AALBORG UNIVERSITY
STUDENT REPORT

Department of Architecture, Design and Media Technology

Medialogy, 10th Semester

Title: SpotAffald: A Citizen Science Approach to Litter in Context

Project Period:01/02/2021 – 28/05/2021

Semester Theme: Master Thesis

Supervisors: Markus Löchtefeld

Projectgroup no. mta211039

Members:
Christoffer Cæsar Fælled
Chatrine Elisabeth Larsen

Abstract:

This paper reports the findings of the potential of citizen-science-driven data collection in an environmental context. Research showed there to be an information gap regarding inland littering. Therefore, a mobile phone application was developed to investigate user motivation in collecting data (images) of litter in its context. The application was developed using the software development kit Flutter with iOS and Android as the target platform. The application allows the user to capture and submit images of litter as well as annotations. Several features based on research into gamification and user motivation were implemented. The application was evaluated using the User Motivation Inventory and further qualitative feedback from users. The results showed that the users were mainly motivated by their intrinsic motivation such as core principles and were less reliant on external factors. The findings and images gathered in a two-week span showed the app's potential as a cheap and widespread data collection tool. However, it is unknown whether the implemented motivational features would ensure a continuous engagement long-term.

SpotAffald: A Citizen Science Approach to Litter in Context

Chatrine Elisabeth Larsen
Cela16@student.aau.dk
Department of Architecture, Design and Media Technology, Aalborg University
Aalborg, Denmark

Christoffer Cæsar Fælled
cfalle16@student.aau.dk
Department of Architecture, Design and Media Technology, Aalborg University
Aalborg, Denmark

ABSTRACT

This paper reports the findings of the potential of citizen-science-driven data collection in an environmental context. Research showed there to be an information gap regarding inland littering. Therefore, a mobile phone application was developed to investigate user motivation in collecting data (images) of litter in its context. The application was developed using the software development kit Flutter with iOS and Android as the target platform. The application allows the user to capture and submit images of litter as well as annotations. Several features based on research into gamification and user motivation were implemented. The application was evaluated using the User Motivation Inventory [5] and further qualitative feedback from users. The results showed that the users were mainly motivated by their intrinsic motivation such as core principles and were less reliant on external factors. The findings and images gathered in a two-week span showed the app's potential as a cheap and widespread data collection tool. However, it is unknown whether the implemented motivational features would ensure a continuous engagement long-term.

KEYWORDS

User Motivation, Littering, Digital Data Collection

1 INTRODUCTION

Environmental issues are a growing problem with plastic pollution being one of the major contributors [6]. The pollution caused by plastics has been attributed to ineffective waste handling with the main source being single-use plastics discarded into the environment through landfills or directly into nature [12]. Due to none of the commonly used plastics being biodegradable it accumulates rather than decomposes [12]. This has caused an increasing interest and effort in minimizing littering in small communities as well as government and international agencies. In 2015 all the United Nations' members adopted the 2030 Agenda for Sustainable Development. At the core, the agenda consists of 17 different Sustainable Development Goals (SDGs) where a large portion of them focuses on environmental issues such as "Responsible Consumption and Production", "Climate Action", "Life below Water", and "Life on Land" [28]. Likewise, citizen-driven projects have seen an increase in numbers [24] with the internet trend "#trashtag" taking off in 2019 where people would take before and after pictures of locations they had collected litter accompanied with the hashtag "#trashtag" [30]. Citizen-science-driven projects have also proven as an effective tool for monitoring littering [29].

Litter in nature can also be monitored by e.g. drones or robots utilizing machine learning algorithms that can recognize litter in nature from images or video. In order for such monitoring solutions to work sufficient data has to be available to train said algorithms. Mikołajczyk et al. [26] have compiled an overview of available datasets containing images of waste. The overview contains datasets compiled of e.g. synthetic images of litter in context, images of objects, close-ups of litter, litter in waterbodies, and similar. However, very few datasets contain images of litter in its context of which the only dataset not behind paid license is the TACO dataset [33]. Thus, limited data in the form of images of litter in context are available, and seemingly none from a Danish context. Therefore, this study aims to explore how data about litter in context can be gathered utilizing citizen science set in a Danish context.

2 RELATED WORK

The majority of studies and data collections conducted to address the problem of littering are performed in coastal/maritime areas. Thereby not prioritizing investigating litter in other areas and nature types, which can have a negative effect on understanding the problem of littering as a whole. Consequently, it can potentially also affect the understanding of some aspects of coastal/maritime littering, as litter is not static and will naturally move through the environment and end up in or near the oceans.

Syberg et al. [38] point to the same information gap as motivation for their study concerning inland littering with a special focus on plastic pollution. To address said information gap they conducted a "Mass Experiment" in collaboration with the Danish National Center for Science Education, Astra [4], utilizing citizen science as a cost-efficient, effective, and far-reaching way of collecting data. The participants were approximately 57.000 schoolchildren and adolescents (6 – 19 years old) throughout the Danish Realm (Denmark, Greenland, and the Faeroe Islands), who collected data during a period of three weeks in the fall of 2019. The participants collected 374.082 plastic items in total, gathered in eight different nature types, the found plastic items were categorized into 22 different categories, which were all found in seven out of eight nature types, indicating that increased monitoring of inland littering is necessary. Moreover, they found that their results did not align with those from other European countries, thus data and findings from other countries are not directly applicable to Denmark. The authors assign the difference to Danish measures taken to reduce littering; thus, it can be argued that more data on inland littering could potentially help monitor whether said measures have the desired effect or not [38].

2.1 Litter in Coastal and Maritime Areas

Currently, the majority of regular monitoring of litter is situated in coastal/maritime areas and not further inland. For example, in

Denmark, six reference beaches are monitored three times annually reporting results to the Marine Litter Watch three of which is also reporting to OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic), which is done to *"assess the state, impact, and trends of marine litter."* [9, 10]

However, no equivalent regular monitoring of inland littering is currently a reality.

A comprehensive analysis covering littering in Denmark made by Operate [3], included a summary addressing the magnitude of the problem, cost, public perception, etc. comprised of existing knowledge and relevant new analyses. One of the main conclusions is, that there is a current lack of data about littering and consistent methods to quantify litter in Danish nature, which results in an incomplete image of the problem and related costs. Thus, not enough data is available to make informed and well-founded arguments to prioritize making a change and fund measures to do so [3].

To compensate for the lack of data, information, and studies concerning inland littering inspiration of e.g. how to approach the topic can be found from litter studies set in other contexts. One can also argue that the results, to some extent, are transferable to other contexts e.g., when looking at littering behavior, motivation for behavior change, and similar.

2.1.1 Citizen Science and Litter Studies. Citizen science is a widely used approach within the subject of littering, as it provides a way of collecting data in a cost-efficient way.

Kiessling et al. [17] conducted a study to identify the origins of riverine litter. They utilized citizen science with schoolchildren as participants, which allowed for sampling 250 spots along large and small rivers in Germany. By analyzing the most frequently occurring items littered at the sampling spots the authors found indicators of the main litter source being recreational visitors along the riversides. The authors see a need for action to decrease litter in and by the rivers, e.g. by providing better education on the subject or through policy measures. The end goal with such measures would be to improve the riverine litter situation and consequently also decrease the input of litter from rivers to the marine environment [17].

Another example is a decade-long study (2005 – 2014 inclusive) by Nelms et al. [29] where data about litter along the British coastline was collected with the purpose of "increasing knowledge on the composition, spatial distribution and temporal trends of coastal debris" [29].

During the study, volunteers contributed *"73,167 h (equivalent to ~25 years of continuous surveying (365 days a year) by a single person working 8 h per day)"* [29], which is a considerable amount of man-hours, that probably would have been unobtainable within the same time-frame if the litter collectors were not volunteers, but would have to be funded by e.g. the government – the 73,167 hours of sampling would have cost approximately £500,000 in salaries alone.

Furthermore, they found that public littering was the source of one-third of the total litter, *"indicating that land-based inputs are likely key sources of marine anthropogenic litter."* [29] These results also seem to align with those of Kiessling et al. [17] concluding recreational activities as the main source of litter, which in this context could include beach visitors.

Moreover, they point to the potential of educating and changing the public's behavior and attitudes towards littering through citizen science projects, which can potentially be a part of the solution to decrease littering.

2.2 Citizen Science

Having touched upon some of the benefits of citizen science it is also important to understand what it is, its potential, and how to define it. Defining citizen science is a complex task, as its definition varies depending on the use context and purpose. Haklay et al. [13] take up the challenge of answering the questions *"what is citizen science?" and "why is it challenging to define citizen science?"* [13]

They explore how citizen science has been defined and used in the past, and how factors such as context influence the definition. The authors indicate what citizen science can be: *"it includes the generation of scientific data…, engages volunteers over a large area…, and address a politically relevant issue."* [13].

The authors encourage to consider which activities the participants are expected to carry out and ensure transparency about it in the applied definition of citizen science. In the context of this study, the definition of citizen science would thus have to convey citizen science as mainly a data collection activity. In addition to transparency concerning the participants' tasks as citizen scientists, the intent of this study is also to be transparent about the purpose of gathering data and the handling of the collected data afterward.

Furthermore, we comply with the notion of citizen science being volunteer-driven and leisure activity, as the app is 100% non-commercial in all aspects and no parties stand to gain anything from participation.

According to this definition, the here presented approach could be considered citizen science where volunteers contribute to the data collection of litter in its context in Denmark.

2.2.1 Open Data. An important part of this study and the data collection is the concept of "open data". This means that the data gathered through citizen-science-driven data collection should be openly available for use e.g. in a scientific context by other researchers. This is important since access to the data is fundamental if future researchers are to build upon and utilize the gathered data. It also emphasizes the importance of usability and access to the entire dataset. *"The work must be provided as a whole and at no more than a reasonable one-time reproduction cost, and should be downloadable via the Internet without charge."* [11].

2.3 App Driven Data collection

Mittal et al. [27] developed an app with the purpose of providing a tool for citizens to report the presence of garbage in their community to the authorities, who can take charge of it being disposed of [27].

The authors argue for the choice of technology (smartphones) by highlighting its powerful cameras and being a device the majority of people possess. The proposed solution can detect garbage in images automatically, making human detection redundant and thereby minimizing human intervention, which could potentially increase the accuracy of the resulting dataset.

The garbage detection on the images is done locally on the users' phone, alternatively to uploading every image to a server where the processing could be performed, which was not done due to *"the slow and at times, erratic network connectivity, and people's mindset of frugal use of internet data plans on their smartphones"* [27]. This decision is a product of the use context, which is a developing country (India) where stable and "free" data is not a guarantee.

However, the local garbage detection results in a processing time of five seconds on average, which significantly decreases the user experience, as the task flow completion time is relatively high. A study by Imperva Incapsula [40] investigated how long people were willing to wait for a page to load while shopping, which showed that 35% of the users will wait between three to five seconds for a page to load, 20% were willing to wait less than three seconds and 7% expecting an immediate response [40]. Thus, the average processing time of five seconds of the SpotGarbage app could result in approximately 30% of the users abandoning the task before completion if a similar tendency was to be observed. The local garbage detection and consequently longer processing time is a conscious decision as the authors aimed to accommodate the users' concerns regarding internet use instead, as it has a monetary value and might discourage usage if opposing the frugal mindset of the users.

In a Danish context, the concerns regarding data usage are not as relevant, thus the user experience would be a higher priority and optimization of the task flow completion time. A fast task flow completion time is in the intended use context of this study an important aspect of the solution, as the users will probably be collecting litter while using the app, leaving only one or no hands free for using the app. Thus, the task of capturing an image of litter in nature should be fast, easy, and possible to complete with one hand.

2.4 User Motivation

Previously various motivational elements have been employed by app developers. The purpose of these elements is usually to incentivize a continuous use of the application and increase user engagement. In the case of a citizen science data collection task, this could also be used to increase data submission rates and in the case of images the annotation rate. Thus it is important to investigate how user motivation works and possible ways of increasing it besides just fulfilling basic user needs and usability.

2.4.1 Intrinsic and Extrinsic. When working with user motivation there are two important types of motivation to distinguish between – intrinsic and extrinsic. Intrinsic motivation is when you do something because you find it fulfilling i.e., you are performing an activity for your own sake rather than because of an external reward. Opposite of intrinsic is extrinsic where you are motivated by an external reward such as money or wish to avoid being reprimanded[36]. Some simple examples of intrinsic versus extrinsic motivation can be seen in Table 1.

Intrinsic	Extrinsic
Playing sports because you enjoy the activity	Playing sports because you want to win a medal
Reading a book because the subject interests you	Reading a book to get good grades
Cleaning your home because you like it clean	Cleaning your home to avoid being judged by visitors

Table 1: Examples of intrinsic and extrinsic motivation.

2.4.2 Gamification. A often utilized method of increasing user motivation is through the use of gamification. Deterding et al. [8] define gamification as the use of game design elements in non-game contexts. Gamification is often implemented in an attempt to improve the user experience and engagement. The incorporation of video game elements has shown to be a successful way of incentivizing the user and increase activity. To prove gamification's ability to increase user motivation and engagement a two-year field experiment investigated the implementation of the game mechanic "badges" into an economic service. A pre-implementation group (N = 1410) and post-implementation group (N = 1579) was monitored each for a full year. The results showed a significant increase in the actions carried out by the users in the gamified implementation [15]. Some studies have however cautioned against relying too much on gamification as they might negatively influence the users' intrinsic interest ultimately causing them to abandon the application or task [7, 20, 37].

Rewards. A common gamification element is rewards in the form of unlockable badges [8]. By performing some activity or reaching a goal the user is presented a visual reward (a badge) like seen in Figure 1. A study by Hakulinen et al. [14] investigated the use of badges in an online learning environment. The students (N=281) were randomly divided into a treatment and control group. The study found a statistically significant difference in some students' behavior when presented with certain badges. Based on their findings they concluding that badges seemed to be a promising method of motivating students and encourage studying.

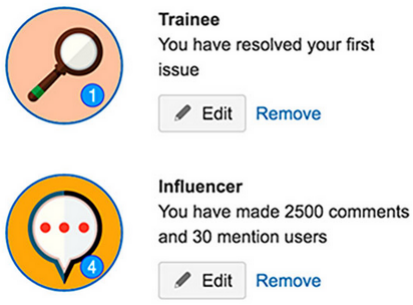


Figure 1: Example of badges implemented as a gamification element[32].

Leaderboards. Another often incorporated game element is leaderboards where the user can compare their progress or activity with other users, an example of this can be found in Figure 2. A study by Mekler et al. [25] (N=273) investigated the influence of points, levels, and leaderboards in an image annotation task. They found that while the gamification elements did not affect the users' intrinsic motivation they did have a significant effect on the users' performance (tag quantity and quality) leading to a significantly higher amount of tags generated compared to the control group. Thus, concluding that in their context points, levels, and leaderboards provided an extrinsic incentive for the user. However, leaderboards are one of the gamification elements that should be used with caution as multiple studies have found that they potentially could cause an adverse effect. Kocielnik et al. [19] investigated the effect of their application "Reflection Companion" which supported the user in engaging reflection on their physical activity measured by their smartwatch. While their implementation was successful in increasing user motivation some users expressed aversion with comparing themselves to others [19]. In a more closely related study by Massung et al. [22] they investigated the impact of different motivational strategies in pro-environmental data collection application. They found that the participants near the top of the leaderboards were competing for the top position and thus provided them with an extrinsic motivation to maintain their usage. However, participants that fell behind often noted the opposite effect and the leaderboards served as a very clear demotivator [22].

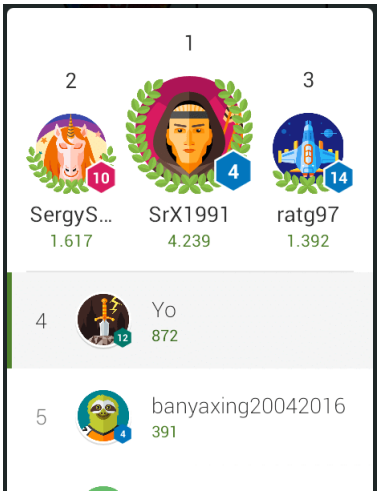


Figure 2: Example of a leaderboard implemented as a gamification element [39].

2.4.3 Motivation Recommendations. In the previously mentioned study by Massung et al. [22] they listed several recommendations to improve the effectiveness of digital data collection. Noting the benefit of targeting online discussion boards with users that are likely to have a lifestyle that would incentivize ongoing contribution. Additionally, competition should be an option that easily could be ignored to avoid the aforementioned possible negative effects. They noted that a number of their participants were motivated by *"doing their bit"* rather than competing to be the top contributor giving the example that providing an average amount of data collected per user could potentially encourage participants to meet this average. The applicable recommendations can be seen below.

(1) *"Seek those whose lifestyle is likely to enable them to participate."*
(2) *"Use passion for a cause as a threshold motivator, but do not assume it acts as an engagement motivator."*
(3) *"Make competition available, but easy to ignore."*
(4) *"Provide information regarding 'community norms' in a way which motivates desired behavior."*

2.4.4 Measuring User Motivation. There are many different ways and methods for measuring motivation, however, most are meant for a specific context such as work, academic, or athletic motivation. Mayer et al. [23] conducted a meta-review of over 75 years of motivation research reviewing over 50 different measurements/methods for motivation, however, the majority of the measures reviewed focused on a non-technological context. Brühlmann et al. [5] propose their multidimensional measurement tool, the User Motivation Inventory (UMI), as a method for evaluating a technology's and system's motivational ability. The UMI is an 18-part Likert scale exploring the users' intrinsic and extrinsic motivation as well as other factors. Their two studies (N = 921) of the UMI confirmed the reliability and validity of the scale thus concluding its potential in investigating user motivation [5]. The UMI and its six subscales are grounded in the Self-Determination Theory (SDT) which is a theory of how human motivation and personality works [35]. The SDT is useful when trying to understand what might motivate an individual's behavior. People with a high level of self-determination tend to have a high level of self-motivation and are thus less reliant on external rewards for them to complete a task.

2.5 State of the Art

Currently littering, and in general, improving on the environment is of great focus all striving to reach the Sustainable Development Goals. In a time where the majority of people own a smartphone, this becomes a powerful tool and ally in the fight for the environment. Several organizations have realized the potential of utilizing citizen science involving the participants through their smartphones. In a littering context some solutions are Litterati [21], TrashBlitz [41], Rubbish [34], and Pirika [31].

Litterati [21] is one of the more known solutions (203.235 participants from 165 different countries), whose purpose is to provide a platform for collecting data about litter in the form of images and tags of the litter in the images. Litterati utilizes different gamification elements of a competitive nature e.g. leaderboards, overviews and statistics of contribution, and a "challenge" feature, all attempts to engage the users.

Although it claims to part of the open data movement this does know align with the definition by Open Knowledge Foundation [11]. The data is not freely accessible, as to obtain more than 50.000 data entries a request must be submitted to be reviewed and accepted by Litterati. Furthermore, they do not share the images uploaded by the users.

TrashBlitz [41] is a web-based application, thus also accessible on smartphones, with the aim of assisting in categorizing litter. It is

a data collection tool consisting of a rather comprehensive tagging process, which could result in precision and potentially higher quality in the dataset, however, it might decrease the user experience. Moreover, no additional features such as e.g. motivational features are incorporated to increase the user experience.

The users might find it tedious and too time-consuming to perform the tagging process. Moreover, it might be inconvenient when out in the field collecting litter, as you would often use one or two hands for picking up the litter. Therefore, the data collection task should be fast and easy, to avoid being a nuisance. Precision and user experience might therefore be a trade-off to consider when creating a litter tagging system.

All of the aforementioned solutions are in English or Japanese, which in a Danish context might exclude or discourage potential users if the solution is not in their native language. Language is, therefore, an important factor to consider when designing for a specific target group and use context. Furthermore, the solutions provide varying degrees of extrinsic motivational features, thus some relying heavily on the users' intrinsic motivation and general interest in the area. Moreover, the solutions are of varying availability as they are not all to be found on both app stores (iOS and Android), thus excluding potential users.

3 METHODOLOGY

Based on the recommendations by Massung et al. [22] it was decided to target Danish citizens with an environmental interest, as they would likely already have an intrinsic motivation towards environmental efforts. This would likely cause a larger initial interest in the proposed solution. However, due to the current pandemic, the circumstances were not ideal to conduct a traditional target group analysis, thus alternatives were sought out and utilized. Netnography being one such alternative. Netnography is an adaption of ethnographic methods to be utilized on the internet to study online communities. Netnography *"can be done by either actively integrating the members of the community or passively monitoring the community and integrating the gathered information, knowledge, and ideas into the new product development process."* [2] A more informal approach to netnographic was used as the potential benefits of a proper/formal netnographic research process did not outweigh the speed and alternative resource allocation of an informal approach.

Thus, inspired by the netnographic approach of passively monitoring online communities and by adopting well-known UX methods to online usage information about the target group was gathered. As a start, groups, communities, events, and similar were identified online through extensive search. Typical search words used was: "affald, skrald, skrald-/affaldsindsamling, miljø," and similar. The search results were investigated for their relevance and mentions and references to other suitable groups, communities, and pages. Moreover, particularly active members of relevant search results were observed in the sense that special attention was paid to their activity and input, which in some cases lead to other online communities.

Images were also informally monitored and analyzed, which gave an insight into the severity of the problem of littering. Moreover, it provided information about phone usage during litter-collection activities. It was found that members of litter-collecting communities often bring their smartphones with them, and to different extent post images of the litter they encounter, both images of the litter in context and images of the total amount of litter collected. The sharing of images and general phone usage (e.g. use of exercise apps) during litter-collecting activities indicated a potential for successfully introducing an app for collecting data about litter in nature. Furthermore, the posting of images indicated a general interest in showcasing the results of their effort, an underlying motivation potentially being seeking acknowledgment of their effort.

Moreover, information about the use context could be derived from descriptions of "litter-collection kits". Kits of tools for collecting litter can be ordered from e.g. the annual "Affaldsindsamligen" [1] containing e.g. gloves, bags, "trash-pickers", and notation tools all occupying one or both hands, indicating that the future user of the proposed solution would most likely only have one hand available for interacting with the application.

The same observation is also indicated through images of people collecting litter, one example being Figure 3.

Figure 3: Example of people posing for a picture while collecting litter [1]. The equipment (bags and trash-pickers) indicate that they would only have one hand available for interacting with the proposed solution.

3.1 Online Workshop

To gain additional insight into the target group we participated in an online event concerning trash and recycling in Odense municipality (09/02/2021) via Microsoft Teams. The event/workshop covered questions such as:

- *"How do we avoid that so many things end up as trash?"*
- *"How do we avoid littering?"*
- *"How can we motivate you to keep sorting your trash?"*
- *"Etc."*

Concerning reducing litter some interesting and relevant suggestions were made during the workshop, e.g. to make progress visible by visualizing statistics as encouragement, but the biggest takeaway (agreed upon by all participants) was: more education! The participants suggested more education on the subject of littering and the consequences thereof, e.g. through campaigns, events with professionals e.g. from the municipalities, and signs at affected areas. An emphasis was put on educating children as they would grow up to have good habits reducing littering in the long run, and could potentially also pass on the good behavior to family members and friends extending the positive effect of the education on the subject.

4 THE PROPOSED SOLUTION

Based on the findings from the previous sections the proposed solution is to be developed as a mobile application for both iOS and Android mobile phones. Only developing e.g. Android could potentially prohibit a large user group from contributing, thus the solution must be available on both platforms. The application has two intended use cases which can be seen in Figure 4 and Figure 5. In the first use case in Figure 4 the user is out doing some activity e.g. collecting trash and they spot a piece of plastic, the user opens the application and uses the application's inbuilt camera to take a picture and immediately upload it before continuing their activity.

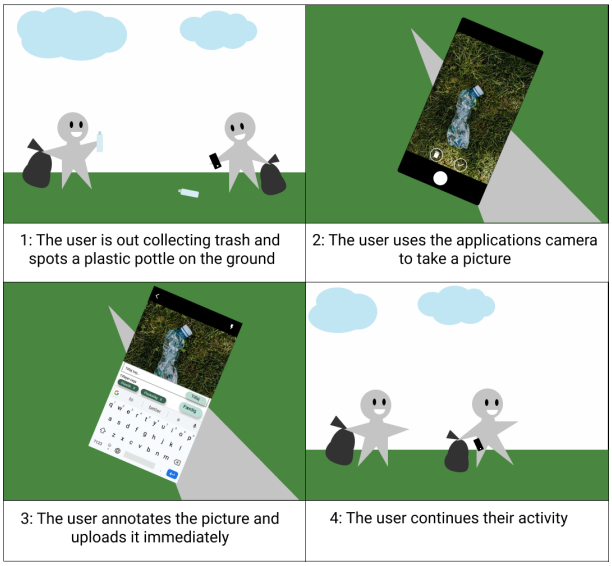


Figure 4: Storyboard of an intended use case using the application's camera.

In the second use case in Figure 4 the user is once again collecting trash where they spot a piece of plastic, however, this time the user utilizes their mobile phone's camera to take a picture before continuing their activity. Once the user has completed their activity and has time available they launch the application, navigates to the gallery, and submits the picture they took earlier.

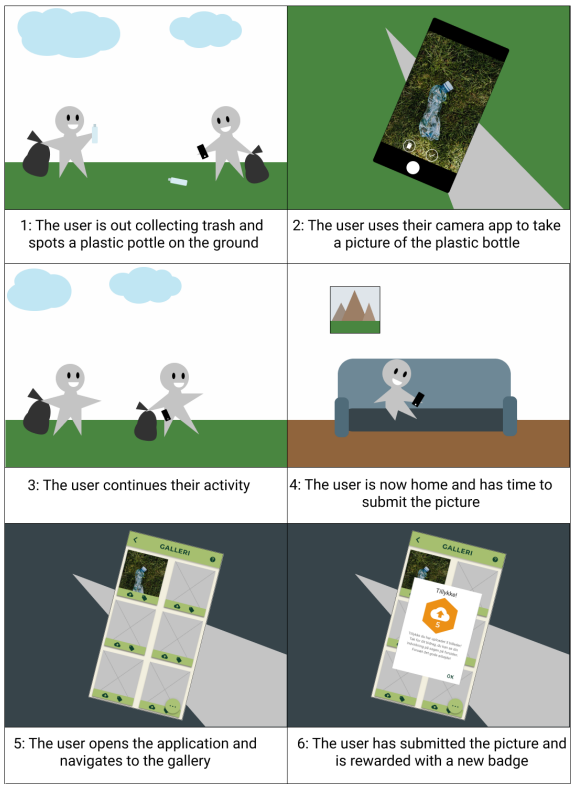


Figure 5: Storyboard of an intended use case using the application's gallery.

Since the intended use cases are performed while already doing some activity it is important to minimize the number of clicks necessary to complete the required action. Thus, creating a quick interaction that would hopefully avoid being a nuisance. The proposed solution has several core features and design considerations. Since most of the state of the art applications are developed in English the proposed solution is to be developed in Danish for two main reasons: users might better be able to describe/annotate the images in their native language resulting in a better annotation quality; and because some users may choose to not use the application entirely because of lacking confidence in their English skills.

The intended user group is people with an environmental interest to create an initial interest in using the app. Likewise, the user should have a lifestyle that should enable active participation in the app, thus members of various trash-collecting communities were an obvious target group for the application. However, like Massung et al. [22] reports it is important to note that an environmental interest is not a guarantee of continuous app usage.

5 DESIGN

The app design is based on the goal of the study, the research performed, and insights gathered about the users and use context described in the previous sections. The app's design and the reasoning behind it are discussed below.

5.1 Thumb Zone

The thumb zone can be defined as the area of a smartphone screen the user can reach and interact with (one-handed) without putting strain on the hand [18]. Thumb zones vary depending on thumb/-hand size and screen/device size.

Kim and Ji [18] conducted a study to identify the natural thumb zone of users on smartphones holding it with a one-handed grip. Their participants were divided into groups based on thumb length (small, medium, large), and tested with devices of different sizes to *"examine the effects of display size of smartphones"*. [18] The device sizes were randomly assigned to the participants.

It was found that the participants from the large thumb group had a natural thumb zone covering more than 50% of the smartphone screens. Participants from the small and medium thumb size group covered approximately 30% - 40% of the screens. Despite the relatively large difference in thumb zone sizes for the groups, common for all was that *"the lowermost region and the upper left region are classified as areas that are difficult to use in one-handed environment"* [18].

Therefore, when designing applications for smartphones it would be advisable to avoid placing core features in these areas, as they would be hard to reach with one-handed use.

5.2 App Design

The design of the application is based on the information described and discussed in the previous sections. The design is created with the technology's and chosen framework's (Flutter) possibilities and limitations in mind as a means to ease the transition from design to implementation. Since the purpose of the app is to collect images of litter in nature a few specific functionalities are required to enable the user to fulfill this goal through the app. The core features are taking a picture, tag images, and upload images.

5.2.1 Camera and Uploading. The users are able to capture images through the app as the app opens the phone's camera. Utilizing the users' phones' cameras ensures the users are familiar with the camera and its settings, compared to an "in-app" alternative as seen in solutions like Snapchat. Additionally, more customization of camera settings is available with the phone's camera, which might be an advantage if the users e.g. put an effort into the quality of their images as they might wish to share them on social media. When an image is captured through the app the users are asked to tag the image using keywords to describe the litter in the image (optional), afterwards the image is uploaded via the upload button which also concludes the task flow.

Alternatively, the user can capture images "outside" of the app, using the phone's camera as normal, then at a convenient time the user can from the gallery in the app tag (optional) and upload the images they gathered earlier. The integration of the phone's local gallery allows for this alternative use-case, which offers greater freedom of when to "complete" the task flow of uploading images through the app. Understanding the users who seem to already take pictures of the litter they encounter, they will be able to continue their routines as before while collecting litter. At a later time when more convenient the users can "act as citizen scientists" by contributing with their images via the app. The task flow of tagging and uploading through the gallery is also kept simple and fast in an effort to increase the user experience and accommodate the special conditions of the use context(s).

5.2.2 Tagging. The tagging system is utilizing a "free-write" method, meaning the users type in one or more keywords describing the litter in the images via the phone's keyboard. A "free-write" option was deemed most suitable to the use context, as State Of The Art (SOTA) solutions showed how pre-defined tagging options quickly can become overwhelming and time-consuming to navigate in (e.g. as seen in the TrashBlitz web app described in subsection 2.5).

As discussed earlier in subsection 2.5 greater accuracy in the data can be achieved through a thorough pre-defined tagging system, however, that being at the expense of increasing the task flow completion time and decreasing the overall user experience especially if used while collecting litter as the user would have to pause their activities to use the app. Hence it is a conscious decision to prioritize user experience and fast task flow above data accuracy, especially since the primary data is the images, and the tags are additional and optional data. Additionally, the object to be tagged should ideally be centered in the image.

5.2.3 Purpose, Goal, and Transparency. As mentioned in subsection 2.2 it is important to make clear what the task of the citizen scientist is, thus emphasis was put on this in the onboarding, on the information screen, and in the help pop-ups. The purpose of the app, thus the users' task, is explained through short text in the onboarding process, which works as an introduction to the app. The users' task is also described in more detail to explain that the goal is images of litter in nature and not e.g. the results of a litter-collection session i.e. images of a pile or bags of trash. This is also explained in the help pop-up on the homescreen.

On the information page, the purpose of the app is described, introducing the user to the idea of contributing to the scientific community with the data they collect. Moreover, what the data can potentially be used for is described in an easily understandable way. Furthermore, emphasis is put on explaining that the data shared via the app is anonymous as no personal information is shared. The concept of open data is also shortly described as the users have a right to know what happens to their data. Transparency concerning the users' data might provide a sense of security, resulting in them being more comfortable using the app.

Images from the users' local phone gallery are shown in the app's gallery, which might feel intrusive to some to see personal images in the app. Therefore, another help pop-up is included, which explains that the images in the gallery can only be seen by the user unless they choose to upload them, again pointing out that no data is shared unless they upload it themselves. Moreover, a sense of security is offered by explaining that images uploaded containing anything that is not litter are removed, thus uploading an image by a mistake is not a problem. However, measures are also taken to prevent uploading an image by a mistake, as the users are asked to confirm their actions in the app (uploading and tagging). Feedback in the form of toasts is included as a visual indication of which actions have been performed. The help pop-up in the gallery also explains why images captured through the app are not shown in the gallery.

5.2.4 Strategic Placement of Core Features. The app interface is designed with the use context in mind. As derived from the online target group analysis (described in section 3) the user will most likely only have one hand available for interacting with the app while collecting litter. Therefore, the application is designed to accommodate one-handed use, which in our optics means placing core features in the users' natural thumb zones and minimizing the task flow completion time. The core features (camera and gallery) and a screen with motivational elements (badges) were included in a floating action button menu placed in the lower right corner as seen in Figure 6. The placement is in the users' natural thumb zone allowing for easy, quick, and effortless access to the features. The task flow completion time is kept fast by making the tagging "free write" and optional, as described in subsubsection 5.2.1 and subsubsection 5.2.2.

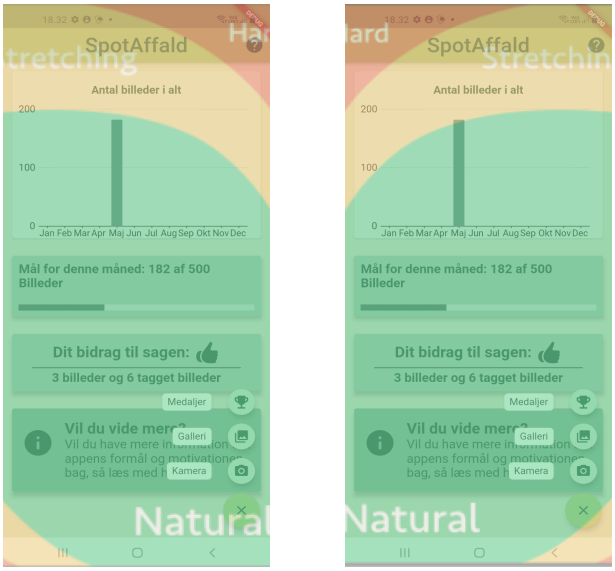


Figure 6: The application's interface with a thumb zone illustration overlaid [16] for both left-handed (left picture) and right-handed (right picture) interaction.

5.2.5 Look and Feel. Since the target group is very broad, the look and feel of the app is kept neutral in its expression to cater to as many as possible. Contrast is also optimized, and interactions are simple to accommodate all levels of smartphone experience.

5.2.6 Design Process. In the design process, the online tool Figma was used as it allows for easy collaboration and communication when working on a design as all involved parties can see the same designs, leave feedback, and create version control. Figma was used to create wireframes and mid-fi's based on sketches made on paper. Moreover, all illustrations in the app are made in Figma, that being the images in the onboarding and badges on the badge screen. Figma has a prototype functionality, with which the different screen designs were connected and assigned an interaction type (e.g. click, swipe, scroll), resulting in a hi-fi prototype suitable for user-testing. A user-test was conducted with the first iteration of the app design in Figma (see Figure 7 for design), which showed that the placement of upload, delete, and tag buttons on both the individual images in the gallery and at the bottom of the gallery screen were confusing, as it was not clear what the difference was. A wish for only one of the options was expressed. Therefore, it was decided to discard the buttons at the bottom of the gallery screen, as during the user-test the buttons on the individual images were used the most.

Figure 7: The home screen of the first iteration of the app design.

5.3 Motivational Elements

In an effort to increase the user experience and give an incentive to continue using the app different motivational features were incorporated. One such feature being badges achieved based on the user's activity in the app, meaning the user achieves badges for tagging and uploading images in the app. Badges are a way to give the users a goal to strive for, as it provides an external/extrinsic reward for their contributions. The badges are issued based on the number of images submitted and annotated. The users are rewarded with their first badge quickly (one tag or one upload) as a way to introduce them to the reward system and to provide an early motivation. The following badges are achieved with an increasing threshold of difficulty to challenge the users and to keep them motivated. An example of one of the badges can be seen in Figure 8. The user achieves badges for tagging, uploading, and combinations of the two activities.

Figure 8: Example of the badges designed for the application.

Initially, the idea was to implement a traditional leaderboard, however, due to the findings by Massung et al. [22] stating that *"It is clear that close competition among leaders is productive, but also clear that it demotivates those not in the leading group"*. Therefore, it was decided to create a more cooperation-focused approach. This approach consists of three different elements:

- A graph showing the total amount of images submitted each month.
- A progress bar showing the goal for the month.
- The user's contribution to the cause.

This approach came with a few different potential benefits similar to what Massung et al. [22] described. The monthly "reset" of the graph could potentially level the playing field avoiding some users feeling that their contribution is inadequate. The second potential benefit was creating a "community norm" where users would try to meet the previous month's numbers and *"doing their bit"* rather than creating a competitive element that potentially could demotivate the users. Moreover, working towards a shared goal along with the other app users might give a feeling of community, which can be a motivating factor for some individuals. Examples of these elements can be seen in Figure 9.

Figure 9: Designs of some of the cooperation elements.

6 IMPLEMENTATION

This section covers the implementation of the application. It was decided to target both iOS and Android to maximize the number of potential users. Thus, it was important to choose a Software Development Kit (SDK) that would allow for the development of both iOS and Android apps with the maximum amount of codebase shared between the two platforms. Several SDKs were considered like React Native and Xamarin, but ultimately Flutter was chosen due to three main reasons. Cross-platform support allowing for the development of an application using one codebase with minimal changes needed between Android and iOS. Its usage of Material Design resulting in the same interface design on both platforms, and finally due to its performance as it does not require a bridge to compile JavaScript similar to what React Native requires. Another benefit of Flutter was its integration and support for the online storage and database hosting service Firebase, allowing for both storage of the submitted images but also the in-app survey. Firebase provides a free plan with a total of 5GB cloud storage with a daily 1GB bandwidth limit as well as a 1GB database. Which was deemed a suitable size for the application.

6.1 Overview

Based on the design phase an overview of the screens and their functionality was created to aid in the co-development of the application. The overview can be found in Appendix A. The application consists of seven different screens. On the first launch, the user is taken to the onboarding screen where they are introduced to the app and can accept the agreements regarding the pictures submitted. Afterward and in future launches the user is then moved to the home screen. Both can be seen in Figure 10.

Figure 10: The onboarding and home screens as implemented in the application.

From the home screen, the user can navigate to an info screen that contains information regarding the application, the project, and how the users' data could be beneficial. Using the speeddial (floating action button menu) the user can navigate to the badges where they can see the locked and unlocked badges. Whenever the user completes the requirements for a badge a pop-up message is displayed on the home screen. Both the info and badge screens can be seen in Figure 11.

Figure 11: The info and badge screens as implemented in the application.

The speeddial also allows for navigation to the two remaining screens. The first is the camera which utilizes the phone's already existing camera app to allow customization of the camera settings if needed. After taking a picture the user can then add an annotation and submit the picture. The last screen is the gallery which is populated using the users already existing gallery on the phone, allowing them to take pictures without using the app but still able to submit them in the app, or e.g. enable them to take multiple pictures while outside and submit the images when done with collecting litter. The camera and gallery screens can be seen in Figure 12.

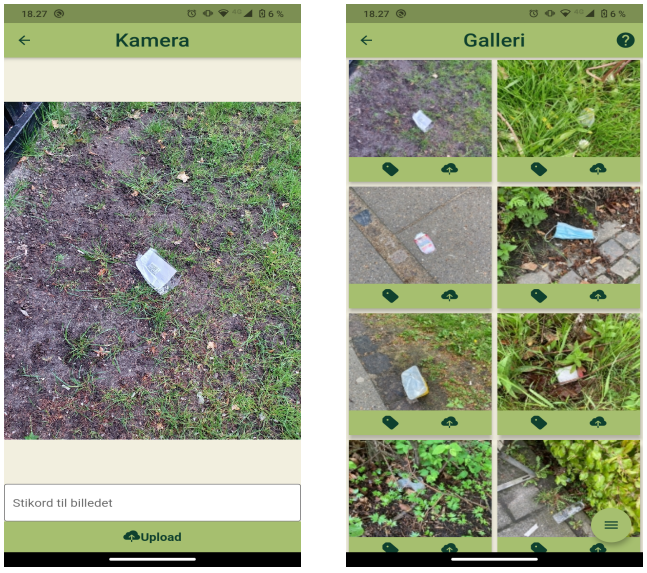


Figure 12: The camera and gallery screens as implemented in the application.

6.1.1 Widgets. The application and its interface are built using flutter widgets. The idea is that you build your entire UI out of widgets and create new widgets by pairing other widgets together. A combination of StatelessWidget and StatefulWidgets were used throughout the application. A stateless widget is a widget that does not require a mutable state i.e it is static. Oppositely a stateful widget can be changed after it has been built e.g. through user interaction. Thus, widgets describe how the screen should look given their configuration and their state.

6.2 System Test

The application was subsequently stress-tested on both iOS and Android devices. In total 100 images were uploaded during the stress test with none failing. However, the stress test revealed that when uploading from the gallery the process was very slow and unresponsive. This was due to an inefficient image compression that was implemented to maximize the available space in the cloud storage. However, the 100 images that were uploaded showed that the storage space was unlikely to become a problem, thus the image compression was disabled. The application was tested manually on both platforms using different phone models and API levels as well as automated tests through the Firebase test lab. The Firebase test lab is a service provided by Google, which allows for cloud-based testing on physical iOS and Android devices with varying API levels and models. In total the automated tests were run on 25 different devices with none of them failing. Following the system test, the application was submitted for review by Apple and Android and afterward publicly released on their respective app stores for users with Danish accounts.

7 EVALUATION

The goal of the evaluation is to explore whether an app like the proposed solution is a suitable way to motivate citizens to collect data to be used by e.g. the scientific community. Exploring whether the app is a "good idea" or not, and the general interest therein, it could provide insights into the foundation for further work potentially resulting in greater benefits to the scientific community and other stakeholders.

The evaluation is two-parted consisting of an in-app survey (UMI) exploring the user's motivation, as well as qualitative feedback from the users. Additionally, a semi-structured interview procedure was prepared to gain a more insight into the users' experience (seen in Appendix B). However, these interviews were not conducted due to time constraints, as the short deployment was a very short period, thus the user would not have had the chance to form a proper impression of the app, get a feeling for its features, and form an opinion of whether they would continue using it or not.

7.0.1 User Motivation Inventory. The UMI [5] mentioned in subsubsection 2.4.4 and its 18 statements were translated to Danish and included inside the application. As per Brühlmann et al. [5] the order of the 18 statements were randomized and answered using a 7-point Likert scale. The 18 original statements and their translated counterparts can be found in Appendix D.

7.0.2 Participants. An important part of the process of recruiting participants was to make the app visible and make them aware of its existence through different communication channels. One aspect of making the app visible and available was publishing it on Apple's and Google's app stores. In an attempt to recruit participants different organizations and groups were sought out by browsing the internet. A similar approach and search words as used in section 3 was utilized. A list of relevant groups to contact was compiled, as seen in Appendix C. The groups of interest were contacted by mail, describing the study, purpose, and their potential role. Furthermore, posts with the same information were made in relevant Facebook groups to get a wider reach. Multiple answered showing interest in a potential collaboration or passing on the word about the app through their own communication channels.

7.1 Short Deployment

The application was deployed for two weeks. During this period it was downloaded 14 times on Android and 12 on iOS. The short deployment resulted in over 220 images being submitted with 92 annotated images. During the short deployment, a total of nine survey responses were gathered and used in the evaluation. The results of which will be discussed below.

7.1.1 Results. The raw results can be found in Appendix E and the averages for each statement in Appendix F. As seen in Table 2 the application scored low in the non-self-determined subscales and higher in the more self-determined subscales. The highest average scores were in the integrated regulation and intrinsic regulation, scoring 5.63 and 5.33 respectively. This tendency seems to point to the fact that the users were most motivated by intrinsic factors. The statement *"I use [X] because it expresses my values"* was one of the highest-scoring statements indicating that the target group was a good match for this type of application. The application scored lower in external- and introjected regulation indicating that the users were less influenced by extrinsic motivators such as feeling pressured by others or guilt of quitting.

		Average
Amotivation	Non-Regulation (AMO)	3,704
Extrinsic Motvation	External Regulation (EXT)	3,556
	Introjected Regulation (INJ)	3,556
	Identified Regulation (IDE)	4,667
	Integrated Regulation (INT)	5,630
Intrinsic Motivation	Intrinsic Regulation (IMO)	5,333

Table 2: Averages of each subscale of the UMI.

7.2 Preliminary Qualitative Feedback

The feedback was gathered from users as well as the contacted organizations and groups. The responses from the organizations contacted via mail were positive and showed an interest in knowing more about the study, what they could help with, and what they could potentially gain from a "collaboration". The interest is an indicator of the proposed solution being relevant and possibly fit with the organizations' agenda. It also shows the potential for further collaboration within the subject.

Common for the user feedback was the wish for being able to see their own and other users' uploaded images, something very similar to how they share images on social media. It was mentioned that a lack of feedback/indication of whether an image had already been tagged and uploaded in the gallery served as a point of confusion. Furthermore, confusion arose concerning how images were categorized into "uploaded images" and "tagged images" in the "your contribution" display on the home screen seen in Figure 13. Users were confused by the fact that only "tagged images" increased after uploading an annotated image and not the "uploaded images" as well. However, no other major usability problems were reported.

Figure 13: The "your contribution" display on the home screen.

8 DISCUSSION

The following sections will discuss results and interesting points found during the evaluation.

8.1 Motivational Elements

While it is difficult to evaluate whether the gamification elements had any effect on the users' motivation and engagement due to not having done a comparative study between two versions of the app, it is clear that the application did some things correctly in regard to motivation. It mainly showed the potential of harnessing the users' already existing environmental interest and engagement to drive such an application, confirming the findings from Massung Et Al. [22] regarding the users' lifestyle and values being an important factor. As mentioned in section 7 the application generally scored higher in the more self-determined subscales and thus seemed to be mainly driven by personal values and interest rather than external rewards. Most of the users were already actively sharing pictures of trash they found and collected in various online environmental communities. However, due to the short nature of the deployment, it is difficult to confirm or debunk whether their environmental interest would have a lasting effect or if the users would shortly abandon the application. As mentioned in section 7 a lot of the feedback received was wishes for the ability to see other users' pictures. The implementation of this feature could possibly enhance the user engagement by a large magnitude as it would likely open further up for the community-based approach where the users potentially would be extrinsically rewarded through acknowledgment/approval by their peers. Likely similar to what is already happening in the various online communities.

8.2 Potential of Citizen Science

While not able to evaluate the motivational elements fully, one clear thing was the potential and maturity of citizen science. In the two weeks, the short deployment lasted over 220 images were submitted with the majority of those being high quality. Both in terms of image quality (resolution, focus, etc) but also people's ability to take a "good" picture. With the increasing trend of new mobile phones having better and better cameras, the actual image quality is likely to continue to rise. Likewise, the users clearly understood what a "good" picture entailed, the litter was almost always visible and centered in the picture and while providing a good view of its surroundings as seen in Figure 14. The study demonstrates citizen science as a cheap and viable approach to data collection in littering contexts even on larger scales much similar to what is reported by Kiessling et al. [17] and Nelms et al. [29]. In an email correspondence with the project leader from Ren Natur, it was mentioned that there had previously been similar ideas and projects but almost always got shelved. These findings could hopefully prove the potential of the idea leading to a full-scale project being successfully started.

Figure 14: A user submitted image with the litter centered and clearly visible.

8.3 User Interface

As mentioned in subsection 7.2 the way the images are categorized as "tagged" and "uploaded" for the "Your contribution" display is not completely clear. The confusion might be cleared up if the wording on the display is changed e.g. to "tagged and uploaded" and "uploaded" or similar.

However, rewarding for uploading (only) should be reevaluated. Rewarding for uploading without adding a tag might discourage tagging as the user otherwise will not be able to achieve the upload and combination badges. The intent is not to disincentivize tagging the images, thus, it could be beneficial to change the reward system to not promote uploading without tagging e.g. by unlocking badges with another activity. Moreover, encouraging the activity of uploading without tagging might result in duplicates in the dataset, as the user could both tag-and-upload and upload the same images to unlock all badges, which should be avoided to ensure the quality of the dataset.

The risk of duplicates can also be decreased by providing indicators of which images have already been uploaded and tagged. A solution to this could be to leave the upload and tag icons on the individual images in the gallery as an outline when the activity has not been performed yet, and filled when the activity has been completed (as seen in Figure 7). User feedback revealed this to be a problem, as it proved difficult to remember which images had already been tagged and uploaded. However, with this point in mind, the data collected from the short deployment did not show the problem of duplicates.

As mentioned by Kiessling et al. [17], Nelms et al. [29], and the participants at the online event concerning trash and recycling in Odense municipality education on the subject of littering shows potential for provoking behavior change regarding littering, thus it could be an idea to include educational features in the proposed solution if developed further and potentially distributed to a broader target group. Educational features were not incorporated in this iteration as the target group for the study are people who are already doing an effort for improving upon littering in nature, hence they are not in need of a behavior change within the area. While a positive benefit, the focus of the study was not to decrease littering, but rather to confirm or refute whether using an app to collect data about litter in nature is a good idea or not. Therefore, incorporating educational features could be a good idea if developing further on the study possibly including other parts of the Danish population that are not already participating in the environmental efforts.

8.4 Online Target Group Analysis

Reflecting on the online approach to conducting user research additional measures could have utilized, which is discussed below. In an effort to better understand the use context it could have been beneficial to participate in litter-collecting events to observe the participants and potential users. Researching the target group and use context is part of the initial processes of a study, in this case, the research process was conducted mainly in February, which was a time with fewer litter-collecting activities, among others, because of the cold weather and the pandemic. Thus, fewer opportunities were available, and alternatives were utilized instead (described in section 3).

Moreover, the online communities could have been utilized to a greater extent. We could as researchers have engaged more in the communities by e.g. asking exploratory questions in the groups, start "voting sessions" to gather information about specific topics or try to engage the members in discussions about their needs and wishes for a potential solution. A more anonymous and passive exploration could be done through posting surveys in the online communities. All examples are measures that potentially could have resulted in a greater understanding of the target group and use context.

The organizations contacted via mail could also have been utilized earlier for example "expert interviews" as some members might have coordinated and participated in many litter-collection events, thus having great insights into the target group, user needs, and use context, which could prove beneficial to the study.

Furthermore, particularly active members of the online groups could have been contacted to participate in e.g. interviews or to form a focus group to enlighten user needs and similar. Establishing contact early could potentially also be beneficial for the evaluation, as it would be easy to distribute the app to already interested and engaged people, who would likely also be willing to provide feedback on the proposed solution.

9 CONCLUSION

The goal of this study was to explore the potential of an application for a citizen-science-driven data collection of littering in its context in the form of images. Online environmental and litter-collection communities were monitored and explored to gain an insight/understanding of the users and use context.

The application was developed using the SDK Flutter and publicly deployed onto the Android and iOS app stores. The evaluation of the application was done using the User Motivation Inventory [5], an 18 part 7-point Likert scale survey, to measure the impact of the application on the users' motivation to collect data. The application was primarily promoted in online communities with environmental and litter-collection interests.

The results showed that the users' use was primarily motivated by their intrinsic motivation such as core principles and interest rather than extrinsically by the implemented motivational elements. Furthermore, the study resulted in over 220 images collected in a two-week span showcasing the potential and benefits of utilizing citizen science. The majority of the collected pictures were high quality, both in terms of actual image quality but also content.

To fully address the application's motivational potential, a comparative study would have to be conducted. Likewise, it is inconclusive whether the usability of the application impacted the users' motivation, therefore, a usability study would need to be completed. However, while not a complete solution, it showed the potential of citizen science as a cheap and valuable way of collecting environmental data. Likewise, a mobile application served as a fitting tool for enabling the users' contribution.

ACKNOWLEDGMENTS

The group would like to thank Hold Danmark Rent/Ren Natur, NatureSays#MeToo, GreenNation-DK, Affaldsinsamlingen/Danmarks Naturfredningsforening for helping spread the word and their insight.

REFERENCES

[1] Affaldsindsamlingen and Danmarks Naturfredningsforening. [n.d.]. *Affaldsindsamlingen.* https://www.affaldsindsamlingen.dk/ Last visited: 23/05/2021.

[2] S. Alavi, V. Ahuja, and Y. Medury. 2011. An empirical approach to ECRM-increasing consumer trustworthiness using online product communities. *Journal of Database Marketing & Customer Strategy Management* 18 (jul 2011), 83–96. https://doi.org/10.1057/dbm.2011.12

[3] Operate A/S. 2008. *BAGGRUNDSRAPPORT Henkastet affald - viden og analyser.* Operate A/S. https://mst.dk/media/mst/70157/Baggrundsrapport_Viden%20og%20analyser.pdf

[4] Astra. 2021. *Astra website.* Astra. https://astra.dk/ Last visited: 19/05/2021.

[5] Florian Brühlmann, Beat Vollenwyder, Klaus Opwis, and Elisa D. Mekler. 2018. Measuring the "Why" of Interaction: Development and Validation of the User Motivation Inventory (UMI). In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3173680

[6] Nature Communications. 2018. The future of plastic. *Nature Communications* 9, 1 (05 Jun 2018), 2157. https://doi.org/10.1038/s41467-018-04565-2

[7] Sebastian Deterding. 2011. Situated motivational affordances of game elements : A conceptual model. *CHI Gamification Workshop 2011* (01 2011), 3–6.

[8] Sebastian Deterding, Dan Dixon, Rilla Khaled, and Lennart Nacke. 2011. From Game Design Elements to Gamefulness: Defining Gamification. In *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments* (Tampere, Finland) *(MindTrek '11)*. Association for Computing Machinery, New York, NY, USA, 9–15. https://doi.org/10.1145/2181037.2181040

[9] DCE Danish Centre for Environment, Energy, Ryan d'Arcy Metcalfe Louise Feld, and Jakob Strand. 2018. *National monitoring of beach litter in Denmark 2018 - Amounts and composition of marine litter on reference beaches.* DCE. https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2018/Beach_litter_at_Danish_reference_beaches_2018.pdf

[10] DCE Danish Centre for Environment, Energy, Ryan d'Arcy Metcalfe Louise Feld, and Jakob Strand. 2020. *National monitoring of marine litter in Denmark 2020 - Amounts and composition of beach litter on reference beaches.* DCE. https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet_2020/N2020_94.pdf

[11] Open Knowledge Foundation. 2021. *Defining Open in Open Data, Open Content and Open Knowledge.* Open Knowledge Foundation. https://opendefinition.org/od/2.1/en/ Last visited: 24/05/2021.

[12] Roland Geyer, Jenna R. Jambeck, and Kara Lavender Law. 2017. Production, use, and fate of all plastics ever made. *Science Advances* 3, 7 (2017). https://doi.org/10.1126/sciadv.1700782 arXiv:https://advances.sciencemag.org/content/3/7/e1700782.full.pdf

[13] Mordechai (Muki) Haklay, Daniel Dörler, Florian Heigl, Marina Manzoni, Susanne Hecker, and Katrin Vohland. 2021. *What Is Citizen Science? The Challenges of Definition.* Springer International Publishing, Cham, 13–33. https://doi.org/10.1007/978-3-030-58278-4_2

[14] Lasse Hakulinen, Tapio Auvinen, and Ari Korhonen. 2013. Empirical Study on the Effect of Achievement Badges in TRAKLA2 Online Learning Environment. In *2013 Learning and Teaching in Computing and Engineering.* IEEE, Helsinki, Finland, 47–54. https://doi.org/10.1109/LaTiCE.2013.34

[15] Juho Hamari. 2017. Do badges increase user activity? A field experiment on the effects of gamification. *Computers in Human Behavior* 71 (2017), 469–478. https://doi.org/10.1016/j.chb.2015.03.036

[16] Samantha Ingram. 2016. *The Thumb Zone: Designing For Mobile Users.* https://www.smashingmagazine.com/2016/09/the-thumb-zone-designing-for-mobile-users/ Last visited: 23/05/2021.

[17] Tim Kiessling, Katrin Knickmeier, Katrin Kruse, Dennis Brennecke, Alice Nauendorf, and Martin Thiel. 2019. Plastic Pirates sample litter at rivers in Germany – Riverside litter and litter sources estimated by schoolchildren. *Environmental Pollution* 245 (2019), 545–557. https://doi.org/10.1016/j.envpol.2018.11.025

[18] Hyo Chang Kim and Yong Gu Ji. 2019. Natural Thumb Zone on Smartphone with One-Handed Interaction: Effects of Thumb Length and Screen Size. In *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)*, Sebastiano Bagnara, Riccardo Tartaglia, Sara Albolino, Thomas Alexander, and Yushi Fujita (Eds.). Springer International Publishing, Cham, 471–477.

[19] Rafal Kocielnik, Lillian Xiao, Daniel Avrahami, and Gary Hsieh. 2018. Reflection Companion: A Conversational System for Engaging Users in Reflection on Physical Activity. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 2, Article 70 (jul 2018), 26 pages. https://doi.org/10.1145/3214273

[20] Jonna Koivisto and Juho Hamari. 2014. Demographic differences in perceived benefits from gamification. *Computers in Human Behavior* 35 (2014), 179–188. https://doi.org/10.1016/j.chb.2014.03.007

[21] Litterati. 2021. *Litterati home.* Litterati. https://www.litterati.org/ Last visited: 20/05/2021.

[22] Elaine Massung, David Coyle, Kirsten F. Cater, Marc Jay, and Chris Preist. 2013. Using Crowdsourcing to Support Pro-Environmental Community Activism. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 371–380. https://doi.org/10.1145/2470654.2470708

[23] John D. Mayer, Michael A. Faber, and Xiaoyan Xu. 2007. Seventy-five years of motivation measures (1930-2005): A descriptive analysis. *Motivation and Emotion* 31, 2 (06 2007), 83–103. https://www-proquest-com.zorac.aub.aau.dk/scholarly-journals/seventy-five-years-motivation-measures-1930-2005/docview/757939085/se-2?accountid=8144 Copyright - Springer Science+Business Media, LLC 2007; Last updated - 2018-10-05.

[24] Bahati S. Mayoma, Innocent S. Mjumira, Aubrery Efudala, Kristian Syberg, and Farhan R. Khan. 2019. Collection of Anthropogenic Litter from the Shores of Lake Malawi: Characterization of Plastic Debris and the Implications of Public Involvement in the African Great Lakes. *Toxics* 7, 4 (2019). https://doi.org/10.3390/toxics7040064

[25] Elisa D. Mekler, Florian Brühlmann, Alexandre N. Tuch, and Klaus Opwis. 2017. Towards understanding the effects of individual gamification elements on intrinsic motivation and performance. *Computers in Human Behavior* 71 (2017), 525–534. https://doi.org/10.1016/j.chb.2015.08.048

[26] A. Mikołajczyk, S. Majchrowska, E. Marczewska, and M. Kortas. [n.d.]. *Waste datasets review.* https://github.com/AgaMiko/waste-datasets-review Last visited: 26/05/2021.

[27] Gaurav Mittal, Kaushal B. Yagnik, Mohit Garg, and Narayanan C. Krishnan. 2016. SpotGarbage: Smartphone App to Detect Garbage Using Deep Learning. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Heidelberg, Germany) *(UbiComp '16)*. Association for Computing Machinery, New York, NY, USA, 940–945. https://doi.org/10.1145/2971648.2971731

[28] United Nations. 2015. The 2030 Agenda for Sustainable Development. https://sdgs.un.org/goals

[29] SE Nelms, C Coombes, LC Foster, TS Galloway, BJ Godley, PK Lindeque, and MJ Witt. 2017. Marine anthropogenic litter on British beaches: A 10-year nationwide assessment using citizen science data. *Science of The Total Environment* 579 (2017), 1399–1409. https://doi.org/10.1016/j.scitotenv.2016.11.137

[30] BBS News. 2019. #Trashtag: The online challenge cleaning places up. https://www.bbc.com/news/world-47536861

[31] Pirika. 2021. *Pirika- home.* Pirika. https://sns.pirika.org/ Last visited: 20/05/2021.

[32] Bug Potion. 2019. *Jiraffe for Jira.* Bug Potion. https://marketplace.atlassian.com/apps/1211379/jiraffe-for-jira?hosting=server\&tab=overview Last visited: 20/05/2021.

[33] P. Proença and P. Simões. [n.d.]. *Trash Annotations in Context.* http://tacodataset.org/ Last visited: 27/05/2021.

[34] Rubbish. 2021. *Rubbish- home.* Rubbish. https://www.rubbish.love/ Last visited: 20/05/2021.

[35] Richard M Ryan and Edward L Deci. 2002. Overview of self-determination theory: An organismic dialectical perspective. *Handbook of self-determination research* 2 (2002), 3–33.

[36] Carol Sansone and Judith Harackiewicz. 2000. *Intrinsic and Extrinsic Motivation : The Search for Optimal Motivation and Performance.* Elsevier Science & Technology, San Diego, UNITED STATES. http://ebookcentral.proquest.com/lib/aalborguniv-ebooks/detail.action?docID=313671

[37] Katie Seaborn and Deborah I. Fels. 2015. Gamification in theory and action: A survey. *International Journal of Human-Computer Studies* 74 (2015), 14–31. https://doi.org/10.1016/j.ijhcs.2014.09.006

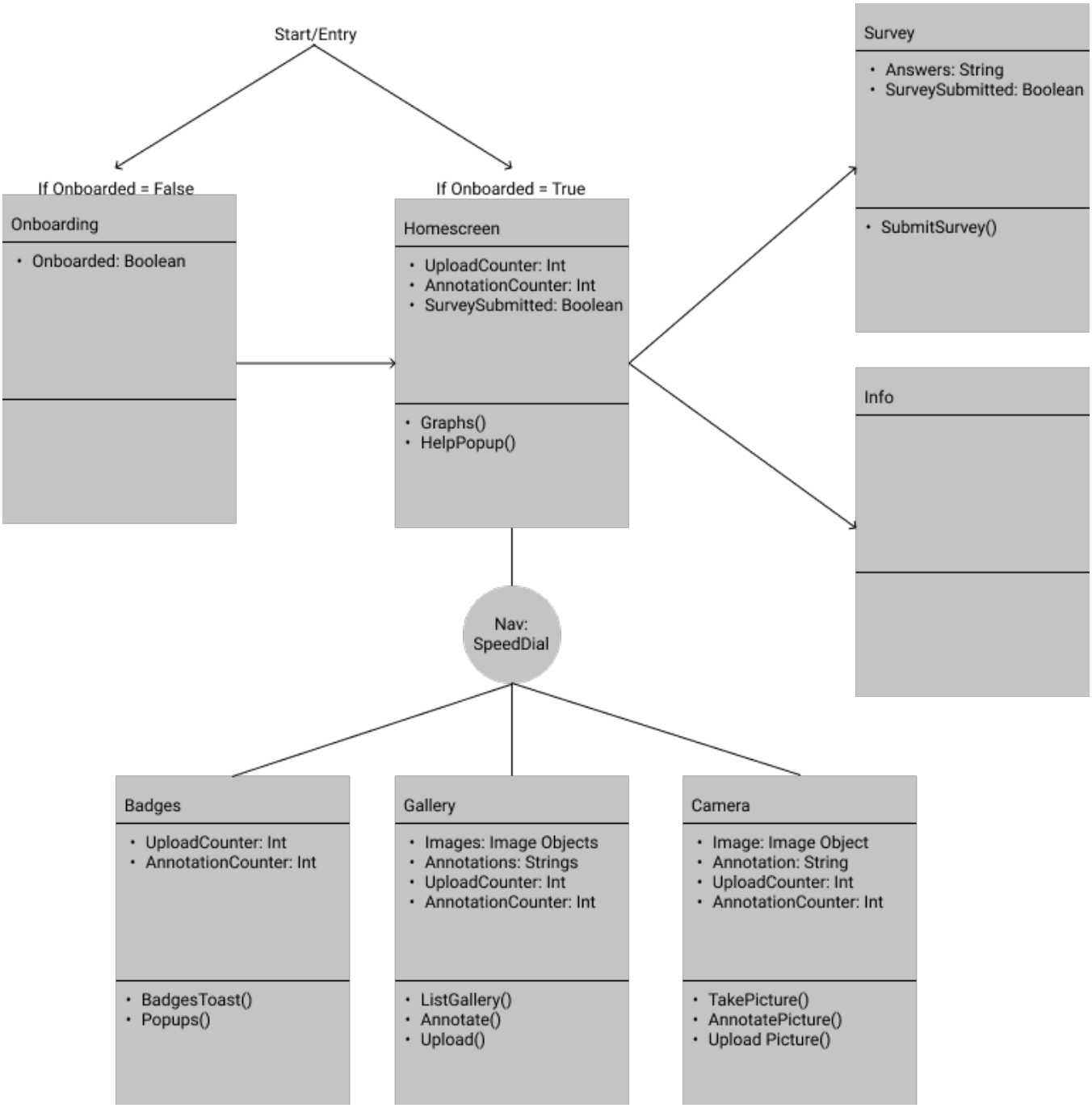
[38] Kristian Syberg, Annemette Palmqvist, Farhan R. Khan, Jakob Strand, Jes Vollertsen, Lauge P. W. Clausen, Louise Feld, Nanna B. Hartmann, Nikoline Oturai, Søren Møller, Torkel G. Nielsen, Yvonne Shashoua, and Steffen F. Hansen. 2020. A nationwide assessment of plastic pollution in the Danish realm using citizen science. *Scientific reports* 10, 1 (Oct 20 2020), 17773. https://www-proquest-com.zorac.aub.aau.dk/scholarly-journals/nationwide-assessment-plastic-pollution-danish/docview/2452982687/se-2?accountid=8144

[39] Cristian Tejedor-García, David Escudero, César González-Ferreras, Enrique Cámara-Arenas, and Valentín Cardeñoso-Payo. 2016. TipTopTalk! Mobile application for speech training using minimal pairs and gamification. (11 2016).

[40] Nicole Banks Tim Matthews. 2016. *Load Time and Mobile Compatibility Top Online Shopper Demands [Study].* https://www.imperva.com/blog/ecommerce-study/?redirect=Incapsula Last visited: 21/05/2021.

[41] TrashBlitz. 2021. *TrashBlitz - home.* TrashBlitz. https://www.trashblitz.org/ Last visited: 20/05/2021.

A OVERVIEW OF THE APPLICATION



B INTERVIEW PROCEDURE AND QUESTIONS

B.1 Introduction

Hello and thank you:
Shortly introduce ourselves and thank them for their participation.
Consent:
Explain that we would like to audio record the interview and why. Ask to sign consent form.
Audio recording is started.
Purpose:
Go through what will happen during the interview and why the interview is conducted.
Make clear that there are no right or wrong answers, that we are interested in their honest opinion, thus criticism and feedback on shortcomings of the app.

B.2 Interview Questions

(1) How did you hear about the app?
(2) How would you rate your experience level with smartphones on a scale from 1 to 5?
(3) Are you a member of a litter-collecting group/community?
(4) Have you used a similar app before?
  (a) If yes: which one (if you remember)? And what was your experience with it?
(5) Can you shortly describe to me what the purpose of the app is?
(6) How often do you use the app?
  (a) If not using the app that often: What is the reason for this?
  (b) How often do you see yourself use the app in the future?
(7) Did you use the app alone or together with others – as a shared activity?
(8) Can you give an example of how you used the app?
(9) Do you feel more motivated to get out and take pictures (and collect litter) now with the app than before?
(10) How was your experience with navigating around in the app?
  (a) Did something cause frustration?
(11) Is there something about the app that causes frustration?
  (a) Does the app seem complex in any way?
    (i) If yes: Can you explain/elaborate further?
(12) Which feature(s)/functionality did you use the most?
(13) If you could change one thing about the app, what would it be?
(14) Does some of the app's elements/functionalities behave in an unexpected way?
  (a) If yes: Which/what/how?
(15) Did you feel the need of an introduction to the app's functionalities before you would be able to use it?
  (a) If yes: If you were in doubt about how to use it, what did you do? Ask somebody for help, trial and error approach?
(16) Do you feel safe regarding how your data is used?
  (a) Do you know how your data is shared and used?
(17) Is there something that have made you hesitate to share/upload pictures via the app?
(18) Is there something about/in the app that keeps you from using it?
  (a) If yes: Can you elaborate on it?
(19) On a scale from 1 to 5 how was your overall experience with the app?
  (a) Can you elaborate on your score a bit?
(20) On a scale from 1 to 5 how likely are you to recommend the app to a friend?
  (a) Can you explain your score?
(21) Is there something that we have not covered that you would like to discuss before we end?

B.3 Thank you and Goodbye

We would like to thank you for your time and participation, we really appreciate it!
We hope you enjoyed the experience.
Bye and thank you.

C CONTACT-LIST

Overview of the groups and organizations contacted.

C.1 Contacted via Mail

INGA - International Network of Green Agents (Replied)
Affaldsindsamlingen (Replied, same contact-person as Danmarks Naturfredningsforening)
Danmarks Naturfredningsforening (Replied, same contact-person as Affaldsindsamlingen)
Greennation-dk
Ren by Aarhus (Replied)
Hold Danmark Rent (Replied, same contact-person as Ren Natur)
Ren Natur (Replied, same contact-person as Hold Danmark Rent)
NatureSays#Metoo (Mail and call) (Replied)
Dråben i havet – Gør en forskel
Plastic change
Waste Hunt (Reply but is no longer active)

C.2 Posted in Facebook Groups

Naturesays#metoo
Aau - søge test-personer
Zerowaste
Greennation-dk
Affaldsindsamlingen

D TRANSLATIONS OF THE UMI AND THE ORIGINAL UMI

Survey Order	Danish Translation	UMI Order	UMI Original
Q1	At bruge appen er en fornuftig ting at gøre	10	1. Using [X] is a sensible thing to do
Q2	Jeg bruger appen, men sætter spørgsmålstegn ved, hvorfor jeg forsætter med at bruge den	1	1. I use [X], but I question why I continue to use it
Q3	Andre mennesker bliver ked af det, hvis jeg ikke bruger appen	4	1. Other people will be upset if I don't use [X]
Q4	At bruge appen er sjovt	18	3. Using [X] is fun
Q5	Jeg bruger appen fordi det er en fornøjelse	16	1. I use [X] because it is enjoyable
Q6	Jeg bruger appen, men jeg kan ikke se hvorfor jeg forsat skulle gide blive ved.	3	3. I use [X], but I don't see why I should keep on bothering with it
Q7	Jeg ville have det dårligt med mig selv hvis jeg stoppede med at bruge appen	7	1. I would feel bad about myself if I quit [X]
Q8	Jeg bruger appen fordi det afspejler essensen af hvem jeg er	13	1. I use [X] because it reflects the essence of who I am
Q9	Jeg bruger appen fordi andre bliver utilfredse med mig hvis jeg ikke gør	5	2. I use [X] because others will not be pleased with me if I don't
Q10	Jeg synes det er en interessant aktivitet at bruge appen	17	2. I think using [X] is an interesting activity
Q11	Jeg bruger appen fordi det udtrykker mine værdier	15	3. I use [X] because it expresses my values
Q12	At bruge appen er en god måde at opnå det jeg har brug for lige nu	12	3. Using [X] is a good way to achieve what I need right now
Q13	Jeg ville føle mig skyldig hvis jeg stoppede med at bruge appen	8	2. I would feel guilty if I quit using [X]
Q14	Jeg bruger appen men jeg undrer mig over hvad formålet med at bruge den er	2	2. I use [X], but I wonder what is the point in using it
Q15	Jeg føler mig presset af andre til at bruge appen	6	3. I feel under pressure from others to use [X]
Q16	Jeg ville føle mig som en fiasko hvis jeg stoppede med at bruge appen	9	3. I would feel like a failure if I quit using [X]
Q17	At bruge appen er i overensstemmelse med mine kerneprincipper	14	2. Using [X] is consistent with my deepest principles
Q18	Fordelene ved at bruge appen er vigtige for mig	11	2. The benefits of using [X] are important to me

E RAW DATA FROM SURVEY

id	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18
0unxggefROLUfOfcXOX6	6	4	5	6	7	5	5	7	5	7	7	4	3	4	3	1	7	4
4jwJO2WKpiOnlFP1ZyFO	7	2	3	4	5	5	1	4	2	6	5	4	4	4	1	3	6	2
UyCiHD3w1JjEmRXhgcLj	6	4	3	4	5	5	3	7	3	6	7	4	5	5	3	1	7	4
XYEyEeFH3hh79o1cq2gz	6	3	6	5	5	2	6	4	7	5	5	5	6	6	3	1	3	5
YcCnM67vzkPV6ZEL4IQ1	4	4	4	6	5	4	4	5	4	6	4	3	3	7	4	2	2	4
YcEYxH7Q5bgDLXlCWMgO	6	3	2	5	5	4	3	5	3	6	7	3	5	2	1	2	7	4
aykAGKYQ8CwU14VnN338	7	4	5	5	6	2	6	7	4	6	7	4	5	3	4	1	6	6
mteff4wmQvOHLbK2yuF6	5	5	6	4	4	3	5	4	3	5	5	2	5	2	1	4	4	4
nWAS36ILRndOVFIvyh35	6	3	4	4	5	3	6	6	3	7	7	5	5	2	4	1	7	6

F AVERAGES OF SURVEY DATA

Subscale	Item	AMO	EXT	INJ	IDE	INT	IMO
Amotivation	1. I use [X], but I question why I continue to use it	3,555556					
	2. I use [X], but I wonder what is the point in using it	3,888889					
	3. I use [X], but I don't see why I should keep on bothering with it	3,666667					
External Regulation	1. Other people will be upset if I don't use [X]		4,222222				
	2. I use [X] because others will not be pleased with me if I don't		3,777778				
	3. I feel under pressure from others to use [X]		2,666667				
Introjected regulation	1. I would feel bad about myself if I quit [X]			4,333333			
	2. I would feel guilty if I quit using [X]			4,555556			
	3. I would feel like a failure if I quit using [X]			1,777778			
Identified regulation	1. Using [X] is a sensible thing to do				5,888889		
	2. The benefits of using [X] are important to me				4,333333		
	3. Using [X] is a good way to achieve what I need right now				3,777778		
Integrated regulation	1. I use [X] because it reflects the essence of who I am					5,444444	
	2. Using [X] is consistent with my deepest principles					5,444444	
	3. I use [X] because it expresses my values					6	
Intrinsic motivation	1. I use [X] because it is enjoyable						5,222222
	2. I think using [X] is an interesting activity						6
	3. Using [X] is fun						4,777778
Subscale Average		**3,703704**	**3,555556**	**3,555556**	**4,666667**	**5,62963**	**5,333333**