Bomaderry	Moss Vale
	Auckland	Hamilton	New Lynn	Silverdale
	Wellington	Lower Hutt	Blenheim	Khandallah
	Perth	Mandurah	Rockingham	Northam
Europe	London	Oxford	Bletchley	Towcester
	Paris	Amiens	Ozoir-la-Ferrière	Montididier
	Madrid	Guadalajara	Tarancón	Villarejo de Salvanés
	Athen	Chalkida	Korinth	Aliveri
	Helsinki	Vantaa	Kerava	Sundsberg
North America	Los Angeles	Victorville	California City	Helendale
	Montreal	Saint-Jean-sur-Richelieu	Sorel-Tracy	Napierville
	Calgary	Red Deer	Okotoks	Rocky Mountain House
	Kansas City	Saint Joseph	Blue Springs	Cameron
	New York City	Paterson	Morristown	Armonk
South America	Rio de Jaeneiro	Magé	Vassouras	Simão Pereira
	Lima	Lurigancho-Chosica	Chilca	Cocachacra
	Santiago de Chile	Melipilla	Peumo	Lo Miranda
	Buenos Aires	Luján	Cañuelas	Sulpacha
	Bogotá	Fusagasugá	Cota	Restrepo

Appendix D. Total number of identified points of interests for Ingress and the OSM approach.



Appendix E. Summarising the shortcomings in the Wayfarer system.

Issue	Recommendations
Inconsistency in evaluation outcomes	1. Automate PoI discovery when possible, by obtaining the PoIs directly from existing open source map databases such as OSM. 2. Clarify the PoI criteria to reviewers, and regularly provide reviewers with feedback on what fulfils the PoI acceptance criteria and what does not.
Inability to provide comprehensive rejection criteria Contributors do not always follow the rules	3. Collect verbal feedback from reviewers when they give a bad score and provide this feedback to the submitters. 4. Conduct manual checks on rejected reviews and seek to identify patterns of certain kinds of PoIs that are constantly rejected. Explain these unclear categories to both reviewers and submitters.

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(*continued*)

Issue	Recommendations
	5. Identify users who repeatedly vote against the official guidelines and provide them targeted information on why their review was against the guidelines.
Subjectivity in reviews is fuelled by complexity of the real world and subjective measures	6. Acknowledge the variance in PoIs within a specific category and clarify if only certain candidates within that category will be accepted, or all of them.
	7. Collecting subjective measures is good for evaluating PoI quality but should not influence the PoI acceptance outcome. Otherwise, submitters will be discouraged.
A slow review processes lead to multiple issues	8. Accelerate the review queue by improving user's motivation to contribute (e.g., better rewards, improved UX), by advertising the system to increase the number of reviewers or by lowering the number of required reviewers per PoI candidate.
	9. Accelerate the review queue by automating parts of the process such as automatic detection of duplicates and automatic rejection of blurred photos.
	10. Help reviewers make faster decisions by utilising open data as a decision support system.
	11. Ask submitters to mark down the specific criteria based on which their submission is acceptable and display this criterion to the reviewers.
	12. Acknowledge contributors who submit PoIs even if multiple users submit the same PoI and it ends up being a duplicate.
Gaming the system	13. React to abuse cases quickly and effectively to discourage future abuse.
	14. Explain to the community which behaviours are not allowed and why.
	15. Triangulate PoIs using open sources to flag cases for further investigation on abuse.

References

[1] F. Alt, A. S. Shirazi, A. Schmidt, U. Kramer, Z. Nawaz, 2010. Location-based crowdsourcing: extending crowdsourcing to the real world. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries* (pp. 13-22).

[2] M. Baer, T. Tregel, S. Laato, H. Söbke, 2022 Virtually (re)constructed reality: the representation of physical space in commercial location-based games, In Proceedings of the Academic Mindtrek Conference, 2022.

[3] R. Ballagas, A. Kuntze, S.P. Walz, Gaming tourism: Lessons from evaluating rexplorer, a pervasive game for tourists, in: International conference on pervasive computing, Springer, Berlin, Heidelberg, 2008, pp. 244–261.

[4] A. Bhattacharya, J.H. Lee, J.C. Yip, J.A. Kientz, Life goes on with Pokémon: reimagining the design of location-based games during the COVID-19 pandemic XRDS: Crossroads, The ACM Magazine for Students 28 (2) (2022) 70–75.

[5] M. Bubalo, B.T. van Zanten, P.H. Verburg, Crowdsourcing geo-information on landscape perceptions and preferences: a review, Landsc. Urban Plan. 184 (2019) 101–111.

[6] D. Butz, K. Besio, Autoethnography. *Geography*, Compass 3 (5) (2009) 1660–1674.

[7] Colley, A., Thebault-Spieker, J., Lin, A. Y., Degraen, D., Fischman, B., Häkkilä, J. & Schöning, J. 2017. The geography of Pokémon GO: beneficial and problematic effects on places and movement. In *Proceedings of the 2017 CHI conference on human factors in computing systems* (pp. 1179-1192).

[8] J. Dunham, K. Papangelis, S. Laato, N. LaLone, J.H. Lee, M. Saker, The Impacts of Covid-19 on Players of Pokémon GO, ACM Trans. Comput.-Hum. Interact. (2022).

[9] Eickhoff, C., Harris, C. G., de Vries, A. P., & Srinivasan, P. (2012). Quality through flow and immersion: gamifying crowdsourced relevance assessments. In *Proceedings of the 35th international ACM SIGIR conference on Research and development in information retrieval* (pp. 871-880).

[10] Y. Feng, H.J. Ye, Y. Yu, C. Yang, T. Cui, Gamification artifacts and crowdsourcing participation: Examining the mediating role of intrinsic motivations, Comput. Hum. Behav. 81 (2018) 124–136.

[11] B. Guo, Y. Liu, L. Wang, V.O. Li, J.C. Lam, Z. Yu, Task allocation in spatial crowdsourcing: current state and future directions, IEEE Internet Things J. 5 (3) (2018) 1749–1764.

[12] Hajarian, M., & Hemmati, S. 2021. A Crowdsourcing and Gamification based Product Ranking Method for E-Commerce. In *2021 7th International Conference on Web Research (ICWR)* (pp. 197-201). IEEE.

[13] D.D. Ingram, S.J. Franco, 2013 NCHS Urban-Rural Classification Scheme for Counties, Vital and Health Statistics. Series 2 (166) (2014) 1–73.

[14] K.T. Jacobs, S.W. Mitchell, OpenStreetMap quality assessment using unsupervised machine learning methods, Trans. GIS 24 (5) (2020) 1280–1298.

[15] Johnson, B. A. 2019. How an augmented reality game (Pokémon GO) affected volunteer contributions to OpenStreetMap. In *Proc. ICA* (Vol. 2, pp. 1-4.

[16] L. Juhász, H.H. Hochmair, Where to catch 'em all?–a geographic analysis of Pokémon Go locations, Geo-spatial information sci. 20 (3) (2017) 241–251.

[17] L. Juhász, T. Novack, H.H. Hochmair, S. Qiao, Cartographic vandalism in the era of location-based games—the case of OpenStreetMap and Pokémon GO, ISPRS Int. J. Geo Inf. 9 (4) (2020) 197.

[18] G.D. Karagiannopoulos, N. Georgopoulos, K. Nikolopoulos, Fathoming Porter's five forces model in the internet era, Digital Policy, Regulation and Governance (previously info) 7 (6) (2005) 66–76.

[19] J. Koivisto, J. Hamari, The rise of motivational information systems: a review of gamification research, Int. J. Inf. Manag. 45 (2019) 191–210.

[20] S. Laato, S.M. Hyrynsalmi, M. Paloheimo, Online multiplayer games for crowdsourcing the development of digital assets, in: In the International *Conference on Software Business*, Springer, Cham, 2019, pp. 387–401.

[21] S. Laato, N. Inaba, J. Hamari, Convergence between the real and the augmented: experiences and perceptions in location-based games, Telematics Inform. 65 (2021) 101716.

[22] Laato, S., Rauti, S., & Hamari, J. 2023. Resemblance of pervasive games and religion: A study among church employees and gamers., *Proceedings of the 2023 CHI conference on human factors in computing systems*.

[23] J. Laso Bayas, L. See, S. Fritz, T. Sturn, C. Perger, M. Dürauer, M. Karner, I. Moorthy, D. Schepaschenko, D. Domian, I. McCallum, Crowdsourcing in-situ data on land cover and land use using gamification and mobile technology, Remote Sens. (Basel) 8 (11) (2016) 905.

[24] N. Liberati, Phenomenology, Pokémon Go, and other augmented reality games, Hum. Stud. 41 (2) (2018) 211–232.

[25] G. Luetzenburg, A. Kroon, A.A. Bjørk, Evaluation of the Apple iPhone 12 Pro LiDAR for an application in geosciences, Sci. Rep. 11 (1) (2021) 1–9.

[26] Ş.S. Macakoğlu, B. Alakuş Çınar, S. Peker, Kiyaslio: a gamified mobile crowdsourcing application for tracking price dispersion in the grocery retail market, Int. J. Web Information Systems 18 (1) (2022) 55–75.

[27] R. Martella, C. Kray, E. Clementini, A gamification framework for volunteered geographic information, in: AGILE 2015, Springer, Cham, 2015, pp. 73–89.

[28] S. Matyas, Playful geospatial data acquisition by location-based gaming communities, Int. J. Virtual Reality. 6 (3) (2007) 1–10.

[29] B. Morschheuser, J. Hamari, J. Koivisto, A. Maedche, Gamified crowdsourcing: conceptualization, literature review, and future agenda, Int. J. Hum Comput Stud. 106 (2017) 26–43.

[30] B. Morschheuser, J. Hamari, A. Maedche, Cooperation or competition–When do people contribute more? A field experiment on gamification of crowdsourcing, Int. J. Hum Comput Stud. 127 (2019) 7–24.

[31] Niantic, 2022, Ingress Intel Map, [ONLINE], available at: https://intel.ingress.com/, visited November 8, 2022.

[32] K. Papangelis, A. Chamberlain, I. Lykourentzou, V.-J. Khan, M. Saker, H.-N. Liang, I. Sadien, T. Cao, Performing the digital self: Understanding location-based social networking, territory, space, and identity in the city, ACM Trans. Computer-Human Interaction (TOCHI) 27 (1) (2020) 1–26.

[33] Procopius, (2022) Geometry of the Sphere: Google's S2 Library. https://docs.google.com/presentation/d/1Hl4KapfAENAOf4gv-pSngKwvS_jwNVHRPZTTDzXXn6Q. Accessed November 8, 2022.

[34] Reddit (2022a), Toxic Ingress Community, [ONLINE], available at, https://www.reddit.com/r/NianticWayfarer/comments/y93zob/toxic_ingress_community/, visited November 3, 2022.

[35] Reddit (2022b), I see your busy street, and I raise... whatever this conga line of Gyms, [ONLINE], available at: is https://www.reddit.com/r/pokemongo/comments/x12mdo/i_see_your_busy_street_and_i_raise_whatever_this/.

[36] M. Riar, B. Morschheuser, R. Zarnekow, J. Hamari, Altruism or egoism–how do game features motivate cooperation? An investigation into user we-intention and I-intention, Behav. Inform. Technol. (2023) 1–25.

[37] Y. Tong, Z. Zhou, Y. Zeng, L. Chen, C. Shahabi, Spatial crowdsourcing: a survey, VLDB J. 29 (1) (2020) 217–250.

[38] T. Tregel, L. Raymann, S. Göbel, R. Steinmetz, Geodata classification for automatic content creation in location-based games, in: Joint International Conference on Serious Games, Springer, Cham, 2017, pp. 212–223.

[39] T. Tregel, Online content generation in mobile applications-adaptation and personalization for location-based game systems, Technical University of Darmstadt, 2021.

[40] T. Tregel, P.N. Müller, S. Göbel, R. Steinmetz, Looking for Charizard: applying the orienteering problem to location-based games, Vis. Comput. 37 (1) (2021) 31–45.

[41] T. Tregel, L. Raymann, S. Gobel, Match our cities: cross-location-based games to enable simultaneous multiplayer, IEEE Trans. Games. (2022).
[42] C. Yang, H.J. Ye, Y. Feng, Using gamification elements for competitive crowdsourcing: exploring the underlying mechanism, Behav. Inform. Technol. 40 (9) (2021) 837–854.
[43] Y. Zhao, Q. Han, Spatial crowdsourcing: current state and future directions, IEEE Commun. Mag. 54 (7) (2016) 102–107.