# Designing for Sustainable Urban Mobility Behaviour: a Systematic Review of the Literature

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**Abstract** Urban mobility poses one of the pressing challenges in cities undergoing growing urbanisation. In order to cope with this issue, a shift in behaviour is necessary towards more sustainable means of transportation. Technology can mediate the process of behaviour change, and concepts such as persuasive technology and reflective learning are approaches in this context. In order to investigate currently envisioned or implemented technological solutions, particular in the context of the smart city notion, this paper presents a systematic literature review. Three areas are thereby of interest: the utilised technology, behaviour change strategies, and citizen participation in the development process of the interventions.
A total of 14 different applications were included in the final review. The findings show that mobile devices are being prevalently used, persuasive strategies are foremost mentioned, and end-user involvement is happening late in the development process and serves primarily testing purposes. This points out that there are still various unexplored possibilities in the aforementioned areas. It is suggested that future research should explore opportunities stemming from ubiquitous technology, employ behaviour change strategies grounded in reflective learning, and approach the current shortcomings in citizen involvement with participatory methods.

**Keywords:** Sustainable Mobility, Behaviour Change, Smart City, Reflection

## 1 Introduction

Cities are increasingly gaining in importance and are considered driving forces of the future [1]. This development stems foremost from growing urbanisation, with more and more people moving and living in urban areas. As of 2016, 54.5% of the world's population were estimated to be living in urban settlements, current trends forecast an increase to 60% in 2030 [28].
Rapid growth assigns cities a significant social, economic and environmental function [1], but also lets them face complex challenges in the process. In this context, the concept of "smart cities" has been coined to indicate cities that

devise strategies to mitigate those challenges in a smart way [12]. Some of these challenges are indicated by greenhouse gas emissions. According to Hildermeier and Villareal [18], urban transport makes up approximately a quarter of $CO_2$ emissions with respect to overall transport. With 73.7% cars represent thereby the prevalent form of travel. Urban transport hence exerts ample influence on the quality of life in a city, being a causer of traffic congestion, noise- and air pollution [18], having harmful effects on public health. Consequently, cities need to respond to this issue by reducing car usage and increasing the utilisation of more sustainable means of urban mobility, such as walking, biking or public transportation, in other words a change in behaviour is inevitable.

Technology is noted for being a "key driver" within smart city initiatives [12]. It can also be utilised to foster behaviour change, here the notion of "persuasive technology" is well-established. Persuasive technology, that is "any interactive computing system designed to change people's attitudes, behaviours or both" [26]. The idea of persuasive technology has certainly underwent criticism [3], and some of its strategies have been contested with regard to their ethics [26], and long-term applicability, with Brynjarsdottir et al. claiming that persuasive sustainability system's "long-term success is susceptible to being undermined by factors outside of what it aims to measure and control" [9]. Considering these circumstances, merely relying on persuasive strategies, guided by prescribed goals, may not result in durable behaviour change, nor does it appear to be suitable in a smart city context, in which projects rather focus on "more informed, educated, and participatory citizens" [12].

An alternative approach appears thus to be that of reflective learning, a mechanism emphasising self-directed learning through experience [21]. Krogstie et al. [21] introduced a reflective learning cycle, short CSRL model, which offers the possibility of individual as well as collaborative learning. The overall model is composed of four main stages, namely plan and do work (1), initiate reflection (2), conduct reflection session (3) and apply outcome (4) [21], with diverse activities at each stage. Notable aspects of the model are, that it considers the absence of teachers, sees reflective learning as a highly iterative process, and acknowledges the importance of social aspects in reflection, as it is frequently accomplished collaboratively [21]. These characteristics may make it hence a suitable model to be employed in a smart city setting.

Still, particularly pertaining to the issue of ethics in behaviour change applications, active citizen involvement needs to be ensured when developing such interventions. Design methods, such as user-centred and participatory design, offer numerous advantages for the development of a service [26]. First and foremost, technology that is developed democratically is more likely to meet citizen needs, and ensures that the user's freedom is maintained, with persuasive technologies aiming at steering individual behaviour towards goals that are not set by the users themselves [26]. Furthermore, participation and empowerment can instill a feeling of ownership in citizens [26]. Eventually, such an undertaking requires effective means of engaging the general public and stakeholders in co-design.

## 2 Motivation and Research Questions

In order to highlight the necessity and contribution of this review, preliminary searches were undertaken to identify similar reviews. A review on persuasive technologies for sustainable urban mobility was published by Anagnostopoulou et al. [2] in April of 2016, making it the most closely related review.
While the overarching theme of "urban mobility behaviour change applications" remains the same, the review at hand emphasises other facets within the studies. [2] mainly evolves around the notion of persuasive technology, and while the review mentions that user characteristics and context should be taken into account, the user has not been the unit of analysis with respect to overall involvement. The review at hand contributes to the theme by focusing on citizen participation and behaviour change through reflection, with the two latter approaches seen as holding great opportunities in a smart city context. This effort is summarised in the research questions below.

**Research Questions**
*RQ*1: Which technologies have been utilised for behaviour change applications?
*RQ*2: Which behaviour change strategies have been employed (persuasive/reflective)?
*RQ*3: Have the final users of the application been involved in the application development? If so, when, to what degree and with what methods?

The rest of the paper is organised as following: In section 3, the process used for the literature review is described. Within section 4, the results of the review are presented in accordance with the research questions. Section 5, discusses the findings and implications from the review. Concluding, section 6 briefly summarises the results and provides future perspectives for research.

## 3 Review Method and Process

A systematic literature review facilitates the process of summarising existing research, assessing where there are gaps, and allows for new research to be placed within the existing research base [20]. This method was chosen, in order to gain an overview of the issue of urban mobility, and on how this matter had been addressed trough respective applications previously, aiming at changing people's behaviour. The search strategy was thereby informed by the guidelines for systematic literature reviews, described by Kitchenham and Charters [20].

**Data Sources**
Relevant documents for the search were retrieved, using two approaches: Foremost through keyword based searches of several online databases, and secondly manual screening of conference proceedings of former Persuasive Technology[1] conferences, as well as the dblp[2] computer science bibliography.

[1] http://persuasivetechnology.eu/
[2] http://dblp.uni-trier.de/

**Table 1.** Keywords for the search string

| | |
|---|---|
| **Population** | - |
| **Intervention** | *sustainable mobility, sustainable travel, sustainable transport, sustainable transportation, green mobility, green travel, green transport, green transportation, personal mobility, personal travel, personal transport, personal transportation* |
| **Comparison** | - |
| **Outcome** | *behaviour change, behavioural change, behaviour choice, behaviour promotion, behaviour encouragement, behaviour management, mobility behaviour, travel behaviour, transport behaviour, transportation behaviour, habit* |
| **Context** | *city, cities, smart city, urban, connected city, intelligent city, digital city* |

Web of Science[3], ACM digital library[4], Elsevier ScienceDirect[5], Elsevier Scopus[6], and Springer[7] were chosen as online databases and queried using keywords, assembled into defined search strings. Those databases were chosen due to their eligibility for the topic, and because they allowed a large number of search terms.

**Search and Keywords**

As suggested by Kitchenham and Charters [20], and applied by Gianni and Divitini [15] in a similar setting, the PICOC framework was utilised to guide the selection of the keywords. PICOC is an abbreviation, constituting the words population, intervention, comparison, and context, which classify the keywords accordingly. Initial keywords were synthesised from the research questions, and expanded through respective synonyms and recombinations, that emerged during iterative pilot searches. Search terms pertaining to ICT were omitted, in order to lower the amount of constraints, and rather assess manually the suitability of the retrieved documents. Table 1 lists the chosen keywords in the PICOC structure. The terms within each row were connected through Boolean OR operators, and the three individual rows were linked using Boolean AND operators.
Not all databases afforded that the search could be conducted in consistently the same search fields, in most cases however it was possible to choose the abstract as search field. Table 2 summarises the outcomes of the searches. The field "Topic" combines here the title, abstract, keyword and index fields of the article. In addition to the here listed documents, manual searches retrieved 3 studies.

**Screening of Papers**

Following the search, the metadata of all documents was organised in a spreadsheet. This facilitated the ordering of the documents by title, and the subsequent removal of duplicates. The remaining documents were then screened individually

[3] https://apps.webofknowledge.com/
[4] https://dl.acm.org/
[5] https://www.sciencedirect.com/
[6] http://www.scopus.com/
[7] http://rd.springer.com/

**Table 2.** Results from the online databases without duplicates removed

| Database | Documents | Field | Date of Search |
|---|---|---|---|
| Web of Science | 137 | Topic | 11.11.2016 |
| ACM | 7 | Abstract | 11.11.2016 |
| Science Direct | 41 | Abstract | 11.11.2016 |
| Scopus | 136 | Abstract | 11.11.2016 |
| Springer | 17 | Overall | 11.11.2016 |
| **Total** | **338** | | |

by the author and supervisor. Inclusion or exclusion decisions were based on the title and the abstract, and guided by the criteria outlined below.
This approach yielded in 29 potentially relevant documents. During a second collaborative screening, this number was reduced to a total of 15 documents that were included in the final review, discussing 14 different applications. The complete list of the reviewed articles is available at *url omitted for anonymity.*

**Report Eligibility**
A report had to be in English; published on a database, conference or journal that is scientific; published in or after 2005 ([15] pointed out, that the notion of "smart city" gained notoriety between 2005 and 2007); fully accessible; short or long, posters and demos had to be excluded.

**Study Eligibility**
A study had to address behaviour change of people; outline technology in the abstract; solely address sustainable mobility; be a primary source.

## 4 Results and Findings

A brief summary of all reviewed studies is given in Table 3.

*RQ*1**: Technologies utilised for behaviour change applications**
Technological solutions, harnessed to support the respective applications, are visualised in figure 1. Smartphones emerge here as the prevailing theme, justified with, among others, their widespread use [22] [11] [27], and their ability to function as sensors, thus obtaining information from the environment, shedding light

**Figure 1.** Technology used for the behaviour change interventions

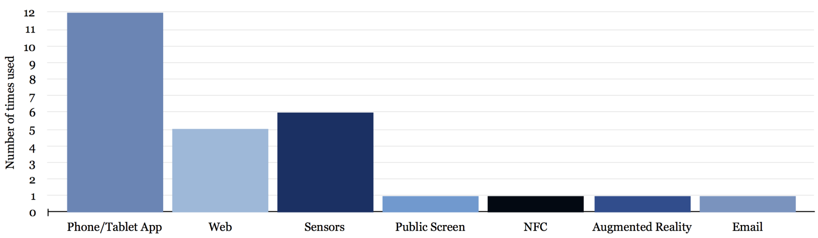


**Table 3.** Summary of reviewed studies

| Reference | Summary |
|---|---|
| [17] | AnachB is an advanced traveler information system, envisioned in the city of Vienna, enabling citizens to compare routes and different mobility modes in real-time, and provides users with information all around planned trips. |
| [22] | i-Tour, an ambient intelligence system, functions as a travel mobility assistant in a multi-modal setting. The service distinguishes itself through its context-awareness, inferring information about the user and the environment. |
| [14] [13] | Superhub is a mobile system utilising diverse motivational strategies in order to influence citizens' mobility choices. A local journey planning service is provided. |
| [6] [5] [7] | The application Peacox is discussed at different stages in [5], specifying technological details on how routes are recommended, [6], informing about the use of choice architecture for a travel recommender, and [7] placing emphasis on persuasive strategies. Peacox provides users with route options suiting their preferences and contexts, and sorts these according to their $CO_2$ impact. |
| [13] | MatkaHupi, uses automated tracking of journeys and emissions and fosters sustainable mobility choices through challenges. This paper furthermore introduces a journey planner system which employs a journey diary. |
| [11] | BikeTogether, a mobile app for cycle commuting, allows users to figuratively cycle together while being connected over the Internet. A bicycle flashlight is used as a metaphor for users to feel accompanied and guided. |
| [27] | Describes a web portal and a mobile application. While the web portal allows users to specify personal, usual travel information, the mobile application senses mobility behaviour and provides the user with travel suggestions, favouring sustainable options, and offers self-monitoring and social activities. |
| [24] | A Real Time Passenger Information system installed in buses and stops or interchange stations. Multi-modal information regarding, departure times, connections or travel time is visualised on screens and on a webpage. |
| [5] | The envisioned recommender provides users with a list of routes that correspond both to their individual preferences and simultaneously focuses on choices that involve less polluting modes, while additionally taking contextual information such as the weather into account. |
| [29] | Traces employs elements from gamification, serious games, and pervasive games, to promote the use of sustainable mobility. The mobile application features both city related quizzes and offline quests. The game goal is to leave colourful digital traces on a city map through the use of multi-modal mobility. |
| [8] | Tripzoom is a concept comprising a web portal, a mobile application, and a city dashboard. The web poartl is linked to social networks, the mobile application supports users in understanding their mobility behaviour, and the city dashboard lets incentives and rewards be managed by individual cities. |
| [19] | Viaggia Rovereto, a mobile route planning application, incentivises sustainable mobility choices through gamification. Sustainable route options are highlighted, and users are rewarded when traveling sustainably. |
| [4] | ViaggiaTrento is a multi-modal trip planning application, developed utilising participatory design practices with students, and incorporating collaborative efforts from its users. |
| [30] | Discusses persuasive strategies, encouraging bike usage, such as triggering messages, or a virtual bike tutorial aiming at increasing biker's self-efficacy towards biking. |

on a user's behaviour [27] [8].
Prevalently, mobile applications feature either a route planning system [14] [17] [22] [6] [27] [19] [4] [7] [13] or are solely focused on illustrating people's mobility behaviour [11] [29] [8] [30]. Sensors embedded in smartphones, provide data that is used to infer information about a users movement [22] [6] [11] [27] [8] [7] [13] (e.g. standing, walking, cycling, use of public transport) and ambient conditions [22] (e.g. brightness, noise). Sensors are also present in the environment [22] [8] [4], collecting information which is used in the applications.
Web applications provide real-time public transport information [24], support users in their mobility decisions with a route planner [17], or collect and visualise mobility behaviour data of a user [27] [30] or a community of users [8].

*RQ2*: **Strategies employed to guide behaviour change**
The review comprises both applications, specifically mentioning persuasive technology or strategies as their approach, and interventions that do not state a particular methodology. In both cases the applications were categorised according to their usage of one, or several of the strategies outlined by Oinas-Kukkonen and Harjumaa in [25]. Krogstie et al.'s CSRL model [21] provided the theoretical underpinning for the identification and assessment of reflection as the employed behaviour change methodology. In the following, the foremost used methods are outlined and complemented by one example of use in the applications.

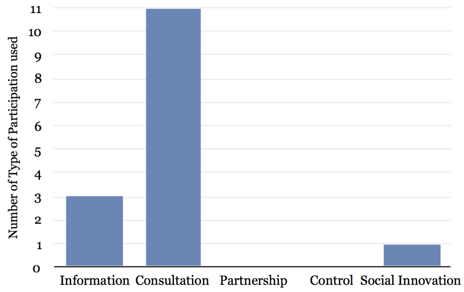
***Persuasive Technology.*** Oinas-Kukkonen and Harjumaa [25] categorise persuasive techniques within four categories: primary task, dialogue, system credibility, and social support. Each category outlines a number of design principles, which have been mapped onto the reviewed studies.
Within the primary task support category Reduction, Tunneling and Self-Monitoring were found to be most frequently employed. Reduction manifests itself in the provision of journey planning services, easing the accessibility of mobility information, for instance by sorting route suggestions according to their environmental friendliness [22] [27] [19]. Tunneling is afforded by sustainability challenges or quests [13] [29] [8], and Self-Monitoring is enabled through the provision of graphical, statistical representations of reported or logged behaviour, comprising, for instance, modes of transport used [14] [13] [27] [29] [8] [30].
In the dialogue support category, Rewards are the most commonly applied strategy, awarded to users which opt for sustainable mobility choices [22] [14] [29] [19], taking the form of such things as points [14] [29] [19] [30].
However, none of the systems outlined any of the principles of the credibility support category clearly. Social Facilitation is the prevalently applied strategy within the social support category, followed by Social Comparison. Social Facilitation is supported by, a shared view on a leader board, listing users performing the behaviour [14] [13] [27]. Also Social Comparison is supported by leader boards, changing images [8] or colours [11], indicating how a user compares to others.

***Reflective Learning.*** None of the reviewed studies names reflection as the

core principle guiding behaviour change. Nevertheless, some of the approaches, found in the studies at hand, have the capability of supporting the CSRL model's four stages: plan and do work (1), initiate reflection (2), conduct reflection session (3) and apply outcome (4) [21]. The studies were thus mapped onto the stage specific activities, in order to observe to what degree existing applications are potentially able to facilitate reflective learning. All of the presented applications support the work, when viewing "the work" as being the "adoption of sustainable transportation means". "Plan work" and "do work" are primarily supported by applications providing a journey planning service, allowing users to plan and conduct their commute. The "plan work" activity, is furthermore supported by allowing users to set personalised, sustainable goals they wish to accomplish [14] [6] [13]. The work is then monitored by either users manually reporting their behaviour [22] [14] [13] [19] [30] [29], or by the system logging behaviour automatically [22] [6] [13] [11] [27] [8] [7].
Three ways can then be identified, in which the applications initiate reflection and set a reflection objective. Firstly, $CO_2$ emissions being displayed along with suggested routes, make users aware of their potential actions [22] [6] [5] [7]. Secondly, sustainability encouraging messages or reminders sent to the user draw attention to sustainable issues and possibilities in behaviour [14] [6] [13] [11] [30]. Thirdly, provided sustainability challenges, set a particular objective to be reached through ones behaviour [13] [27] [8].
The stage concerned with conducting the reflection session is partially supported by some applications by displaying the aforementioned $CO_2$ emissions along with the respective routes, making related information available, and by visualisations of behavioural information, reconstructing work experiences.
The final stage of applying the outcome is facilitated in part by [6] by providing the user with feedback on personal, previously caused $CO_2$ emissions, highlighting the issue requiring change. The app also provides the user with routes that would aid reducing the said emissions, helping in making a change.

*RQ*3**: End-user involvement in the application development**
In order to highlight the respective point of involvement and the degree of participation, the systems development life cycle [23] and typologies of citizen participation [10] were utilised to frame the assessment.
The systems development life cycle as described in [23] depicts five steps in the development of an information system: (1) project selection and planning, (2) requirement analysis, (3) system design, (4) development, and (5) testing and deployment. Pertaining to the overall distribution, there appears to be a significant user involvement during the testing phase, primarily constituting itself through the implementation of user studies [17] [14] [13] [11] [27] [24] [19] [4] [7] [30]. Involvement in the other stages is rarely implemented. Eventually, [4] poses as the only reviewed article involving users at all stages through social innovation.
Carpa [10], in the context of smart city citizen participation, merged traditional typologies of citizen participation, and concepts of social innovation Citizen participation, as defined by Carpa, reaches from "information", a mono-directional

**Figure 2.** Types of Participation (terms according to [10])

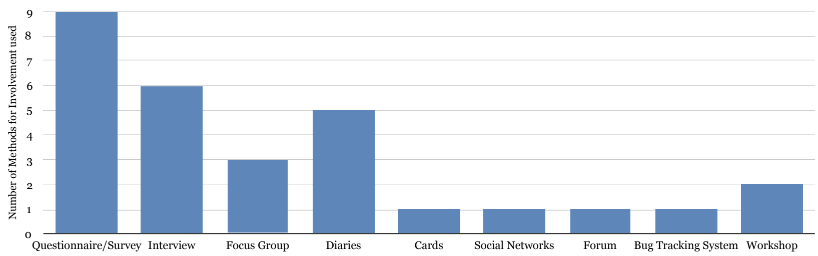



flow of information, to "social innovation", being citizen led, collective initiatives that address their specific needs. Those typologies built the basis for the assessment of degrees of citizen participation and participatory methods utilised in the reviewed studies. Figure 2 illustrates which types of participation foremost took place, whereas figure 3 visualises the methods used to facilitate participation.
Users foremost contribute through consultation, a bi-directional flow of information intended to gather feedback, during user studies. This involvement constitutes itself primarily through questionnaires, allowing to observe changes in, for instance, participants travel behaviour [17] [14] [13]. Furthermore interviews [17] [14] [13] [7] and diaries [17] give information about the users' experience with a system. Focus groups are used to collect feedback on an ideal design [17], issues with current conditions [4], application usage and behavioural changes [7].

## 5 Discussion

*RQ*1**: Technologies utilised for behaviour change applications**
Mobile devices emerge as prevalently used technical mediators, with 12 reviewed applications envisioning or implementing services being supported by them.
A systematic mapping of technology-enhanced smart city learning, conducted by Gianni and Divitini [15], revealed similar results. Thereby, the authors identified unexplored technical opportunities, namely interactive objects and the Internet of Things (IoT). In a later article the authors then also pinpointed limitations of

**Figure 3.** Methods used for User/Citizen Invovelement



smartphone apps, when being used for learning in smart cities, including that of sustainable behaviours [16]. The essential shortcomings are the restricted interaction strategies provided by mobile devices, hindering the tailoring of the user experience towards a specific scenario. Here ubiquitous computing opportunities such as tangible user interfaces, affording an embodied interaction with digital information, and augmented objects are alternatively proposed, with the ability to create "rich and unobtrusive user experiences", allowing the capturing of various data types. Therefore, besides the evident benefits of mobile technologies, a large body of possibly valuable, yet unexplored technological possibilities exists.

*RQ*2**: Strategies employed to guide behaviour change**
Reduction, tailoring, and self-monitoring emerge as prevalent persuasive strategies. These and other persuasive strategies or application functionalities have been found to support aspects of the CSRL model. While none of the studies outlines reflection as guiding behaviour change, some mention the term self-reflection, as being supported by application features [14] [13] [29], and [7] mentions that self-reflection support will be subject of further research.
Given earlier outlined criticism of persuasion, reflection may pose as an alternative approach. This is supported by Brynjarsdottir et al., proposing that behaviour should not merely be prescribed, rather, systems should foster open-ended reflection, meaning for users to "reflect on what it actually means to be sustainable in a way that makes sense in the context of their own lives" [9].

*RQ*3**: End-user involvement in the application development**
There appears to be a significant user involvement during the testing phase, primarily constituting itself through the implementation of user studies. Involvement in the other stages is rarely implemented. Eventually, [4] poses as the only reviewed article involving users at all stages.
During user studies, users primarily contribute through consultation. While focus groups or interviews may thereby allow participants to speak more freely about their concerns or opinions, questionnaires and similar approaches are potentially more restrictive. Moreover, how feedback is eventually exploited and translated into system functionality might not be up to the participants to decide. Also Brynjarsdottir et al. found, that desirable behaviour is foremost predetermined, in a top-down approach, by professionals involved in the development of behaviour change systems, with only 3 of their 36 reviewed papers stating participatory design. Eventually, the authors suggest to include users more thorough in the design process through participatory design methods, with the prospect of ensuring that the system's definition of sustainability corresponds to user's daily life, thus making the applications more accepted and useful [9], this approach is also supported by [26] in order to democratise development and empower people. In terms of the IoT, tools such as TILES Toolkit[8] can be utilised to foster end-user participation at the design and development stages, allowing non-experts to design and subsequently prototype smart objects.

[8] http://tilestoolkit.io/

## 6 Conclusions

Three themes have been guiding this review, namely the utilised technology, the applied behaviour change strategies and the degree of citizen or end-user participation in the process of application development. Altogether the outcomes imply that, various possibilities in the aforementioned areas are still unexplored, which is underpinned by previous research in related areas. Future research efforts will focus on exploring ways in which end-users can actively and meaningful participate in the stages of design and development. Ultimately, an ideal solution would create conditions that empower and inform citizens, enabling them to create their own change through social innovation.

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