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ABSTRACT

In this paper, we compare two approaches for exploring large, hierarchical data spaces of social media data 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. We have conducted a between-group experiment of the two approaches with 24 subjects (20 male, 4 female) executing the same set of tasks of typical mobile users' information needs. The results show that the grid-based approach requires significantly more clicks, but subjects need less time for completing the tasks. Furthermore, it shows that the additional clicks do not hamper the subjects' satisfaction. Thus, the results suggest that the grid-based approach is a better choice for faceted search on touchscreen mobile devices. To the best of our knowledge, such a summative evaluation of different approaches for faceted search on mobile devices has not been done so far.

INTRODUCTION

The Web 2.0 has brought an explosion of social media data to mobile devices. Exploring this social media data while being on-the-go is an important task to, e.g., find answers to trivia questions like retrieving information about a building or landmark, finding locations like sights or restaurants, or events (cf. [15]). Aggregating social media data from various Web 2.0 sources like Wikipedia¹, event directories such as Upcoming² and Eventful³, places and restaurants from Qype⁴, and images from Flickr⁵ results in a large, hierarchical data space. Exploring such a large, hierarchical data space is a difficult task, which becomes even more challenging when limitations of mobile devices like smaller display size and limited interaction possibilities have to be taken into account. Thus, an appropriate approach is needed to find the right piece of information in the social media data space. Providing an application that supports the mobile users in exploring the social media data space is an interesting research question, as the social media data can provide answers to many typical mobile users information needs [15].

To alleviate the problem of finding the right piece of information, the approach of faceted search has been developed in

¹<http://wikipedia.org/>

²<http://upcoming.yahoo.com/>

³<http://eventful.com/>

⁴<http://qype.com/>

⁵<http://flickr.com/>

the past. Initially designed for desktop computers [18, 5, 2], the idea of faceted search has been transferred to mobile devices [12, 11, 4]. 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. Thus, a facet can have one or multiple sub-facets. A sub-facet can be associated to more than one facet, resulting in a poly-hierarchical tree. Finally, a facet that does not have any sub-facet is called a leaf facet (cf. [14]).

The existing applications for faceted search on mobile devices differ in their approach how to arrange the facets on the screen and using these facets for exploring the data space. The FaThumb system [11] 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 [12, 4]. While the grid-based approach by design starts with a full result list of resources, the initial result list of the list-based approach is empty. In addition, the amount of space used for displaying the facets differs between the approaches.

In this paper, 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, such a comparison has not been conducted so far. Thus, no clear recommendation for mobile faceted search has emerged yet [9]. We have developed MFacets following the grid-based approach and MobileFacets providing the list-based approach for faceted search. Goal of this comparison is to investigate the differences of both approaches regarding their usability. To this end, we formulate the null hypothesis saying that there is no significant difference between the grid-based approach for faceted search and the list-based approach for faceted search regarding effectiveness, efficiency, and satisfaction.

In order to investigate this hypothesis, we have conducted a summative evaluation where two independent groups of subjects have conducted the same set of tasks but each under different conditions. One group has used the grid-based MFacets and the other group has worked with the list-based MobileFacets. In total, 24 subjects (20 male, 4 female) have participated in this evaluation. Our results show that the grid-based approach requires significantly more clicks (t-test/Mann-Whitney U, $P \leq 5\%$). However, the tasks are executed faster than using the list-based approach. Thus, one

cannot reject the null hypothesis with respect to efficiency in general. The results show further that the additional clicks do not hamper user satisfaction with respect to general usability questions and specific features for faceted search. Thus, overall we suggest that the faster grid-based approach is a better choice for faceted search on mobile devices.

The remainder of this paper is organized as follows: In the next section, we introduce the two approaches for faceted search. Subsequently, we describe the evaluation design, including the tasks the subjects have performed and the data set that is used. We present the results of our evaluation with respect to effectiveness, efficiency, and satisfaction and provide an interpretation of the results. Finally, we discuss the related work, before we conclude the paper.

GRID-BASED VS. LIST-BASED FACETED SEARCH

The first system (MFacets) provides a grid-based faceted search. It is inspired and based on the keypad-based FaThumb system [11]. Therefore, we first describe the original FaThumb system and subsequently present its adaptation and extension to touchscreen mobile phones. In contrast, the second system (MobileFacets) implements a list-based faceted search. The principle differences with respect to faceted search between MFacets and MobileFacets are depicted in Figure 1 and summarized in Table 1. In the following, we introduce the two approaches for faceted search and their implementation in MFacets and MobileFacets. We illustrate the important characteristics of the grid-based approach and the list-based approach and explain their differences.

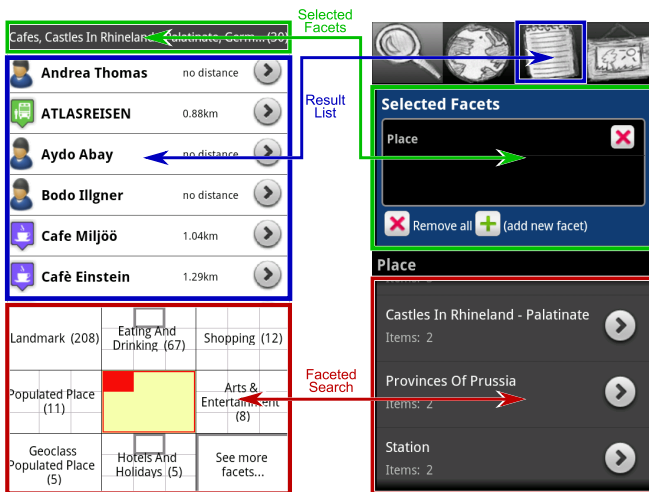


Figure 1. Grid-based (left) vs. List-based Faceted Search (right).

	MFacets	MobileFacets
Arrangement of facets	3x3 grid	List
Display mode of facets	Half/full-screen	Half-screen
Initial result list	All resources	Empty

Table 1. Overview between MFacets and MobileFacets.

FaThumb

FaThumb [11] provides a grid-based faceted search on mobile devices with a physical numeric keypad as shown in Figure 2. It has been developed by Microsoft Research and uses a closed data set from Yellow Pages for the Seattle metropolitan area (about 39,000 entries). The facet navigation takes place in a 3x3 grid, which is located right below the result list (see Figure 2(a)). Since FaThumb is developed in Pico.NET for smartphones without touchscreen capabilities, the phone’s numeric keypad is used to navigate through the facets. To facilitate the navigation, the fields resp. facets in the grid are appropriately linked to the keys 1 to 9. For example, the key 1 is linked 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 is used to display 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 respective 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, i.e., only those facets which have no further sub-facets. Facets depicted with a grid in the background (see, 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 to the facet. 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, those facets are shaded in gray such that they cannot be selected anymore (see 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. The background shows a colored rectangle according to the position of the selected facet at the grid (see Figure 2(d)). The color indicates the level of the selected facet. The result list can be filtered by keyword if the focus is on the filter region (see Figure 2(d)). If there are no facets selected, the textual filter can act as a 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 navigation, result list, and filter region of FaThumb. To indicate which region has focus, a border in orange color is displayed around the according region. If the result list is focused, it is expanded to show more results (see 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 a field at the lower left corner of the screen, which imitates the phone’s left option key. With this key, more results can be accessed. The right option key can be used to order the result list by different attributes, e.g., by alphabet, distance, or rating.

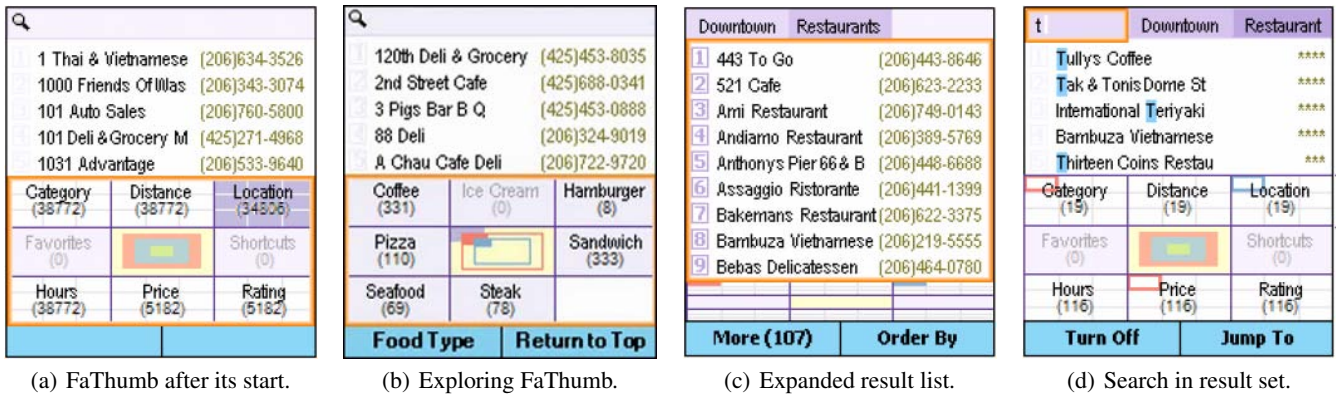


Figure 2. Grid-based Faceted Search in FaThumb.

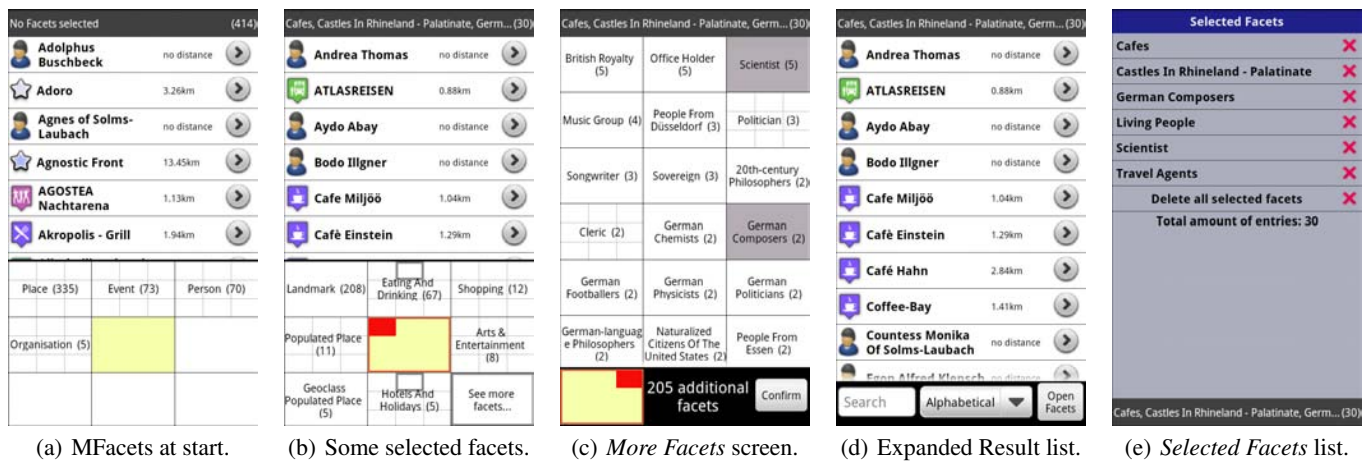


Figure 3. Grid-based Faceted Search in MFacets adopted from FaThumb.

MFacets

Unlike FaThumb, MFacets is developed for Google Android mobile phones. As motivated by Hearst [9], MFacets aims to be a modernized version of FaThumb such that FaThumb’s approach for faceted search can be used on current touchscreen mobile phones. Thus, the user interface of MFacets is very similar to FaThumb and can be seen in Figure 3. However, there are also some differences due to the adoption from a keypad-based mobile phone to the touchscreen phone and the use of open data sets, which will be described below.

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. [15] 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). It can be seen that MFacets and FaThumb are basically built up the same way, but FaThumb’s physical numeric keypad has been transformed into a virtual keypad on the touchscreen in MFacets. Thus, instead of using physical keys, the facets as well as the items in the result list can be directly selected in MFacets using the touchscreen.

Since FaThumb uses a closed data 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, MFacets is designed to use an open data set where the data is publicly available. Using such open data sets, one cannot make assumptions about how many facets are retrieved, which facets will be retrieved, and how many resources are associated to these facets. Thus, the design of the system has to be independent of the amount 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, MFacets introduces the *More Facets* screen as shown in Figure 3(c). If there are more than eight facets to display, the lower right field of the facet navigation will turn into a *More Facets* button to reach that screen (see Figure 3(b)). This *More Facets* screen is organized as a scrollable grid list. Thus, the original design of the facet navigation as provided in FaThumb remains.

In MFacets, selected facets are displayed in a bar at the top of the screen just like in FaThumb. Since this bar in FaThumb can only show a limited number of facets, it has been mod-

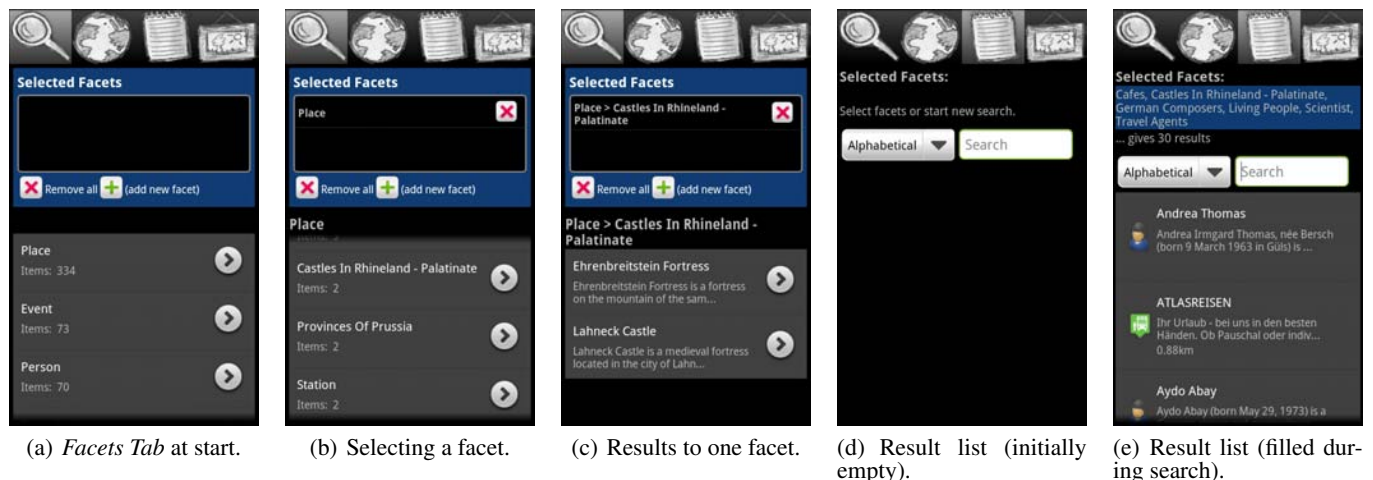


Figure 4. List-based Faceted Search in MobileFacets.

ified in MFacets and can be pulled down to show a list of currently selected facets as shown in Figure 3(e). Here, the selected facets can either be deleted individually or all at the same time. Finally, the list can be closed either by pulling the bar up or clicking on the mobile phone's back key.

Some minor extension to FaThumb is the scrollable result list that can be expanded by clicking on any entry. In addition, the retrieved resources can be ordered by alphabet or distance and be filtered by keyword (see Figure 3(d)). A window with detailed information about a resource can be accessed through the arrow button (no screenshot provided).

MobileFacets

MobileFacets implements the list-based faceted search. It has been developed based on a participatory design of five experts and formally evaluated by 12 additional subjects [12]. Like MFacets, also MobileFacets is developed for Android mobile phones. One apparent difference to MFacets is that the navigation within the application MobileFacets is based on tabs as it can be seen in Figure 4(a). From left to right, there are a *Facets Tab* for exploring and selecting facets, a *Map Tab* showing results on a map, a *Result List Tab* displaying results as a list, and a *Gallery Tab* to depict images in a gallery. For the comparison of MobileFacets with MFacets, only the Facets Tab and Result List Tab are relevant, so only these two tabs will be elaborated in the following. A description of the other tabs is described elsewhere [12].

The Facets Tab is illustrated in Figure 4(a) and is divided into two regions. The upper region is used to display and edit selected facets and the lower region to select new facets. Initially, the list of selected facets is empty. During faceted search, iteratively one facet after the other is added to the facet list (see Figure 4(b)). In contrast to MFacets, the selected facets are shown in MobileFacets in the upper region of the screen as breadcrumb [8] (see Figure 4(c), *Place > Castles In Rhineland - Palatinate*). The facets are explored during search by using a scrollable list. In this list, each facet

is displayed by its name and the number of resources related to that facet. Just like in MFacets, going deeper into the facet hierarchy of MobileFacets is done by clicking on a facet and jumping back a level can be done through the mobile phone's back key. If the user reaches a leaf facet, all resources associated to this facet will be displayed (see Figure 4(c)). By this, the user does not need to switch to the Result List Tab to see results and unlike to MFacets only results associated to this leaf facet are shown. Clicking on the "add new facet" button adds the current facet to the selected facets and resets the facet navigation to its initial state in order to allow for adding further facets. A facet can be removed from the current selection when pressing the mobile phone's back key during faceted search. Facets can also be explicitly removed by clicking on the delete button located right to the facet's name or by using the "Remove all" button.

The Result List Tab as shown in Figure 4(d) initially does not contain any results. If a facet is selected, resources will appear at the result list and the selected facet and the number of results will be indicated right below the tab icons (see Figure 4(e)). Next to the name of a resource, a possible excerpt describing the resource and the distance to the search location are shown. If necessary, the resources can be ordered by alphabet or distance or filtered through text input. Clicking on a resource opens a window with detailed information about the resource (no screenshot provided).

Please note that both applications do not support a screen rotation to landscape view. This would result in displaying too little results in MFacets and less vertical space for the selected facets and facet navigation in MobileFacets.

System Architecture and Common Data Set

MFacets and MobileFacets base on a common three-tier architecture and use the same data for evaluation. The architecture is illustrated in Figure 5. The communication between the mobile clients and the Tomcat server is established through Representational State Transfer (REST) and param-

eters like geographical coordinates for the search are transmitted. The server is in charge of retrieving resources from different data repositories. The data repositories used are DBpedia⁶, a Semantic Web version of Wikipedia, which provides descriptions and images about places, organizations, and persons. DBpedia is accessed via the W3C query language SPARQL. 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. These data sources are accessed by their corresponding Web APIs. From the data sources, we retrieve resources such as places, persons, events, and organizations. The response of each data repository follows a different XML-based data structure so that the gathered resources have to be merged into one response with a definite structure both applications MFacets and MobileFacets understand. These repositories offer open data since they are 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.

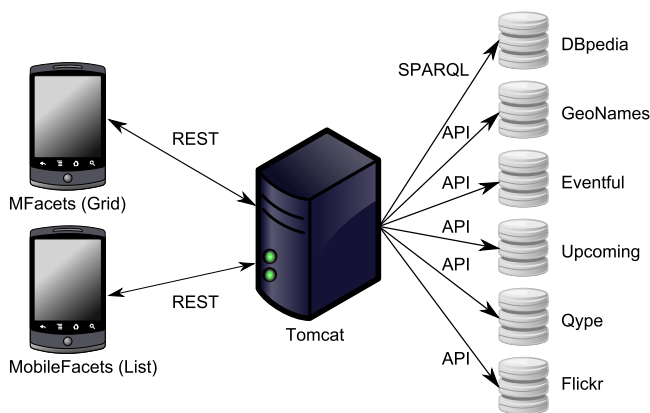


Figure 5. Common architecture of MFacets and MobileFacets.

Due to the data coming from open social media sources, the two approaches for faceted search considered here do not use multiple faceted taxonomies like in FaThumb (cf. [14]). In contrast, one dynamic taxonomy is used where the different dimensions, i.e., facets of the data are combined by conjunction. Reason for this decision is the sparseness of the resources with respect to the facets it covers, i.e., a resource typically does not cover many facets but is associated on average to one or two facets only.

EVALUATION DESIGN

We have designed a task-based, summative evaluation where two independent groups of subjects have conducted the same set of tasks on the same data set. However, each group has conducted the tasks under a different condition. One group has worked with the grid-based approach implemented by MFacets, whereas the other group has used MobileFacets providing the list-based approach of mobile faceted search. The evaluation has been conducted with 24 subjects (20 male, 4

⁶<http://dbpedia.org>

female). The subjects have been randomly assigned to the groups. The subjects are between 19 and 35 years (mean = 25.96, SD = 3.64). There have been 17 graduate students and 2 PhD students, who are studying in a course related to computer science, and 5 graduate students of non-computer science courses. All subjects have been familiar with mobile phones with touchscreens prior to the evaluation. They have received 10 Euros as compensation for their effort.

Evaluation Process

The evaluation consists of three phases, namely *introduction*, *observation*, and *feedback*. The introduction phase familiarizes the subjects with the application in general and the use of the faceted search in particular. Subsequently, the subjects have to execute the same tasks in the observation phase. We measure the three usability aspects effectiveness, efficiency, and satisfaction as defined in ISO 9241-110:2006. Effectiveness is examined by checking whether the subjects have successfully completed the tasks. Efficiency is measured by how quickly the subjects have finished the tasks and how many interaction steps, i.e., clicks are necessary. To this end, both applications have been enhanced with a logging mechanism to record the time and clicks needed to complete the tasks of the evaluation. For measuring the subjects' satisfaction, we apply the IsoMetrics⁵ questionnaire for summative evaluations [6] in the feedback phase. In addition, we have conducted a short de-briefing with the subjects and asked for qualitative feedback.

For running the actual data collection sessions, we have started both applications using the same smartphone, an usual HTC Desire with Google Android 2.2 operating system. The Internet connection has been established via WLAN and the GPS module has been deactivated so each subject has used the same previously set geographical coordinate as starting point. This coordinate corresponds to a larger city in Germany. To this given coordinate, both applications have retrieved the data from the same data repositories as described in Section *System Architecture and Common Data Set* within a radius of about 7km. The tasks are then performed on the received data. The data retrieved from the different sources contained about 400 resources, which are associated to about 330 facets.

Tasks

Each subject has to execute seven tasks T1-T7, which target two of the most relevant categories of mobile information needs as investigated by Sohn et al. [15], namely *trivia* and *searching for points of interest*. The tasks are selected to investigate the differences between the applications with the following specific hypotheses (a)-(c):

- The grid-based approach for faceted search is more usable than the list-based approach (a).
- Displaying facets in a combination of half and full-screen is more usable than scrolling facets in a half-screen only (b).
- An initial full result list is more usable than an initial empty result list (c).

In the following, we briefly introduce the seven tasks and relate them to the specific aspects (a)-(c) of faceted search.

T1, T2 Specific Resource: The first two tasks are simple tasks. In T1, the subjects need to find a specific café given the instruction to use the facet cafés. In T2, the subjects need to find the path to a specific facet containing a specific Mexican restaurant. Since subjects only need to follow a given facet resp. an obvious facet, no significant difference between both applications is expected.

T3 Result List: T3 deals with the directed, textual search for resources. Although the main goal of both applications is to provide a proper faceted search, they also implement a functionality to filter the result list by textual search. In this task, subjects have to search for a specific basilica. As pointed out earlier (see Table 1), MFacets initially displays all resources whereas MobileFacets starts with an empty result list, which is iteratively filled by selecting facets during search. Thus, T3 is associated with (c).

T4, T7 Exploring: Both T4 and T7 aim at exploring facets and resources. This means that unlike in T1 or T2, the subjects do neither know the path to navigate nor what specific resource shall be found. In these tasks T4 and T7, the subjects had to find in total four facets and places, respectively. In T4, the subjects had to find a book shop, a 3 star hotel, a fast food restaurant, and a shopping center. In T7, they need to find a bar, a night club, a video rental store, and a vegetarian restaurant. The difference between both tasks is that the facets in T7 are more difficult to find than in T4 since they are either located deeper in the facet hierarchy or are not among the first facets displayed. Both tasks are associated to (a).

T5, T6 Finding: T5 and T6 are about finding a facet among more than 100 facets. In T5, subjects have 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 T6, subjects have to find another three professions (Architect, Soccer Manager, and Olympic Athlete) and write down the name of a person to each of those professions. T6 differs from T5 in a way that the facets to be found are located far further below in the grid of facets resp. list of facets. These tasks aim at evaluating how the applications perform if there are many facets in one level. So, it is a matter of how quickly the subjects can scroll and find a facet in MFacets' "More Facets" screen, if the facet is not within the first seven facets, and MobileFacets' facets list. Thus, both tasks are related to (b).

The feedback phase completes the evaluation. Here, we have measured the satisfaction of the subjects using a questionnaire based on IsoMetrics^S for summative evaluations [6]. In total, the questionnaire contained 20 statements for MFacets and 19 statements for MobileFacets. MFacets has an additional statement about displaying the faceted search and result list on the same screen, which is not applicable for MobileFacets. The questions are divided into two groups: The first nine questions F1-F9 deal with faceted search and the result list. The

following ten questions G1-10 target at general issues like the user interface and different functionalities of the applications. Each question is answered on a continuous Likert scale, which ranges from *strongly disagree* to *strongly agree*. The subjects provided their ratings by drawing a cross on the scale as shown in Figure 6. Subsequently to rating these statements, the subjects could express free comments.

strongly disagree |—————×—————| strongly agree

Figure 6. Continuous Likert scale (not the actual size as it was used in the evaluation).

RESULTS

For each subject, we have gathered measurements for effectiveness, efficiency, and satisfaction. The results are presented in the following sections.

Effectiveness

Effectiveness is measured by checking whether a subject successfully completed a task. The subjects of the MFacets group have successfully performed all tasks whereas two mistakes were made in the MobileFacets group. The wrong answers result from selecting wrong facets. For each group, there are $12 * 7 = 84$ tasks to be performed, thus resulting in a completion rate of 100% for MFacets and 98.51% for MobileFacets. Since the rates are almost the same and the wrong answers in MobileFacets are caused from subjects just selecting wrong facets as the solution to the tasks (which is not an inherent issue of using the application itself), the differences in effectiveness are not further discussed in the remainder.

Efficiency

We have measured the efficiency by measuring the time needed for completing a task in seconds and the number of clicks the subject needed per task. The performances are illustrated in Figure 7 and the relevant measurements and statistical analyses are shown in Table 2. In order to test for statistical significance of the measured performance differences, we have computed t-tests, if applicable, and Mann-Whitney U-tests, where t-test cannot be applied due to non-normal distribution. Values, where we have measured statistically significant differences ($P \leq 5\%$), are printed in boldface and italics is used, if there is almost a statistically significant difference ($P \leq 7.5\%$).

Efficiency in Time

There is no significant difference in time for executing tasks T1 and T2, which is expected as both are designed as simple tasks. T3 shows that MFacets is statistically significant faster with an effect size of Cohen's $d = -0.841$ (large) and Pearson's $r^2 = 0.162$ (medium). T4 states that MFacets is almost statistically significant faster with medium effect sizes of $d = -0.508$ and $r^2 = 0.109$. According to Figure 7, it might seem that MobileFacets is significantly faster in T5, yet the analysis does not verify it. For T6, MFacets is significantly faster with medium effect sizes of $d = -0.736$ and $r^2 = 0.129$. Once again, no difference can be seen in T7 between MFacets and MobileFacets. The total time for the evaluation from the

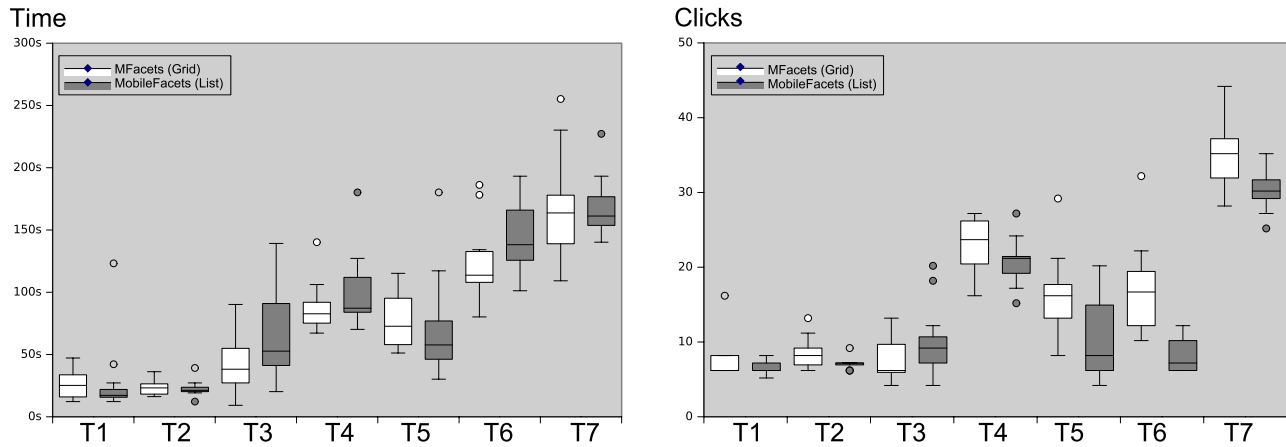


Figure 7. Boxplots showing the efficiency of executing the tasks in seconds (left) and number of clicks (right). Each boxplot shows the min., max., and median values. The box itself represents the values from lower and upper quartile. Outliers are indicated as circles.

first click in T1 until the last click in T7 shows again that MFacets is almost statistically significant faster with medium effect sizes of $d = -0.629$ and $r^2 = 0.101$. In summary, the results show that in 5 out of 7 tasks subjects using MobileFacets need more time completing the tasks. About half of them show significant differences.

Efficiency in Clicks

Both T1 and T2 show significant differences regarding the number of clicks, with less clicks needed by subjects using MobileFacets. Here, T1 has an effect size of $d = 0.52$ (medium) and $r^2 = 0.257$ (large) and T2 has an effect size of $d = 0.827$ (large) and $r^2 = 0.233$ (medium). There are no significant differences in T3 and T4, although MFacets needs less clicks in T3 and MobileFacets in T4. T5-T7 show clear statistically significant differences with less clicks for MobileFacets. T5 has an effect size of $d = 0.994$ (large) and $r^2 = 0.211$ (medium). There are large effect sizes in T6 with $d = 1.874$ and $r^2 = 0.681$. T7 has a large effect size at $d = 1.053$ and a medium one at $r^2 = 0.232$. Comparing the total number of clicks results in another clearly significant difference between MFacets and MobileFacets with large effect sizes of $d = 1.788$ and $r^2 = 0.466$. In summary, the results show that in 6 out of 7 tasks subjects using MFacets need more clicks in completing the same tasks than subjects using MobileFacets. Five tasks show significant differences.

Satisfaction

The subjects' satisfaction has been measured during the feedback phase by rating the statements F1-9 and G1-10. The statements and results are shown in Table 3. The subjects' rating have been precisely captured from the questionnaires using a ruler and translated to a standard Likert scale where 1 means predominantly disagree and 5 refers to predominantly agree. As shown in Table 3, only two statements show significant differences, while another one is almost significant. Regarding F3, MobileFacets has an almost significant better satisfaction with medium effect sizes of $d = -0.646$ and $r^2 =$

0.102 . F6 indicates that the subjects of MobileFacets are significantly more satisfied with large effect sizes of $d = 1.346$ and $r^2 = 0.331$. At last, a significant difference with a better satisfaction for subjects of MFacets can be noted from G3 with medium effect sizes of $d = 0.649$ and $r^2 = 0.117$.

DISCUSSION

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

Efficiency

The results show that subjects need less time for conducting the tasks using MobileFacets but more clicks using MFacets. More clicks have especially been necessary for T1 and T2. A closer look at the two tasks in Table 2 shows that the difference in the average number of clicks is 1.09 for T1 and 1.33 for T2. Regarding T1, one subject in the group of MFacets is an outlier with twice as many clicks as the rest (see Figure 7). Therefore, only a difference in mean and not in median can be observed. For T2, we find a difference of one click in the median. We have analyzed the log files produced for tasks and investigated why there is a difference. The reason is the different approach for selecting and deselecting facets in the applications. MobileFacets offers an implicit deletion of facet by using the mobile phone's back key as well as an explicit deletion by clicking on the according button (see description of *MobileFacets*). However in MFacets, there is no implicit deletion but only explicitly deselecting (one click) or explicitly deleting facets through the Selected Facets list (three clicks). This difference causes a slight but constant additional click, which results in a significant difference.

The results for T3 show that MFacets needs significant less time as well as less clicks than MobileFacets, which suggests (c) to be correct.

The exploration for facets in T4 and T7 is aiming at (a). Here, the results show that MFacets needs almost significantly less time in T4 but about just the same in T7. The fact that T4

			Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Total
Time	MFacets	Mean	25.83	23.5	41.17	87.42	77.17	122.58	167	790.33
		Median	25	23	38	82.5	72.5	113.5	163.5	771.5
		SD	11.98	6.56	24.31	20.87	21.88	32.23	43.52	92.01
	MobileFacets	Mean	28.42	22.5	68.83	100.58	69.92	145.42	168	852.92
		Median	17.5	21	52.5	87	57.5	138	161	800
		SD	30.96	6.37	39.68	30.17	42.14	29.76	23.7	106.32
	relative	Mean	91%	104%	60%	87%	110%	84%	99%	93%
		Median	143%	110%	72%	95%	126%	82%	102%	96%
		SD	39%	103%	61%	69%	52%	108%	184%	87%
	Z or t		Z = -0.808	t = 0.379	t = -2.06	Z = -1.617	t = 0.529	t = -1.803	t = -0.07	Z = -1.559
P		0.212	0.354	0.026	0.054	0.301	0.043	0.472	0.061	
Clicks	MFacets	Mean	7.42	8.25	7.58	22.5	16.33	16.67	34.75	133.58
		Median	6	8	6	23.5	16	16.5	35	132
		SD	2.84	2.14	3.23	4.01	5.31	6.23	5.14	18.41
	MobileFacets	Mean	6.33	6.92	9.92	20.5	10.67	7.92	30.33	104.25
		Median	6	7	9	21	8	7	30	105
		SD	0.78	0.79	4.76	3.12	6.07	2.19	2.96	14.12
	relative	Mean	117%	119%	76%	110%	153%	211%	115%	128%
		Median	100%	114%	67%	112%	200%	236%	117%	126%
		SD	365%	270%	68%	129%	88%	284%	173%	130%
	Z or t		Z = -2.483	Z = -2.367	t = -1.405	t = 1.364	Z = -2.252	Z = -4.041	t = 2.58	t = 4.379
P		0.007	0.009	0.087	0.093	0.012	<0.001	0.009	<0.001	

Table 2. Statistical analysis of efficiency shows that less time is needed for conducting the tasks in MFacets but significantly more clicks are needed.

shows almost significant differences in time and for T7 it was almost the same was surprising to us. We rather expected that both tasks either show significant differences or not, as in both tasks the subjects had to find four specific facets by exploring the facet hierarchy. The significant differences regarding time in T4 can be explained by the different conditions of the systems, i.e., a grid-based approach for faceted search is faster to use than the list-based approach. The higher number of clicks of MFacets is again caused by the different approaches for removing the selected facets. In contrast to T4, in T7 the subjects had to find facets that are much more difficult to find. These facets are rare, i.e., have a few resources only and are thus located deeper in the list of facets to explore. In addition, these facets were to be selected from a facet node that has several dozen sub-facets which makes spotting the right one difficult. Thus, in T7 the subjects did spend about twice as much time for finding the four facets using faceted search compared to T4. In addition, they visited about one fourth more sub-facets as in T4, which is reflected by the log-files collecting the amount of clicks. In the open feedback, some subjects even mentioned that they almost believed that the facets did not exist in the hierarchy at all. Thus, in this task the different conditions of MFacets and MobileFacets got blurred by the fact that we have asked for some rare facets and being sub-facet of a facet node that has quite a lot of sub-facets. Reason for these characteristics in the data set is the varying quality of the data provided by the social media data sources. For example, in the area of Koblenz were quite a lot of resources for facets like *Place* with 335 resources. However, there were only five resources for the facet *Organisation*. In addition, some facets had quite a lot of sub-facets like the facet *Person* having 212 sub-facets. As the inherent characteristics and the quality of the data provided by the social media data sources is out of our scope of this work, it is subject to future work to improve the data quality and deal with this variance. Overall,

with regards to (a), we can say that subjects using MFacets need less time but more clicks in tasks T4 and T7.

Finding a facet among many in T5 and T6 is aiming at (b). With regards to time, there is no difference in T5. But in T6, the advantage of displaying more facets on an additional screen in MFacets results in a significant difference. However, MFacets needs about twice as many clicks as MobileFacets. On the one hand, this is caused by the different approaches for removing selected facets as already mentioned above in the discussion of T1 and T2. On the other hand, the use of the “More Facets” screen in MFacets results in two more clicks per task, one for opening and one for closing the “More Facets” screen. Whereas in MobileFacets, there is no additional click necessary to reach facets after the first seven facets. With regards to (b), these tasks show again that MFacets needs less time but more clicks.

In order to decide whether the time and the number of clicks should be weighted equally or differently with regards to evaluate the overall usability of MFacets vs. MobileFacets, the following discussion about the subjects’ satisfaction can be helpful.

Satisfaction

Two statements indicate that the time necessary to perform a task should be weighted more than the number of clicks. These are G1 “*The application requires no redundant entries.*” and G5 “*The number of steps needed to conduct a task is appropriate.*”. The results reported in Table 3 show that there is no significant difference and that the subjects are slightly more satisfied with MFacets. Thus, one can say that subjects using MFacets have needed more clicks to perform a task, but the subjects have not reacted negatively about this with regards to their satisfaction.

	Statements	MFacets			MobileFacets			Z or t	P
		Mean	Median	SD	Mean	Median	SD		
Facets	F1: Selecting a facet is intuitive.	3.08	3.28	1	2.81	2.99	0.98	t = -0.651	0.261
	F2: Selecting multiple facets is easy.	4.42	4.58	0.61	4.37	4.49	0.63	t = 0.2	0.422
	F3: Deselecting selected facets is intuitive.	3.72	4.35	1.35	4.4	4.54	0.65	t = -1.582	0.064
	F4: Navigating through facets is intuitive.	4.03	4.09	0.64	3.82	4.2	0.93	t = 0.622	0.27
	F5: It is easy to find the facets needed for conducting a task.	4.04	4.09	0.6	3.59	3.57	1.04	t = 1.301	0.103
	F6: I always know which facets have already been selected.	3.23	3.58	0.73	3.93	3.96	0.1	t = 3.298	0.002
	F7: The arrangement of facets is appropriate.	3.94	4.16	0.99	3.9	3.72	1.09	t = 0.082	0.468
	F8: Refining a search by facets is comprehensible.	4.48	4.68	0.64	4.61	4.83	0.46	Z = -0.346	0.363
	F9: Searching for resources within the result list is intuitive.	4.44	4.7	0.62	4.6	4.75	0.45	t = -0.714	0.241
General	G1: The application requires no redundant entries.	4.18	4.22	0.77	3.68	4.01	1.28	t = 1.152	0.131
	G2: The application supports me properly in performing the task.	3.74	3.69	0.88	3.94	3.8	0.87	t = -0.571	0.288
	G3: The application provides all functions necessary for the tasks.	4.36	4.73	0.88	3.64	3.84	1.31	Z = -1.674	0.048
	G4: The execution of tasks is intuitive.	3.14	3.22	0.56	3.1	3.22	0.65	t = -0.193	0.424
	G5: The number of steps needed to conduct a task is appropriate.	3.81	4.01	1.11	3.67	4.1	1.08	t = 0.312	0.379
	G6: The information visualization supports me in performing the task.	4.1	4.3	0.85	4.06	4.49	1.07	t = 0.096	0.462
	G7: It is easy to find the functionality for executing a task.	4.12	4.22	0.74	3.99	4.35	1.05	t = 0.351	0.364
	G8: The application is consistent with respect to its interaction design.	3.27	3.81	1.13	3.65	3.83	0.46	Z = -0.693	0.245
	G9: The interaction design of the application is intuitive.	4.23	4.26	0.52	4.23	4.6	1.07	Z = -0.866	0.192
	G10: It is easy to move back and forth between different screens.	4.14	4.24	0.79	4.46	4.62	0.78	Z = -1.27	0.102

Table 3. Subjects satisfaction with respect to faceted search (F1-F9) and general usability questions (G1-G10).

The significant difference in G3 *"The application provides all functions necessary for the tasks."* and the tendency for a better satisfaction of MFacets in F5 *"It is easy to find the facets needed for conducting a task."* indicate that there is a lack of functionality in MobileFacets. This has been mentioned by the subjects in the free comment section of the debriefing session. The main feedback was that the subjects like to have a possibility to conduct textual searches for facets. 17% of the subjects of MFacets expressed that wish, whereas it has been a clear majority of 67% of the subjects using MobileFacets. This is mainly caused by the longer scrolling phases in T5 and T6 using MobileFacets. Overall, this indicates a higher satisfaction for displaying more facets on an additional full screen in MFacets.

The almost significant difference in F3 *"Deselecting selected facets is intuitive."* and the significant difference for better satisfaction of MobileFacets in F6 *"I always know which facets have already been selected."* are related to the "Selected Facets" list in MFacets. The method of pulling down a bar to access this list is especially unfamiliar for subjects who have no Android experience. Thus, two subjects of the MFacets group expressed the wish to remove any selected facet on the same screen. While this is understandable, it is contrary to the rating of the MFacets specific statement. The subjects of MFacets rated an additional statement (not shown in the table) *"Showing faceted search and result list on the same screen is intuitive."* quite positively (mean = 4.56, SD = 0.54). This rating complicates finding a compromise since the screen of a smartphone does not give much more space.

F7 *"The arrangement of facets is appropriate."* shall be further discussed as well. This statement aims at the different approaches for faceted search. Table 3 shows that there is no difference with regards to satisfaction, yet MFacets is rated a bit better in median. Therefore, it can be said that the grid-based approach of MFacets is more satisfactory than the list-based approach of MobileFacets.

Finally, we take a closer look at G10 *"It is easy to move back and forth between different screens."*. This statement aims at the general design of both applications, i.e., displaying the faceted search and the result list on the same screen (MFacets) against reaching those by switching between tabs (MobileFacets). The ratings of both groups show that there is a slightly higher satisfaction for tabs, even though this difference is not significant. Since both designs have scored more than 4, a general separation of the functionalities for faceted search and showing the result lists in different tabs (as conducted in MobileFacets) is not necessary to reach a high satisfaction.

Summary

Considering the aforementioned results and discussion about effectiveness, efficiency, and satisfaction, there is no clear result whether MFacets or MobileFacets is better with regards to usability. It has been shown that both applications are effective, yet both are efficient in different aspects. By design, subjects using MFacets need statistically more clicks but less time in conducting the tasks. Whereas, subjects using MobileFacets need less clicks yet generally more time. However, the satisfaction of the subjects have not been hampered by the more clicks in MFacets and they have been more satisfied regarding the completeness of functionality and the easiness of faceted search. Summing up all arguments and in order to decide for one of the two approaches, it seems that the grid-based approach is a better choice for faceted search on mobile devices.

RELATED WORK

In this section, we discuss various approaches of faceted search. First, we present faceted search on desktop computers. Then, we discuss related work of faceted search on mobile devices and its specific challenges regarding the use and arrangement of facets.

The Flamenco system [18] is an early implementation of faceted search. Here, top-level facets are used as captions to group sub-facets and to differentiate between categories on a website. Since the facet hierarchy is usually implemented as a tree, the facets can be presented in a tree as well. Camelis [5] uses this presentation with expanding and collapsing branches to make jumping between several levels of the hierarchy easier. Polestar [2] groups facets in panes and depending on which facet is selected a new pane with facets appears. Also depending on the selected facets, the content of panes can change or the whole pane can disappear. A zooming presentation to explore facets is implemented in ZEUS [7]. Here, facets are displayed as little windows, which can be zoomed-in at each level until a resource is reached. A combination of different grouping and zooming presentations can be found in FacetLens [13]. To emphasize relations between facets, gFacet [10] displays facets in a graph as nodes, which are connected by labeled edges. In those nodes, sub-facets can either be selected in a regular list or in a drop-down list, if only one selection is possible.

When moving from desktop to mobile applications, these user interaction metaphors cannot be easily used as mobile devices have smaller screen sizes resulting in less space for displaying facets and they have only limited interaction possibilities. Thus, novel interaction and presentation metaphors are needed. With mSpace Mobile [17], there is a pen-based mobile application implementing faceted search. Here, facets are grouped into tiles of lists, which can be expanded to display more entries at once yet scrolling is necessary to explore all facets. Another pen-based mobile application is Mambo [3], which uses zooming operations to explore facets. Due to the zooming implementation, no scrolling is needed during exploration. As already presented above, there is FaThumb [11] as a keypad-based application displaying facets in a 3x3 grid. The Mobile Cultural Heritage Guide [16] is a tourist guide application for touchscreen phones and displays two levels of facets in two rows. Since this application is specifically designed for the cultural heritage domain, the user can only choose between a maximum of four facets per row. The OntoWiki Mobile [4] is another application for touchscreen phones using faceted search. Here, the facets are displayed in lists, which are ordered in pages. Thus, no scrolling is necessary. We have developed MobileFacets [12], as introduced above, that provides also a list-based approach for faceted search but makes use of the scrolling interaction metaphor when there are many facets. Unlike OntoWiki Mobile, MobileFacets does not display the facets on a full screen, but on a half screen since already selected facets are shown on the same screen as well. Another work aiming at evaluating faceted search on touchscreen mobile devices is based on the Diamond Browser [1]. There, a system architecture and a prototype for different faceted interfaces is developed, yet no comparative evaluation has been conducted like in this 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 [9]. To this end, we have implemented a touchscreen-based version of FaThumb's grid-based approach. We decided to choose a list-based approach

to compare it with FaThumb's grid-based approach, as the list-based approach is according to the amount of related work currently the most favorite approach for faceted search on mobile devices. For the list-based approach, we use our own implementation that has been developed in a participatory design with five users and evaluated formatively with additional 12 users [12]. To the best of our knowledge, a summative evaluation of different approaches for faceted search on mobile devices as presented in this paper has not been conducted so far.

CONCLUSION

We have presented a summative evaluation of a grid-based approach and list-based approach for faceted search on touchscreen mobile devices with regards to their usability. To this end, we have introduced the grid-based MFacets, which is inspired by FaThumb, and the list-based MobileFacets and described their principal differences. Both systems rely on a common backend architecture and use the same data set. We have conducted an evaluation with 24 subjects in a between-group design. The results show that MFacets requires significantly more clicks, but subjects need less time for completing the tasks. Furthermore, it has been shown that those additional clicks do not hamper the subjects' satisfaction, resulting in an overall better usability for MFacets' grid-based design.

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