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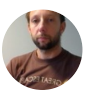
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WasteApp: Smarter Waste Recycling for Smart Citizens

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***Abstract*—Waste recycling and disposal is an increasingly pressing issue for the preservation of the Earth natural environment. A considerable amount of research has been carried on factors influencing household waste recycling behaviors and a plethora of supporting tools have been investigated in the last few years. Despite this, recycling waste is still perceived as a cumbersome task, and people around the world are often struggling to find efficient ways to recycle their waste. We argue that, among many factors, a lack of user centered design in waste recycling support tools can be one of the causes. For such reason, we approach the design of a new waste recycling support application, the "WasteApp", by merging behavioral studies and common features of existing mobile apps with a co-design methodology. We present the outcomes of several co-design sessions aimed at gathering real user needs for waste recycling, an initial design of the "WasteApp" and we discuss the results of a preliminary small-scale user study on the application usability.**

I. Introduction

People living in cities are crucial for effective waste recycling and even the smallest change in recycling habits might highly impact the ecological (and economical) sustainability of a city. However, achieving virtuous behaviors is not a trivial task since people living in urban areas are heterogeneus, have different cultural and social backgrounds, and nationalities. Achieving an active citizen engagement in this area can, therefore, be a real challenge.

In the waste domain, several sparse efforts already exploit mobile applications as a way for engaging users in better recycling waste [1]. Municipalities are releasing apps providing up-to-date waste collection calendars and waste recycling guides. However, they mostly provide static information which too often leads to scarce adoption. A quick search on the Google Play Market, for example, can easily report more than fifty (50) apps referred to waste recycling. Nevertheless, by analyzing existing solutions, the lack of a strong and sounded user centric approach seems to be a relevant factor, and resulting applications seldom account for behavioral studies to bootstrap and sustain interaction with citizens. Moreover, a quite low readiness for future smart city platforms and emerging IoT solutions can be noticed, which prevents most of the current solutions to effectively exploit live information generated at the city level, e.g, the current fill-level of waste bins near to the user position.

Among the currently open smart city projects and platforms, the ALMANAC project has selected the waste management domain as one of the most relevant scenarios in which smart city platforms could make the difference. In this work, a set of requirements is presented for waste recycling apps in terms of content and interaction, which are built on top of: a literature review on behavioral theories related to the waste domain, an initial survey of currently existing mobile apps and co-design sessions held with a small community of users, in Turin, Italy. The initial design of the WasteApp, a recycling support mobile application developed in the context of the ALMANAC Smart City project is then presented, implementing a relevant subset of gathered requirements and introducing some novel functions to foster better recycling habits in citizens of smart cities. A preliminary user study confirms the validity of the approach and contributes to the definition of next steps to be carried in this research.

II. Related Works

Several factors are actually influencing the willingness of an individual to duly recycle waste. According to literature the most prominent behavioral intentions stemming from the theory of reasoned action [2], and integrated by Chu and Chiu [3] for the waste domain, include: personal attitude (PA), subjective norms (SN), perceived behavioral control (PBC) and perceived moral obligation (PMO). Among the 4 intentions, the first and the last 2 are the most targeted when addressing recycling support. Personal attitude can be successfully changed through gamification approaches [4], [5], often exploiting social networks [6], [7]. In this last case, i.e., for approaches based on social reputation, the PMO factor is also targeted. PBC is an ideal candidate for mobile apps. By acting on the perceived difficulty in carrying the recycling task, it might, in fact, be possible to achieve significant improvements in the overall waste disposal behavior of people. The influence of PBC over recycling or other environmental behavior has been widely studied in the 90's [8]–[11]. For example, both old and recent studies [12], [13] consistently found that a person's knowledge of how to recycle and the types of materials eligible for recycling is an important factor influencing recycling participation.

III. App Inventory

To investigate the typical design choices adopted by mobile app developers to engage users and support behavioral changes, we performed an inventory of currently existing recycling applications for smartphones. For the sake of simplicity we report here the main outcomes only. We surveyed 37 different applications, mainly from the Android Market. Among surveyed apps 5 refer to Italian, 16 to American, 8 to Australian and 8 to Canadian users. Interestingly, most applications are designed for specific municipalities, this is especially true for the US, CA and AU market, whereas in Italy most applications are offered by waste collection companies. Among the US, CA and AU applications a clear trend emerge to outsourcing, as most (32) waste applications are developed by two different software houses only.

For each municipality-specific app, the number of reviews and user downloads is very low with respect to the city population. For example, Toronto Waste, the waste app for the city of Toronto (CA), has only a couple of hundreds installations and 12 reviews, whereas the total city population counts around 2.6 millions people. Similarly, installations of Surrey Waste, the recycling app for Kingston (CA) range between 1000 and 5000, with 214 reviews, while the city has around 117000 inhabitants. This situation is common to almost all surveyed apps, meaning that even when municipalities are trying to push recycling improvements through smartphone apps, the percentage of engaged population is still far from the critical mass needed to trigger sensible changes in recycling behaviors.

We argue that among many factors, a lack of user centered design can be a cause for such a low adoption and, that the currently achieved rate of "simplification" for users, i.e., the PBC cited before, is still too low for ensuring a real engagement. To confirm such an hypothesis, we gathered the common features of surveyed apps and we tried to distill requirements for designing better waste apps through a co-design approach. Many commonalities emerged between solutions and interactions adopted for fostering behavior changes into citizens. Almost all waste applications provide a waste dictionary, reporting a description of the different types and a list of sample products included in each one of them. In most cases, the basic waste dictionary is complemented by some recycling guideline (how-to) and in some cases (nearly 50%) by a search by keyword function for quick identification of waste types. However, in all cases, exploited information is static and search is quite basic, mainly matching keywords against sample waste reported in the dictionary. Given a product to dispose, identifying the right waste-bin, or collection method, always requires to either browse the dictionary or perform a keyword-based search. Only one app, "il Rifiutologo Hera" considers bar code scanning as a way for getting a quick and precise identification of waste type and of the relative disposal directions.

Almost all applications provide a waste collection calendar, mainly static. Calendars are endowed with the capability of generating notifications for users, to support timely garbage collection and help them keeping at a pace with the waste collection schedule. Only one app, "Calendario differenziata" exploits users' submissions to harvest collection calendars in every municipality, with a crowd-sourcing approach. Location of nearby wastebins is another important information which appears to be lacking in surveyed apps. Most apps in fact do not support this function at all, and the ones providing maps are only offering informations about drop-off locations. While this lack might be justified by door-to-door collection, curbside collection is part of almost all waste management systems, door-to-door included. Therefore, having a quick way for identifying bins nearby the user's position, can be a valid aid. No app supports, or plans to support data from future waste monitoring systems in order to provide, for example, the current fill-level of collection bins nearby the citizen's home or location. Gamification approaches and crowd-sourcing [14] solutions (i.e., solutions to harvest knowledge distributed among large groups of people) are almost absent from surveyed applications.

IV. Co-design

Based on the argumentation that a lack of user centered design approach can be one of the reasons for a low adoption rate of the existing Recycling applications, a co-design methodology has been selected to design and develop a recycling support tool for Smart Citizens in a Smart City. The activities have been carried in collaboration with the community of a temporary social housing project in the city of Turin[1] to mutually produce the desired value outcome. Interactions with the selected community were carried over a 6 months timespan. The community involvement was strategic and driven by a very specific purpose, i.e. the definition of an effectively engaging recycling support application, limiting the interaction with the group to a few interviews and a one-off workshop. The heterogeneous and dynamic nature of the sample did not allow for participation over a longer period of time since the group consisted almost entirely of exchange students and posted workers. However, the quality of interactions compensated for fewer encounters and kept the community willing and happy to engage in the co-creation process.

Early meetings were mainly focused on obtaining as much information as possible about the community. A set of interviews was conducted with professional operators running the social housing project (e.g. administrators, workers, technicians) that allowed us to get enough insight about people's habits, rules of the structure, and available waste infrastructure and service in the area. After completing this first phase, a co-creation workshop was held involving a sample of 15 people with different ages, backgrounds and nationalities. The activities were structured in three stages starting with a very brief presentation of the ALMANAC EU-funded project mainly focused on the importance of proper recycling in urban areas. Successively, an individual round of exercises took place: a session of Q&A was held where the group was presented with several questions aimed at guiding them to gather their concerns and ideas related to the waste recycling process in a Smart City context (i.e. where objects have

[1] http://www.sharing.to.it/index.php/en.html, last visited on January, 2016.

gained connectivity and open data sources are available). The participants were asked to write down their answers in post-its that were collected and then organized in a white board for further discussion. A group brainstorming was then initiated and guided by the moderators to jointly identify the group needs and wishes on the matter. The information generated during the workshop was collected in individual folders and later analyzed.

The co-design workshop main findings corroborated the fact that people are often incapable to proper recycle simple and composite materials, and that this can lead to frustration and poor recycling habits. As a result of the early interactions with the community, we learned that there are three ways to collect waste in the city of Turin: door-to-door, Underground Ecological Areas (UEI) and curbside collection. The selected community is located in one of the door-to-door collection areas where garbage is collected following a weekly calendar established by the City Municipality. Although the waste collection in the neighborhood is made using the door-to-door system, people in the city have often the need to find a specific recycling bin near them, either because they live in areas of the city with curbside collection and they approach waste bins that are overfilled (which is the case of community workers living in other neighborhoods); or just because they are walking around in the city and need to dispose some packaging, e.g. a plastic bottle of water.

Other findings from the co-design workshop included the obvious but relevant facts that people do not always know “what goes where”, and sometimes forget - or are not completely aware of- the type of waste that will be collected on a specific day of the week.

V. Requirements

Discussions and results obtained during the first workshop were translated into use cases. A first set of high-level requirements for waste recycling mobile applications was derived from the use cases, and is summarized in the following:

- Availability of an updated waste collection calendar, indicating which type of waste is collected during each day of the week
- Possibility to receive reminders with relevant collection information the day before or even during the same day
- Access to a recycling guide, to support them during the recycling process, providing relevant information in a clear and accessible way
- Possibility to locate waste bins near a specific place or location, together with the possibility to receive the corresponding walking directions
- Possibility to locate nearby drop-off locations and have access to relevant information such as opening hours, provided services and associated costs.

During the co-design workshop, participants also emphasized the importance of having access to a collaborative recycling support tool with up-to-date and trustworthy information. This is due to the fact that already available resources are characterized by a lack of openness and dynamicity, and most of the times are also out of date (e.g. ”Il Rifiutologo”[2] the official recycling guide of the city, was last updated in February 2013, almost 3 years ago).

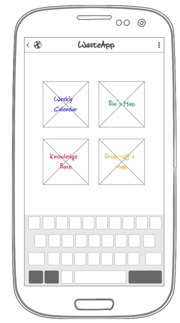

Fig. 1. The logic organization of the low-fi paper prototype.

Most of the requirements emerged from the co-design workshop, match quite well the design choices adopted by current waste recycling applications. However, waste-bin location and direct waste type identification in real time, are deemed as relevant by the sample group but not yet addressed by any of the surveyed apps. The WasteApp will therefore be designed to tackle these needs, while supporting already established features.

VI. WasteApp Design

By building upon the previously discussed requirements, we designed an android application, namely the “WasteApp” aimed at supporting better recycling behavior by impacting the users’ perceived behavioral control. This initial design choice is open to further improvements aimed at engaging with other user intentions, such as the personal attitude and the perceived moral obligation. The design process was deployed in two phases involving a low-fi paper prototype in the first, and an hi-fi interactive prototype in the second.

A. Low-fi prototype

According to our design, the prototype presents 4 different areas corresponding to 4 different functions: waste collection calendar, waste recycling guide, waste bin location and drop-off locations. The recycling guide offers common browse and search features. Additionally, it is extended by including crowd-sourcing techniques, for harvesting waste classification from users, and direct barcode scanning for easing the waste recognition process. Areas in the prototype home screen (Figure 1), correspond to 4 different tasks and they are organized in two vertical columns, one on the left that refers to routine waste recycling (calendar and recycling guide) and one on the right aiming at satisfying immediate needs: where to drop waste in nearby positions or where to drop-off special waste. The former need is supported through a map centered on the user position and populated with waste bins (and their current

[2]http://www.amiat.it/cms/comunicazione/91-press-room/news/raccolta-rifiuti/152-nuovo-rifiutologo, last visited January, 2016.

Fig. 2. The WasteApp Home activity and Recycling calendar.

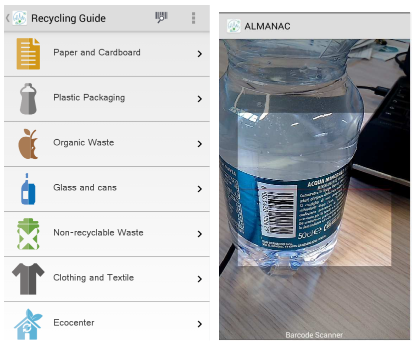

Fig. 3. The WasteApp Recycling Guide and Barcode scanning feature.

fill level), the latter, instead shows a map of drop-off locations together with opening hours and other relevant information.

The initial paper prototype was aimed at testing the initial division in 4 different areas and at spotting possible issues with functions and interactions foreseen for each area. Two HCI/Ubicomp experts evaluated the prototypes to spot weaknesses in the interface concept and inconsistencies in designed interactions. After two cycles of revision, the resulting prototype has been evaluated using a *think-aloud* protocol with one group of 4 participants. The group mainly included technical people with quite a good experience on using mobile applications. Participants ages ranged between 24 and 31 years, with a mean age of 28.25 years (SD = 2.68). All participants live with more than one person and without their parents. Participants in the group successfully completed most of the assigned tasks thus confirming the initial design based on 4 different areas. Feedback was also collected on proposed features, although many interactions were almost impossible to test in this first, static phase.

B. Interactive prototype

Given the encouraging opinions expressed by the group of participants, we proceeded with a second, interactive prototype (screenshots in Figure 2 and Figure 3) aimed at investigating possibilities to enhance support to waste recycling collection. The prototype has been realized in form of an Android 4.x application, connected with the ALMANAC Smart City platform and populated with data referred to the Turin municipality, which is part of the ALMANAC project consortium. Functions for each area have been extended and initial concepts implemented. They encompass: (a) a static calendar of waste collection populated and updated by the municipality; (b) a configurable notification system enabling the user to set up notifications for timely dropping required waste (e.g. paper on Thursday morning); (c) a searchable recycling guide with a direct access bar code scanner able to take a picture of a packaging bar code and give back information associated to the type of waste; in case bar codes are not in the app database, a crowd-sourcing feature allows to define and share a classification, which might then be improved through collaborative filtering and ranking (still under design); (d) an interactive map showing bins nearby the user together with their current fill-level (thanks to the ALMANAC Smart City Platform) and (e) a drop-off location map with information on opening hours and accepted materials.

C. Prototype implementation

The logic architecture of the interactive WasteApp prototype is reported in Figure 4. The application exploits the ALMANAC Cloud APIs [15], which provide RESTful access to waste bin locations and fill-level, whereas map visualization and barcode scanning leverage on native services provided by the Android OS. The WasteApp is deployed over 4 different layers, from top to bottom, including: a view layer hosting all the activity views (according to the Android MVC development paradigm); an activity layer, hosting the view controllers; an ALMANAC service layer hosting clients to the ALMANAC platform, i.e., to real-time fill-level, bin location and barcode-package association services; the native Android services layer, which expose common APIs exploited by components defined at the higher levels.

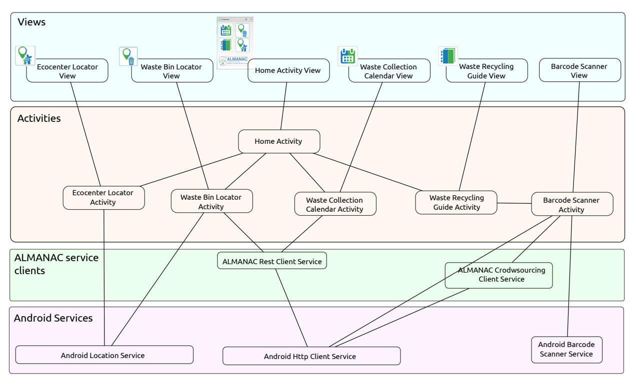

Fig. 4. The WasteApp interactive prototype logic architecture.

The Waste App prototype is composed by 6 main activities: one home activity offers access to the 4 function sets discussed in previous sections, 4 function-specific activities implement area-specific logic and the latter activity provides the barcode scanning feature. The interaction flow over activities is highly dependent on user choices and is typically rooted at the main activity showing the initial area selection interface (see Figure 5).

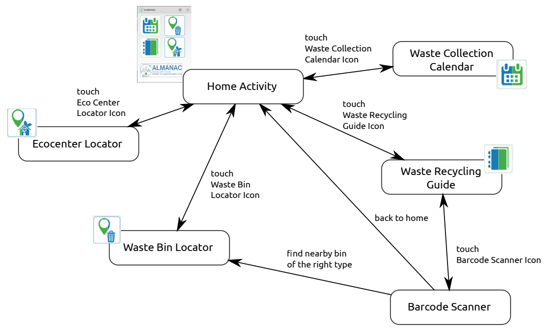

Fig. 5. Interaction flow between WasteApp main activities.

The full prototype is available for private download by users involved in usability tests and on-the-field experimentation.

VII. Preliminary Usability Study

The interactive prototype of the WasteApp, has been tested for usability, with a selected group of users. This preliminary test was aimed at spotting the main usability issues in the prototype, thus allowing for corrective actions to be carried before final testing with users from SHARING and other connected communities in Turin (see Section VIII). To evaluate usability of the interactive prototype, 6 participants used the WasteApp in a controlled environment, performing 4 tasks each (see Table I). Tasks were planned by accounting requirements and needs emerging from the co-design workshop and, they have been tailored to the ALMANAC project waste scenario. The set of tasks performed by participants of the user study reflect the typical interactions we envision for the proposed application. Participants never met during the evaluation. Their observations, together with data collected about their sessions with the WasteApp, allowed us to perform a qualitative analysis of the application usability, and helped to identify strong and weak points of the interface as well as to direct future works and research activities. Our analysis focuses on 5 basic questions about the usability of the WasteApp:

TABLE I
The 4 tasks used for the preliminary, small-scale study.

Task	Description
T1	Given an object, find the right way of disposing it between the 4 differentiated fractions;
T2	Identify the day of the week in which *paper* is collected;
T3	Identify the nearest bin in which disposing a plastic bottle;
T4	Set/Modify preferences for notification of collection days.

1) How easily do users understand the meaning and intended use of the 4 main sections of the app?
2) How quickly can users identify where a specific item shall be disposed, i.e., the type of waste?
3) How easily can users understand where to go for disposing waste of a given type?
4) How easily users identify and understand the curbside collection calendar?
5) How easily can users configure the app to send collection notifications?

A. Methodology

We recruited 6 participants for our user study: 3 females and 3 males, aged 25-39, (with an average of 32.8, SD 4.92). They were selected within our institution and did not include participants from the preliminary validation cycle. All of the participants own a smart-phone and use it on a regular basis to complete daily tasks, manage their schedules, interact with their own social networks, etc. Interviews were carried in Italian. All involved participants work in technical fields, not concerning IoT or Smart Cities; they all live in Turin and have experienced the current waste collection system. All of them can be considered experienced users of mobile applications.

A *within-subject* design was employed where each subject performed each task in counterbalanced order, to reduce ordering effects. Experiments were conducted in a controlled environment consisting of a medium-sized meeting room equipped with 4 chairs, one for the user, one for the moderator, located near to the user, and two for observers positioned in the background and not interfering with the test activities (simple single-room setup). In general, we followed recommendations for typical user studies as reported in [16].

B. Test deployment

After a short introduction to the usability study, the initial "page" of the WasteApp was shown to the participant, to collect a first impression on the interface, by querying his/her agreement with the sentences:

1) I like the appearance
2) I think that the main functions are clearly understandable
3) I think that the app is intuitive

Each user was asked to perform 4 tasks, one at time. For 3 tasks, the participant was asked to use the *think-aloud* protocol to verify his/her actions. User comments, suggestions and complaints were collected both during the task execution and at the end of the test session. For each task, observers recorded any "unusual" or "unexpected" behaviors, and they kept track of time needed for completion.

C. Results

According to Nielsen's Alertbox[3] we calculated the success rate of each participant as the percentage of tasks that users were able to complete correctly, also giving credit for partially completed tasks, i.e., tasks completed with minor errors. We expected the participants to easily grasp the app main features and to successfully accomplish all tasks.

Due to the limited size of the user sample and to the small number of tasks to accomplish, quantitative results are not particularly significant, however some evidence for possible improvements emerge. Table II reports the task success rates, where S indicates a successful task (score of 100%), P a partial success (score of 50%), and F a failed task (0%).

Although generally good, results in terms of success rate were a little lower than expected. By integrating observations

[3] http://www.useit.com/alertbox/20010218.html, last visited on May 23, 2016

TABLE II
SUCCESS RATE OF THE STUDY.

User	T1	T2	T3	T4	Success Rate(%)
U1	P	S	P	S	75.0%
U2	S	S	P	S	87.5%
U3	P	S	S	S	87.5%
U4	S	S	P	S	87.5%
U5	P	S	F	S	62.5%
U6	S	S	F	S	75.0%

and quantitative data, we identified two main issues in the current design. First, although useful and easy to understand, the barcode scanning feature was not easy to notice, therefore half of the users identified the fraction in which a given object shall be disposed by peering into the recycling guide. We penalized this behavior and counted it as partial success as we wanted to stress the "responsiveness" of the Waste App support to recycling.

The second issue relates to the lack of a "filtering" function on the waste bin map. Most users were successful at finding the bins nearby their position. However, identifying bins for a selected type of waste resulted cumbersome as it was almost always done by touching small icons on a map. The main "pattern" we imagined was through the barcode scanning feature. Such a feature offers, in fact, disposal information and directions (map) to the nearest bin collecting the identified waste type. However, in most cases this was not the pattern selected by users, therefore better interaction shall be supported, e.g., by adding filter by fraction functionality to the map, and by making barcode scanning easier to reach in the interface.

Comments from the users where in general very good. They appreciated the notification ability and the easiness of its configuration (in fact all users achieved 100% success in T4). Moreover, they judged the application easy to use and supportive of their needs, even with the minor issues emerging from the quantitative analysis.

VIII. CONCLUSIONS AND FUTURE WORKS

In this paper we presented the design and initial implementation of a waste-recycling support app for mobile phones and tablets based upon principles of user-centered design. We performed a preliminary small-scale user study to harvest first user impressions and to tune the final application design to maximize the perceived utility and ease of use. Results of the user study are encouraging and, interviewed participants show a nice acceptance of the proposed application. Some issues in accessing the "barcode" scanning feature and in finding specific bin types near to the location of the user have emerged, which will be accounted for in the next development cycle. In the future we are planning a more extensive experimentation deployed in two phases. First the WasteApp will be tested for usability with 10 users from the SHARING community and 10 users from the CAMPUS S.PAOLO university residence[4], two communities reflecting quite different demographics and needs, as it is likely to happen in a smart city scenario. Second, the app, incorporating revisions from user studies, will be tested for a month in the CAMPUS S.PAOLO premises, with a selected group of 10 volunteers.

[4]http://www.campussanpaolo.it, last visited on May 23, 2016

IX. ACKNOWLEDGEMENTS

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