Enabling Mobile Access to Distributed Recycling Knowledge

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***Abstract*—From the consumer perspective, classifying a product regarding its environmental impact is a difficult task because relevant knowledge is usually not only diverse, but also distributed over several information sources. In this work, an analysis of mobile "green" applications formed the basis of a mobile application, which aims at providing all recycling-related information in-situ. Its domain model integrates recycling knowledge from several information sources and is capable of decomposing a product into its elementary parts. The mobile application enables the user to initiate interaction with this model over three different ways of describing a product. Beside insights concerning information access and user interaction, a first evaluation of the prototype indicates that the employed fused domain model may outperform results achieved with a traditional approach to web-based information search concerning recycling information.**

Keywords-Sustainability; decision support; mobile computing; case study

I. Introduction

Limitation of natural resources affects everyday decision making in diverse ways: indirectly through increasing costs for products, e.g., based on oil, or directly due rationale insight and ecological awareness. Unfortunately, such *sustainable decision making* is a non-trivial task for various reasons. For instance, a product has to be chosen that should be "easily" recyclable. From the viewpoint of sustainability, recycling is affected by materials the product is consisting of, the recycling process for decomposing the product, the extent such decomposition is possible, and even the (potentially future) context that determines efforts needed to insert the product into the recycling process.

In order to make an informed decision, the decision maker may have to acquire all of that knowledge – and to fuse it: While there are efforts towards the integration of sustainability-related information along the supply chain [1], community-driven information sources may provide additional hints [2], and of course, the current context (e.g., location) may bias the sustainability of a decision.

This complexity partially explains why expert advice in-situ may increase people's will to do such decisions [3]. Information has to become more available [4], and be explained to the user [5]. Thus, it is little surprising that there exists a considerable amount of "green" mobile applications, which seek to support their user in-situ in solving tasks related to sustainability.

This article reports on user feedback concerning a mobile application and a linked information service, which address decision making concerning consumable products based on recycling-related information. In the following, Section II reviews typical characteristics of such mobile applications. Then, Section III reports on a data mashup, which seeks to fuse different kinds of recycling-related knowledge originating from potentially distributed sources. It produces a domain model, which is accessed by a mobile information service, which combines the services of various previously reviewed applications at a single point. Afterwards, Section IV reports on user feedback concerning the interaction with the new service in comparison with alternative ways of acquiring similar information. Finally, the article closes in Section V with a summary of achieved results and an outlook on future work.

II. Related Work

In 2011, a preparatory internal study addressed the state-of-the-art of mobile applications supporting sustainable decision making. The survey comprised mobile applications offered at the Android Market and the Apple App Store. Search terms were "energy consumption", "energy efficiency", and "green life" and led to a result of 23 relevant mobile applications in the Android Market and 25 mobile applications in the Apple App Store. The result was sorted into four categories:

Promotion (4 mobile applications). Mobile applications in this category, typically, promote energy saving technologies, such as solar energy systems, low-energy devices of certain product classes (e.g., fridges, air conditioning systems, etc.), or energy saving techniques (e.g., monitoring tools and programmable thermostats). For example, the mobile application Lennox [6] calculates the energy savings achievable by a new air conditioning system, provides product information and directs the user to the next local dealer.

Education and Information (20 mobile applications). References, encyclopedia, decision support systems, and games form a category on its own. The majority of such mobile applications provide information in form of references, tips, or links and news collections. For example, the mobile application "this is green" [7] offers information that is thematically organized by a picture of a layout of a common one family house. If the user tabs on the garage he will find information on fuel consumption of the car, if he

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tabs on the bathroom information on how to save water is provided. The application “low carbon life” [8] is a collection of little games that tries to teach the user, e.g., how to use the washing machine in an efficient way and how to recycle trash that occurs in a common household.

Calculators (9 mobile applications). Other mobile applications support the user in calculating balances concerning sustainability-related factors. They can be distinguished in mobile applications meant for the private and for the business domain. The former ones focus on an individual’s habits and objects, e.g., flights and TV. The latter ones focus on business branches such as architecture or lamp industry. In general, the user has to enter data manually into the respective mobile application, which is a major difference to mobile applications classified as “monitoring and controlling”. For example, the “green footprint calculator” [9] is filled manually with data such as monthly bills (oil, gas, and electricity), number of flights, and recycling behavior. Once filled with this data, the mobile application calculates the yearly carbon footprint and visualizes it with a maximum of six green trees if the carbon footprint is very good/small. The application “MeterRead” [10] captures energy consumption. The number of kilo watts is synchronized manually with the electrical meter over a graphical meter that looks similar to the one that can be found in households. After data gathering, the mobile application provides a prediction for the consumption over the next 30 days.

Monitoring and Controlling (15 mobile applications). Finally, there are mobile applications which connect to energy consuming devices in the private and the business domain. In the private domain, they focus on devices common for an individual’s environment, e.g., house, car, and mobile phone. In the business domain, such mobile applications focus on branches, e.g., IT, manufacturing industry, and facility management. For example in the private domain, the “power tutor” [11] analyzes system and power usage of the mobile device and provides chart views e.g., for the consumption of the LCD, CPU, and Wi-Fi. The “green gas saver 1.0” [12] shows the greenest way of acceleration in a car and a lot of mobile applications visualize energy consumption (electricity, oil, and gas) and provide remote control features (e.g., switch on/off, timer configuration, etc.) and alarms when consumption exceeds a defined threshold, e.g., “GSH ienergy” [13] from the business domain and “DONG Energy eFlex” [14] to control home environments in the private domain. Community features are included in some mobile applications, where the user’s green performance can be compared to the performance of the user’s friends.

General observations included that mobile applications for sustainable decision making were either highly specialized (focus on product advertisement or industrial applications) or very general (dictionaries, household / lifestyle consulting). Furthermore, the reviewed applications rely on data from a single information source, which does not reflect diverse and distributed character of such information mentioned in the beginning. Finally, despite the mobile platform, there was little use of the mobile sensing capabilities.

This article reports on how these gaps could be addressed for a specific application scenario: an “Eco-Advisor” should support consumers in ranking products according to their environmental impact, and in making informed decisions concerning recycling options regarding a product at hand using information from distribute recycling knowledge. An overview of related work in the area of mobile mashups was already provided in previous work (cf. [15]).

III. FUSION OF RECYCLING KNOWLEDGE

According to the previously introduced classification of related work, the Eco-Advisor could be categorized in the first place as an “information and education” service, which includes aspects of a “calculator”. While the service as such could be employed also for user support in non-mobile scenarios, its particular focus is on decision support concerning a product “at hand”.

Therefore, the service has to support the user in establishing a link between the subject of interest – a physical product instance – and relevant information concerning this individual artifact. This information may originate from distributed sources, and may differ in format and semantics. It may describe aspects of the artifact, this kind of artifacts, resources used for creating the artifact, and related services. Efforts needed in performing this task strongly depend on the way data are organized and structured by the service – its domain model.

A. Requirements

As the mobile application is meant to provide information for products, its domain model has to be capable to represent a product’s most important properties. The model is kept as generic as possible because it is a storage for all kinds of data, structured and unstructured.

A product is defined in an economic sense as the output which is the result of the transformation that was initiated by humans. This transformation consumes scarce resources, such as materials and energy. In this article, we will focus on physical products and exclude virtual products, such as information or services.

Three core requirements for the model were identified:

- **Requirement 1:** The domain model has to carry information in form of various data patterns from distributed sources on an abstract and a concrete level and is open for extensions.
- **Requirement 2:** The domain model has to enable a disassembly of products in terms of kind and amount of materials included in the product’s (current) physical form.
- **Requirement 3:** The domain model has to match the interaction implemented by the mobile application.

Requirement 1 asks for a domain model which supports the mapping of a product at hand to recycling-related information. As recycling information is not provided by all manufacturers, such information can be found on the abstract level in the absence of manufacture specific information. If product specific information is available, it is stored on the

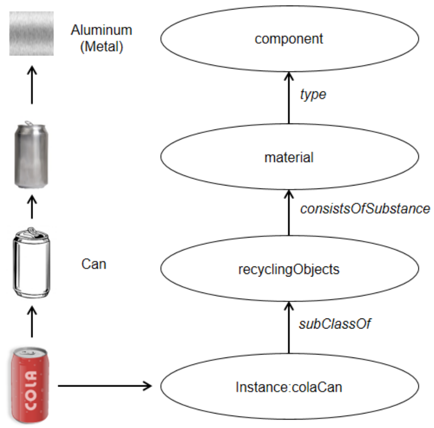

Figure 1. Ontology representation of the product structure.

instance level. Additionally, the model has to ensure a degree of extensibility which allows an adaption for specific needs. The last criterion is related to the open/close design principle from object-oriented programming. To integrate data from distributed sources, the model has to be able to carry data in heterogeneous patterns, and to make information available in a unified format.

Requirement 2 demands a domain model able to reveal a product's components and materials down to an elementary resource level. For example, a beverage can consists of aluminum, which is a chemical element in the boron group with the symbol Al, the third most common element, and most abundant metal in the Earth's crust. Such information can be employed by the service in order to perform calculations involving a product's durability, kind of resources used, and recycling potential. Thus, while a resource used within a product may be scarce, this may be less crucial if the resource can be extracted with limited efforts during recycling for later reuse.

Requirement 3 demands that the domain model supports the particular kind of user-product-service interaction that forms the background of the envisioned kind of support. In order to communicate with the service, the user has to communicate the product to be investigated. Ideally, this product will be at hand, and even be shipped with a label (e.g., Radio-frequency identification (RFID) referenced as ISO 14443, Quick Response (QR) Code referenced as ISO 18004) describing the individual product instance. Other situations may widely differ, and require the user to describe in some way the product. Therefore, the overall system provides the user with three ways of initiating interaction with the service (search by text, search by category, and search by image). The domain model has to reflect this diversity with an organization, which facilitates information retrieval starting from unique identifiers, visual features, keywords and product categories.

B. *Designing the Domain Model*

The assembly information on a product was modeled in the Ontology Web Language (OWL) [16]. In the model shown in Figure 1, a product is an instance of a sub class of

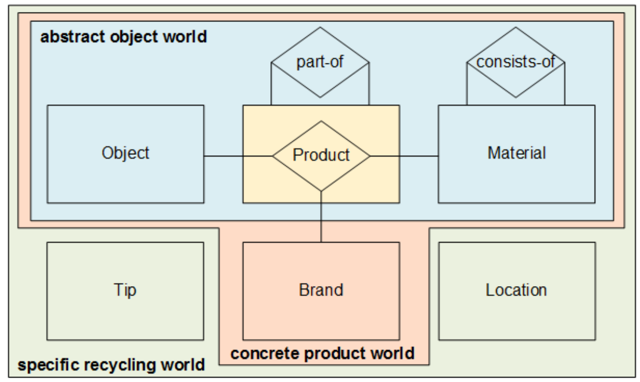

Figure 2. Entity Relationship Model (ERM) of the domain model (most relations and attributes are faded out).

recycling objects, which consist of one or multiple substances of a certain type.

According to Requirement 1, the final domain model is open for extensions; it was developed as an onion layered architecture. In the innermost layer lies the core, most abstract model which is the nucleus of the model that is visualized in Figure 2, the "abstract object world". Objects consist of different Materials, the bill of materials, and have thereby a certain composition (Requirement 2). This kind of product assembly is discussed for electromechanical products by Rachuri et al. [17], an extension of the Core Product Model 2 (cf. Fenves et al. [18]) that covers a product's function, form, and behavior. The entities in the next layer, the "concrete product world", form the world of products and contain all entities from the object world. Objects are manufactured differently by different companies under different Brands. The combination of the entities Brand, Object, and Material forms a Product. These two worlds, the object and the product world, represented by the two innermost layers can be transferred on numerous use cases where product data is involved. Two kinds of products are allowed: products with a structure of certain materials and products that provide a structure under a certain brand. All products can contain sub-modules. This hierarchical modelling approach, indicated by the part-of relation, allows the subordination of sub-products which are produced under a different brand by a certain supplier. A similar classification hierarchy was provided by Pels [19], which distinguishes between product instances, classes, and types to reduce the complexity of product models. In a similar way substances, contained in a material are modeled which allows the decomposition of a product in its most atomic elements. In the outermost layer, the most specific one ("specific recycling world"), the entities for the use case at hand are modeled and set in relation to the entities in the other layers. The entity Tip contains creative recycling tips, the transformation of old objects into something new, for Products, Objects, and Materials. Location contains recycling points where Products, Objects, and Materials can be recycled. The specific (recycling) world is open for more extensions to extend the Object and Product worlds according to specific needs. The decision for an onion layered design of the domain model supports extension of the model: it is possible to add layers for specializing the model and to remove layers for generalizing the model. A similar way of abstraction was provided by Lee et al. [20], which proposed a generic and independent multilevel product model that is divided into data, model, and metamodel level.

To support the interaction (Requirement 3), textual definitions from WordNet [21] are used to identify the entities Object, Material, and Brand that are denoted as things following the notion “Internet of Things”. This kind of identification allows text searches on the IDs and users to find the Object, Brand, or Material of interest. The relation among those three entities allows the presentation of related Materials and Brands when an Object is searched, the presentation of related Brands and Objects when a Material is searched, and the presentation of related Objects and Materials when a Brand is searched. Related products from the overlapping of all three entities can be presented. Additionally to the concept of definitions, word forms – a set of synonyms – are assigned to Objects, Materials, and Brands, respectively. These synonyms support a query expansion mechanism that guarantees search results for a set of valid search terms. For example, “Al” leads to the same result as “aluminum”, “aluminium”, or “atomic number 13”. Recycling Tips are assigned to Objects and Materials. A product taxonomy is used to categorize Products, which allows a search for products by category. Products have additional attributes which are amount and unit. This allows for storing information on the quantity of materials which are obstructed in one object. Locations own the additional fields latitude and longitude to store the GPS position.

C. *Implementation*

The mobile mashup was realized as a mobile application that combines the contents of multiple heterogeneous and distributed information sources. It was decided to integrate all such source into one database, which allows faster query responses and limits the access to one interface. For that reason, the ontology model depicted in Figure 1 was transferred to a relational database according to the ERM in Figure 2. The integration and adaptation of information, for example recycling tips were retrieved from World.org [2], was described from a technical perspective in [15] by the authors of this paper. In the database, per default, each entry consists of the tuple {ID, Name, Description, Image}. The ID is a unique identifier, Name depicts the designation of the data entry, and Description contains a long text that helps to characterize the thing. An Image visualizes the entity and can be stored in form of a file path. Each entity is expandable by additional attributes that might be appended to the 4-tuple.

The application that runs on a mobile device with Internet connection communicates with the backend that runs as a web service and is accessible over a REST interface. The user interacts with the mobile device and things – in our scenario for the experiment an aluminum can, a plastic or a glass bottle. Three ways of interaction were realized, search by text, search by category, and search by image. Search by image was realized by using the IQEngines API, which delivered acceptable results (in most cases the labels and not

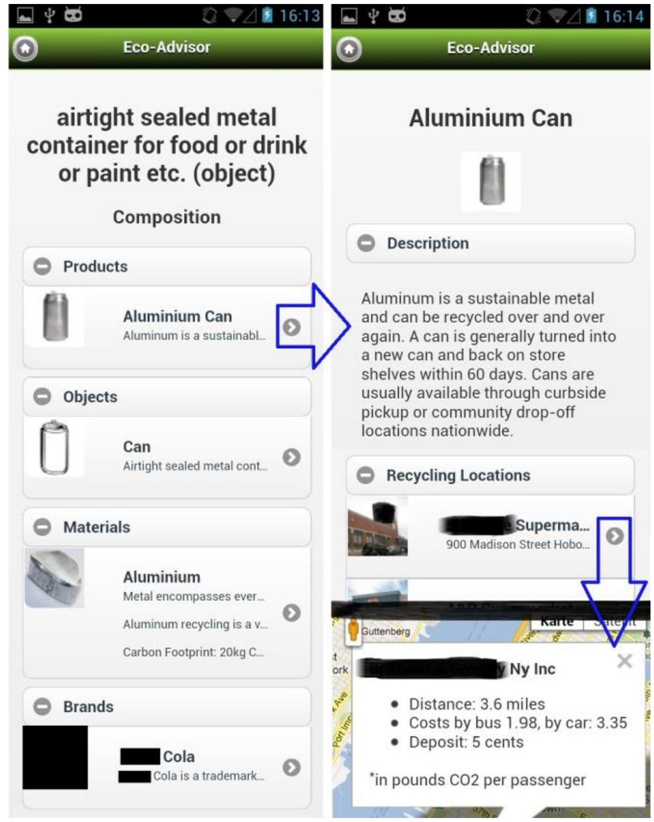

Figure 3. Composition, detail, and location view for a Thing/Object.

the things are recognized) that can be improved by training the image recognition algorithm. Search terms from all three ways of interaction are expanded by synonyms from the WordNet [21] dictionary to match additional entries in the database. The system architecture is kept modular to support adding and removing information sources. The system architecture, navigation, and interaction are described in detail in [15]. A screenshot from the mobile application is presented in Figure 3 and shows the search result for an aluminum can manufactured by a certain brand.

IV. CASE STUDY

In the following, a survey is presented that evaluates the mobile mashup and its underlying data mashup built on top of the domain modelin terms of usability and usefulness. First, the user interface is evaluated to check if the navigation and interaction method is easy to handle for the user. Second, the data mashup stored in the aforementioned domain model is evaluated to find out if the integrated information sources are helpful (1) in the way they are presented, (2) while the user has to solve different tasks from the recycling domain.

A. *Research Question and Experimental Design*

When the first running prototype of the Eco-Advisor mobile application was finished, feedback was gathered by involving a small probe of people in order to validate concept and basic design decisions. The main question the experiment sought to answer was the following one:

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Do the mobile mashup and the domain model help a user to achieve recycling goals more efficiently compared to a stationary Web browser?

Here, "efficiency" comprises various facets of the original task, including quality of result (subjective measures such as user satisfaction, objective quality of recycling), efforts required to perform this kind of recycling, as well as efforts needed to deal with the application (time, interaction steps). In addition, the experiment aimed at gathering information concerning the preferred way of interaction with such a service. Acquiring information from such a service can be realized in quite different ways of interaction ranging from search by text, category, to image taken from the subject of interest.

In order to address these questions, three experimental tasks were defined, which had to be executed by participants of an experiment. These tasks had to be solved with the mobile application on a mobile device ("app variant"), and with a regular web browser ("browser variant"), respectively. The web browser was installed on a regular desktop PC in order to remove effects from potential issues specific to the interaction with mobile web browsers from the experiment (e.g., entering URLs, need for zooming gestures). Furthermore, the web browser was pre-configured in order to support participants in the requested tasks. This setup was chosen based on the assumption that users interested in recycling would have created bookmarks and other pointers to knowledge relevant for performing such tasks. Thus, the browser configuration seeks to reduce search for information sources as such, and instead to leverage search for information using these sources.

During **Task1 (Conventional Recycling)**, the participant is confronted with an object that has to be recycled in a conventional way in the vicinity. In the browser variant, the participant will find his or her location in an opened Google Maps tab and additional tabs with websites about recycling. The offer of opened websites on a workstation instead of an empty browser on the mobile phone makes the comparison between browser and app variant fairer and prevents the occurrence of a bias. During the study of results, the reader should keep in mind the difference between the two settings.

During **Task2 (Environmental Impact)**, the participant is confronted with a set of objects and is asked to choose the most environmental-friendly one among them. During task execution in the browser variant, the participant can continue his or her Web browser session from Task1.

During **Task3 (Creative Recycling)**, the participant is confronted with one of the objects from Task2. For this object, the participant should search a creative way of recycling which stands in contrast to conventional ways of recycling in Task1.

During the three tasks, the main factor is the Search for Information regarding the domain of sustainability. Every participant interacts on both levels Web browser and mobile application. Each task is related to one particular hypothesis:

H1: *The mobile application supports a more efficient search for conventional ways of recycling than a common stationary Web browser.*

H2: *The mobile application supports the user in judging an object's environmental impact more efficiently than a common stationary Web browser.*

H3: *The mobile application supports a more efficient search for creative recycling methods than a common stationary Web browser.*

For measuring support of these hypotheses in the respective tasks, the study relies on several parameters: one measurement is time. The time a participant takes to accomplish one task is measured and allows for comparing which kind of search method (stationary browser/mobile application) leads faster to results. Another measurement is the satisfaction of the user concerning search result and interaction comfort. The participants are asked to rank their opinion in both categories (satisfaction and comfort) on a five point Likert scale (ranging from 1 (disagree) over 3 (neutral) to 5 (fully agree). To check a user's preference, the participant has to select the preferred search variant per task (stationary browser/mobile application). To check if the domain model and the information it provided was helpful, each participant specified the criteria taken into consideration for the decision eventually made at the end of each task.

To receive feedback on usability related aspects, a user rating in the dimensions usefulness, readability, navigation, and visualization is gathered on a 5 point Likert scale, respectively.

Questions about the preferred search mechanism (by text / by category / by image) and ideas for improvement are meant to provide the developer some feedback for further improvements.

The (potential) persuasive nature of the mobile application is tested by asking about the influence of the mobile application on the participant's current recycling behavior: if the information offered by the mobile application would be available during decision making, would people expect a change in their behavior?

Finally, at the end of the study, an overall preference (stationary browser versus mobile application) is asked for.

B. Setup

The experiment was conducted in-lab under the supervision of one instructor. The participants sat at a table in front of a common PC workstation. On the workstation, participants filled out questionnaires and solved the tasks in the browser variant. The instructor guided through the experimental procedure, explained the tasks, and answered questions. For the mobile setting the mobile device Google Nexus S by Samsung was used.

The objects during task execution contain three objects from the category soda pop beverages. It was decided to use beverages from one well-known brand, to allow a brand specific search and to avoid that an unknown product will confuse a user. As questions of the survey are answered on the workstation, it can be profited by the advantage of fast result analysis and automated time measurements during the experiment. Most of the questions were of closed nature, while in some cases open questions were asked where the participant had to fill in an answer into the text field, for

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example the result of each task. All questions were mandatory, except the questions for problems during execution and ideas for improvement. During operations in the browser variant, the browser's history was used to log visited pages and used search terms. During operations on the mobile phone, search terms and navigation paths were logged on server-site.

C. Procedure

The experiment was divided into three phases: In the first phase, the participant had to answer a set of questions on his or her demographical background, the experience level concerning computer, mobile phone, and Internet usage, and the knowledge about recycling.

In the second phase, all participants had to solve three tasks. To solve these tasks two tools were provided: a Web browser on the workstation and a mobile phone with an application. For each task the participant had to use the Web browser in the first run and the mobile application in the second. After each run the participant had to answer a set of questions. In order to balance competition of mobile application and browser variant, in the latter one, 7 Web pages were already open in the browser's tabs once a session started. Those pages contained the same content that is integrated in the data mashup behind the mobile application. However, during task execution the participants were allowed to open new tabs and to start an own free search.

In the third phase, the study concluded with questions about the preferred search method, problems during task execution, and ideas for improvement. Additionally, it was asked if the presented mobile application could influence the participant's recycling behavior and if he or she preferred the mobile application over the stationary browser or not.

D. Result

The study lists 22 records, 2 experts and 20 non-experts. The average participant was 26 (median) years old. In the following presentation of the results percentages are rounded to integers. 13 female (59%) and 9 male people (41%) took part. Regarding the occupation, among the participants were 2 pupils (9%), 18 students (82%), and 2 professionals (9%, one software engineer and one researcher). Areas of work are wide spread and include linguistics and translation, computer science and IT, literature and culture, business administration and economics, and education.

The technical experience level regarding the usage of stationary and moveable computers was relatively high. 22 (100%) use a computer that is connected to the Internet, 16 (73%) use a mobile phone with Internet. On the stationary computer 8 (36%) surf more than 20 hours per week and 8 (36%) less or equal than 10 hours per week. On the mobile, only 4 (25%) spent more than 10 hours per week in the internet, while 8 (50%) are only between 0 and 2 hours online. While browsing the Web on the mobile, 4 out of 16 (25%) use predominantly applications. 4 (25%) additionally search for information about products during a shopping trip.

The participants' recycling knowledge was diverse. 19 (86.36%) are recycling their trash, 13 (68%) self-motivated, and 11 (58%) through regulation (multiple selections possible). 13 (68%) consider a product's environmental impact while coming to a decision during a shopping trip. Those who do, consider all different kinds of factors, energy consumption during operation as well as production and packaging. Those who do not, don't have time, are not informed enough, or have other reasons. Additionally, 8 (36%) knew what a carbon footprint is and were able to explain it, in most cases precisely.

Task1: Browser. All participants except one (the participant was not really motivated to spend some minutes on a location search) found a location for the glass bottle. The average distance to the user location was 0.71 miles. Two locations (9%) were subtracted out, one location was a container service and the other a junk hauling service. 4 (19%) identified trash cans, 5 (24%) chose supermarkets, and 10 (48%) identified a recycling center as point of disposal. Decision criteria were distance in most cases (15 / 71%), deposit value in 4 cases (19%), the "fastest result" in 2 cases (9%), and missing information on trash cans in 1 case.

Task1: Mobile application. All participants found a location for the glass bottle. The average distance to the user location was 0.36 miles, 0.35 miles lower compared to the results from the browser search. Distance was the most frequently mentioned decision criteria. Only one participant named carbon emissions associated with the trip as a decision criterion.

The preferred search method for Task1 was the mobile application (15 votes out of 22 / 68%).

Task2: Browser. All participants except one were able to identify one product out of three (glass bottle/plastic bottle/aluminum can) as the most environmental friendly one. 12 (57%) decided for the glass bottle, 6 (29%) for the plastic bottle, and 3 (14%) for the aluminum can. The decision criteria were carbon footprint (17 / 77%), the product's composition into materials (6 / 27%), and studies found through a search engine (1 / 5%). One participant said: "glass bottle is re-usable and I am safe from molecules from the plastic bottle entering my drink".

Task2: Mobile application. All participants were able to identify one product out of three (glass bottle/plastic bottle/aluminum can) as the most environmental friendly one. 9 (41%) decided for the glass bottle, 10 (45%) for the plastic bottle, and 3 (14%) for the aluminum can. While 43% of the participants changed their mind, 57% kept the decision from the browser variant.

The preferred search method for Task2 was the mobile application (16 votes out of 22 / 73%).

Task3: Browser. All participants except one (95%) found a creative way of recycling for the aluminum can. Several creative ways of recycling were discovered: potting plants, lanterns, aluminum boat, pen and pencil holder, build a children's telephone, tinker decorative items, sculptures, art, camping cooker, solar furnace, ashtray, money box, and so on. Asked, if the knowledge about reusing a product would influence the participant's buying decision was approved by 5 out of 21 / 24%).

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Task3: Mobile application. All participants identified a creative way of recycling for the aluminum can. Additional results were a children's drum set, a candy box, a seed storage, a picture frame, gift wrapping, hooks, and film canisters. All participants except 3 (86%) found a new creative way of recycling different from the one they found in the browser variant. Knowledge about reusing the product could influence the participant's buying decision in 9 (41%) out of 22 cases, 17% more compared to the browser variant.

The preferred search method was the mobile application (14 votes out of 22 / 64 %).

Satisfaction and Comfort during the tasks is shown in Figure 4. The time measurement during the tasks resulted in the values that are presented in Table I.

TABLE I. AVERAGE EXECUTION TIME IN MINUTES

	Browser	*Application*
Task1	8:17 min.	7:10 min.
Task2	7:09 min.	5:17 min.
Task3	6:26 min.	5:25 min.

The concluding questions showed that most participants preferred the traditional search mechanisms "search by text" (13 / 59%) to the "search by category" (4 / 18%) and the uncommon "search by image" (5 / 23%). In the four categories usefulness, readability, navigation, and visualization the lowest average rating received the navigation (3.27) on a scale between 1 (worst) and 5 (best). Visualization was rated with 3.36, usefulness with 4.05, and readability with 4.14. Many participants experienced problems to find information placed at the leaf level of the navigation tree although a legend with hints on the underlying content was given on the screen. Room for improvement was seen in the navigation ("too complicated", "less clicking"). One participant suggested placing favorites on the home screen. Another one suggested integrating more pictures to improve the visualization, e.g., to visualize the creative ways of recycling. Asked if the mobile application could influence the participants recycling behavior, 73% responded with "yes". After all, the mobile application was mentioned as the preferred method of acquiring recycling information (15:7 / 68% : 32%).

E. Findings and Discussion

Feedback obtained in the categories navigation and visualization indicates that potential for improving the mobile application lies in the optimization of navigation concept and the presentation of content. For example, some participants had difficulties to find the content that was necessary to solve the task. Especially pieces of information on recycling locations which is provided in bubbles on the map, for example information on carbon emissions associated with a trip from the user location to the recycling location, are hard to discover. This information lays 5 navigation steps away from the start screen and hidden behind a 4 categories menu, which is too far. Especially users not familiar with mobile applications in general became frustrated very fast, as they did not understand the mobile application's concept.

Figure 4. Satisfaction (1=not satisfied, 2=satisfied in parts, 3=indifferent, 4=satisfied, 5=very satisfied) and comfort (1=not comfortable, 2=comfortable in parts, 3=indifferent, 4=comfortable, 5=very comfortable) during task execution.

An interesting phenomenon is the development of time that was necessary to solve the tasks (cf. Table I). The first task took in average 7:10 minutes on the mobile application. For Task2 and 3 the duration lowered by about 2 minutes. This fact supports the statement of one participant who said, "after I was used to the mobile application I found it very helpful". However, since a mobile application might be installed right before a situation where its support is needed, it should be usable with little to no training. Therefore, this barrier has to be overcome. It has to be mentioned that in this experimental setting only a brief introduction to the mobile application was given. Usually, the user reads a description from the app store and may have a better understanding of the mobile application in advance. Thus, further experiments should start with an informing page about the mobile application as it is common in the big mobile application portals.

Nevertheless, having a look on the average task execution times in the stationary browser and the app variant, the app variant outperforms the browser variant in all three tasks. This result underlines that, after understanding the mobile application, the participants were able to find information faster using the mobile application than using the Web browser. Having a look at the level of satisfaction concerning the investigated result in Figure 4, the level of satisfaction was higher for the mobile application in all tasks. The perceived comfort during task execution was also higher when searching with the mobile application. The fact that the average distance to the identified recycling location during Task1 was about 0.35 miles lower in the app variant, while distance was the most important criterion for the participants shows that the implemented map visualization was easy to understand. These aforementioned results show that the three task-related hypotheses are supported in all categories, time, satisfaction, comfort, and user preference. Table II depicts the "delta" in all categories that were used to measure hypotheses support. Only some users used the uncommon search method "search by image". People with a great interest in technics found this search variant "very nice".

TABLE II. HYPOTHESES MEASUREMENTS APPLICATION VS BROWSER

Delta[a]	*Time*	*Satisfaction*	*Comfort*	*Preference*
H1	-1:07 min.	+0.71	+0.36	+36%
H2	-1:52 min.	+0.05	+0.53	+46%
H3	-1:01 min.	+0.45	+0.15	+28%
Avg.	***-1:20 min.***	***+0.40***	***+0.35***	***+37%***

a. Delta = Measurement(Browser) - Measurement(Application).

16 out of 22 (73%) participants reported that the mobile application could influence their recycling behavior. 15 (68%) participants reported that the mobile application is the preferred method of research for the tasks given. Both facts together support the appropriateness of the provided kind of support and indirectly of the employed domain model.

V. CONCLUSION AND FUTURE WORK

Sustainable behavior requires people to take a considerable amount of diverse information from distributed sources into account for decision making. This article reported on a domain model for a mobile mashup, which integrates such sources automatically. In order to gain feedback concerning the appropriateness of model and system architecture, a case study was conducted. In an experimental setup, participants had to perform recycling-related tasks with a mobile application implementing the mobile mashup approach, and with a browser-based solution on a desktop PC providing similar, but non-integrated features. Findings include that participants were able to find faster more accurate results when using the mobile application. Beyond, they were more satisfied with the mobile application's results and with the way of interaction provided by the mobile application.

Thus, the mobile mashup concept turned out to be of value for supporting people in making recycling-related decisions. However, this conclusion is limited in some ways. For instance, the user group shares certain demographic aspects, and the experiment did not involve true real-world interaction, where time pressure, interruption, and cognitive load might influence the results. Consequently, potential directions of future research should include a revision of the proposed interaction method in order to support new users in getting familiar with the mobile application. Furthermore, positive feedback obtained during the experiment indicates that persuasive technics might combine well with the mobile application concept. A context model could help to involve more user related constraints during decision support.

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