

A Comparative User Study of Faceted Search in Large Data Hierarchies on Mobile Devices

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ABSTRACT

We compare two approaches for exploring large, hierarchical data spaces on mobile devices using facets. While the first approach arranges the facets in a 3x3 grid, the second approach makes use of a scrollable list of facets for exploring the data. As concrete scenario, we use category hierarchies that are dynamically obtained from different, distributed social media sources. We have conducted a between-group experiment of the two approaches with 64 subjects (41 male, 23 female) executing the same set of tasks of typical mobile users' information needs. The results show that subjects using the grid-based approach require significantly more time and more clicks for completing the tasks. However, regarding the subjects' satisfaction there is no significant difference between the two approaches. Thus, if efficiency is not the primary objective, the grid-based approach might be of interest as it provides a navigation element that allows the users to see the exact position in the data space. This might be a very useful feature in scenarios where knowing the exact position is quite crucial such as browsing classification schemas in digital libraries or other formal taxonomies.

Keywords

Faceted search, category hierarchies, FaThumb

Categories and Subject Descriptors

H.1.2 [Information Systems]: User/Machine Systems—*Human factors*; H.1.2 [Information Systems]: User/Machine Systems—*Human information processing*

General Terms

Experimentation, Human Factors, Measurement

1. INTRODUCTION

Exploring large, hierarchical data spaces is a difficult task. This becomes even more challenging when limitations of mobile devices like smaller display size and limited interaction possibilities have to be taken into account. To alleviate the problem of finding the right

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piece of information in a large hierarchical data space, the approach of faceted search has been developed in the past. Initially designed for desktop computers [23, 8, 4], the idea of faceted search has been transferred to mobile devices [12, 7]. A facet can be understood as a dimension in the data space and allows for better exploring the data by limiting the amount of data instances shown to the user. Facets can be arranged hierarchically, i.e., they can be organized in a tree-like manner [18, 2]. The existing applications for faceted search on mobile devices differ in their approach how to arrange the facets on the screen for exploring the data space. The FaThumb system [12] developed by Microsoft makes use of a 3x3 grid for arranging the facets. On the contrary, one finds applications pursuing a list-based approach for faceted search on mobile devices such as [7].

Given the increasing need to deal with large, hierarchical data spaces on mobile devices and motivated by Hearst [10], we compare both approaches for faceted search on touchscreen mobile devices with respect to their usability, i.e., effectiveness, efficiency, and satisfaction. To the best of our knowledge, a summative evaluation like this has not been carried out so far. In order to conduct our experiment, we have developed a system that dynamically integrates the category hierarchies from different, distributed social media data sources. We aggregate social media data from Wikipedia¹, event directories such as Upcoming² and Eventful³, places and restaurants from Qype⁴, and images from Flickr⁵. Overall, this results in a large, hierarchical data space. Exploring this data space of social media data while being on-the-go is important to find answers to trivia questions, retrieve information about a building or landmark, and finding locations like sights, restaurants, or events (cf. [20]).

In our experiment, we have developed two different user interface approaches for the mobile social media retrieval system described above. While one user interface approach provides a grid-based design for faceted search (called Grid-Design), the other interface approach offers a list-based design (called List-Design). As the goal is to compare both approaches regarding their usability, we formulate the following research hypothesis:

There is a difference between the grid-based approach and the list-based approach for faceted search in large data hierarchies regarding effectiveness, efficiency, and user satisfaction.

In order to investigate this hypothesis, we have conducted a between-group experiment. Two independent groups of subjects

¹<http://wikipedia.org/>

²<http://upcoming.yahoo.com/>

³<http://eventful.com/>

⁴<http://qype.com/>

⁵<http://flickr.com/>

have conducted the same set of tasks but under different conditions. One group has worked with the Grid-Design and the other group has used the List-Design. In total, 64 subjects (23 female) have participated in the evaluation. Our results show that subjects using the grid-based approach require significantly more time (two-tailed t-test, $p \leq 5\%$) and more clicks (two-tailed t-test/Mann-Whitney U, $p \leq 5\%$) for conducting the tasks. However, the design approaches for faceted search do not differ significantly in the subjects' subjective rating regarding how easy they are to use.

The remainder of this paper is organized as follows: Subsequently to the discussion of related work, we introduce in Section 3 the two user interface approaches for faceted search in large hierarchical data spaces on mobile devices. In Section 4, we describe the evaluation design, including the tasks the subjects have performed, and the data set that is used. In Sections 5 and 6, we present the results of our evaluation regarding effectiveness, efficiency, and satisfaction and provide an interpretation of the results.

2. RELATED WORK

Faceted search is understood as the interactive exploration of a large, hierarchical data space along its different dimensions [6]. In each iteration, the result list is refined by selecting further facets. Facets can be organized orthogonally and only return those items that are conform with the selected facet(s) [12, 2]. They can also be arranged hierarchically [18, 2] allowing for a refinement of the result list along a taxonomy. This hierarchical organization can also be conducted in so-called multitrees [16], where a facet node appears more than once in the facet hierarchy. This is the case for the data considered in our experiment. Faceted search has a long history on desktop computers and has been well studied [10, 6, 19, 23, 2, 11]. One of the most well-known systems is Flamenco [23] providing a set of top-level facets for grouping and exploring a set of resources such as images. The mSpace Platform [19] and the Relation Browser [2] arrange several lists of facets horizontally for the search task. Facets selected from across lists are combined using an and-operator. Users can also select multiple facets from within a single facet list, which are combined by using an or-operator. Similar, also /facet [11] makes use of several facet lists that are nested hierarchically. A formal comparison of different approaches for faceted search on desktop computers was conducted by Mc Guffin and schraefel [16]. In addition, Clarkson et al. [3] provide an extensive overview of different design models for faceted search on desktop computers.

However, when moving from faceted search on desktop computers to mobile devices, the existing user interaction approaches cannot be easily transferred. This is due to the smaller display sizes of mobile devices resulting in less space for displaying facets. In addition, mobile devices have limited interaction possibilities. Thus, novel interaction and presentation metaphors are needed. One approach is the pen-based mobile application Mambo [5], which uses zooming operations to explore facets. FaThumb [12] is a keypad-based application displaying facets in a 3x3 grid. It is used as foundation for the grid-based design of our faceted search interface. Thus, it is described in detail in Section 3.1. The Mobile Cultural Heritage Guide [21] is a tourist guide application for touchscreen mobile phones and displays two levels of facets in two rows. Since this application is designed for a specific domain, users can only choose between a maximum of four facets per row. With mSpace Mobile [22], there is a pen-based mobile application providing the facets as lists. The lists are arranged in tiles, which can be modified to display more or fewer resources. OntoWiki Mobile [7] is an application for touchscreen phones providing a list-based user interface for exploring a hierarchy of facets. The hierarchy of facets is

organized in different pages. When a facet is selected, a new page containing the sub-facets is shown. The users browse into facets through the pages until a leaf node is reached, i. e., a resource with further information is shown. Unlike our List-Design, OntoWiki does not show a list of results together with the facets. The Diamond Browser [1] is a system architecture and prototype for different faceted interfaces on mobile devices. However, no comparative evaluation has been conducted like in this work. Finally, we find a very recent work where the authors have developed algorithms for determining the optimal navigation trees in voice-based applications [14]. The authors performed user experiments with the goal to understand the relations between different facets in voice menus and voice-based navigation and the cognitive load of the subjects.

In contrast to the related work, we have conducted a comparison of a grid-based vs. list-based approach for exploring a large, multidimensional data space as suggested by Hearst [10]. To this end, we have implemented a touchscreen-based version of FaThumb's grid-based approach. We have decided to choose a list-based approach to compare it with FaThumb's grid-based approach, as the list-based approach is currently the most favorite approach for faceted search on mobile devices according to the amount of related work. The list-based exploration of facets follows a similar design as the OntoWiki system. To the best of our knowledge, a summative evaluation of different approaches for faceted search on mobile devices presented here has not been conducted so far.

3. MOBILE FACETED SEARCH

Before we describe the specific characteristics of the List-Design and Grid-Design, we first introduce the common user interface elements of our mobile application for faceted search. Both user interface approaches for faceted search make use of a tripartite separation of the screen as shown in Figure 1. At the top, a list of currently selected facets is shown. It can be dragged down to inspect the facets in detail or to deselect facets. The middle part shows the result list. It provides an ordered list of resources that match the selected facets. The top area (called: Selected Facets) and the middle area (called: Result List) are exactly the same for both the grid-based approach and the list-based approach for faceted search. The only difference in the two user interface approaches lies in the bottom part for searching in the large hierarchical data space of social media data (called: Faceted Search). As shown in Figure 1, the left user interface approach provides a grid-based design while the right user interface approach implements a list-based design for faceted search. The middle area showing the result list can be extended by hiding the lower part providing for the faceted search. To this end, the users just click on the folder icon at the top right of the faceted search. The current facet node is shown at the top left of the faceted search, in our example: *Place > Shopping*. In the following, we introduce the two user interface approaches for faceted search in more detail.

Please note that the hierarchical data space for faceted search considered here does not consist of multiple faceted taxonomies like in FaThumb (cf. [18]). In contrast, one dynamic taxonomy is used where the different dimensions, i.e., facets of the data are combined by conjunction (cf. [2]). Reason for this decision is the sparseness of the resources distributed over the facets, i.e., a resource typically does not cover many facets but is associated on average to one or two facets only. This has been discussed in an earlier work, where we have applied the method of participatory design for developing a list-based approach for faceted search on mobile devices [13]. We have asked the subjects whether they prefer the term "filter" or "facet" for navigating through the dynamic

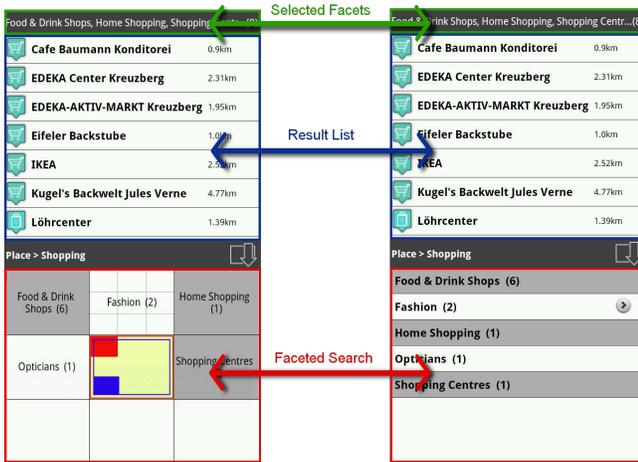


Figure 1: Grid-based (l.) vs. List-based Faceted Search (r.).

taxonomy of categories obtained from the social media sources. All but one subject has decided in favor of the term “facet”.

3.1 Grid-based vs. List-based Approach

The Grid-Design is based on the FaThumb system [12] developed by Microsoft Research. FaThumb is designed for mobile devices with a physical numeric keypad as shown in Figure 2. It is designed for a closed data set taken from the Yellow Pages of the Seattle metropolitan area (about 39,000 entries). The facet navigation takes place in a 3x3 grid, which is located below the result list (see Figure 2(a)). Since FaThumb is developed using Piccolo.NET for smartphones without touchscreen capabilities, the phone’s numeric keypad is used to navigate through the facets. For navigating through the facet hierarchy using the grid, the keys 1 to 9 are used. For example, the key 1 refers to the upper left facet *Category* and the key 9 is linked to the bottom right facet *Rating*. The middle field of the grid has a special purpose. It displays the current location within the facet tree by showing the path from the root to the current node. To indicate the different levels of the hierarchy, different layers with different colors are used to show which facets have been previously clicked. In Figure 2(b), it can be seen that the upper left facet has been selected at the first, second, and third level. FaThumb supports hierarchies up to five levels, which results in at most four different layers for the navigation field. In FaThumb, only leaf facets can be selected. Leaf facets are those facets which have no further sub-facets. Facets depicted with a grid in the background (e. g., Figure 2(a)) indicate further sub-facets, whereas leaf facets have a solid background. The number of results that will be received after selecting a facet are shown below the facet name. Since multiple selected facets are combined by conjunction, it is possible that selecting an additional facet results in an empty result list. To prevent this, facets leading to an empty result list are rendered in gray and cannot be selected (e. g., Figure 2(b), *Ice Cream*). If a facet is selected by a user, the facet name is added to the bar above the result list (see Figures 2(c) and 2(d), top of the screen). In addition, a selected facet is indicated in its super-facets’ background. It is shown as colored rectangle according to the position of the selected facet in the grid (see Figure 2(d)). The color indicates the level of the selected facet in the hierarchy. The result list can be filtered by keyword if the focus is on the filter region (see Figure 2(d)). The textual filter acts as direct search within all results. The phone’s navigation keys (up, down, right, left) can be used to move between the different regions, i.e., the facet naviga-

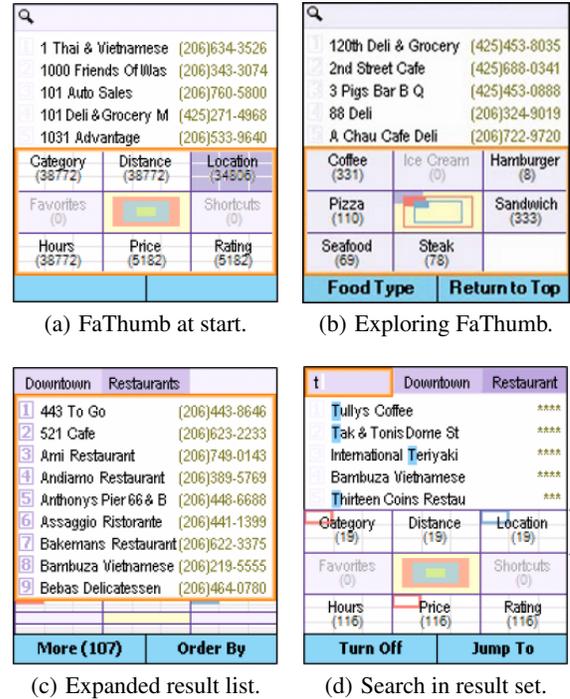
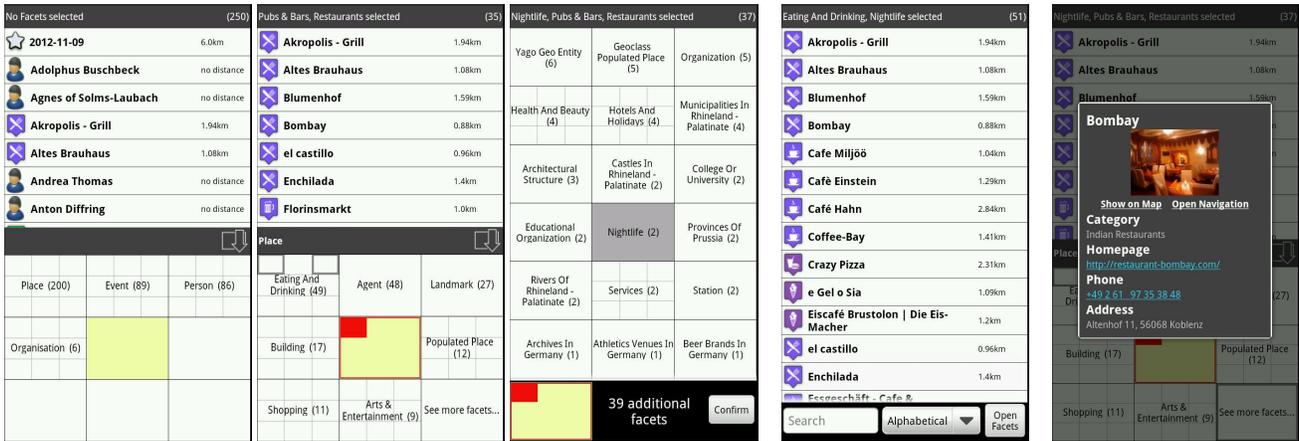


Figure 2: Grid-based Faceted Search in FaThumb (from [12]).

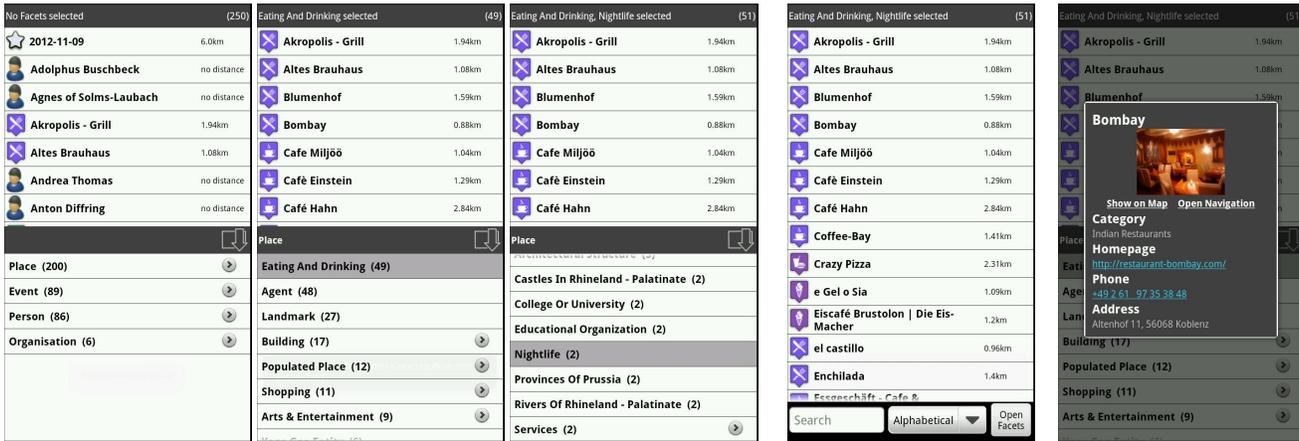
tion, result list, and filter region of FaThumb. To indicate which region has focus, a border in orange color is displayed around the region. When the result list window is focused, it is expanded as depicted in Figure 2(c). The list only displays nine results, which can be inspected through the number keys. The total number of results is shown in the lower left corner of the screen, which imitates the phone’s left option key. It can be used to show more results on the touchscreen. The right option key can be used to change the ordering of the result list by alphabet, distance, and rating.

The **Grid-Design** of our system is depicted in Figure 3. Unlike FaThumb, the Grid-Design is developed for Google Android mobile phones with touchscreens. Being inspired by FaThumb, the Grid-Design is very similar to its original. However, there were also some inevitable differences due to the adoption from a keypad-based mobile phone to the touchscreen and the use of open data sets. As initial facets, we start with *Place*, *Event*, *Person*, and *Organization* as shown in Figure 3(a). These facets are motivated by Sohn et al. [20] as *trivia* and *searching for points of interest* are two of the most frequent mobile information needs. Clicking on the facet *Place* results in the grid of sub-facets as shown in Figure 3(b). As shown in the figures, facet selection in the Grid-Design and FaThumb are basically built up the same way. However, FaThumb’s physical numeric keypad has been transformed into a virtual keypad on the touchscreen for the Grid-Design. Thus, instead of using physical keys, which are associated with corresponding facets on the screen, the facets as well as the items in the result list can be directly selected by using the touchscreen. Like in FaThumb, the middle field is used to indicate the current position while navigating through the facet hierarchy. At the left side above the faceted search, the name of the current node is displayed, e. g., *Place* in Figure 3(b). In addition, the button at the right side above the faceted search (depicted by a folder with an arrow) allows to provide more space for the result list. Since FaThumb uses a closed data



(a) Grid-Design at start. (b) Selected facets. (c) More Facets screen. (d) Expanded results. (e) Detailed information.

Figure 3: Grid-based Faceted Search adopted from FaThumb: The users browse through the facet hierarchy using the grid-based navigation elements (a, b). If there are more than eight sub-facets, the “See more facets ...”-button is shown (b). When clicking on it, the users reach a scrollable list of less popular facets (c). Data filters can be (de-)selected by long press on the facets. The grid-based navigation can be hidden to provide more space for the results (d). Clicking on a result shows its details (e).



(a) List-Design at start. (b) Selected facets. (c) More selected facets. (d) Expanded results. (e) Detailed information.

Figure 4: List-based Faceted Search: This approach is implemented by scrollable hierarchical lists (a, b, c). Apart from this difference, the list-based faceted search is identical to the grid-based faceted search depicted above.

set, the facet hierarchy is created in such way that each facet has at most eight sub-facets. Thus, the 3x3 grid always provides enough fields to display all sub-facets of the hierarchy. In contrast, our Grid-Design makes use of open data sets where the data is publicly available. Using such open data sets, one cannot make any assumptions about how many facets are retrieved, which facets are retrieved, and how many resources are associated to these facets. Thus, the design of the system has to be independent of the number of facets and resources and has to take into account that there can be facets with more than eight sub-facets. To solve the challenge of displaying any number of sub-facets, the Grid-Design introduces the *See more facets...*-screen as shown in Figure 3(c). If there are more than eight facets to display, the bottom-right field turns into the “See more facets ...”-button to reach the additional screen as shown in Figure 3(b). The additional screen is organized as scrollable grid list. Thus, the original design of the facet navigation as provided in FaThumb remains. The facets selected by the users are displayed in a bar at the top of the screen just like in Fa-

Thumb. Since this bar in FaThumb can only show a limited number of facets, it has been modified in our Grid-Design. It can be pulled down to show a list of currently selected facets. The selected facets can be inspected in detail, deleted individually, or deleted all at the same time (no screenshot provided for reasons of brevity). The list can be closed by pulling the bar up or clicking on the back key.

The **List-Design** of our system has been developed in parallel with the Grid-Design. The basic difference to the Grid-Design is that we have implemented the bottom part for faceted search in form of nested lists as discussed in the related work section. This allows for browsing the facet hierarchy as depicted in Figures 4(a) to 4(c). The List-Design has been adopted from OntoWiki Mobile [7]. However, OntoWiki Mobile does not provide the upper part showing a result list. Except of the Faceted Search, all other parts of the List-Design work exactly the same as in the Grid-Design, i. e., the Selected Facets and Result List shown in Figures 4(a) to 4(c) as well as the expanded result list (Figure 4(d)) and detailed info (Figure 4(e)).

3.2 Comparability of the Two Approaches

It is important to note that exactly the same number of facets are shown on the screen in the List-Design as in the Grid-Design. Exactly seven-and-a-half facets can be depicted in the List-Design as shown in Figure 4(b). In the Grid-Design, either eight or seven facets can be shown at the same time. As shown in Figure 3(a), there are eight spots arranged around the middle field used to display facets. If there are more than eight facets at the current level of the hierarchical data structure, only seven facets are displayed together with the “See more facets ...”-button at the bottom right corner (see example in Figure 3(b)). As a consequence of using a list for depicting the facets, an additional screen for showing more facets is not required in the List-Design. Like in the Grid-Design, the number of resources are shown in brackets next to the facet name in the List-Design. The availability of sub-facets is indicated in the List-Design by a small round icon with an arrow to the right (see Figures 4(a) and 4(b)).

There are some minor extensions to the original FaThumb application, implemented in both the Grid-Design and List-Design. The retrieved resources can be ordered by alphabet or distance and can be filtered by keyword as shown in Figures 3(d) and 4(d), respectively. A window with detailed information about a resource can be accessed by clicking on it as shown in Figures 3(e) and 4(e), respectively. Please also note that both user interface approaches do not support a screen rotation to landscape view. This would result in displaying too little results in the Grid-Design and List-Design.

3.3 Data Set

The Grid-Design and List-Design use the same data for the evaluation. We make use of a set of different data sources where the results of the queries are merged. One of the data repositories used is DBpedia⁶, a Semantic Web version of Wikipedia. It provides descriptions and images about places, organizations, and persons. Further data sources are GeoNames, an inventory of places, the event directories Eventful and Upcoming, places and restaurants provided by Qype, and social media photos provided by Flickr. From the data sources, we retrieve resources such as places, persons, events, and organizations. These repositories provide open data since the data is publicly available and open to changes and enhancements at any time. Thus, one cannot make any assumption which facets and how many facets are retrieved and how many resources are associated to these facets. This poses additional challenges to the design of a mobile user interface for faceted search. These challenges are addressed in the Grid-Design and List-Design by their ability to not only deal with a dynamically generated hierarchy of facets but also an arbitrary number of facets and resources.

4. EVALUATION DESIGN

We designed a task-based, between-group experiment where two independent groups of subjects have conducted the same set of tasks on the same data set. However, each group conducted the tasks under a different condition. One group has worked with the grid-based approach for mobile faceted search (Grid-Design), whereas the other group used the list-based approach for mobile faceted search (List-Design). When designing the experiment, we decided not to apply a within-group design. One reason is the potential learning effect when executing the tasks on the social media data [15]. In addition, the pre-test subjects needed between 30-40 minutes to conduct the experiment. Thus, overall we would have risked to introduce a systematic error into the experiment in

terms of the subjects' fatigue towards the end of the data collection sessions [15]. The experiment was conducted with 64 subjects (23 female) that have been randomly assigned to the conditions. The subjects were between 18 and 46 years (mean = 22.72, SD = 5.58). There were 15 computer science students, one computer science PhD student, and three IT specialists. Otherwise, there were nine students of non-computer science subjects and 36 non-IT employees of various professions ranging from mechanics, storemen, office clerks, teachers, engineers, assistant tax consultants, police officers, pilots, and pupils. All subjects were familiar with touch-screen mobile phones. They have received 10 euros compensation for their effort in participating in the experiment.

4.1 Evaluation Process

The evaluation consisted of three phases, namely *introduction and training*, *observation*, and *feedback*. In the introduction and training phase, the subjects were first informed about the purpose and goals of the study. They were introduced into the mobile social media retrieval application and its features. In addition, the subjects have signed an informed consent form. Subsequently, we performed a training of the subjects in using the user interface of our application. The training was conducted to eliminate potential bias due to different prior knowledge of the subjects in using mobile devices. The subjects had to successfully conduct 22 distinct tasks for faceted search in order to qualify for participating in the experiment. In these tasks, the subjects were familiarized with all features of the investigated system and user interface design, respectively. Among others, the subjects had to find specific facets, selecting and deselecting facets, change sorting criteria for the result list, explore results on the map, and others. If a task was not conducted successfully, the participants have repeated it. In addition, any questions stated by the subjects about how to use the application have been answered in this phase of the evaluation. User interface features that were unclear have been demonstrated by the supervisor or repeatedly executed by the subjects. In the end, the subjects using the list-based design as well as the grid-based design were equally familiarized with the application in general and the specific user interface features for faceted search in particular. We have not performed a full longitudinal study collecting performance data over a longer period of time. This would have been very difficult to handle with 64 participants in parallel; in particular as many participants were not available during a longer period of time or did not want to spend a longer period of time participating in the experiment. Subsequently to the introduction and training phase, the subjects executed the same set of tasks in the observation phase. The order of the tasks has been changed after every subject based on a Latin-Square design to minimize carry-over effects. The subjects performed the tasks at normal pace, i. e., there was no instruction given like conducting the tasks as quickly as possible. Finally, we did a short de-briefing with the subjects and asked for qualitative feedback.

4.2 Apparatus

For running the actual data collection sessions, we started both applications using the same smartphone, a usual HTC Evo 3D with Google Android 2.3.4 operating system. The Internet connection was established via WLAN and the GPS module was deactivated so each subject has used the same previously set geographical coordinate as starting point. This coordinate corresponds to a larger city in Germany. As stated above, both system variants used the same data from the same data repositories. To retrieve data for the predefined coordinate a radius of about 7 km is set. The data re-

⁶<http://dbpedia.org>

trieved from the different sources contained 250 resources, which are associated to 357 facets.

4.3 Tasks

Each subject had to execute seven tasks T1-T7, which target two of the most relevant categories of mobile information needs as investigated by Sohn et al. [20], namely *trivia* and *searching for points of interest*. The tasks were selected in order to investigate the differences between the two user interface approaches of a grid-based design vs. a list-based design for faceted search. Please note, except for tasks T1 to T3 the remaining tasks T4 to T7 consist of a set of three subtasks and four subtasks, respectively. In the following, we briefly introduce the seven tasks used in our evaluation.

T1 Search: T1 deals with the direct, textual search for resources. Although the main goal of both applications is to provide for a proper faceted search, they also implement a functionality to filter the result list by textual search as it was requested by subjects in a previous study [13].

In this task, subjects have to search for a specific basilica. The search functionality of both design approaches works equally, so we do not expect a significant difference between the Grid-Design and the List-Design in T1.

T2, T3 Find a Specific Resource: In T2, the subjects need to find a specific café given the instruction to use the facet Cafés. In T3, the subjects need to find the path to a specific facet containing a specific Mexican restaurant.

T4, T5 Exploring Multiple Facets: In tasks T4 and T5, the subjects had to find in total seven facets and places. Both T4 and T5 aim at exploring facets and resources. This means that unlike in T2 or T3, the subjects do neither know the path to navigate nor what specific resource shall be found.

In T4, the subjects had to find a doctor, 3-star hotel, and fast food restaurant. In T5, they needed to find a bar, castle, university, and train station. The difference between both tasks is that the facets in T5 are more difficult to find than in T4 since they are located deeper in the facet hierarchy or are not among the first facets displayed.

T6, T7 Finding Multiple Facets: T6 and T7 are about finding a facet among more than 200 facets. In T6, subjects had to find three different professions (military person, football player, or physicist) under the Person facet and check if the name of a given person is associated to one of those professions. In T7, the subjects had to find another three professions (architect, jurist, and singer) and write down the name of a person for each of those professions. T7 differs from T6 in a way that the facets to be found are located far further below in the grid of facets and list of facets, respectively. Overall, T6 and T7 aim at evaluating how the approaches perform if there are many facets in one level of the data hierarchy. Thus, it is a matter of how quickly the subjects can scroll and find a facet in the Grid-Design screen after clicking on the “See more facets ...”-button and the list of facets in the List-Design.

4.4 Measurements

During the data collection sessions, we gathered measurements for effectiveness, efficiency, and satisfaction for each subject. We measured the effectiveness of the users in conducting the tasks by checking the answers with a gold standard, i. e., the pre-determined solutions of the tasks. We measured the efficiency in carrying out the tasks by taking the duration in milliseconds the subjects needed

to finish a task. In addition, we collected all interaction steps that the subjects have performed with the application. This includes all navigational clicks into the category hierarchy as well as backward steps going up in the hierarchy, selecting and deselecting facets or group of facets, hiding and opening the facets bar, opening the additional screen in the grid-based design, and others. We measured the users’ satisfaction in the feedback phase of our experiment. In order to collect information about user satisfaction, we have adapted the IsoMetrics^S questionnaire for between-group experiments [9]. We use IsoMetrics^S as it has been successfully used in the past for conducting between-group evaluations. In addition, it comes with an extensive list of pre-defined questions that can be tailored to the research questions in the concrete experiment. The first ten questions F1-F10 dealt with faceted search and the result list. The eleventh question F11 referred to the depiction of the current navigation hierarchy in the middle of the grid. As this navigational element is only available in the Grid-Design, question F11 was not asked to the participants using the List-Design. The subsequent ten questions G1-G10 targeted general issues about the user interface and different functionalities of the application. Details of the questionnaire are provided in Section 5.3. Each question was answered on a visual analogue scale (VAS) [17], which ranges from *strongly disagree* to *strongly agree*. The subjects provided their ratings by drawing a cross on the scale. The subjects’ ratings were precisely captured from the questionnaires using a ruler. We translated the obtained values to a standard Likert scale for reasons of presentation where 1 means predominantly disagree and 5 refers to predominantly agree. Subsequently to rating these statements, the subjects could express free comments in the questionnaire.

5. RESULTS

We present the results regarding the effectiveness, efficiency, and satisfaction of the users in conducting the tasks. A discussion of the results is presented in the subsequent section.

5.1 Effectiveness

Effectiveness was measured by checking whether a subject successfully completed a task. The subjects of the Grid-Design group have successfully performed all tasks. Two tasks were not completed in the List-Design group, which was due to technical problems. For each group, there were $32 * 7 = 224$ tasks to be performed, resulting in a completion rate of 100% for the Grid-Design and 99.11% for the List-Design. Since the rates are almost the same and the missing answers in the List-Design are caused by technical problems in T1 and T2 (which is not an inherent issue of the application), the differences in effectiveness are not further discussed.

5.2 Efficiency

The performance of the subjects with respect to completion time and number of clicks are illustrated as boxplots in Figure 5. In order to test for statistically significant differences, we have first verified if the scores follow a normal distribution using Kolmogorov-Smirnov test. Subsequently, we have tested if the variances of both groups are equal using Levene’s test (details of both tests omitted for reasons of brevity). If this has been the case, we have applied two-tailed t-tests to compute the t value, p value, and 95% confidence interval (CI). In case of a non-normal distribution, we have applied Mann-Whitney U-tests to compute the Z value and p value and have determined the 95% CI using Hodges-Lehmann estimator. The relevant measurements and statistical analyses are summarized for convenience in Table 1. Values, where we have measured statistically significant differences ($p \leq 5\%$), are printed in boldface.

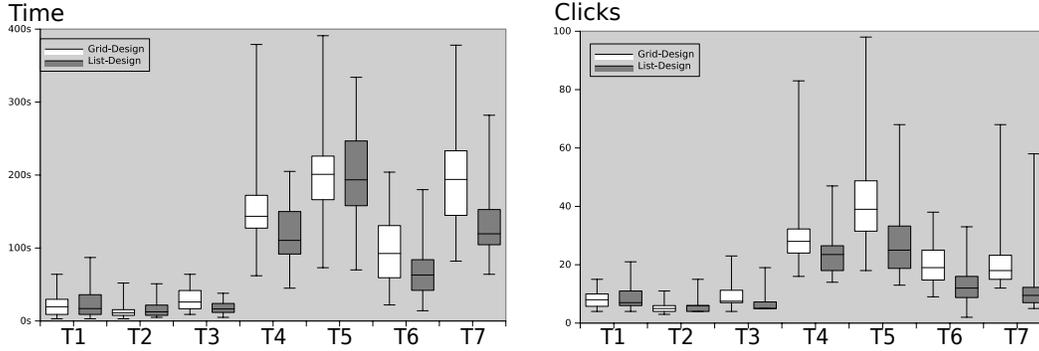


Figure 5: Boxplots showing the efficiency of executing the tasks in seconds (left) and number of clicks (right). Each boxplot shows the min., max., and median values. The box itself represents the values from the lower quartile and upper quartile.

			T1	T2	T3	T4	T5	T6	T7	Total	
Time (in s)	Grid-Design	Mean	22.28	13.41	28.97	161.84	206.88	96.5	195.75	725.63	
		Median	19.5	11	26	143.5	201	92.5	194	724	
		SD	16.32	10.04	14.88	69.14	73.26	46.88	65.84	199.6	
	List-Design	Mean	25.74	17	17.78	119.22	199.97	68.09	137	584.13	
		Median	17	13	16.5	110.5	193.5	63	119.5	599.5	
		SD	20.79	11.84	8.49	45.39	61.1	36.89	56.59	140.52	
	t		0.74	1.3	-3.7	-2.92	-0.41	-2.69	-3.81	-3.28	
	p		.47	.2	.001	.005	.684	.009	<.001	.002	
	95% CI	Lower		-5.94	-1.93	-17.27	-71.85	-40.62	-49.49	-89.43	-227.76
		Upper		12.86	9.12	-5.1	-13.4	26.81	-7.33	-28.07	-55.24
Number of Clicks	Grid-Design	Mean	8.22	5.13	9.56	31.81	41.81	20.41	21.84	138.78	
		Median	8	5	7.5	28	39	19	18	129	
		SD	2.98	1.52	4.24	15.45	18.07	7.71	11.79	39.75	
	List-Design	Mean	8.45	5.68	6.91	23.91	28.44	12.59	11.63	97.53	
		Median	7	6	5	23.5	25	12	9.5	95.5	
		SD	3.68	2.18	3.08	8.25	14.29	6.34	9.52	22.45	
	Z or t		t = 0.28	Z = -1.11	Z = -3.48	Z = -2.88	t = -3.29	t = -4.42	Z = -5.42	t = -5.11	
	p		.78	.27	<.001	.004	.002	<.001	<.001	.001	
	95% CI	Lower		-1.45	0	-3	-9	-21.51	-11.35	-12	-57.47
		Upper		1.92	1	-1	-2	-5.24	-4.28	-6	-25.03

Table 1: Summary of statistical analysis of efficiency measures. The results show that less time (top) and less clicks (bottom) are needed for conducting the tasks in the List-Design.

5.2.1 Efficiency in Time

The results for T1 show that the Grid-Design is not statistically significantly faster than the List-Design, $t(61) = 0.74$, ns , $p = .47$, 95% CI [-5.94, 12.86]. There is also no statistically significant difference in time for executing task T2, $t(61) = 1.3$, ns , $p = .2$, 95% CI [-1.93, 9.12]. In contrast to T2, the next task T3 shows a significant difference in time where the List-Design is the faster approach with a mean of 17.78 seconds against a mean of 28.97 seconds of the Grid-Design, $t(62) = -3.7$, $p = .001$, 95% CI [-17.27, -5.1]. The results for T4 show that the List-Design is statically significantly faster, $t(62) = -2.92$, $p = .005$, 95% CI [-71.85, -13.4]. No statistically significant difference can be found in T5 between Grid-Design and List-Design, $t(62) = -0.41$, ns , $p = .684$, 95% CI [-40.62, 26.81]. The List-Design is statistically significantly faster for T6, $t(62) = -2.69$, $p = .009$, 95% CI [-49.49, -7.33]. For T7, the List-Design is statistically significantly faster, $t(62) = -3.81$, $p < .001$, 95% CI [-89.43, -28.07]. The total time for the evaluation from the first click in T1 until the last click in T7 shows again that the List-Design is statistically significantly faster, $t(61) = -3.28$, $p = .002$, 95% CI [-227.76, -55.24]. In summary, the results show that in four out of seven tasks subjects using the List-Design need statistically significant less time for completing the tasks.

5.2.2 Efficiency in Clicks

For T1, there is no statistically significant difference related to the efficiency in clicks, $t(61) = 0.28$, ns , $p = .78$, 95% CI [-1.45, 1.92]. The same holds true for T2, $Z = -1.11$, ns , $p = .27$, 95% CI [0, 1]. T3 shows significant differences with less clicks needed by subjects using the List-Design approach, $Z = -3.48$, $p < .001$, 95% CI [-3, -1]. Also the remaining tasks T4 ($Z = -2.88$, $p = .004$, 95% CI [-9, -2]), T5 ($t(62) = -3.29$, $p = .002$, 95% CI [-21.51, -5.24]), T6 ($t(62) = -4.42$, $p < .001$, 95% CI [-11.35, -4.28]), and T7 ($Z = -5.42$, $p < .001$, 95% CI [-12, -6]) show a statistically significant difference, i.e., the List-Design needs less clicks than the Grid-Design. Comparing the total number of clicks shows a significant difference between the Grid-Design and List-Design, $t(61) = -5.11$, $p = .001$, 95% CI [-57.47, -25.03]. In summary, the results show that in five out of seven tasks the subjects using the Grid-Design need significantly more clicks in completing the same tasks than using the List-Design.

5.3 Satisfaction

The subjects' satisfaction has been measured in the feedback phase by rating the statements F1-F11 and G1-G9. The results for the statements are depicted as boxplots in Figure 6. The data

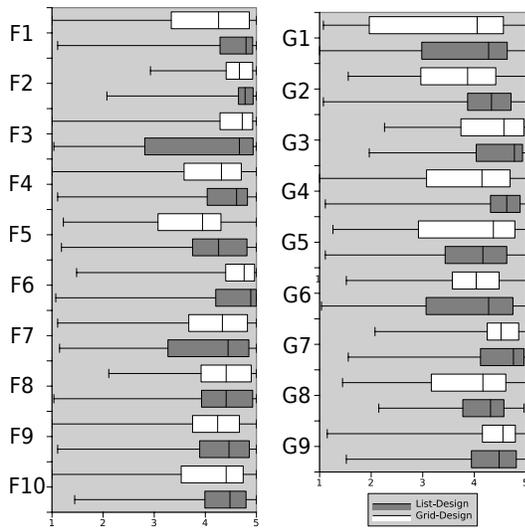


Figure 6: Boxplots for adopted IsoMetrics^S questionnaire capturing the subjects' satisfaction with respect to faceted search (F1-F10) and general usability questions (G1-G10). There are no statistically significant differences, except for F1.

obtained from the questionnaire does not follow a normal distribution. Thus, we apply Mann-Whitney-U tests and compute the Z value and p value. The only statistically significant difference between the groups is observed for statement F1 "Selecting a facet is easy.", $Z = -1.94, p = .05$. Thus, the selection of facets is easier in the List-Design. The results for all other statements are statistically non-significant.

In addition to F1 "Selecting a facet is easy.", we have asked further questions to obtain feedback regarding (de-)selecting facets namely F2 "Selecting multiple facets is easy." ($Z = -1.05, ns, p = .3$) and F3 "Deselecting selected facets is easy." ($Z = -.6, ns, p = .55$) as well as F4 "Navigating through facets is easy." ($Z = -1.32, ns, p = .58$). These questions were complemented by question F5 "It is easy to find the facets needed for conducting a task." ($Z = -1.65, ns, p = .1$) to find the right facet(s) and F6 "I always know which facets have already been selected." ($Z = -.23, ns, p = .82$) to check whether the participants were able to memorize their choices while conducting the tasks. To obtain feedback if the subjects found the organization of the facets as hierarchical lists versus hierarchical grids appropriate, we have asked question F7 "The arrangement of facets is appropriate.", $Z = -.05, ns, p = .96$. Regarding the process of refining search results and searching for resources suspected under specific facets, we have asked F8 "Refining search by facets is comprehensible." ($Z = -.2, ns, p = .85$) and F9 "Searching for resources within the result list is easy." ($Z = -.65, ns, p = .52$). Finally, we have asked if the design approach of combining faceted search (lower part of the screen) and showing the result list (upper part of the screen) is appropriate by asking F10 "The combination of facets and the result list in the same screen is intuitive.", $Z = -.92, ns, p = .36$.

Only the subjects in the Grid-Design group have been asked question F11 "The navigation field is easy to use." to get feedback if they were able to use the additional user interface element. The result for question F11 (not depicted in Figure 6) shows a high rating in terms of easiness of using the navigation field with a median of 4.09 ($SD = 1.25$). Please note, this question is not applicable to the List-Design group as it does not have this navigation field.

Besides questions regarding faceted search, we have also asked general questions about our application such as G1 "The application requires no redundant input.", $Z = -.96, ns, p = .34$. An application might be considered not to provide all functionalities needed to conduct a task. Thus, we have asked questions G2 "The application supports me properly in performing the task." ($Z = -1.77, ns, p = .08$) and G3 "The application provides all functions necessary for conducting the tasks." ($Z = -.68, ns, p = .5$). These questions are complemented by G4 "The execution of tasks is easy." ($Z = -1.9, ns, p = .06$), asking for judging the effort when conducting the tasks using the application. Sometimes, an application might behave differently than a user expects. Thus, we have asked with question G6 if "The interaction with the application is according to my expectations.", $Z = -.13, ns, p = .9$. As the judgement of the application's behavior might depend on the appropriateness of the returned results when conducting the faceted search tasks, we have asked G7 "The returned results met my expectations.", $Z = -.9, ns, p = .37$. The usefulness of an application also depends on whether its interaction elements are intuitive to use. To this end, we have asked question G8 "It is clear how to use the interaction elements of the application.", $Z = -.64, ns, p = .52$. In particular, we wanted to know if the subjects found it easy to switch between the faceted search screen and the map screen. Thus, we have asked question G9 "It is easy to move back and forth between different screens.", $Z = -.07, ns, p = .36$.

6. DISCUSSION

We discuss the results presented above with particular attention to the statistically significant differences between the two approaches regarding efficiency and satisfaction.

6.1 Efficiency

The search task T1 deals with the directed, textual search for resources, which works the same for both approaches. Thus, we did not expect a statistically significant difference between the Grid-Design and the List-Design for T1. Rather, the task was designed to investigate if the two groups of participants in our experiment are comparable (see also the discussion in Section 6.3). Indeed, the analysis of T1 shows that there is no statistically significant difference in time and clicks.

The further results show that subjects need less time and less clicks for conducting the tasks using the List-Design compared to the Grid-Design for most of the faceted search tasks: T2 is a simple task where the subjects have to find a specific resource, the nearest cafe. It is very easy to find as we can see from the median values of 11 seconds and five clicks in the Grid-Design and the median values of 13 seconds and six clicks in List-Design. We could not observe a statistically significant difference for T2, which we assume is due to the low complexity of the task. Like in T2, the task T3 is to find a specific resource. Here, we find a significant difference in time and number of clicks in favor for the List-Design. Looking at Table 1, we see that the Grid-Design is much worse in terms of time efficiency than the List-Design. This is an interesting result with regards to the fact that the Mexican restaurant the subjects had to look for is only five clicks away from the initial system status. We hypothesize that the subjects spent a lot of time browsing the first seven facets in the grid, before clicking on the "See more facets"-button to explore the remaining ones. This might be caused by the ranking of the facets (those with many instances are ranked higher) and the subjects believing that the requested solution can be found among the top seven facets in the Grid-Design. Another reason might be just the fact that additional effort is needed to reach the further facets by clicking on the "See more facets"-button. We will

analyse the observation that the Grid-Design requires more clicks and more time in more detail in Section 6.2.

T4 and T5 are facet exploration tasks where the subjects had to find several facets. The difference between T4 and T5 is that the facets in T5 are much more difficult to find. T4 shows significant difference in time and clicks. In contrast, T5 shows no significant difference in time but significant difference in the number of clicks. It was surprising to us that we could not find a significant difference in time for T5. The facets to find in T5 such as a Castle, University, and Train station are rare and located deeper in the facet hierarchy. Overall, this ended up in both groups spending a lot of time finding the facets with a mean difference of 3% only. In the tasks T6 and T7, the subjects had to find specific facets among many. In both tasks, we find a significant difference in time and clicks. We explain this result by the additional effort needed to go into the “See more facets”-screen in the Grid-Design condition (for two of the three resources in task T6 and all three requested resources in T7).

6.2 Detailed Analysis of Efficiency Results

From the results obtained for efficiency in times and clicks, we assume that the subjects using the Grid-Design tend to look into the hierarchy of the first seven facets before clicking on the “See more facets ...”-button. In order to answer this question, we have further investigated the subjects’ clicking behavior in the Grid-Design. To this end, we have analyzed the logfiles of the tasks T3-T7. T1 and T2 have not been investigated as using the “See more facets ...”-button was not required to solve these tasks. Our analysis explains the significant differences that have been observed.

In general, T3 could have been solved without using the “See more facets...”-button by selecting the facet Restaurant and simply clicking on the resource Enchilada in the result list. However, 29 of 32 subjects (91%) used the “See more facets...”-button to find the requested resource. The logfiles show that they needed about 7 seconds in mean before the first appearance of the “See more facets...”-button. Instead of clicking on it and following the right path to the facet of interest, namely Mexican restaurant, the subjects spent further 7.41 seconds in mean browsing through the other facets before selecting the “See more facets...”-button. Thus, in total the subjects needed 14.41 seconds in mean to find the right path to the facet Mexican restaurant, which contains the restaurant Enchilada. They need further 23.41 seconds in mean to finally find the resource Enchilada (please remember, this mean value is computed for the 29 subjects and thus differs slightly from the value in Table 1). In contrast, the subjects using the List-Design needed only 4.59 seconds in mean to browse into the right part of the facet hierarchy (compared to the “See more facets...”-button in the Grid-Design) and another 17.78 seconds to find the resource. In total, the subjects using the Grid-Design needed about three times as much time to find the right path in the facet hierarchy than in the List-Design.

In T7, the subjects searched for three facets among more than 200 facets and all of them could only be found by using the “See more facets...”-button. We have measured that the subjects needed 15.94 seconds in mean to click the first time on the “See more facets...”-button to follow the right path. This makes about 26% of the mean time of 60.63 seconds to find the facet German architect containing the first result. In contrast, for the List-Design the time needed to find the facet German architect was only 24 seconds in mean compared to 60.63 seconds in the Grid-Design. The tasks T4 to T6 are composite tasks where the subjects had to find multiple facets using the “See more facets...”-button and facets without using it. Similar to T3, our analysis of the logfiles for T7 shows that the subjects using the Grid-Design tend to look first in the seven facets before clicking on the “See more facets...”-button. Overall, the sub-

jects using the Grid-Design needed about three times as much time to find the right part of the facet hierarchy than in the List-Design. Looking into the details of the logfiles for tasks T3 to T7 reveals that subjects using the Grid-Design tend to explore the first seven facets before actually clicking on the “See more facets...”-button.

In summary, the decision of the 29 subjects to browse first into the seven facets lead to the significant difference in efficiency regarding time and clicks. Such a preference for the first seven facets could not be observed for the List-Design, where the subjects rather browse through the entire list of facets.

6.3 Satisfaction

From the subjects’ feedback in the questionnaire, we cannot clearly conclude that one of the two design approaches is easier to use than the other. The only statistically significant difference we observe is for statement F1 “*Selecting a facet is easy.*” indicating that the List-Design is easier to use than the Grid-Design. The result may be biased by the assumption that the subjects are more accustomed to the List-Design from their daily use of mobile applications such as the phone book. However, we did not find any difference in the other questions F2, F3, and F4 w.r.t. the easiness of using the Grid-Design vs. List-Design. In general, selecting and deselecting facets is considered easy in both approaches indicated by the high likert-score of more than four in median (see results for F2 and F3). F4 “*Navigating through facets is easy.*” shows that the use of the Grid-Design is comparable to the faceted search in the List-Design. The high median of 4.09 for question F11 “*The navigation field is easy to use.*” supports this and suggests that the navigation field is a good enhancement for faceted search. Overall, we can state that the navigation field did neither help nor disturb the subjects’ satisfaction.

Although the Grid-Design requires more time and more clicks (for most of the tasks the differences are statistically significant), the results for question G5 “*The number of steps needed to conduct a task is appropriate.*” shows no significant difference. Also question F7 “*The arrangement of facets is appropriate.*” shows no difference between the two approaches. This indicates that taking more time and more clicks did not impact the acceptance of arranging facets in a List-Design vs. Grid-Design. F8 “*Refining a search by facets is comprehensible.*” supports this statement as both interface approaches are also considered equally w.r.t. their comprehensiveness for faceted search. The lack in finding a significant difference for G1 “*The application requires no redundant input.*” and G3 “*The application provides all functions necessary for conducting the tasks.*” further supports this statement.

We assume that the two groups of subjects are comparable as we did not find a statistically significant difference for F9 “*Searching for resources within the result list is easy.*”. This meets our expectations, since the textual search in the result lists work exactly the same in both user interface designs. We also did not observe a significant difference for G7 “*The returned results met my expectations.*”. This can be explained by the fact that both groups have received the same data. Finally, the very similar execution time for the simple task T1 (see Section 5.2) further supports our assumption that the two groups of subjects seem to be comparable.

6.4 Summary and Practical Implications

Considering the aforementioned results and discussion about efficiency and satisfaction, one can argue that there is a good indicator that the List-Design is a better approach for faceted search compared to the Grid-Design. This is based on the observation that for most faceted search tasks, the subjects using the List-Design need statistically significantly less time and less clicks for complet-

ing the tasks. However, one would assume that this is also reflected in the subjective ratings of the two design approaches in the questionnaire. Thus, it is interesting to observe that the satisfaction of the subjects has not been hampered by the more clicks and more time needed using the Grid-Design. In addition, both approaches have been rated equally regarding easiness of faceted search. Thus, in total it seems that the List-Design is a better approach for faceted search. Nevertheless, one might adopt a grid-based layout with the navigation element when efficiency is not the primary objective. Using the grid-based layout with the navigation element has the advantage that the users see at any browsing step the exact position where they are in the data space. Such a feature is not provided by list-based faceted search. This might be a very useful feature for data sets where knowing the position in the hierarchy is quite crucial like taxonomies or classification schemas used in digital libraries. The navigation field might support users in not getting lost when navigating through the hierarchy.

The results presented in this work may be influenced by the ranking function used to sort the facets. Instead of ranking the facets by the number of instances they might be ordered, e. g., alphabetically. This might change the differences regarding efficiency between the two approaches. In the Grid-Design, the users had to click on the “See more facets”-button before reaching a scrollable list of further facets. Also this additional click did not hamper user satisfaction, the efficiency in terms of task performance might be different when the Grid-Design had also only a single scrollable screen. This might give the users a better sense that the facets are not ranked and increase the incentive to browse deeper into the facets. However, investigating these potential factors remains tasks of future work.

7. CONCLUSION

We have presented a between-group experiment comparing a grid-based approach and list-based approach for faceted search of a large, hierarchical data space on touchscreen mobile devices. Both approaches rely on a common architecture and use the same data set to ensure comparability. As concrete scenario, we use category hierarchies that are dynamically obtained from different, distributed social media sources. Our evaluation with 64 subjects from various different professions show that using the Grid-Design requires significantly more clicks and more time for completing the tasks for faceted search than the List-Design. This suggests that the List-Design might be a better choice for mobile faceted browsing. However, the evaluation also shows that the subjects’ satisfaction is not hampered by the additional time and clicks.

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