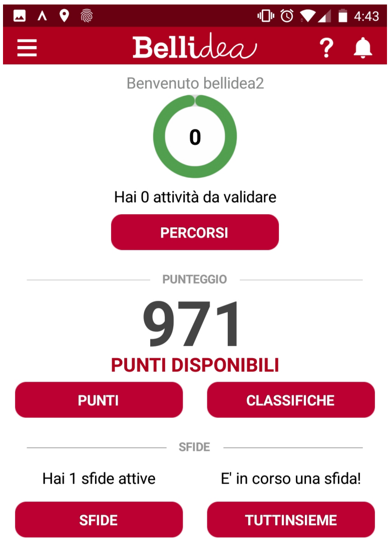

Outcomes of a smart city living lab prompting low-carbon mobility patterns by a mobile app

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Abstract

Cities seek to improve alternatives to car to counteract problems associated with traffic and carbon-intensive lifestyles. Novel tools that exploit ICTs to persuade mobility behaviour change are emerging as effective supports for existing structural and regulatory tools. For instance, in Bellinzona a living lab was created to co-design with citizens a persuasive smartphone app promoting individual mobility behaviour change by means of gamification and tangible prizes. In this paper we present the co-designed smartphone app, named *Bellidea*. Based on the commercial *Moves* tracking app and algorithms developed on purpose, *Bellidea* automatically tracks routes travelled and modes of transport used, thus allowing citizens to get aware of travelling time, distances and the related energy and climate impacts. *Bellidea* also invites its users to enrol in individual and collective challenges. Travelling time performed by sustainable modes and completed challenges are rewarded with points, which can be redeemed with tangible prizes. Besides expected tangible effects on local traffic reduction, use of the Bellidea app by a large number of citizens will provide city managers with low-cost, high-quality and high-granularity real life data on their citizens' mobility patterns, to directly inform future policy-making.

Keywords

mobility tracking, behaviour change, smartphone, living lab

1 Introduction

People living in Switzerland have grown surrounded by an extensive transport network that allowed the redistribution of production assets and of people's knowledge and experience, being a key enabling factor for the prosperity this country has reached. This does not imply that average mobility patterns by Swiss citizens are sustainable. Actually, private motorized transport by car still accounts for 66% of the total distance an average Swiss citizen travels on land, and for 74% if we consider an average Canton Ticino citizen (FSO, ARE, 2015). Also, in 2015 the transport sector was responsible for 36% of the final energy consumption and 39% of the total CO_2 emissions, with private cars producing around two thirds of such emissions (FSO, 2017). Furthermore, the Swiss government has calculated that traffic congestion annually costs the country CHF 1.6 billions in lost time, wasted fuel, environmental damage and accidents. The cost of time lost in traffic accounts for around 70% of such a cost and rose from 1.1 billions CHF in 2010 to 1.25 billions CHF in 2014, with a tendency to keep rising (ARE, ASTRA, 2016).

Cities have been trying to counteract problems associated with such an intensive use of private cars, by improving infrastructures and implementing regulatory tools. For instance, since 2016 the Municipality of Bellinzona (the capital city of Canton Ticino) has created seven low speed zones, introduced traffic calming measures along two roads and built cycle-pedestrian lanes in two districts, investing a total of 2.1 million CHF (Municipio Città di Bellinzona, 2016, 2017).

However, frequently structural and regulatory tools alone are not sufficient to break car-dependant habits and produce tangible reductions in car use at the community level. Nowadays improving a city system does not solely mean building new infrastructures or repairing aging ones: transportation does not only rely on concrete and steel, increasingly also depending on information and communications technologies (ICT) (Ezell, 2010). In fact, with the digitization of data related to transport, in a bunch of years our society observed the introduction of electronic ticketing systems, the bloom of intelligent transportation system (ITS) and the appearance of automatic vehicles, somewhat turning transport into another software industry.

In this context, soft policy measures can strengthen traditional urban mobility management and favour adoption of more sustainable mobility patterns (Bamberg *et al.*, 2011). In particular, novel possibilities are offered by the growing diffusion of smart city programmes and ICT tools (Gössling, 2018), which facilitate adoption and effectiveness of cognitive-motivational tools promoting more sustainable mobility patterns (Steg and Tertoolen, 1999), in the framework of behaviour change support system (BCSS) approaches (Oinas-Kukkonen, 2013).

Acknowledging that digitization, and in special BCSS, can have a huge potential to transform the current situation, the City of Bellinzona decided to develop an ICT tool capable of actively promoting a change in citizen's mobility behaviour.In order to have a tangible impact in the Bellinzona region, such a tool had to be available to a large group of citizens.It also had to be portable and with a minimal impact in the life style of its users. Considering that Switzerland has a penetration share of smartphones of 71.7% (Newzoo, 2017) and that smartphones are already deeply integrated into people daily lives, the decision was to create a persuasive mobile app, directly exploiting the phone's inbuilt sensors that enable mobility behaviour tracking (GPS, accelerometer and gyroscope).

This paper briefly introduces the main characteristics of already existing persuasive apps in the mobility domain (Section 2), highlighting main open challenges and showing how we addressed them in the app for Bellinzona, which was developed by means of a co-design process involving interested citizens (Section 3 to Section 5). We conclude by discussing remaining challenges for future research activities in this field (Section 6 and Section 7).

2 Persuasive apps in the field of mobility

Many persuasive smartphone applications (BCSS) have recently been popping-up throughout the world, as summarized in Table 1. Some of such apps are based on manual trip detection, requiring a strong interaction with the user. For example, the CicloGreen app requires users to manually enable tracking before starting a trip, indicate the mode of transport they are going to use and manually stop tracking, once the trip has ended.

However, the large majority of apps are currently trying to move towards automatic mobility tracking frameworks, in order to minimize the need for explicit user input (Bothos *et al.,* 2014). Thanks to fast progress in the quality of mobility tracking processes, in fact, several persuasive apps are already able to automatically detect trips and transport modes. These apps run in the background and automatically detect start and end of the trip, being also able to recognize the mode used. Jonietz and Bucher (2018) however note that at some degree all current apps would still benefit from a manual checking of the transport mode by the user, provided that a good level of accuracy is sought. A recent trial run in Toronto to assess effectiveness of state-of-the-art mobile tracking apps also confirmed that automatic detection capability is still limited (Harding *et al.,* 2017). Therefore, apps frequently adopt a mixed approach, combining automatic detection with manual validation by the users. An example is the GoEco! app, that we have recently developed and tested in Canton Ticino and in the Zurich area (Bucher *et al.,* 2016): for every recorded route, GoEco! predicts a mode of transport, but it always asks user to manually validate it, thus ensuring high accuracy in the identification of individual mobility patterns.

Table 1: Persuasive apps aimed at reducing individual car use.

App	**Country**	**Mode of transport detection**	**Points**	**Reference**
SMART, 2017	Netherlands	Automatic, manual validation is possible	Proportional to kilometers travelled by soft modes	www.smartintwente.nl
Bellamossa, 2017	Italy	Manual: user has to start/finish an activity and select the mode	Proportional to kilometers travelled by soft modes	www.bellamossa.it
Ciclogreen, 2017	Spain	Manual: user has to start/finish an activity and select the mode	Proportional to kilometers travelled by soft modes	www.ciclogreen.com
GoEco!, 2016	Swtizerland	Automatic, with manual validation	No points system; goal setting	Bucher *et al.* (2016)
QT, 2015	USA	Automatic, with manual validation	No points system	Jariyasunant *et al.* (2015)
BetterPoints, 2015	UK	Manual: user has to start/finish an activity and select the mode	Proportional to kilometers travelled by soft modes, including running	www.betterpoints.uk
Peacox, 2014	Ireland	Automatic	Based on challenges	Bothos *et al.* (2014)
Matkahupi, 2013	Finland	Automatic (though stability issues were encountered)	No points system	Jylhä *et al.* (2013)
Tripzoom, 2012	Netherlands	Automatic, with manual validation	Based on challenges	Bie *et al.* (2012)
UbiGreen, 2009	USA	Automatic, with manual validation	No points system; visualizazion of progress	Froehlich *et al.* (2009)

One of the most frequently adopted approaches to persuade behaviour change in such apps is *gamification*, wihch is usually defined as the use of game elements in non-gaming contexts (Deterding *et al.,* 2011). Particularly, many apps rely on a points system, by automatically attributing points if the mobility data tracked by the app show users perform sustainable mobility choices, coherently with a set of given rules. Depending on the app, points can then be redeemed for real-life goods and services or remain just virtual achievements inside the app. As shown by Table 1, apps usually acknowledge points based on the kilometers travelled with a given set of modes of transport, frequently soft modes such as walking and ciclying. To simplify user interaction and avoid computational burdens related to user profiling and consequent app-customisation, the same rules are usually applied to all users, without taking into account their initial mobility patterns or the mobility options actually available to them, with respect to their daily needs.

Acknowledging that adopting such "one-size-fits-all" rules could be detrimental to their motivational effectiveness (Huber and Hilty, 2015), some apps opted for adding a few customisation options, by relating points to achievment of individual, voluntary challenges, or even for directly avoiding them, exploiting instead other motivational elements, such as individual goal setting (Cellina *et al.,* 2016) or intuitive visualization of progress towards change (Froehlich *et al.,* 2009). Such approaches also allow not to lose sight of the "big picture" of one's own mobility patterns, by focusing on overall mobility choices, instead of single trips. In fact, attributing points proportionally to the kilometers travelled with a given mode of transport, such as the bycicle for example, might lead to paradoxical situations: users who add bicycle rides during their leisure time, instead of replacing car use when commuting to work, would be rewarded with points, even though they are not contributing to addressing current mobility problems. As remarked by Froehlich (2015), such points systems might encourage people to take more trips simply to earn more points, leading to increase consumption, emissions and the related environmental impact. Namely, exactly the opposite of what persuasive apps are designed for.

3 Co-creation in the *Bellidea* living lab

With the aim of developing a persuasive mobile app, the City of Bellinzona built on the above knowledge and particularly on the experience gained in the app-based, persuasive GoEco! intervention, which was run in the same area. GoEco! had shown two main limitations:

- *preaching to the converted*: the app had mainly attracted citizens with high environmental awareness, which had already lead them to significantly change their behaviour, thus not being representative of mainstream "car-dependent" citizens;
- *high drop-out rates and early abandon*: level of engagement of smartphone app users decreased over time: frequently users quitted app use before they had modified their mobility patterns.

To overcome such limitations and favour enduring and large scale diffusion of the new app to the whole population, the City opted for:

- encouraging social inclusion and sustaining app use with a set of tangible prizes (extrinsic motivational factors), directly targeting mainstream citizens who otherwise would not show any interest in the app;
- favouring empowerment, retention of interest and enduring engagement by opening-up the design of the app main contents and functionalities to the citizens themselves.

The hypothesis was that, if citizens owned the tool, they would have been stimulated to use it for a longer period of time and to promote its diffusion among their circle of family and friends.

Therefore, in line with recent understandings of the smart city concept as "smart technology, smart people, smart collaboration" (Nam and Pardo, 2011), the City of Bellinzona decided to activate a *living lab* process, named *Bellidea*. Living lab processes, defined as "user-centred, open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real life communities and settings" (Pallot, 2009), were in fact assessed as particularly suitable to address the needs of the City. More specifically, the *Bellidea* living lab aimed at engaging citizens in co-designing and testing the *Bellidea* mobile app, namely a persuasive app rewarding sustainable mobility choices, thus supporting the whole community in the transition from car-dependency to car-alternatives.

In early 2017 the City of Bellinzona launched a public campaign inviting citizens to join the *Bellidea* living lab. Such a campaign was targeting both car-drivers and public transport users, in order to guarantee sufficient diversity and enhance creative discussion. It also explicitly targeted students, elderly people and citizens from foreign communities, with the aim of preventing risks of exclusion of such social categories from effective use of the *Bellidea* app. On average twenty citizens attended the monthly lab meetings, held from April 2017 to February 2018, with a break during Summer. First meetings were mainly shaped as participatory workshops, dedicated to the exploration of already existing apps, the identification of the key functionalities to include in *Bellidea*, and the discussion on the gamified rewarding mechanics to be activated. Later meetings were instead organized as test-beds for the prototype versions of the app, which were step-by-step released. A website and online forum further supported discussion and reporting errors (http://www.bellidea.ch). The outcome of co-creation in the lab was the *Bellidea* app, developed for iOS and Android operating systems, which respectly have 55,5% and 43,4% of the Swiss market share (StatCounter, 2016). *Bellidea* was available to the general public since the end of April 2018, when a press conference and related communication and advertising activities launched it to the whole population living and working in the area of Bellinzona.

4 The *Bellidea* mobile app

As indicated above, activities in the *Bellidea* living lab were first aimed at understanding functionalities and limitations of previously developed apps and, later on, at identifying effective persuasive elements to stimulate app users to behaviour change. To this purpose, we referred to the effective persuasive techniques to stimulate pro-environmental behaviour identified by Froehlich (2015) and Anagnostopoulou *et al.* (2016), which can be summarized as follows:

- *Provide information:* when providing information to a user, it is most valuable if it is related to the user's behavior and is given as timely as possible (close to the triggering element, in both space and time). This makes it easier to understand and remember. In our case, possible information could be on available transport alternatives tailored to the individual's needs, interests or living context;
- *Provide occasions for social comparison:* offer individuals the opportunity to compare their choices and performances with the ones of other people or groups, which users perceive as comparable to themselves (e.g., members of the same community). This generates both peer pressure and a desire for imitation;
- *Provide goal setting opportunities:* if target values are really challenging for the individual, self-setting goals can have powerful effects, since they create a self-competitive setting in which the individual strives for personal progress and mastery (intrinsic motivation for change);
- *Provide feedback:* since individuals require a baseline to assess their performances, giving feedback is complementary to and essential for goal setting activities;
- *Provide rewards (incentives) or punishment (disincentives):* these can be either tangible or intangible, expressed in monetary terms or in physical unitsProvided as an outcome of the individual's performances, they can either reinforce individual motivation to adopt a certain behavior (reward of good performances) or stimulate a user to increaseher efforts, in case of poor performances. The use of punishment, however, is controversial (Foster *et al.,* 2011), since it might quickly lead to the unwanted effect of demotivating users.

The result of co-creation in the *Bellidea* lab is an app that performs automatic mobility tracking, provides users with (eco-)feedback on their individual mobility patterns, stimulates them with mobility-related challenges and invites them to collect points, which are proportional to the weekly percentage of travelling time by public transport, bicycle or walking. Points can be redeemed for prizes, such as discounts on energy bills and vouchers for local stores and public transport tickets. A summary of the key motivational elements introduced in *Bellidea* to persuade behaviour change is offered in Figure 1.

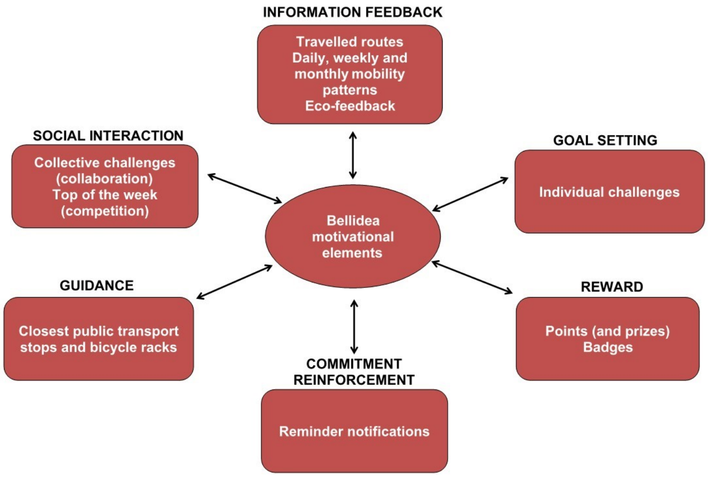

Figure 1: Components of the *Bellidea* motivational mechanics.

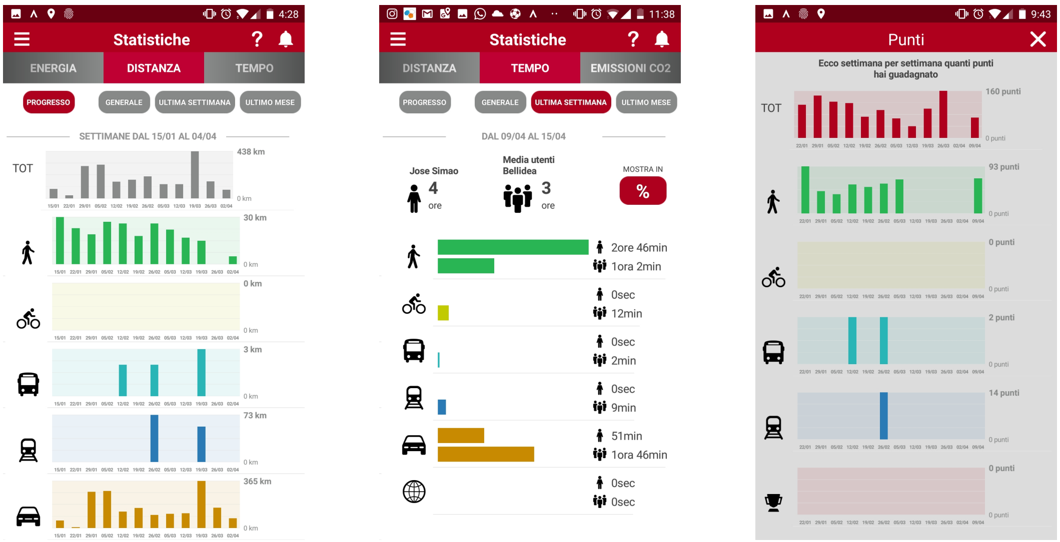

Figure 2: Example of feedback charts offered by the *Bellidea* app (only available in Italian). From left to right: weekly evolution of kilometers travelled; weekly share of transport modes and comparison with average *Bellidea* users; weekly evolution of points.

The feedback on individual mobility patterns is performed by means of a series of charts (Figure 2), which summarize the share of use of the modes of transport on a daily, weekly and monthly basis, both in terms of kilometers travelled and travelling time, as well as energy consumption and CO_2 emissions (eco-feedback). Some charts also show how the user performs with respect to the average *Bellidea* users, with the goal of enhancing occasions for social comparison.

Since the aim of *Bellidea* is to persuade a change at all levels in mobility choices, as indicated points are attributed on a weekly basis, by taking into account all the routes travelled over seven days, from Monday to Sunday. In more details, points are attributed according to the percentage of the weekly travelling time with sustainable means of transport. At the end of every week, provided that the user has travelled at least four routes, the total travelling time is computed:

if it is entirely travelled with a mix of sustainable means of transport, user is attributed 100 points. Otherwise, she is attributed a smaller amount of points, in a linear proportion to such a percentage. This means that points are attributed by taking into account mobility choices of a user as a whole, including both systematic and non-systematic routes, travelled for any purposes. The contribution of such routes is in fact getting increasingly significant, both in term of kilometers travelled and travelling time: according to the last Swiss Census on Mobility and Transport, on average 45.2% of the daily travelling time and 44.3% of the daily travelled kilometers are due to leisure reasons (FSO, ARE, 2015).

Occasions for goal setting are offered by individual challenges, that stimulate users to commit themselves to adopt certain mobility patterns, such as *This week I will not use the car during peak hour*, or *This week I will opt for public transport, when I go out in the evening*, or *This week I will opt for soft mobility for all my shorter than three kilometers routes*. Such challenges are always available in the app and users can freely decide if and when engaging in them. Since *Bellidea* monitors all the routes performed by a user, it is also capable of automatically checking completion of a challenge, by comparing the user's mobility data with respect to a set of rules, which are also made explicit to the users themselves, in the description of the challenge. If the rules are respected, the challenge is achieved and the user is directly rewarded with points. She is also intangibly rewarded by receiving a virtual trophy, visible in the app, and checking her progress in the weekly statistics charts. Challenges are structured in levels: at the entry level, the challenge lasts for one week; if they achieve it, they are invited to progress to the next level, which lasts two weeks and so on. Four levels of difficulty are envisaged, with the fourth level lasting for four weeks. Once the user completes all the four levels, she can still keep engaging in the same challenge, remaining at the highest level of difficulty.

Users are also rewarded with surprise badges, which are attributed when specific sustainable mobility choices are detected by the system, such as *using the bicycle every day for at least five consecutive days* or *travelling long than 100 kilometer trips by train*. Differently from challenges, in which users are voluntary and consciously engaged, badges are unexpectedly delivered by the app. This aims at making users aware of positive actions they perform and stimulates them to repeatition in the future. Moreover, badges reinforce commitment and rekindle user interest.

Participants to the *Bellidea* living lab opted for further relying on challenges, exploiting the power of social interactions: to this purpose, *Bellidea* also offers community-level challenges, that can periodically be launched throughout the year, such as *This month, let's use the bicycle for at least 20% of our overall travelling time* (Figure 3). If app users collaborate in achieving such a challenge, they do not earn points; instead, the community as a whole gets a prize, such as for example discounts on public transport season tickets, public transport excursions for school

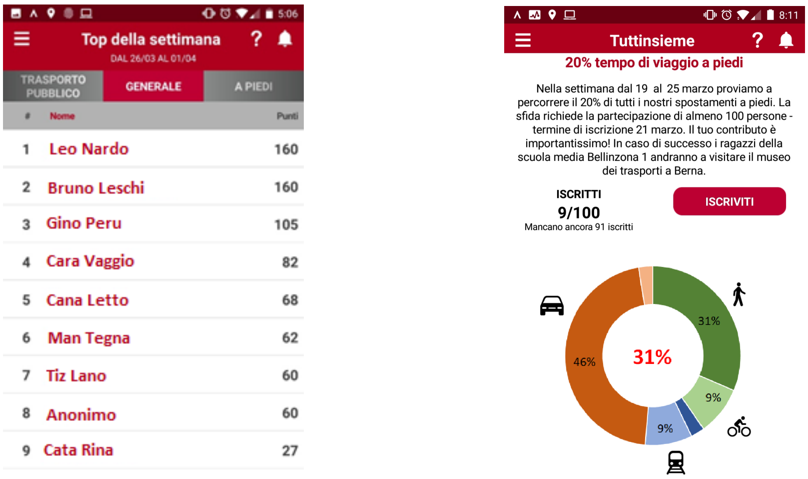

Figure 3: The functionalities of *Bellidea* exploiting social interaction elements (only available in Italian). On the left, the weekly leaderboard; on the right, a collective challenge.

classes or cargo-bike transport services for elderly people. Such a mechanics is expected to further motivate people to keep level of activity high, since it builds on their feeling of belonging to the local community, besides on their desire for attractive prizes. Collective challenges will only be activated in specific periods of the year, accompanied by dedicated communication campaigns aimed at engaging new citizens in app use.

Besides exploiting collaborative group mechanics, *Bellidea* also builds on competitive feelings among its users, and provides them with weekly leaderboards, based on the number of points they earn during the week: users can compare themselves with the other members of the community based on the overall amount of points gathered and also on the subset of points they earned by walking, cycling or using public transport (Figure 3). Since the leaderboard is always updated by just considering the points collected during the previous week, potentially every week any user has the chance to be in the top positions - and, if not in the general leaderboard, maybe at least in one of partial leaderboards related to single modes of transport. This guarantees that the leaderboard keeps its motivational impact over time. Since however not all individuals might appreciate being included in public comparisons, an opt-out rule is followed: in principle, all users are shown in the leaderboard, but they can ask to leave it at any time - in which case, their user name is replaced with an anonymous one, in order to keep a stimulating comparison for the other app users.

To support users in opting for public transport and soft mobility choices, *Bellidea* also offers practical information on the position of closeby public transport stops, bicycle racks and cycling lanes. This functionality is expected to guide and reassure inexperted users in their attempts to reduce car use, thus leaving less room for commonplace statements such as *I keep using the car because I am unfamiliar with the other mobility options and would not even know where to take* *the bus from or where to park the bicycle*.

Finally, a notification system is always active, in order to recall users about ongoing activities in the app: *Bellidea* provides its users with one daily notification about the tracked routes (and the possible related need for validation), one weekly notification when statistics are updated and points are attributed and one notification when a challenge the users is engaged into is close to conclusion. The type and frequency of notifications is designed with the aim of reducing intrusiveness, while keeping users' interest in the app and reducing app churn. In the future, possibilities to customize the number and type of notifications will be offered.

5 Automatic mobility monitoring

Effectiveness of the above persuasive elements critically depends on the capability of the app to correctly and automatically detect mobility data, particularly in terms of routes travelled and modes of transport used. For this reason, here we focus on the main challenges that were discussed and addressed in the *Bellidea* lab regarding how to monitor individual mobility data.

5.1 Data acquisition

Due to time and budget limitations, developing a tracking app from scratch was not possible within the *Bellidea* living lab. Therefore, to track raw mobility data we had to rely on existing commercial tools. We opted for using another app, instead of other tools such as GPS devices or bracelets, since requiring to buy external devices would have been too high a barrier preventing app diffusion among the citizens. Following the findings of Bucher *et al.* (2016), we opted for using the activity tracker Moves app (https://moves-app.com/), originally developed for fitness purposes. Main advantages offered by Moves can be summarized as follows:

- it runs in background and is capable of automatically identifying transport activities, without any user interaction, provided that GPS location services are enabled;
- it records GPS points with a reasonable accuracy,allowing to reconstruct actually travelled routes to a good approximation, though at the same time guaranteeing low battery consumption and usual phone usage during the day without extra recharging;
- it has inbuilt pre-processing algorithms able to organize GPS data into routes and activities as well, in case different means of transport are used in the same route;

- it already effectively detects some modes of transport (the fitness-related ones, namely walking, running and cycling); all the other transport activities are identified and segmented in routes/activities, though in such cases the mode of transport is generally classified as "transport";
- it provides an application programming interface (API) that enables other apps to automatically access these data and process them for further elaborations;
- it is freely available, both for iOS and Android operating systems.

Nevertheless, the use of Moves as a tracking provider presents a few downsides:

- there is no direct control on the data collected, nor on the models and procedures used to get them: Moves produces data under a black-box approach;
- data are also stored in third-party servers abroad, which might comply with less restrictive data protection laws and requirements with respect to the Swiss ones;
- the service might be disrupted at any time, which implies high dependency on the willingness of its developers to keep it available;
- it is an external app, which cannot be integrated in *Bellidea*, therefore compelling users to install two apps instead of one.

Notwithstanding such limitations, due to the lack of other equally good performing alternative options, we opted for using Moves.

The mobility tracking data collected by Moves and imported in the *Bellidea* database are organized in routes and activities, which are segments of routes travelled with the same transport mode. For each activity, Moves provides the following characteristics: distance, duration, start and arrival time, GPS coordinates of a few tracking points (their number depending on the specific route and activity), and estimated transport mode (walking, running, cycling, or "transport").

5.2 Data processing

If being unable to tell the difference between a car, a motorbike, a bus or a train is not a problem for a fitness tracker app, such as Moves, it becomes critical in a mobility tracking app aimed at reducing car use, such as *Bellidea*. In particular, since in *Bellidea* the feedback on individual mobility patterns is one of the key persuasive elements towards behaviour change, and, depending on such mobility patterns, real prizes are offered, detection of the mode of transport is crucial in *Bellidea*.

To address automatic mode detection, in our GoEco! earlier project in which we had exploited Moves as well, we had developed algorithms performing a further classification of Moves estimates of the transport mode, achieving an overall average accuracy of 82,9% (Bucher *et al.,* 2016) in automatic mode detection. In GoEco!, however, we had always asked users for a manual validation of the mode of transport we had identified: namely, for every recorded activity, the app asked users to either confirm the detected mode or indicate the correct one. Such a request for validations turned out to be critical for app users, up to the point that in final project survey and individual interviews they indicated it as a major reason for app churn, that is users' early abandon of regular app use (Rizzoli *et al.,* 2014, Cellina *et al.,* 2016). Moreover, as already noted, requesting users for a manual validation of the mode of transport leaves room for cheating the system, which would not be accceptable in *Bellidea*, where real-life prizes are at stake.

Having learnt such lessons, in *Bellidea* we aimed at avoiding as much as possible to ask users to confirm or correct the mode of transport automatically detected by the app. However, we were aware that we could not totally remove validations: in fact, as remarked in the above literature review, current smartphone-based automatic detection capability is limited (Harding *et al.,* 2017) and therefore, even adopting different algorithmic approaches, errors in the identification of the mode of transport would still have been common. If we removed validations, users would at first appreciate not having the burden to regularly validate their routes, but in the end would in any case be led to quit using the app, due to dissatisfaction with detection accuracy. Therefore, in agreement with the citizens involved in the *Bellidea* living lab activities and with policy-makers in Bellinzona, we opted for an hybrid configuration, underlying a relationship of trust between the app and its users. We decided in fact to improve the classifying algorithms we had developed for GoEco!, with the aim of limiting both users' validation effort and mode detection errors, while not totally eliminating either the former or the latter.

The hybrid configuration works as follows: at app download, all users first enter a short training period, during which they are required to validate all the activities they travel and do not get any points. This period, which on average lasts for a couple of weeks, allows to calibrate and train our algorithms, in order to improve their performances. Then, validation of an activity is only asked when the estimated probability of a mode of transport identified by our algorithm falls below a given threshold.

Figure 4 schematizes the *Bellidea* app data acquisition and processing activities. Once a day the mobility data of the day before, collected by Moves API, are pushed into the Bellidea datastore, which sends them to the *Bellidea Classifier*. The Classifier is based on a random decision forest algorithm (Breiman, 2001). Basically, it takes as input the points of an activity (i.e. the geographical coordinates, but also the corresponding timestamps), from whom it computes a number of features charaterising the activity itself. The full set of estimated features for each activity is the following one:

- transport mode indicated by Moves (bike, walk or motorized transport);
- user identifier;
- average speed;
- total traveled distance;
- maximum distance between two (consecutive) track-points;
- average change of direction between track-points;
- start hour of the activity (0-23);
- start day of the week (1-7);
- distance between first track-point and closest bus stop and distance between last track-point and closest bus stop (a direct connection between the two stops must exist);
- delta between actual travel time and bus travel time between the two stops;
- distance between first track-point and closest train stop and distance between last track-point and closest train stop (a direct connection between the two stops must exist);
- difference between actual travel time and train travel time between the two stops;
- first track-point latitude and longitude;
- last track-point latitude and longitude.

The Classifier processes such data and returns the probability distribution over the following transport modes: walk, cycling, train, bus, car, other. Namely, it returns the probability that each activity has been travelled with each mode of transport. Then, the two modes of transport with the two highest probability values are considered. If the difference between such probability values if higher than a given threshold value, then the mode of transport with the highest probability is considered correct and is sent to the *Bellidea* datastore, to be shown in the app as the detected mode of transport, with no possibility for the user to modify it. Otherwise (the difference between the two highest probabilities is below a given threshold value), it means the *Bellidea* Classifier is not capable of reliably detecting the mode of transport to a good approximation. Therefore, a validation is requested to the user. In such a case, the *Bellidea* datastore receives the indication of the mode of transport with the highest identified probability, but the app asks the user for a validation, namely to confirm or modify it. After validation, the mode of transport validated by the user is sent to the Bellidea datastore as well.

The above process refers to the classification phase, but there is also the training phase. A preliminary training was initially performed on the data collected by the GoEco! app during the related research project (62'956 activities collected by 220 users between March, 14 2016 and April, 30 2017); after, training was periodically launched, also including new activities validated

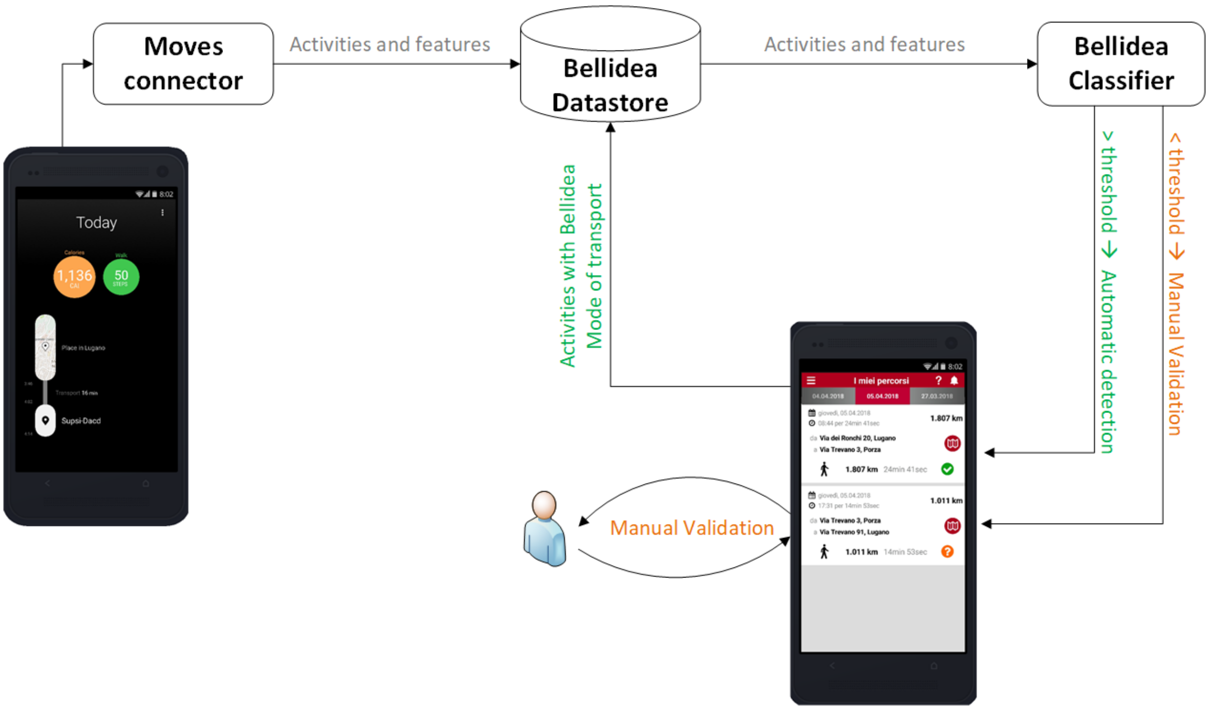

Figure 4: Architecture of the *Bellidea* system for detection of the mode of transport.

by participants to the *Bellidea* living lab, when they were testing prototype releases of the app. Every time a new training is performed, accuracy in the detection of the transport mode is further improved. If in the classification phase the algorithm considers one activity at a time, in order to detect its mode of transport, in the training phase the Classifier is fed by the whole set of activities for whom the transport mode is already known (i.e. the set of activities already validated by the users). Doing so, the Classifier can be trained, and also updated if a substantial amount of new data is available, and overall detection accuracy increases. While the classification phase must be run online (the user has to immediately receive the indication of the mode of transport), but it is very fast, the training phase can take a non neglectable amount of time (depending on the amount of training data), but it can be done offline, for instance during night time, once per week.

It is important to say there is only one instance of the Classifier, common to all users: the approach of developing a set of classifiers, one per every user, has also been explored, but discarded. In fact, despite adopting multiple classifiers would allow to better detect the features of every user, it would also have two important drawbacks. The first one is that the amount of data needed for every user would be much larger if compared to the single Classifier solution; the second, and more important, is that having single classifiers for every user would be more sensitive to cheating. In fact, if during the first validation period a user untruthfully indicates a transport mode which provides more points (e.g., bicycle) for all activities, then the individual classifier would attribute that same transport mode to all her future activities; unlike, the single common classifier, which does not differentiates between users, would only slightly be biased. However, analyses we performed on the performances of the single Classifier showed that totally ignoring the differences between users providing validations reduces the overall performances of the Classifier. Therefore, the implemented Classifier also considers the identity of the user as an input parameter, thus allowing for a certain degree of customization of the classifier to suit each particular individual. As a consequence, the customized single classifier is more sensitive to cheating than the common one, yet, it is more robust than a set of user-specific classifiers.

5.3 Assessment of performances

Performances of the whole *Bellidea* Classifier and hybrid system for the detection of the mode of transport were assessed by means of the data collected by the citizens involved in the *Bellidea* living lab. In fact, after being involved in co-creating the app functionalities, participants to the *Bellidea* living lab supported us in testing the *Bellidea* app prototype, as long as its functionalities were released over time. In particular, they were invited to validate the mode of transport for all their activities, both those for whom the Classifier considered the mode of transport as correct and those for whom the Classifier requested for a manual validation. To visually differentiate these two situations in the app, the user interface showed the former type of activites with a blue icon, while the latter with an orange icon. After validation, in both cases the icon turned to green (Figure 5). This procedure allowed us to assess the following indicators:

- the frequency of the requests for validation (namely, the number of "orange icons" per day per user);
- and the accuracy in automatic detection of the means of transport (namely, the percentage of the "blue icons" for whom the transport mode validated by the user corresponded to the one considered correct by the *Bellidea* Classifier).

The test took place from January, 15 to March, 11 2018, involving 28 living lab participants. A total number of 8’687 activities were collected, of whom 85.8% were regarded as correct by *Bellidea* ("blue" icons) and 14.2% were instead required a manual validation ("orange" icons). On average, such "orange" icons correspondend to 0.78 activities per day per user. Overall, 69.6% of such activities (6’047 activities) were manually validated. Such validations showed that the *Bellidea* Classifier was able to correctly detect the mode of transport for 89.6% of the "blue" icon activities.

Starting from these indicators, a sensitivity analysis was performed in order to assess performances of the *Bellidea* Classifier, on varying the threshold used to differentiate "blue" from

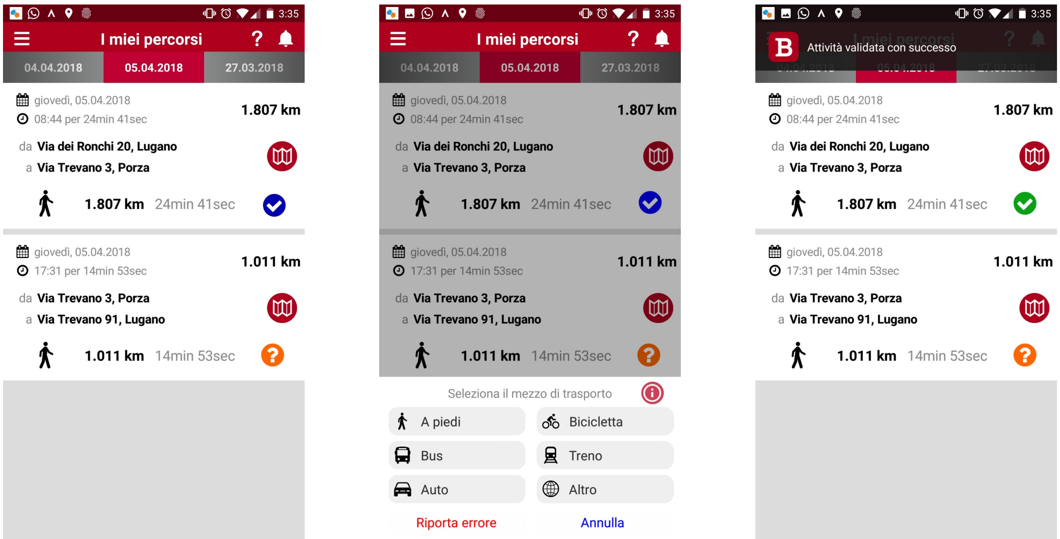

Figure 5: User interface for the validation of the transport mode during the test with living lab participants. Blue icons were shown if the *Bellidea* Classifier considered the transport mode as correct, while Orange icons indicated *Bellidea* Classifier requested for a manual validation. In both cases, manual validation was required. Once it was performed, both icons became green. Note that in the final version of the *Bellidea* app, blue icons were replaced by already green icons and their validation was blocked.

"orange" icons - namely the value against whom the difference between the two highest probabilities of a transport mode is compared. The goal was in fact to determine a threshold value with a good tradeoff between Classifier performances and amount of activities to be confirmed by the users. To assess performances of the Classifier, three indicators were considered:

- the *recall*, which indicates how many of the activities validated as a particular mode were classified as such;
- the *precision*, which indicates how many of the activities classified as a particular mode were actually validated as that mode;
- the overall *accuracy*, which is the number of modes correctly identified divided by the total number of classified activities.

Table 2 shows how the percentages of manual validations, accuracy, recall and precision vary with the value of the threshold. Based on such analysis, we decided to use a 20% threshold, which is expected to produce an overall 90% accuracy of the Classifier, without stressing the number of manual validation requested to the users: on average, users would in fact be called to validate 14% of their activities. This was assessed as not critical with respect to cheating, since it would only allow users to modify 14% of the recorded activities, if they wanted to gain more points. Also, it was regarded as not critical in terms of validation effort: according to the average data collected by participants to the *Bellidea* lab, for whom on average 38.8 activities were registered every week, every user would only be requested to validate 5.5 activities per

Table 2: Results of a sensitivity analysis on the value of the threshold to be used to identify activities that need to be manually validated.

		Threshold [%]						
		0	5	10	15	20	25	30
Manual validation [%]		0	4	7	11	14	18	21
Recall [%]	bicycle	67	69	69	70	71	72	72
	bus	17	13	13	13	13	14	12
	car	90	92	92	93	94	94	95
	train	68	68	71	73	75	78	81
	walk	93	93	94	95	95	96	96
Precision [%]	bicycle	76	78	80	81	82	85	85
	bus	78	67	68	68	67	73	67
	car	77	79	81	82	84	85	85
	train	90	90	91	92	91	92	95
	walk	93	94	95	95	95	96	96
Accuracy [%]		85	86	88	89	90	90	91

week, which is less than one per day. Finally, a 10% error in the detection of the transport mode was assessed as still acceptable, with respect to the risk that users abandon, due to a lack of satisfaction in the quality of automatic mobility monitoring.

6 Discussion

In this section we comment on the implications of a few design characteristics of the *Bellidea* app and indicate how we addressed them. Practical implementation of the motivational elements introduced in Section 4, coupled with the mobility tracking system we implemented, in fact led us to address a few challenges. The main aspects we dealt with can be summarized under the following dilemmas:

- dynamism versus rigidity;
- trust versus control;
- global versus local.

6.1 Dynamism versus rigidity

The first challenge refers to the opportunity to develop a dynamic system, as much as possible capable of operating in real-time. This is in fact what citizens expect: if their phone is tracking their mobility data, they expect they can immediately see their routes and activities on their phone, and possibly also see the immediate increase in the amount of points available to them. Indeed, Moves provides routes and activities in (nearly) real-time, as soon as they have ended. *Bellidea*, instead, imports them in a bulk, once per day: tipically, every day at 3 p.m. it imports all the activities travelled on the day before (from midnight to midnight) and then at 6.30 p.m. sends a daily notification informing about possible activities to be validated. This rigidity was decided in order to guarantee data imported from Moves are complete and stable, since they refer to activities that have definitely concluded. In our previous experience with GoEco!, instead, we had opted for maintaining activty import as dynamic as possible, though this frequently resulted in importing partial data and incomplete activities, about whom users frequently complained. In fact, Moves updates an activity while the user is still moving, and already makes it available among its APIs, ready for export. However, Moves might keep updating it, depending on the specific route the user is travelling. Importing an activity as soon as it gets available in the APIs might therefore imply the risk of importing an incomplete activity (wrong destination points, lack of tracking points characterizing the path, more likely errors in the detection of the mode of transport). Since the specific procedures and rules followed by Moves in data processing were not known to us, we decided to favour data quality, to the expense of frequency of update: *Bellidea* might look a bit static, though activity data are correct.

Another aspect impacting dynamism is related to the rules to attribute points. Since we explicitly aimed at attributing points based on the users' mobility patterns as a whole, instead of the single trips they travel, for point attribution the real-time framework had to be necessarily abandoned. Instead, we set a time-step during which mobility patterns are assessed, with points being attributed at the end of such time-step. We opted for a weekly time-step, believing the week allows to take into account the variety of mobility needs users usually have, including both work/study-related and leisure-related ones, and therefore is particularly adequate to perform an overall assessment of how sustainable mode transport choices are. A shorter period (e.g. one day) would result in too much variability: one day might result more sustainable than the other not because of active decisions by the users, but simply because of different external factors influencing one's mobility needs. A longer period (e.g. one month), instead, would be as interesting to summarize mobility patterns, though it would imply way too little dynamism: feedback offered by the app would be too rare to have an impact and users would easily lose interest in the app.

For these reasons, points are updated on a weekly basis and refer to the mobility data collected from Monday to Sunday. They cannot be updated on Sunday evening, however, since the validation issue comes into play. The need for a validation, which is only introduced for a limited amount of activities, implies users are left some time to check their activities and validate the mode of transport, before points are attributed. We decided to keep the same rule for all the users, setting the update to Tuesday mornings at 10 a.m. Every Monday evening at 6.30 p.m. the daily notification also recalls to validate any "orange icon" activities regarding the previous week (from Monday to Sunday) and indicates validations will only be possible until Tuesday at 10 a.m. If on Tuesday at 10 a.m. any "orange icon" activity is still present in the app, meaning that not all requested validations have been performed, no points are attributed for that week. Moreover, validation of such "orange icon" activities will no longer be possibile, since activities of the past week will be turned to gray and no interaction possibilities will remain available. Again, the system is quite rigid and precludes possibilities for users to validate old activities and correspondingly get the points updated. This choice was mainly due to avoid retroactive management of the point system, which was considered too complex with respect to the time and budget available. However, it was not only compelled by technical limitations. In fact, we preferred to force users to at least one weekly interaction with the app, in order to guarantee that they still remember about the routes they travelled throughout the previous week, therefore being able to correctly validate the transport mode. Moreover, the need for at least one weekly interaction contributes to rekindle interest by the users and is expected to reduce app churn, thus at least partially counteracting possible app churn due to lack of real-time dynamism.

6.2 Trust versus control

The second challenge we addressed refers to the dilemma of trust versus control. As already discussed in the previous sections, the general approach followed in the *Bellidea* app reflects a "controller" attitude: fearing that allowing too much validations can lead users to cheat the system, due to availability of tangible prizes, automatic detection of the mode of transport is favoured, to the extent possible. Participants to the *Bellidea* lab in fact preferred to accept a 10% risk of not attributing points to users who deserve them (the percentage of errors in mode detection for the "green icon" activities) instead of leaving users free to validate any activity.

In oder to manage and monitor such errors, we introduced the possibility for users to automatically notify them. Four categories of errors have been envisioned: not performed activity, wrong duration, wrong address(es), and wrong mode of transport. For the time being, the system automatically deletes activities of the firts type. It is not unfrequent, in fact, that GPS devices track short activities that actually have not been performed, for instance around a place where user is standing still for a few hours. The other types of errors, instead, are not followed by any practical action, apart for being monitored. Any automatic cancellation of activities might in fact pave the way to cheating - a bit more difficult for users than by validation, but, in any case, possible. Therefore, such error reporting is manually analyzed: if specific users are seen to frequently report errors, they are directly contacted to investigate their problem.

Accepting that around 14% of activities need in any case to be validated by the user (the "orange icon" activities), the control attitude at least partially opens up to a trust attitude. Indeed, the most effective way to cheat the system would be very easy: users might simply disable Moves or leave the smartphone at home whenever they are going to travel by car. Every week, they would just need to register four routes by foot, bicycle or public transport, to be rewarded with 100 points (four being the minimum number of weekly routes needed to get points). This recalls us that at the heart of the *Bellidea* concept is an attitude of trust between the City of Bellinzona and its citizens.

6.3 Global versus local

The third challenge deals with considering the whole mobility of a user, no matter where it takes place, or only considering the part of mobility that involves the Bellinzona region. Again, this issue was debated since tangible prizes are at stake, and such prizes are offered by the City of Bellinzona, by relying on the municipal budget. In principle, everybody in the lab was convinced of the need to stimulate global improvements in one's mobility patterns, be them in Bellinzona, Lugano, London or wherever else in the world. However, they also acknowledged that current administrative organization had to somehow be taken into account: if the City of Bellinzona is paying for prizes, it should be in exchange for tangible improvement of individual mobility patterns over its territory. If improved mobility patterns are also registered outside the City, it is definitely valuable, but the City cannot be called to be directly responsible to reward them. Acknowledging this implied introducing boundaries: *Bellidea* in fact only considers routes with either a starting or an arrival point in the area of Bellinzona (for the sake of simplicity, schematized in a rectangular box). Any route travelled completely outside such a box is not imported in *Bellidea*, even though it is regularly tracked in Moves.

Note that this choice could lead to paradoxical situations, such as citizens being rewarded with points (and prizes) for always using the bicycle in Bellinzona, even though every day they travel by car to their workplace in Lugano - which is pretty common - and alway stop at the service station outside Bellinzona for a coffee. Being entirely out of the "Bellinzoa box", the route from the service station to Lugano (and vice-versa), which is about 25 kilometers, would be totally ignored by *Bellidea*, leading to wrong assessment of the mobility patterns of the user. The only option to avoid such boundary effects would be to enlarge the boundaries of the area taken into account, for example by securing collaboration between cities or with the Canton, thus enlarging the box as to account for the areas which are most likely to be covered by daily mobility needs of average citizens.

7 Conclusions

With the *Bellidea* app we tried an innovative approach to prompt people living or working in Bellinzona to more sustainable mobility patterns. The app was co-designed with interested citizens within a smart-city living lab process, which spanned over one year. Being developed by computer software professionals, it was launched to the whole population at the end of April 2018, at the very time we are writing. Therefore, for the time being we cannot yet assess its effectiveness in tangibly impacting individual mobility patterns in the area of Bellinzona. However, we can remark the steps forward we performed, with respect to previous persuasive apps, and indicate the main open challenges to be addressed in future applied research.

The first innovation lies in the *process* of development itself: since the *Bellidea* app was developed with the active contribution of its future users, in the living lab framework, it is expected to get a wider diffusion, thus producing a wider impact. The second innovation refers to the *hybrid system to detect the mode of transport* we implemented: the compromise solution of combining largely automated detection with limited manual validation by the users was not found in any other currently available app. This mechanism takes over the tedious task of manual checking all travelled trips, while limiting detection errors and avoiding potential cheating effects. The third innovation lies in the choice of rewarding app users by *considering their mobility patterns as a whole*, instead of rewarding them for single trips they travel - which might paradoxically lead to adding more trips instead of replacing those travelled with less sustainable means of transport.

In developing the *Bellidea* app, however many compromises were made, in order to manage proposals by the living lab participants with current technological limitations and budget constraints. The main challenge we wish to address in the near future is to remove the *Bellidea* dependency on the Moves app, which is out of our direct control both in terms of quality and frequency of data collection. Also, we would like to further develop the "guidance" functionalities offered by *Bellidea*, which currently are very limited. Citizens involved in the lab have in fact explicitly asked for the integration of multi-modal navigating systems, capable of providing them with practical and real-time suggestions about the most convenient available alternatives to car. Finally, we would like to work on customization, by providing app users with personalized suggestions for change, as long as we acquire data allowing us to learn their mobility patterns and available alternatives to them.

To conclude, we are well aware that the solutions implemented in *Bellidea* are not the panacea to solve all the problems related to personal mobility. However, they are an attempt to integrate and support already existing policies and regulations in the mobility sector, worth of being monitored and continually improved, as well as replicated in other cities or regions. Also, we believe that positive impacts will go further than persuading some citizens' mobility behaviour. In fact, the *Bellidea* app will provide the City of Bellinzona with low-cost, high-quality and high-granularity real life data on the citizens' mobility patterns, that could be used to directly inform future policy-making activities.

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