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DESIGN OF A SMART ALARM CLOCK TO FOSTER SUSTAINABLE URBAN MOBILITY

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Abstract

In this paper we describe the design of a smart alarm clock, conceived as a persuasive system to foster a sustainable urban mobility. Automatically retrieving and elaborating information available on the web, such as means of transport and weather forecast, the device is able to suggest to the user the most sustainable travelling solution, to help him/her to wake-up and reach the destination on time. Following a user-centered design approach the elaboration of the best travelling solution takes also into account, together with his/her next day appointments, user's needs and habits such as: the time he/she needs to get ready in the morning; his/her travelling preferences. A functional prototype has been built to test the effectiveness of the device using as a context the city of Milan.

Keywords: Sustainability, Multisensory product experience, User centred design, Smart mobility, Design for sustainable behaviour

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1 INTRODUCTION

A recent study of the World Health Organisation (2016) shows an increase of 8% of the *global urban air pollution levels* from 2008 to 2013. Obviously, different polluting sources are responsible of this rise, but our travelling behaviour is one of these since the use of private cars is still a dominant mobility choice (e.g., see (Nilsson and Küller, 2000; Steg and Gifford, 2005)). Therefore, events and campaigns are organised every year to get us aware of the worsening of these levels in our cities. Besides, some transportation companies, e.g. the ones offering railway or bike-sharing services, have implemented original communication strategies to show to travellers the amount of CO2 saved, using their services, with respect to alternative mobility solutions. Together with promoting a business in case of private services, these actions sensitise citizens about the impact of their daily mobility choices. "Car-Free Days" and the technological advancements introduced in the new generation of cars are probably the most well-known strategies to decrease CO2 emissions. Technological advancements are fundamental to control emissions however, they are not sufficient to decrease the car usage (Steg and Gifford, 2005) because several reasons and factors inevitably control our mobility choices, among which, the dependence of our traveling path on the infrastructures available (Schafer and Victor, 2000).

Our *decisional model*, as travellers, is also characterized by limited choices which do not fully cover the number of alternatives available (Van Exel and Rietveld, 2009); our model lacks, for example, of a proper travel time perception, which inevitably leads us to exclude the use of public transportations whose travelling time are often overestimated (Van Exel and Rietveld, 2009). Hence, as underlined in (Van Exel and Rietveld, 2009) an effective strategy that policy makers should follow could be not to fight against car ownership, but rather to make travellers more aware of the existing range of travel possibilities. Indeed, since the urban population is expected to increase, to face with this challenge a quick transformation of the mobility plan of our cities is mandatory (e.g., see (Banister, 2011)). Policy makers have also to consider that, together with the flexibility offered by cars, there are also important *symbolic and affective* reasons behind this widespread need of car ownership and use such as, simply, the fact that we love driving (Steg, 2005). Together with the lack of information on the travelling alternatives, studies highlight also another aspect that should be explored by policy makers, which is the need of considering travellers as not a unique category but rather as individuals, characterized by different travelling *needs*, *expectations* and *motivations* (Beirão and Cabral, 2007). All these considerations imply that to foster a change towards more sustainable travelling behaviours, successful awareness mechanisms should be designed giving high relevance to the following aspects: suggestions should be tailored on the basis of individuals' habits and needs; all available alternatives have to be provided leaving the final decision to the traveller; the elaboration of the alternatives should rely on reliable data otherwise the risk of not trusting anymore such interventions is high. A great help towards this change is given by the wide, quick and easy accessibility to real-time and usually free data and information related e.g., to traffic and weather conditions, whose validity is even more certified by the improvement of the algorithms used to calculate them. These two classes of data strongly influence our decision-making model.

Leveraging on all these aspects, in this paper we focus on the design of a behaviour change solution towards a more sustainable mobility, thought to be used within an urban context such as the city of Milan. We describe the development of a smart alarm clock designed to suggest to users the optimal wake-up time and the best travelling solution, among the ones available, considering user's goals and needs as well as specific boundary conditions. Goals and needs are: user's daily working or personal duties in terms of appointments; the time he/she usually takes to get ready in the morning; the willingness to reduce his/her environmental impact. As boundary settings, we considered the next day weather conditions as well as the necessity to guarantee a healthy sleep time. The decision to merge all these pieces of information has been taken considering as relevant the necessity to tailor the information about the suggested travelling possibilities on the basis of multiple aspects such as the ones dealing with traveller's *preferences* and *circumstances* (Gabrielli et al., 2014). To enable the extrapolation and elaboration of all these data we designed and prototyped this smart alarm clock using the MATLAB® development platform which allowed us to access information provided by Web APIs (Application Program Interfaces). Therefore, the designed alarm clock can be seen as a *persuasive system*, with the capability of automatically retrieving all the information needed to suggest to the user the most sustainable travelling option as well as to wake the user up at the right time. It is worth underlining that the platform at the basis of the alarm clock functioning is open and modular and it is able to integrate data coming from the web with the preferences settled by the user. We decided to embed our persuasive system into an alarm clock since, as underlined in (Schmidt, 2006), this product represents a ubiquitous technology that can be nowadays embedded everywhere, from dedicated products to smartphones and watches. This fact could open up different implementing scenarios and contexts. In addition, some alarm clocks evoke trust and security (Klauser and Walker, 2007), which are feelings of great relevance when designing a persuasive system.

In this paper, we first discuss about some awareness strategies already described in literature (Section 2) and the possibility offered by ICT infrastructures on building integrated solutions. Then, in Section 3 we detail the design and prototyping aspects that have driven the development of the functional prototype of our smart alarm clock. Section 4 describes some tests we performed to validate the functionalities of the system. Finally, in Section 5 conclusions are drawn and next steps are discussed.

2 BACKGROUND

Several persuasive strategies/applications are described in literature to foster a more sustainable urban mobility. These strategies belong to the so-called Voluntary Travel Behaviour Change (VTBC) programmes: they are considered as "*soft policies*" to make a distinction between the "*hard policies*" which are the measures focused on improving transport systems and infrastructures (e.g., see (Brög et al., 2009; Stopher et al., 2009)), that increase the cost of the use of cars, or prohibit and ration their use (see also (Bamberg et al., 2011)). In (Anagnostopoulou et al., 2016) a classification and an analysis of different persuasive strategies is provided; the common denominator behind these approaches is the use of *visual feedback* in the form of *visual designs* to communicate messages and explain concepts and of *charts* for summarising statistics related to the user's behaviour (Anagnostopoulou et al., 2016). Some of these approaches use *gamification* as the awareness strategy and are usually developed for mobile applications. For example, dedicated reward mechanisms and visual feedback are used to reach a strong engagement of the user and motivate him/her towards the change (e.g. see (Jylhä et al., 2013; Kazhamiakin et al., 2015)). In (Jylhä et al., 2013) the authors experimented the use of *trip challenges* to stimulate travellers in reducing their weekly CO2 emissions and in selecting the most sustainable mobility alternative.

However, the design of gamified applications, need some further steps forward. Indeed, as discussed in (Huber and Hilty, 2015), it is fundamental that users are conceived as individuals whose decisions are inevitably influenced also by the social context around them and whose decisional autonomy should be preserved. Hence, considering the traveller as a decision maker, rather than mainly a user, appears to be a key aspect: as discussed in (Banister, 2008), one of the four key elements for a more sustainable mobility paradigm is the necessity to provide to travellers more targeted information.

What is evident, nowadays, is that a great help towards the development of strategies for building a more sustainable urban mobility is coming from Information Communication Technologies (ICTs) and thus from the possibility of having a direct and real-time access to data. Interesting ICT implementations are related e.g., to the development of *Eco-Feedback* that could allow us, whether implemented into cars, to make our driving modality more sustainable (e.g., see (Tulusan et al., 2011)). Enlarging the perspective at a system level, ICTs are one of the key assets of smarts cities since they are fundamental for developing and implementing effective urban planning and thus mobility strategies; however, despite their relevance, we do not have to focus only on the technological side when planning the evolution of our cities, since a more holistic approach is needed, involving also people and institutions (Letaifa, 2015). Indeed, this necessity of addressing the sustainability issue at a broader scale (i.e., at a system level) is also highlighted in the analysis of the evolution of the Design for Sustainability approaches currently available, provided by Ceschin and Gaziulusoy (2016).

Hence, smart cities represent a favourable context for the design of persuasive systems focused on building more sustainable mobility paradigms. Indeed, several applications are already installed in our mobile phone, which provide us with different travel alternatives (e.g., the Google Maps) or give us insights about the ecological travelling solutions available within the city (e.g., bike sharing services). However, most of them work as stand-alone applications making more difficult to the user the identification and exploration of the range of the available alternatives.

In literature, the idea of developing smart alarm clocks is not new. In (Landry et al., 2004), the authors put a great emphasis on developing solutions to push travellers avoiding routine decisions providing them with the right information. Their smart alarm clock helps users in taking the following three decisions: at what time to set the alarm (the night before); when to wake-up (the morning after); what to wear (the morning after). The setting of the alarm time is suggested considering the weather forecast and the next day appointments of the user. The morning after, for taking the decision about whether and when to get out of the bed when the alarm is on, the alarm updates the user about unexpected events caused by e.g. traffic jams and weather conditions. These ones are also used to suggest the way of dressing. Another example of a smart alarm clock is described in (Zhang et al., 2008). In their paper the device is used to demonstrate the effectiveness of the proposed framework for the development of smart home control systems. The authors demonstrate the possibility to combine, into a unique device, pieces of information coming from different external sources, such as, for example weather and traffic conditions.

Hence, starting from this literature review we decided to focus our research on enriching the user's decision making model developing, on the one hand, a system able to integrate and elaborate information coming from different web sources and travel possibilities/services and, on the other, enabling him/her taking conscious decisions on the basis of his/her preferences and daily routine.

3 DESCRIPTION OF THE FUNCTIONAL PROTOTYPE OF THE SMART ALARM CLOCK

In this Section, we describe the main steps of the implementation of the functional prototype of the smart alarm clock. This prototype has been developed to test the technical feasibility and the functionalities of our system. We first describe the software component, including the design of the basic graphical user interface (GUI), and then the hardware component. The prototype has been developed using the MATLAB® programming language (https://www.mathworks.com/), some Web APIs (Application Program Interfaces) and the Arduino (https://www.arduino.cc/) platform.

3.1 The control unit and the user interface

The application gets information from several data sources freely available on the web and elaborates them to send an auditory and/or a visual message to the user to wake-up and inform him/her about the best travel solution. For the development of the prototype, we used the following Web APIs: Google APIs (i.e., Google Maps Distance Matrix API, Google Calendar API, Google Maps Geocoding API); Geolocation (ip-api.com); OpenWeatherMap (http://openweathermap.org); Brighter Planet (http://impact.brighterplanet.com). Figure 1 summarizes how the processing unit of the alarm clock works.

Once gathered the information from these sources, and based on some user preferences, the smart clock is able to set the alarm in order to make the user able to reach the destination on time and to suggest him/her the potential best means of transportation for the day. To do this, the smart clock analyses the information available in the user's smartphone calendar. The smart alarm clock is set to know the Calendar ID of the user, i.e. an identifier of the calendar from which it gets the needed information. As an example, the device reads the time and place of the next morning event, and in particular the online version of this timetable, which is synchronized with his/her device. The user's location is determined thanks to the Geolocation API (ip-api.com) with the procedure of the Internet Geolocation that converts the IP address of the connection in latitude and longitude. Furthermore, using the Google API it is possible to make a Reverse Geocoding in order to get the address of the location from the latitude and longitude. The position of the first appointment in the morning is stored in the Google Maps as an address but the processing unit needs again to convert it into latitude and longitude using the procedure previously described.

Once the coordinates of the start and finish points of the travel are available, we can evaluate the possible paths that connect the two positions. The means of transportations analysed are Car (Driving in Google Maps), Transit (Bus and Rail, that includes all the transportations by rail, such as tram, subway and train) and Walking. For each means of transportation we can get the distance and the duration of the journey. Especially for car, this duration is calculated taking into account the forecast of the traffic conditions.

Once the travel information is known, it is possible to calculate the associated CO_2 emissions. We used the Brighter Planet API that returns, for each means of transport, the total amount of kg of CO_2 emitted.

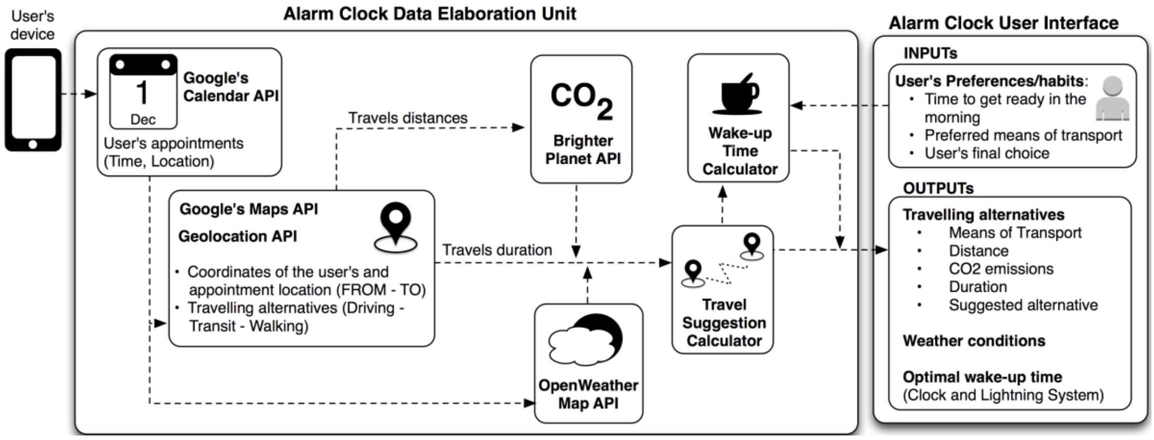

Figure 1. How the MATLAB processing unit of the smart alarm clock works: APIs are used to get the on-line data while through the user interface of the device user's preferences/habits are collected. The outputs of the computation are: travelling alternatives; the indications of the weather conditions; the automatic set-up of the wake-up time and of the lightening scenario used to wake-up the user

In parallel, through the alarm clock interface (see Figure 1), the user is able to specify his/her settings in terms of preferences, such as: the possibility for the user to select the means he/she prefers to reach the destination the day of the event; the amount of time he/she needs to get ready in the morning.

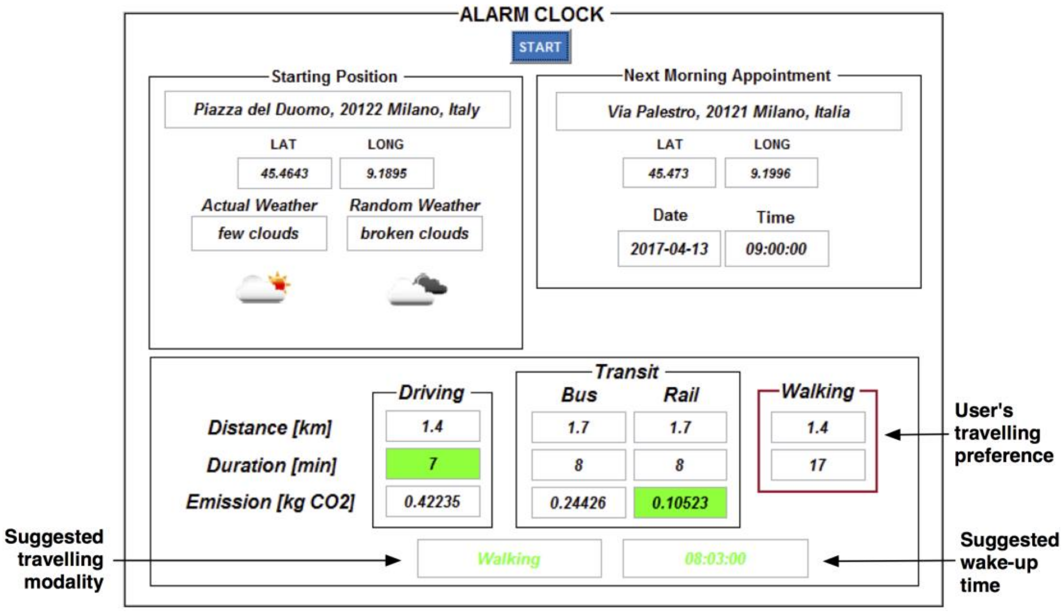

Figure 2. The MATLAB GUI, not visible to the user (these data are displayed through the physical interface of the alarm clock), developed to test the outputs provided by the processing unit. These outputs are: weather conditions; travelling alternatives information; user's travelling preference; the suggested travelling modality and wake-up time

The latitude and longitude of the alarm clock location are also used to get the weather from the Open Weather Map API. The weather information is very important for the smart alarm clock since, as it will be explained later on, the MATLAB unit will use these data to elaborate the suggested travelling alternative. To simplify the calculation of the travelling possibilities, we decided to consider and split the weather data into three main categories: *good*, *bad* and *very bad*. The "Travel Suggestion Calculator" (see Figure 1) will use the information about the travels, the weather conditions and the CO2 emissions to derive the suggested travel alternative.

Figure 2 illustrates the MATLAB GUI (whose data are not visible to the user but accessible through the physical interface of the alarm clock) that we have developed to test the application and through which the outputs of the processing unit are shown (see also Figure 1). Indeed, this GUI provides the following information: the starting position and the final destination; the real weather condition (i.e. "Actual"); a

simulated weather condition (we called it "random weather condition" since it represents a simulated condition that we have used for testing the functionalities of the prototype during the development phase); the information related to the different travel alternatives (i.e. distance [km]; duration [min]; CO2 emissions [kg]); the travel solution suggested by the application among the ones available; the user's travel preference (i.e., "Walking" in the example provided in Figure 2). The information about the suggested travel solution and the user's preferences are elaborated to calculate the optimal wake-up time and when the lighting system needs to be activated. Indeed, as it will be explained in Section 3.2 we decided to use, together with sound, a light source to wake-up the user.
To suggest the travel solution we elaborated the following algorithm (see also Figure 3). In case of "Good Weather" condition all different means of transportations could be theoretically used. In case the user has expressed a preference for the car, it is likely that this solution will coincide with the one suggested comparing the values of the travel durations. In case the user has not expressed a preference for the car, the unit priorities the available options considering the values of their CO2 emissions. This means that the following order will be applied: Walking → Transit → Driving. This is a consequence of the fact that this alarm clock has been conceived to foster a more sustainable urban mobility. However, to meet user's needs in terms of adequate travelling and sleep time, we decided to apply a further reasoning, summarised in Figure 3. We settled at 90 min the maximum travel time within the city. The unit starts the elaboration checking, as first priority, the duration of the "Walking" alternative (if this one represents the user's preference). If the duration of this travel is less than 90 minutes and it takes at maximum 20 minutes more with respect to the minimum travel time among the ones available, the "Walking" solution will be chosen. In case this condition is not satisfied, the same check will be performed for the "Transit" mode. If also the "Transit" condition is not satisfied, the suggested alternative will be "Car" (Figure 3).

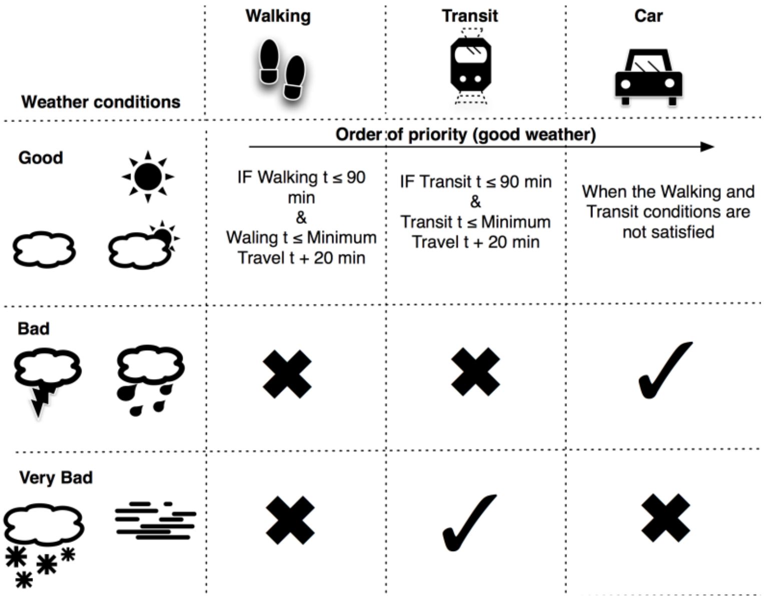

Figure 3. How the algorithm developed for identifying the suggested travel alternative works: in case of bad or very bad weather the "Walking" alternative is never suggested while in case of good weather the order of priority is defined analysing CO2 emissions and travel times (giving an "advantage" of 20 minutes of extra time to the "Walking" modality)

In case of "Bad Weather", such as rain or thunderstorm, the unit gives priority to the "Car" modality. This is the more polluting solution, but it could be also the most practical with respect to public transportations or walking. Finally, in case of "Very Bad Weather" conditions (e.g., snow or fog) the smart clock suggests to the user to take public transportations for his/her security.

3.2 The physical prototype

The development of the physical prototype of the smart alarm clock is based on the Arduino Mega platform. The device is equipped with (see Figure 4): 7 push buttons; 1 piezo buzzer; 6 LEDs; 1 LCD screen; the Arduino MEGA board; 1 potentiometer; several resistances. The 7 buttons are used to set the clock time (4 buttons) and the wake-up one (3 buttons), which are automatically calculated by the

MATLAB unit (see Figure 1). These two tasks should be automatized in a future version of the prototype. Three LEDs are used as a feedback to communicate to the user the suggested means of transport, while the other three are used as the awakening strategy. Indeed, together with sound the device implements another awakening methodology that is based on the dawn simulation by means of a light bulb (Figure 5). This approach is not new since it is currently implemented in several commercial alarm clocks.
Our bulb is provided with 3 LEDs, 2 yellow and 1 red, which are fed in an analog way. This means that their light intensity can vary over time. From 30 minutes before the alarm it is activated, a yellow LED changes its brightness gradually in the following 30 minutes. The same strategy is used to control the red and the other yellow LEDs, which are however activated respectively 20 and 10 minutes before the alarm.

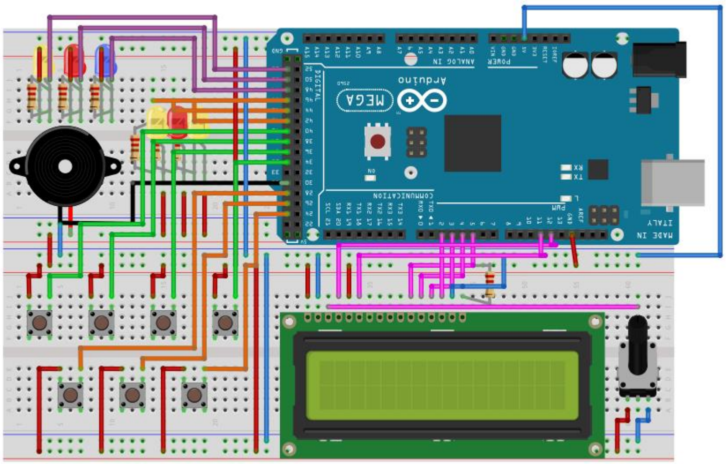

Figure 4. The main hardware components of the prototype (image created using the Fritzing software, http://fritzing.org). They consist in: 1 Arduino MEGA board; 7 push buttons; 1 piezo buzzer; 6 LEDs; 1 LCD screen; 1 potentiometer; several resistances

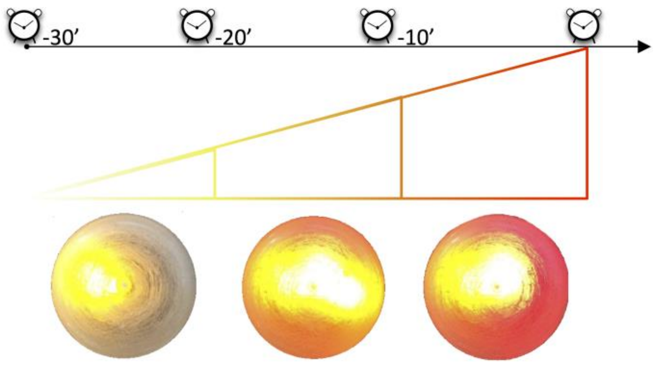

Figure 5. How the lightening system of the alarm clock simulates the dawn: 30 minutes before the alarm a yellow LED is activated, then also the red LED (20 minutes before) and finally, the second yellow LED (10 minutes before)

The LCD screen is used to show to the user the time needed to reach the final destination according to the means of transportation chosen. It also displays the means of transportation using textual (Figure 6, right) and graphical information (Figure 6, left). It is also important, for the “Transit” option, that the LCD distinguishes between bus and rail, as shown in Figure 6.

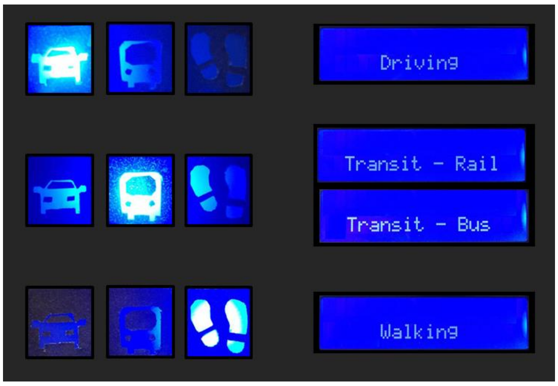

Figure 6. The traveling options as displayed through the LCD of the smart alarm clock

4 CASE STUDY

To demonstrate the functionality of the alarm clock we report here 2 examples of suggestions provided by the device. In both cases the starting point is the same and it is represented by the Milan city center, i.e. the Piazza del Duomo (i.e. Cathedral Square). This is a strategic starting point since it offers to the user different travelling possibilities. In Figure 7 these two examples are summarized.

To reach the Piazza Gae Aulenti (Figure 7a), with good enough weather conditions (i.e. “few clouds”) the processing unit of the clock suggests to reach the destination by walking. Indeed, the travel time of this alternative is below 90 minutes and does not exceed the 20-minute limit with respect to the minimum travel time (i.e. 15 minutes going by car). On the contrary, to reach the Piazza Duca D’Aosta (Figure 7b), with similar weather conditions (i.e. “broken clouds”), the unit suggests going by rail (i.e. the underground). In this case, the “Walking “solution has been excluded for two reasons: the user did not select it as a preferred alternative (in this example this one was “Transit”) and its duration overcomes the minimum travel time (i.e., 11 minutes of the transit alternative) plus the 20 minutes of extra time (i.e. the 38 minutes overcome the 31-minute limit). It is worth underlining here that in both cases the user’s preference (highlighted in red in Figure 7) has been satisfied.

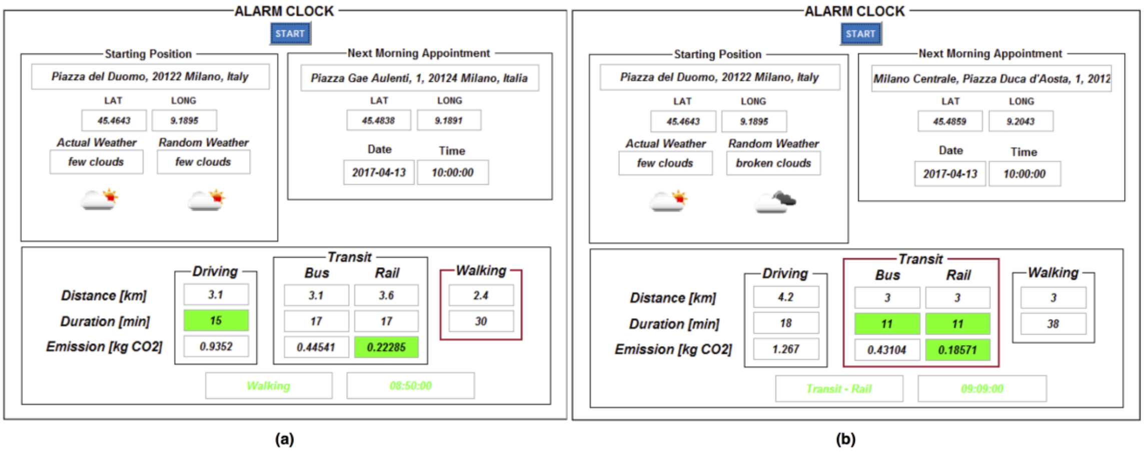

Figure 7. Two examples used to test the device functionalities: in (a) the smart alarm clock suggests to the user to reach the destination by walking since it represents the most efficient solution comparing travel times and the CO2 emissions; in (b) the transit alternative is selected since it is more time-efficient with respect to walking, it is more sustainable than travelling by car and coincide with the user’s preference

Starting from these two examples, as well as from additional tests we have made, we can derive the following considerations. In case of a city the “Driving” alternative seems always to be the best solution in terms of time especially for short travels. This is a consequence of the fact that the parking time is not considered while it may significantly affect the time spent within the car. In addition, the cost of the pass necessary for entering some areas of the city is not considered in this solution. Consequently, the selection of public transportations (or walking) appears to be quite always the best solution especially when moving within the downtown of a city. In addition, another interesting aspect is that the percentage of time saved using a car is significantly lower with respect to the percentage of CO_2 emissions saved when using "Transit" modalities (considering also that in case of travelling within a city the extra time spent in travelling using public transportations is usually 15 minutes). For what concerns walking, the travelling time is usually considerably higher with respect to public transportations. Indeed, only in case of very short distances or the pleasure of enjoying a walk within the city, the walking alternative is the best option.

5 CONCLUSIONS

In this paper, we describe the design of a smart alarm clock to use as a persuasive system for spreading a more sustainable urban mobility. The device suggests the best travelling solution and indicates the proper wake-up time to the user, taking into account the following aspects: his/her preferences/habits in terms of time to get ready in the morning and travel preferences; his/her morning appointments; the necessity to stimulate a more sustainable behavior suggesting the less pollutant mobility alternative, but without going against his/her needs. This last point is extremely important when designing a strategy whose aim is to change the behavior of individuals. The need of this kind of approaches/solutions is due to the necessity of fostering more sustainable mobility choices when travelling in order to face the continuous rise of the levels of pollution in our cities. The ideation and design activities of this device are grounded on the new scenarios opened up by ICTs: easy accessibility and the wide availability of data. A functional prototype has been developed to test its functionalities within an urban context; this design choice is justified by the fact that the number of people living within cities is rapidly increasing. We used the MATLAB® environment for designing the processing unit of the alarm clock, and the Arduino Mega Platform for developing the physical prototype. The city of Milan has been used as context of the research. Two examples are discussed to demonstrate how the device works. As it has been designed the prototype is potentially scalable in case one wants to consider new kinds of means of transportation (i.e., cycling). However, despite the tests performed have clearly shown the potential of our smart alarm clock, several are the open issues to address. First, we have not performed tests with users, neither we have inquired them about their willingness to use/buy the device. Furthermore, the algorithm used for prioritizing the travelling alternatives does not currently consider important aspects such as the parking time (in case of cars) and the travelling costs; it could be also further extended in order to give to the user the possibility to insert other preferences and to push him/her towards more sustainable mobility choices or healthier lifestyles (e.g., as done by other applications already available, the device could also suggest the time the user should go to bed in order to guarantee a minimum sleeping). Furthermore, the device suggests the best travelling solutions, but it does not send to the user the details about the travel. This feature could be quite easily implemented in the future developments of the prototype, which should be no more a functional one but it should also include aesthetic features especially for performing tests with the direct involvement of the end users.

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