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Comparing viewing and filtering techniques for mobile urban exploration

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The exploration of the immediate surroundings through mobile location-aware devices is starting to become an everyday urban activity. Due to the increasing amount of available geo-referenced information, advanced viewing and filtering techniques need to be investigated as a complementation to simple present-day 2D-map presentations. This article examines both well-established techniques (2D map, list view, category view) and advanced concepts (3D map, tag cloud) regarding their support of mobile urban exploration. In a field study, 26 participants used an experimental multi-view prototype for viewing and filtering tasks on a route through an urban environment. The results show that content-based views may provide similarly good support for viewing the content as spatial interfaces. Furthermore, the experiment provides evidence that the advantages of content-based filtering techniques are increasingly preferred to spatial ones in regard to the amount of available information.

Keywords: mobile urban exploration; user-generated content; location-based service; spatial interface; filtering

1. Introduction

Mobile devices are increasingly used for location-related tasks on the move. Studies show that the usage of mobile maps grows much faster than the access of online maps via desktop PCs (comScore 2008). Mobile maps can help us to find our way through a new city, get noticed when friends are in our proximity and to fetch information about nearby real world objects. Especially, the exploration of urban surroundings by pedestrians to find spatially anchored information, so-called points-of-interest (POIs), is starting to become an everyday activity for a growing user population. While for tourists general information about sights is of primary value, residents of a city are increasingly accessing and contributing dynamic and individual information, such as reviews and recommendations (MobileIn Research 2009).

The growth of location-based content is mainly driven by end-users, who provide geo-referenced images, Wikipedia articles, restaurant reviews and so on.

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This special form of user-generated content, so-called volunteered geographic information (VGI) (Goodchild 2007), poses new challenges to mobile interfaces for spatial information. With this development, we will encounter more and more unstructured digital data bound to real world locations. Advanced mobile spatial interfaces have to cope with this increasing amount of available information and therefore, have to provide users with appropriate mechanisms to explore this content.

The activity of exploring spatial information might show similarities to browsing web sites, a well-investigated task in the field of information seeking. Similar to the traditional web, users have to find their way through the data by performing complementary viewing and filtering activities. In addition to a web browser, an efficient mobile interface for spatial information must consider both the contentual and geographical component of the underlying data set and integrate such different views into one consistent interface.

The current standard way of presenting such spatial content to mobile users is a 2D map and accordingly placed POI icons superimposed on it. We furthermore see a development towards increasing the spatial granularity by 3D and even augmented reality (AR) interfaces. Although there is a growing amount of knowledge on how to visualise such content to mobile users, so far no comprehensive knowledge is available on how mobile users can be supported best in viewing and filtering hardly structured spatial information.

Common approaches such as 2D maps and category selections for POI filtering might not provide the best solution for interacting with VGI. Established techniques for handling VGI in desktop systems such as tag clouds could also improve the browsing experience on mobile devices. Furthermore, the impact of the spatial and non-spatial components of such information on a user's personal exploration strategy is unknown.

In this article, we shed light on these increasingly important aspects of mobile urban exploration. For this purpose, we developed a custom prototype that combines several POI viewing and filtering techniques for mobile urban exploration. With the help of this tool, we conducted a comprehensive user study evaluating mobile users' viewing and filtering behaviours with regard to traditional and novel interfaces and the effects of environmental properties such as the content density. The study provides evidence that the provision of multiple views on an underlying dataset is preferable to the available single view tools. The results achieved will help to design user-oriented mobile spatial interfaces supporting these upcoming tasks.

2. Related work and research questions

In this section, we outline multiple aspects of creating efficient interfaces for mobile urban exploration as basis for our investigations. We subdivide into different challenges and summarise related work regarding the mobile representation of the user's environment, spatial- and content-driven filtering methods, the presentation of user-generated data and theories of information seeking. Finally, we introduce concrete open research questions derived from the survey of related work.

2.1. *Spatial representation*

Due to inherent limitations of mobile devices, such as smaller displays and lower resolutions in comparison to desktop systems, the design and implementation of efficient visual interfaces for spatial information on mobile devices is challenging (Chittaro 2006).

Among the first location-aware exploration tools were Cyberguide (Abowd *et al.* 1997) and GUIDE (Cheverst *et al.* 2000) using abstract 2D maps for displaying the user's location and additional spatially-referenced information. Since then, several mobile guide systems were developed making use of 2D maps (e.g. Baus *et al.* 2001, Pospischil *et al.* 2002, Kray 2003, Krösche *et al.* 2004). Bridging the gap to 3D representations, researchers used 2D maps enhanced with exposed 3D cuboids symbolising conspicuous landmarks (Krüger *et al.* 2004).

In the last years, technological advances enabled full 3D representation of urban surroundings even on mobile phones (e.g. Rakkolainen *et al.* 2001, Laakso *et al.* 2003, Burigat and Chittaro 2005a, b, Nurminen 2006, Coors and Zipf 2007). Some researchers (e.g. Rakkolainen *et al.* 2001, Laakso *et al.* 2003) combined the 3D model with an additional 2D map. In a study, users preferred a combined visualisation over one single view (Rakkolainen *et al.* 2001).

In the meantime, similar products reached the mass market. Google Maps Mobile (Google 2010) is a well-known example for a 2D map application. One of the first public available 3D city guides is Mobile 3D City (Newscape Technology 2009).

Despite visually appealing 3D prototypes, field studies comparing 2D maps with 3D models for usage in common mobile spatial tasks often show advantages for 2D maps. 3D maps were found to be slower to use both in initial orientation and route finding compared to 2D maps (Kray 2003). Rakkolainen *et al.* (2001) speculated that realistic 3D models eased the recognition of a user's own position and landmarks. A comprehensive study with opposed results was presented in Oulasvirta *et al.* (2009) where users had to localise building from a map in the real world. Hereby, the 2D map fared better than the 3D urban model which is partly explained by users' rich experience with paper-based guide books and maps.

Whereas such orientational issues are well-investigated today, so far no studies have been conducted evaluating environmental presentations for viewing and filtering nearby spatial information. Furthermore, research has often focused on engineering challenges, e.g. for enabling advanced 3D views. Yet, the relation between such spatial views and contentual views on the underlying data is still unclear for mobile urban exploration.

2.2. *Spatial-driven information filtering*

One common way to alter or restrict the currently displayed information on a map-based representation is to modify the viewport. Appropriate methods include zooming and panning (Chittaro 2006) which allow the navigation on maps which are larger than the device's display by dragging the view point and zoom in and out. The approach of 'Speed-dependent automatic zooming' for small screens (Jones *et al.* 2005) combines the two concepts of zooming and panning into one operation.

Despite the zoom possibility, users can easily lose the relation between the current visible view and the overall area.

The overview and detail concept (Chittaro 2006) tries to solve the problem of disorientation by providing a second view in form of a narrowed overview map. Being a practicable solution on desktop computers, the overview map is often hard to read on mobile devices to limited display sizes.

A combination of detail and overview is provided by the focus and context concept (e.g. Zipf and Richter 2002). Whereas the view's centre is presented in detail, the surroundings are distorted to show larger areas. A well-known applied effect is a fish-eye view (cf. Keahey 1998) magnifying the map centre. Using only one view, the focus and context approach is suitable for small displays, but can be computationally intensive dependent on the chosen distortion algorithm.

An innovative technique to graphically formulate custom spatial queries on a map is proposed in Lodha *et al.* (2003). The user is able to draw geometric shapes on the map and use them as input parameters for spatial queries.

2.3. *Content-driven information filtering*

Providing context for viewing and filtering in mobile urban exploration does not need to be restricted to such spatial cues, but can refer to the properties of the surrounding content. A well-known example for content-based filtering techniques is the category search applied in many car navigation systems and maps such as Google Maps for mobile phones (Google 2010). This approach can also be adapted for VGI as different sources (e.g. user-provided images from a photo sharing service or articles from an online encyclopaedia) can be mapped to categories.

An advanced filter technique originating from desktop systems are dynamic queries. The application Magda Aesthetic Graph Drawing Application (MAGDA; Burigat and Chittaro 2005a, b) follows this approach and places common graphical user interface (GUI) widgets like checkboxes and sliders below a 2D map. By adjusting these controls, the user changes the criteria for the POI filtering and may view the result immediately on the map. MoViSys (Carmo *et al.* 2008) combines the dynamic queries concept with a degree of interest value calculated for each POI. Due to the size and number of involved GUI widgets, dynamic queries with common GUI widgets are feasible for mobile devices used with a stylus but less practicable for a today's touch screen device controlled with a finger tip. Furthermore, the usage of dynamic queries requires structured underlying content which cannot be assumed in the case of user-generated data.

Some location-aware mobile exploration tools exploit artificial intelligence techniques (Cheverst *et al.* 2000, O'Grady and O'Hare 2005). They make use of additional contextual attributes such as time and user preferences to automatically tailor the provided information and offer personalised recommendations. Again, this approach relies on a well-structured and maintained underlying dataset.

The relation of content-driven and spatial-driven filtering in the context of mobile urban exploration has not been investigated so far. We assume that the number of available at the current location, i.e. the location's POI density, influences the choice of the filtering method.

2.4. *Dealing with unstructured content*

Unstructured user-generated content is often organised through freely chosen labels, so-called tags. Appropriate tags are in most cases assigned by the authors but can also be automatically extracted from full texts by text mining tools. Based on a dataset's tags, a tag cloud can be generated showing the frequency of assigned single tags in form of a weighted list. Such a representation is useful for several tasks such as gisting, i.e. getting an overview and browsing (Rivadeneira *et al*. 2007).

Jaffe *et al*. (2006) presented a novel visualisation approach which combines common 2D maps with tag overlays resulting in the so-called tag maps. An exploratory cycle for filtering content via a spatial map as well as via an aspatial cloud representation is presented in Slingsby *et al*. (2007). Nevertheless, scientific work investigating the use of tagged data and its representations in a mobile spatial context is scarce. A mobile representation technique similar to tag maps is proposed in Jones *et al*. (2007) where the authors placed recently conducted web search queries of nearby mobile users on a map providing insights into a location's character.

As an emerging concept on modern websites, tag clouds might also be an interesting concept for mobile urban exploration. Generated from nearby POIs, such ambient tag clouds abstract from a location's concrete POI density and could serve as a location summary. Additionally, it is unclear whether the usefulness of such a novel concept depends on a user's technical background and affinity.

2.5. *Information seeking*

Basically, a geo-referenced item is a digital resource such as a text or a media file featuring an additional component in the form of a spatial identifier. Thus, both spatial and aspatial exploration techniques of such content are possible. In the last few years, several models for information seeking behaviour have been developed.

Based on a study on web browsing, researchers derived three types of browsers (Catledge and Pitkow 1995): the serendipitous browser, the general-browser and the searcher. Whereas the searcher has a clear target, the serendipitous browser's strategy is undirected navigating by interest and curiosity. The general-browser shows characteristics of both other types. Similarly, another team of researchers (Choo *et al*. 2000) divides different browsing strategies into the four modes of undirected viewing, conditioned viewing, informal search and formal search. Undirected viewing refers to browsing with no specific need. During conditioned viewing, the user focuses his browsing behaviour on selected topics. An informal search then aims at deepening the knowledge. Finally, conducting a formal search the user wants to obtain specific information.

Obviously, different browsing strategies require different types of user interfaces. A search field might be impractical during undirected viewing; an overview representation inefficient during a formal search. To support each user in her personal browsing strategy, exploration tools with several different views on the underlying dataset seem preferable.

2.6. *Research issues*

Based on the preceding survey describing related work in the field of mobile urban exploration, we identified the following research issues:

- Q1: To what extent do content-based views support users in getting an overview during mobile urban exploration, as compared to spatial techniques?
- Q2: To what extent do content-based filtering techniques support users in browsing during mobile urban exploration, as compared to spatial filtering techniques?
- Q3: Do properties of the environment, most importantly the POI density, influence the technique's support for mobile urban exploration?
- Q4: To what extent do advanced spatial techniques, especially 3D maps, support users during mobile urban exploration, as compared to a standard 2D map view?
- Q5: To what extent do advanced content-based approaches, such as ambient tag clouds, support mobile urban exploration?

3. Method

A field study was designed to address these research questions. The study took place in the city centre of Vienna, an area with historical streets and squares, as well as hundreds of stores, restaurants and cafes and included several exploration tasks involving various viewing and filtering techniques.

The subjects (13 female, 13 male) were aged between 20 and 68 (mean = 30.2 and median = 24.5). As remuneration, each subject received a voucher for a consumer electronics store. Due to the growingly mundane character of mobile urban exploration, we deliberately recruited residents of Vienna, not tourists. All subjects lived in other parts than the city centre, only sporadically visiting the historical city centre (on average for 2.6 days per month), mainly for leisure activities. 40% of the participants reported to use their mobile phone for accessing the Internet. Furthermore, 66% used the web for accessing location-based information on a daily basis.

Each participant passed 14 predefined positions along a 3.5 km route through the inner city of Vienna on foot, accompanied by a test moderator. At each position, the participant was asked to perform a specific exploration task with a certain setup of the experimental prototype.

3.1. *Experimental prototype*

Our prototype combined several visualisation methods for spatial content with different ways to filter the currently available POIs. It consisted of a Java application running on a Nokia N97 mobile phone (Figure 1). This model features a built-in global positioning system (GPS) receiver and a high-resolution touch screen with a size of 640×360 pixels. The application communicated with a remote service platform serving 2D map tiles, 3D building geometry and POI information.

Figure 1. The study application was installed on a Nokia N97 mobile phone featuring a high resolution touchscreen and a built-in GPS receiver.

We aimed at designing a consistent user interface for our prototype (Figure 2) accommodating several views. Therefore, we made a clear visual distinction between the viewing and filtering techniques. The three buttons at the top switch between different POI views. From left to right, the buttons offers a textual POI list (Figure 2a), a 2D map (Figure 2b) and a 3D map (Figure 2c). On the maps, POIs are symbolised by overlaid category icons. Both the list entries and category icons are touch-sensitive. Touching one of the POIs opens the description screen. In case of multimedia content, the image or video is displayed; otherwise, textual information about the chosen POI is presented. Pushing the, back button, the user returns to the former POI view.

At the bottom, we placed buttons to apply filtering techniques. From left to right the buttons trigger a tag view (Figure 2e), a category view (Figure 2d) and a text search (via the phone's standard on-screen keyboard) and, in case of a map, perform zoom operations. Whereas zooming acts as a spatial filter, the other techniques rely

Figure 2. Three POI viewing (a, b, c) and two POI filtering techniques (d, e) implemented in the presented prototype.

on the content of the POIs. They are used to set a filter criterion and then switch to a POI view via one of the upper buttons to see the remaining POIs. These filters are mutually exclusive, e.g. selecting a category disables a former set tag filter.

For the various tasks in the user study, single buttons can be easily disabled by the test moderator to focus on specific techniques. In unrestricted mode, the free combination of viewing and filtering techniques is possible. For later analysis, each button touch of a user is recorded in a local log file.

Table 1. The route consisting of 14 points with varying POI density was divided into four phases. Starting with a training phase to get used to the application the following three phases tested different viewing interfaces and filtering methods.

Location	POI density	Phase	View	Filter
0	Low	Training	Unrestricted	Unrestricted
1	High	Gisting	2D map	None
2	Low		3D map	None
3	Low		Tag view	None
4	High		Category view	None
5	High	Restricted exploration	2D map	Zoom
6	High		3D map	Zoom
7	High		Tag view	Tag selection
8	Low		Category view	Category selection
9	Low		Text search	Keyword
10	Low	Unrestricted exploration	Unrestricted	Unrestricted
11	High		Unrestricted	Unrestricted
12	High		Unrestricted	Unrestricted
13	Low		Unrestricted	Unrestricted

3.2. *Route description*

The route's positions and the associated POI contents were chosen due to varying different urban terrain types, the POI density and different thematic focus of the POIs. For each location, POIs in a radius of 150 m were considered for visualisation. We systematically selected locations that could be allocated to a high POI density (large squares or shopping promenades) or low POI density (smaller streets with few shops, cultural attractions, etc.). The mean number of POIs within the aforementioned range was 13 for locations with a low POI density and 42 for locations with a high POI density.

The route was divided into four phases as given in Table 1: an initial training phase (at the first location, to get familiar with the prototype), the gisting phase (four positions), the restricted exploration phase (the following five positions) and the unrestricted exploration phase (four positions). In a final interview, the participants' overall reflections of the experienced situations and prototype setups were gathered.

In order to avoid learning and preference effects, as well as biases by the respective terrain and POI characteristics, the different user interfaces presented to the participants were systematically varied within the phases. As these phases differ in terms of tasks, procedure and the involved visualisation techniques, they will now be explained separately.

3.3. *Gisting phase*

This phase aimed at understanding how different visualisations support impression formation on first sight, without interacting ('to get the gist'). At each of the four positions, the participant was confronted with one of the following visualisations:

- The category view (Figure 2d) lists all available categories such as 'restaurant' with the respective number of contained POIs.

- The tag view (Figure 2e) is generated from describing labels attached to each POI. A tag's font size indicates the relative frequency this tag was assigned to currently nearby POIs.
- On the 2D map (Figure 2b), visible POIs are symbolised by appropriately overlaid category icons.
- Finally, the 3D map (Figure 2c) shows a model of the surrounding buildings in a 45° bird's eye view. Again, the map is augmented with category icons placed at the appropriate POI locations. To minimise the possible occultation of icons by buildings as effectively as possible, the icons are raised on top of comprising buildings. The applied urban model is highly detailed but is not textured to provide better contrast against the coloured category icons.

During this phase, filtering and any interaction possibilities were disabled. After 30 s, the users were asked to describe in their own words the information offered at the respective location. Furthermore, they provided a rating of how well they could get an overview of the available information with the respective presentation.

3.4. *Restricted exploration phase*

The study continued with a phase named restricted exploration. This phase's aim was to gain knowledge about the usefulness of different POI filtering methods. Thereby, both spatial and aspatial filtering methods were evaluated. The aspatial, i.e. content-related filtering methods are extended with a non-interactive 2D map to view the filter results. Switching back to the filtering method was enabled by a 'back' button.

We asked the participants to imagine the following scenario: the participant has arranged to meet a friend in the city. Because the friend is late, the participant wants to pass the time and decides to explore the meeting point with her mobile phone. The goal was to find a POI that is interesting or relevant to the user.

We confronted the subject with one of the following filtering techniques at the next five points:

- The aspatial category view (Figure 2d) allows the selection of one category. Only POIs belonging to the chosen category are then displayed on the map.
- Also in the tag view (Figure 2e) one entry can be selected to restrict the POIs on the non-interactive 2D map to the ones labelled with the chosen tag.
- The text search allows the input of arbitrary keywords. Only POIs with a name matching the keyword are then displayed on the 2D map.
- The interactive 2D map with zoom (Figure 2b) is used as a spatial filter. Zooming restricts or expands the current viewport map and therefore, modifies the set of currently visible POI icons.
- Finally, the 3D map with zoom (Figure 2c) works like the 2D map zoom but shows a 3D representation of the surroundings.

No time limit was given for experimenting with the filtering techniques. After the participants had chosen a POI and the task was completed, we asked them to rate the respective filter technique's general support for browsing the content. Next, we wanted to know how well the participants could spot the relevant POIs using the given technique. Finally, the participants were asked for situations where they considered the presented technique to be useful.

3.5. *Free exploration phase*

In the free exploration phase including the last four points of the route, the functionality of our prototype was unrestricted. Users were allowed to freely combine all implemented viewing and filtering techniques. For representing single POIs they could chose between a POI list, the 2D map and the 3D map. Filtering was supported via the tag cloud view, the category view, the text search and the zoom feature.

This phase aimed at learning about preferred views and at understanding the interaction of spatial and aspatial content representations. Furthermore, the task was designed to possibly uncover favourable browsing strategies.

The scenario we described for the participants was the same as in the preceding phase, i.e. passing time while waiting, with the goal to choose an interesting POI among the available information. During this phase, no subsequent questions were asked. To evaluate the participants' behaviours, we carried out a clickstream analysis based on our application's log file.

3.6. *Final interview*

The final interview aimed at gathering a comparative conclusion of the subjects' overall experiences throughout the study. The first three questions aimed at comparing the overview visualisations. The participants were shown screenshots of the category list, tag view, 2D map and 3D map and were asked to rank them according to their usage preference – first in general, then for locations with much content, and then for locations with less content. The next three questions asked for a preference ranking with regard to the four filtering techniques (tag, category, keyword and zoom), again first in general, then for high and low POI density. A final open question asked about further comments.

4. Results

In this section, the results from the five phases of the study are subsequently presented. The statistical analysis was based on the data from 25 of the 26 participants (participant 5 was excluded from the sample, due to insufficient compliance with the test procedure). Mean differences were calculated with non-parametrical techniques for dependent samples (Friedman and Wilcoxon tests). Error bars in the figures indicate 95% confidence intervals.

4.1. *Gisting phase*

None of the four viewing styles (category, tag cloud, 2D map and 3D) appeared to provide a particular advantage for impression formation. When the participants were asked to provide a rating on how well they could get an overview, no significant difference was found. Furthermore, no effects by age, gender or mobile Internet usage were found.

From the transcribed verbal descriptions of the available information, we extracted and counted the number of mentioned content items. Also here, we did not find many notable differences between the overview techniques. The only statistically significant result was that more items were mentioned with the category overview than with the 3D overview.

4.2. *Restricted exploration phase*

The analysis of the data from the restricted exploration phase concentrated on analysing the ratings perceived for browsing support.

4.2.1. *Satisfaction with filtering method*

As Figure 3 shows, both category and tag filtering received scores higher than 4 with regard to 'support for browsing'; the mean score for category was higher than tag (4.5 vs. 4.1), but the difference did not reach statistical significance. Zooming a 2D map achieved the third-highest ratings (3.72); the mean score was significantly lower than category, but not significantly lower than tag. Keyword and 3D zooming were rated least supportive; their mean scores (3.2 and 3.0) did not differ between each other, and they were significantly lower than those of the best-rated category and tag alternatives. Notably, 3D zooming was rated as significantly less supportive than 2D zooming.

Many participants regarded category and tag filtering as a means to raise curiosity and willingness for exploration. Zooming was often chosen as a means to more clearly arrange the view for browsing. Zoom and keyword were regarded as

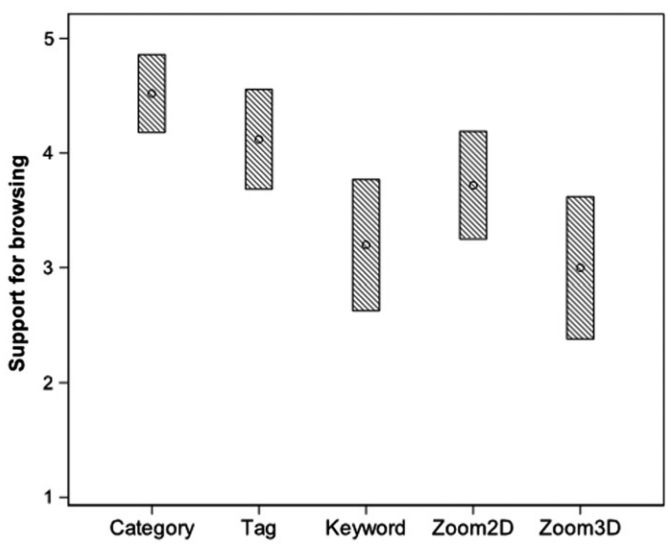

Figure 3. Mean ratings for the filtering techniques, regarding the support for browsing.

rather specific filter methods, whereby zoom required knowledge of the location, and keyword knowledge of the searched name.

4.2.2. *POI density*

Comparing each filtering techniques' support for browsing at locations with high vs. low POI density only revealed one significant difference: keyword search was rated better when used with much content than with few content ($Z = -2.042$; $p < 0.05$).

4.3. *Unrestricted exploration phase*

The log file data of the four unrestricted exploration sessions was analysed to get an impression of how much the various filter and viewing strategies were actually used.

4.3.1. *Filtering content*

Figure 4 shows the mean frequency of button presses for the category, tag, keyword and zoom filter, as well as the respective 95% confidence intervals. Participants used category filtering most often (8 times per location); the frequency was significantly higher than tag (4 times) and keyword (2 times, for all differences $p < 0.05$). On average, zooming was used similarly often than categories (7 times), but the usage frequency was only significantly higher than keyword. As illustrated in Figure 4, keyword was used fewer times than all others (all differences $p < 0.05$).

4.3.2. *Viewing filtered content*

To get an impression of which kind of POI view was chosen, we analysed the durations how long a list view, a 2D map and a 3D map were active. The mean

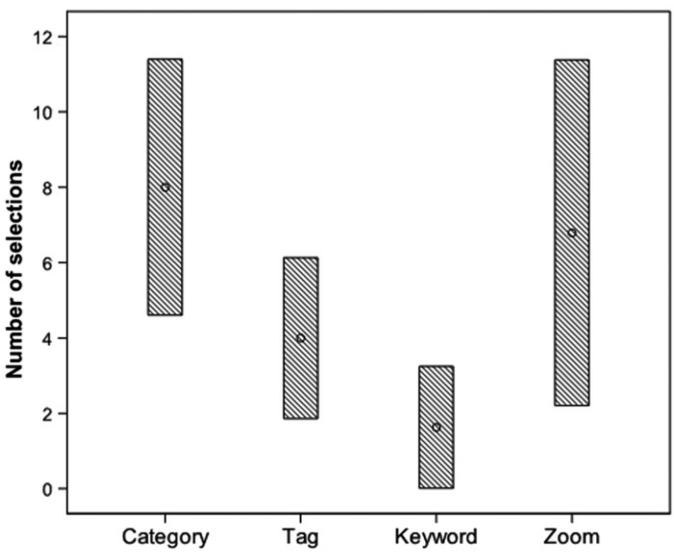

Figure 4. Mean number of selecting the buttons category, tag, keyword and zoom per location.

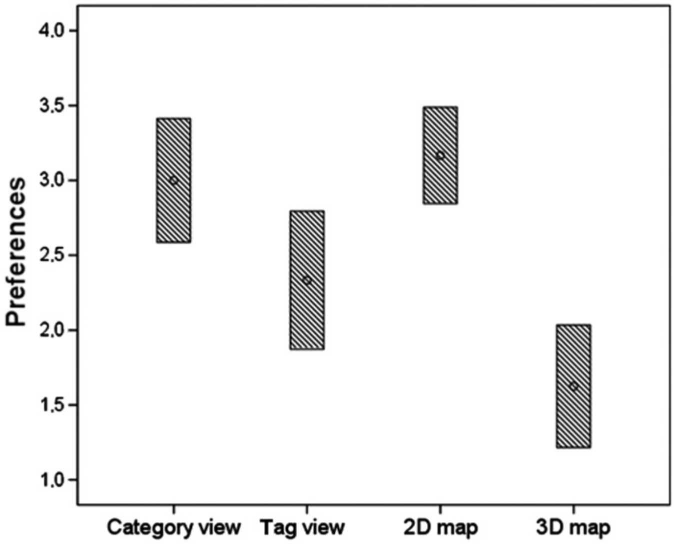

Figure 5. Mean preference rankings for the overview techniques.

durations differed significantly among the three POI views (25 s for 2D map per location, 12 for list and six for 3D map; all differences $p < 0.05$). The same applied for the times a view was on average selected at a location: 16 selections presses for 2D map, 10 for list and 4 for 3D map (all differences $p < 0.05$). Observations and user comments indicate that 2D maps were mainly selected to get an overview and to look at a certain location in more detail (by zooming). The short durations and few selections for 3D maps were mainly due to problems of visibility. For example, POIs were partly hidden due to higher buildings.

4.3.3. *Selecting POI descriptions*

Only about 25% of all button presses were related to selecting the actual description of an item. POI descriptions were most often accessed from a 2D map (2.4 per location on average), followed by the list (1 per location) and the 3D map (0.22 per location).

4.3.4. *POI density*

Comparing the usage of filtering techniques at locations with high vs. low POI density, we found one significant difference: the list view was significantly more often selected at locations with a high POI density. According to user comments, the list was rather selected as a means to filter or to circumvent the 2D map in case of much content.

4.4. *Final interview*

The results for the preference rankings are illustrated in Figures 5–7. We first report on the overview visualisations comparison, then on the filter techniques comparison, and finally on effects of POI density and participant characteristics.

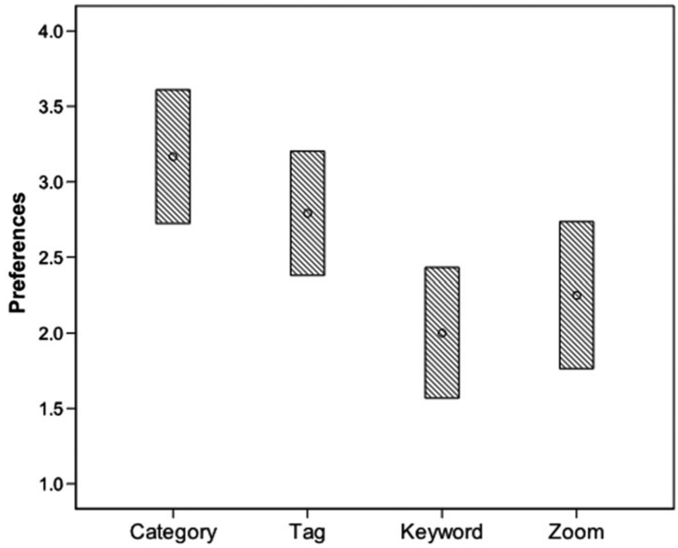

Figure 6. Mean preference rankings for the filtering techniques.

4.4.1. *Overview visualisations*

According to the mean preference ranking results (Figure 5), 2D map and category view were preferred to tag view and 3D map (all respective pairwise differences were significant, $p < 0.05$). The mean rankings for the two preferred overview visualisations 2D map and category view did not differ significantly from each other. Similarly the mean ranking for tag view was notably higher than for 3D view, but also this difference did not reach significance ($Z = -1.863$; $p = 0.062$).

4.4.2. *Filtering techniques*

Figure 6 shows the mean ranking scores of the filtering techniques: category (3.2), tag (2.8), keyword (2.0) and zoom (2.25). While the mean ranking for category was not higher than tag, it was significantly higher than zoom and keyword. Tag was not significantly higher than zoom ($p = 0.18$), but it was than keyword. The ranking of keyword was significantly lower than all other alternatives.

4.4.3. *POI density*

Comparing the participants' rankings for locations with high vs. low POI density, several differences were found. Figure 7 shows that 2D and 3D map overview visualisations were less preferred for high than for low-density locations. On the contrary, category and tag views were more preferred for high than for low-density locations (all differences significant, $p < 0.05$). For the filtering techniques, the zoom technique was preferred significantly less for high than for low-density locations ($Z = -2.071$; $p < 0.05$). Other pairwise differences did not differ significantly.

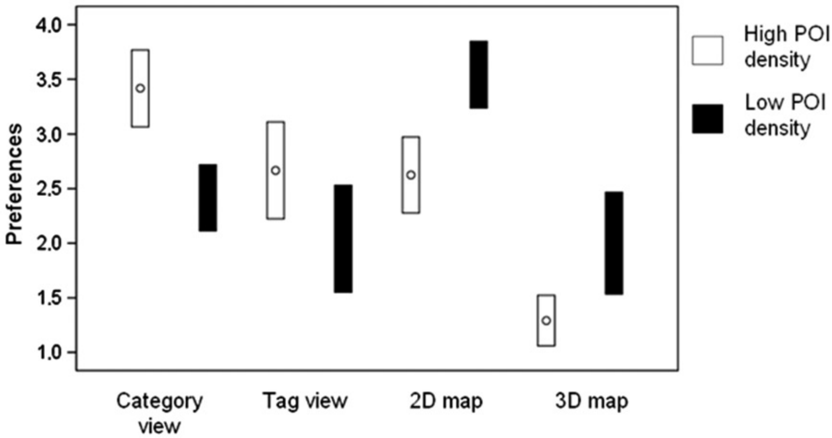

Figure 7. Mean preference ranking results for the overview visualisations, each for much vs. few content.

4.4.4. *Participant characteristics*

Also here, no significant gender or age related differences could be found. However, participants with mobile Internet experience ranked the tag cloud significantly better ($Z = 2.290$; $p = 0.026$).

5. Conclusion

In the following, the results are summarised with regard to the research questions.

5.1. *Q1: Content-based vs. spatial-based viewing techniques*

The predominant focus on (2D) spatial views in current mobile urban exploration services is not fully justified by our study. We did not find evidence that 2D maps provided better support for impression formation than other techniques (see gisting phase). Furthermore, category lists were seen as a similarly well suited tool for getting an overview of the overall surrounding content as 2D maps (see interview). While 2D maps were the preferred alternative for viewing the selection of filtered POI, a list overview was still chosen in about one third of the observed cases (see unrestricted exploration phase).

5.2. *Q2: Content-based vs. spatial-based filtering techniques*

Our results also show that the currently prevalent singular provision of zooming and keyword entry for content filtering may not be optimal for urban exploration. While browsing, users often used the category technique as zooming technique (see unrestricted search phase). The users' judgements even indicated a clear advantage of both category and tag-based filtering.

5.3. *Q3: The impact of content density*

We found evidence that content-based (at least category and tag) approaches are more supportive than spatial-techniques, when more content is around. For example, the list view appeared to be a good mean to avoid overcrowded POI maps (unrestricted search). The users' statements directly after usage and in the interview made this advantage even clearer.

5.4. *Q4: Advanced spatial techniques (3D map)*

Our results show that with the current state of the art design knowledge, 3D views do not yet provide much support for mobile urban exploration. Users did barely use 3D views during the unrestricted exploration, and they complained about POI hidden behind other objects.

5.5. *Q5: Advanced content-driven techniques (tag cloud)*

This first introduction of the tag cloud concept in the mobile urban exploration context has shown highly encouraging results. Especially for filtering it was seen as an interesting alternative. Based on the identified inter-individual differences (Section 4.4.4), one might argue that people with technology affinity persons might better benefit from tag clouds than others.

6. Discussion

In this article, we presented the first comprehensive comparative study on everyday mobile urban exploration techniques. To make sense of the growing quantity of VGI, optimal support for content viewing and filtering are indispensable. In our study, we included common and advanced techniques for content- and spatial-driven browsing strategies: a 2D map with zooming feature, a list representation, a category selection and a text search, as well as a 3D map and a tag cloud generated from the nearby content. The tag cloud concept has been evaluated for the first time in a mobile spatial context. We designed a prototype mobile urban exploration service that should both allow to compare these techniques and to investigate potential efficient combinations. The service environment also deliberately accounted for typical densities of geo-referenced content.

An interesting result related to viewing spatially-referenced content is that the summarising aspatial category view was rated similarly well as the common 2D map. This indicates that spatial cues are not primarily necessary for getting the gist of the surrounding content. This finding can also partly explain the low usage and acceptance of the 3D map. Even though the task was to get an overview of the surrounding information, participants confronted with the 3D map focused on spatial cues and were occupied in orienting themselves. In the context of finding interesting information in the vicinity, such a quasi-realistic representation appears to be far too detailed and offers too much unnecessary information which increases the user's workload and distracts from the actual task.

Furthermore, the placement of symbols for user-generated geo-referenced content in a 3D model is challenging. POIs that are referenced inside a building can be displayed at the building's roof but still the placed symbol could be occluded by a larger building in front.

The tag view, which had actually been designed for getting the gist of the underlying data, was not favoured for such a purpose. However, as technology-affine users were more positive towards the tag view, this may change as tag clouds get more 'mainstream' on the web.

Concerning the filtering techniques, the failure of the keyword search was expectable, as our tasks focused on browsing, and not a concrete search for a specific POI known by name. Surprisingly, the content-driven category filters were preferred to the zooming feature. We explain this result with the special characteristics of mobile urban exploration: users browse their immediate surroundings, and therefore zooming is hardly necessary because the complete relevant area can be displayed on the device's screen. We expect different results if we would use our prototype for the mobile exploration of arbitrary remote places.

During filtering, the proposed novel tag approach performed similarly to the best-rated category filter. We suppose that, even though most of the subjects were not familiar with the actual cloud concept, uncommon tag labels arouse their curiosity and the filtering was intuitive.

Finally, our study showed that users utilise several views on underlying dataset besides the common 2D map. In this sense, current mobile map solutions are not optimally designed for mobile urban exploration. If existing solutions offer multiple views, they are often hidden in a settings menu or similar. The modular research prototype presented may provide valuable insights for improved developments.

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