Vertical Colour Maps – A Data-Independent Alternative to Floor-Plan Maps

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ABSTRACT

Location sharing in indoor environments is limited by the sparse availability of indoor positioning and lack of geographical building data. Recently, several solutions have begun to implement digital maps for use in indoor space. The map design is often a variant of floor-plan maps. Whereas massive databases and GIS exist for outdoor use, the majority of indoor environments are not yet available in a consistent digital format. This dearth of indoor maps is problematic, as navigating multistorey buildings is known to create greater difficulty in maintaining spatial orientation and developing accurate cognitive maps. The development of standardized, more intuitive indoor maps can address this vexing problem. The authors therefore present an alternative solution to current indoor map design that explores the possibility of using colour to represent the vertical dimension on the map. Importantly, this solution is independent of existing geographical building data. The new design is hypothesized to do a better job than existing solutions of facilitating the integration of indoor spaces. Findings from a human experiment with 251 participants demonstrate that the vertical colour map is a valid alternative to the regular floor-plan map.

Keywords: indoor, visualization, cartography, vertical colour map, indoor space

RÉSUMÉ

La rareté des données de positionnement intérieur et le manque de données de construction géographiques limitent le partage de la localisation dans les environnements intérieurs. Récemment, plusieurs solutions ont commencé à mettre en œuvre des cartes numériques utilisées à l'intérieur. La conception des cartes constitue souvent une variante des cartes basées sur les plans d'étage. Il existe des bases de données massives et des SIG pour usage à l'extérieur, mais la majorité des environnements intérieurs ne sont pas encore disponibles en format numérique uniforme. Cette pénurie de cartes intérieures pose problème, car il est reconnu que l'orientation dans des bâtiments à étages multiples rend plus difficile le maintien de l'orientation spatiale et la création de cartes cognitives fidèles. La mise au point de cartes intérieures normalisées plus intuitives peut régler ce problème frustrant. Les auteurs présentent donc une solution de rechange à la conception courante de cartes intérieures qui explorent la possibilité d'utiliser la couleur pour représenter la dimension verticale sur la carte. Cette solution n'a aucun lien avec les données géographiques existantes de construction, ce qui est important. On pose en hypothèse que le nouveau concept réussit mieux que les solutions existantes à faciliter l'intégration des espaces intérieurs. Les constatations tirées d'un essai effectué avec 251 participants démontrent que la carte couleurs verticale constitue une solution de rechange valide aux plans d'étage ordinaires.

Mots clés : intérieur, visualisation, cartographie, carte couleurs verticale, espace intérieur

1. Introduction

Location sharing is becoming increasingly popular in social media platforms. Indeed, all of the major platforms such as Facebook, Twitter, Foursquare, and Google include functionality for location sharing (Facebook 2012; Foursquare 2012; Google Latitude 2012; Twitter 2012). Despite this trend, full utilization of location sharing in social media platforms has not been fully realized. Indoor environments represent one such domain with significant, unmet potential. Reports indicate that about 90% of the time spent by people is inside buildings (US EPA/Office of Air and Radiation 2012). Despite this skewed distribution of time compared to that spent outdoors, utilization of location sharing in indoor space remains a largely unexplored area for social media platforms. One of the obstacles is the lack of widespread positioning technologies, owing primarily to the absence of GPS positioning inside buildings. GPS signals require a direct line of sight from the satellites to the receiver and signal attenuation due to walls and building infrastructure makes positioning performance inaccurate and unreliable (Yang and others 2007). There are, however, several alternatives for GPS-based positioning indoors, with WiFi positioning being one of the most promising technologies expected to experience significant advances in accuracy and availability in the near future (Schrooyen and others 2006; Liu and others 2007; Mok and Retscher 2007; Mautz 2009; Curran and others 2011).

With the promise of reliable indoor positioning being a reality in the near future, the need for expanded knowledge of visualization of indoor space is required for immediate navigation support and full utilization of indoor positioning systems. Current visualization techniques of indoor space consist largely of variants of floor-plan maps. In this context, floor-plan maps are considered to include maps that cover a single floor in one map, with its contents providing details about the interior geometry of this floor. The variants differ in the abstraction level of the data. Often, a low abstraction level is observed, where the complete building data are mapped, similar to architectural drawings. Architectural floor-plan maps are often used as you-are-here maps for emergency purposes. Other uses of floor-plan maps are often depicted with higher abstraction levels, where the level of detail is lower, and there is a focus on specific parts of the building's structure and entities within it. These types of floor-plan maps are commonly found in airports, hospitals, and shopping centers (My Way 2011; Point Inside 2011; Floorplanmapper 2012). The style and representation of floor-plan maps rarely follows a cohesive design and varies greatly among buildings. Without widely recognized and intuitive map designs for indoor environments, current map solutions can be difficult to use and often require time and effort by the user to be learned and comprehended effectively. We postulate that the development of intuitive and consistent map designs will make reading and using the maps easier for users, as well as provide them with an important tool facilitating improved cognitive understanding and navigation of multistorey buildings.

Recently, indoor maps, represented with floor-plan maps, have been integrated with commercial Web maps of outdoor space (Bing Mall Maps 2011; Google Maps 2011; OpenStreetMap 2012). Integrating floor-plan maps in outdoor maps requires that the floor-plan data exist and are available to use; however, the problem is that neither of these requirements is often the case. In addition, adapting the data can be associated with a large economic cost, both in terms of time and monetary resources. Data models, ontologies, and standardizations are still in development, which inhibits production and availability of geographical databases of indoor space (Giudice and Li 2012). This challenge motivates the need for investigating other equally efficient, or better, visualization methods that can communicate location information inside buildings where data are otherwise scarce or non-existent.

Until recently, most research on cartographic applications in indoor environments has focused mainly on indoor positioning systems, rather than the visualization itself (Ciavarella and Paterno 2004; Schrooyen and others 2006; Dahl and Svanæs 2008; Yang and others 2007; Huang, Gartner, and Ortag 2009; Mautz 2009; Curran and others 2011). The result of this technical work has been invaluable to the evaluation and development of new and better positioning systems for indoor space. But corresponding development and evaluation of information visualization methods for the same spaces has not garnered this level of attention (Puikkonen and others 2009; Nossum 2011). Indeed, seemingly arbitrary variants of floor-plan maps have been the visualization method in many of the projects focusing on indoor positioning (Butz and others 2001; Ciavarella and Paterno 2004; Radoczky 2007). One of the exceptions to this argument is the literature on you-are-here maps for emergency purposes and other symbol-specific evaluations. The work within this topic has been extensive including work on symbolization, standardization, and visualization (Klippel, Freksa, and Winter 2006; Klippel, Hirtle, and Davies 2010; Pakanen, Huhtala, and Häkkilä 2011). Floor-plan maps have been the favoured visualization method for you-are-here maps, but little is known as to whether an alternative exists that facilitates the cognitive integration of multistorey buildings. We posit that such an alternative can also be designed to not be dependent on existing geographical data of the building.

Complex multistorey buildings often cause people to become frustrated, disoriented, or to get lost during navigation. The literature demonstrates that people in general are significantly less accurate when pointing between floors than within floors. The reason for disorientation is argued to be due to problems synthesizing inter-floor knowledge both in physical and virtual environments (Passini 1992; Montello and Pick 1993; Soeda, Kushiyama, and Ohno 1997; Richardson, Montello, and Hegarty 1999; Wiener, Schnee, and Mallot 2004; Hölscher and others 2006; Hölscher and others 2009; Giudice, Walton, and Worboys 2010). The performance of indoor way-finding with floor-level changes has been shown to decrease with disorientation during vertical travel (Soeda, Kushiyama, and Ohno 1997).

Based on the popularity of location sharing and indoor positioning technologies, we believe an increasing demand exists for new visualization methods of indoor space. Floor-plan maps are the most common visualization method and are reasonable to use as a benchmark for comparison.

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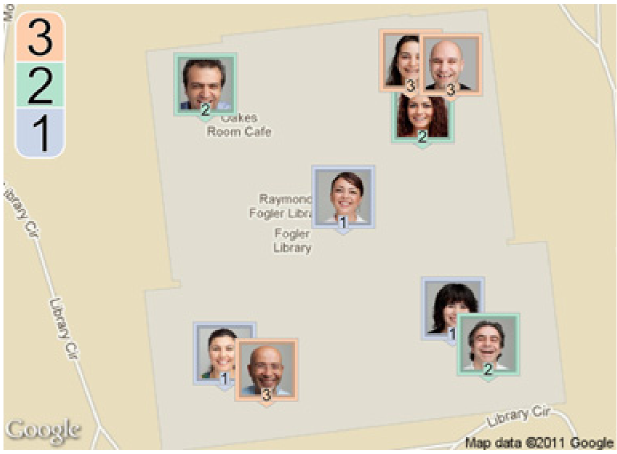

Figure 1. Example of the proposed map design showing Facebook friends inside a three-storey building. Colour indicates the vertical location of the friend. Map data © 2011 Google

Figure 2. An example of using a sequential colour scale for different floors. This can give an impression of depth in the different floors. Map data © 2011 Google

We postulate that increasing the ability for visualization methods to facilitate integration of multistorey buildings will lead to increased use and greater development of indoor maps and indoor navigation tools. As a direct effect, this will help ameliorate the known cognitive challenges associated with travel in indoor environments. Visualization of multistorey buildings needs not only to maintain and facilitate the horizontal orientation but equally well the vertical orientation within the building. In addition, new visualization methods are in particular demand when the availability of geographic data, which is necessary for making floor-plan maps, is scarce. Users are already asking the question, Where are my friends? Soon they will be asking the question in the context of indoor space. We posit that widespread solutions for this demand require developing new visualization methods for complex indoor spaces, particularly one that emphasizes vertical displacements. In light of this challenge, we propose and evaluate a visualization method called the *vertical colour map*, which is capable of visualizing both the horizontal and vertical location of friends inside a building. Importantly, this is done without the need for existing floor-plan maps or other geographical data.

2. Vertical Colour Map

The vertical colour map was developed to enable visualization of information across floors without requiring geographic building data, as is needed for regular floor-plan maps. To support these features, the map uses colour to communicate the vertical location and building outlines to communicate the horizontal location; an example map is depicted in Figure 1. The use and study of colour has a long tradition in cartography and graphic design and has also been employed to visualize indoor environments (Giudice and Li 2012). Earlier research shows that colour can be categorized into a set of graphic variables that describe the different properties of these key variables (Bertin 1983; Spence 2007; Ware 2012). One of the key properties is the ability to differentiate between objects, often called selection (Spence 2007). The variables that are best suited for selection are size, value, texture, and colour (hue). The vertical colour map takes advantage of the knowledge of visual variables by using colour, or more specifically hue, to represent objects in different floors, which, according to the theory, should be able to promote visualization of objects from multiple floors while clearly being able to differentiate between them. Stacking of overlapping symbols and labels with the floor number in both the symbols and the legend are used to represent the vertical information together with the colour variable. The maps used in the experiment, however, only manipulated the colour in both the symbols and legend. Figure 1 illustrates an example of the map design displaying Facebook friends inside a three-storey building.

An illustrative example that fits well within the scope of the vertical colour map is a student who wants to see where her friends are inside a familiar library on campus. Both the horizontal and vertical location is of interest and should be easy to differentiate. An underlying assumption is that the student wants to get this information as fast as possible.

The map in Figure 1 uses a qualitative colour scale to maximize the selective properties of colour (Harrower and Brewer 2003; Spence 2007; Ware 2012). An alternative to this approach is to look at different floors as quantitative information and use a sequential colour scale for the different floors (Harrower and Brewer 2003; Nossum 2011). A sequential scale gives the impression of depth and vertical relationship between floors. We believe that this can be particularly useful for situations with many

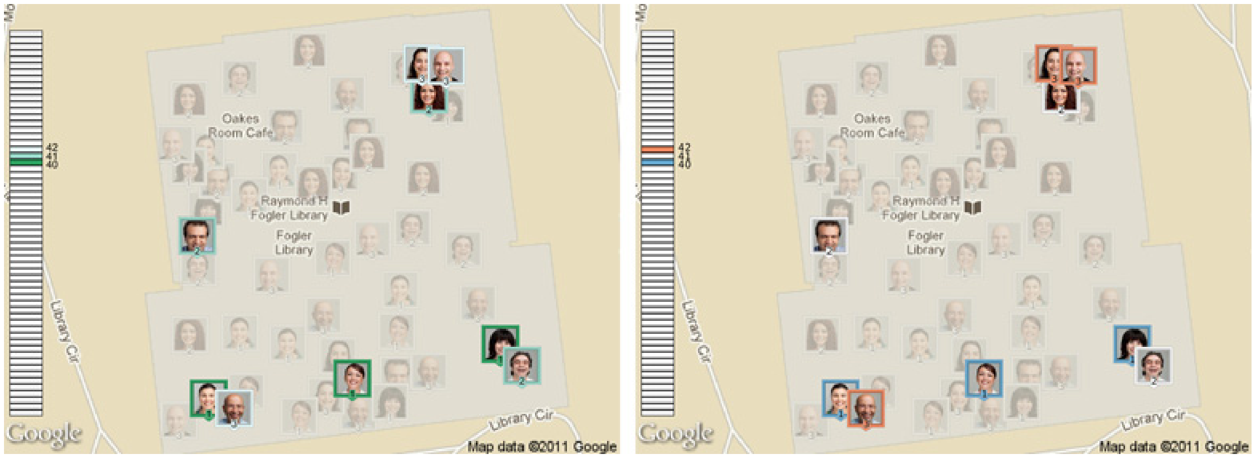

Figure 3. Overcoming colour limitations for multistorey buildings by selecting a floor of interest and showing nearby floors with a sequential or diverging colour scale while the rest of the floors are faded out. Map data © 2011 Google

floors where ordering of the floors can aid in the perception of the vertical relationship between floors. A sequential colour scale is better suited to support both differentiation as well as ordering of the objects (Spence 2007). An example of a map implementing a sequential colour scale is shown in Figure 2.

The building chosen in this initial project is a three-storey library. Other, taller buildings will challenge the limits of the vertical colour technique, although this was not evaluated in this project. Both the qualitative and sequential colour scale techniques have similar limitations for high, multistorey buildings. In these environments, overlapping information will become an increasing problem combined with problems of differentiating between floors, even with a qualitative colour scale. One obvious example where such an issue will occur is when many friends are at the same horizontal position at the same time. Aspects of generalization and clustering techniques will be required to properly overcome such issues. This is similar to problems faced in outdoor cartography. Another approach, relevant to the vertical colour map, is to only display a subset of the floors and the friends within those floors. The user can select a defined subset or a range of floors above and below either a selected floor or, automatically from, the user's vertical location. The remaining floors and friends not in the selected range can be de-emphasized by using a transparent grey colour. Figure 3 depicts two examples of this solution where one floor is selected and three nearby floors are emphasized while the rest are faded out. The first example uses a sequential colour scale while the second uses a diverging colour scale to give a vertical egocentric view of the different floors. Both of these two examples were considered premature and were not included in the empirical investigation conducted for this article. Three floors are selected in the examples in Figure 2. Three floors were used to allow for easier comparison with the design used in the experiment, which is depicted in Figure 1. The optimal subset of floors to display is currently unknown and remains as a topic for future studies. A sequential colour scale, as used in Figures 2 and 3, introduces the question as to which degree such a colour scale facilitates rendering of vertical information. Another issue relating to a sequential scale is whether it is perceived as communicating the horizontal proximity; that is, whether a friend is close in the horizontal dimension. These issues are left up to future investigations. Depicting subsets of floors introduces the already mentioned issue of generalization in both the horizontal and vertical dimension.

3. Empirical Investigation

An experiment was conducted to empirically investigate the benefits of the proposed vertical colour map technique and to assess how it compared to a regular floor-plan map. The previously mentioned example, where a user is searching for her friend, is used throughout the design, development, and experiment. Based on this example, a prototype was developed that implements the vertical colour map using a qualitative colour scale to maximize the differentiation capabilities of the map.

3.1. PARTICIPANTS

Participants were recruited from the student population of the University of Maine through the university intranet, Facebook pages, flyers, and stands around the campus. A raffle was used as compensation, where each participant had a chance to win one Amazon Kindle Fire. In total, 251 students participated in the study. The median age of all participants was 21. There was no pre-filtering of participants based on participant variables, although these variables were gathered, as will be detailed in the experimental design.

Figure 4. Screenshots of the prototype with the two map types used in the experiment: the floor-plan map which was used at the chosen building and the vertical colour map with a qualitative colour scale. Map data © 2011 Google

3.2. MATERIALS

The developed prototype was designed in two versions with the only difference being the map type, where one included the vertical colour map and the second, a regular floor-plan map, similar to current indoor Web map solutions. Screenshots of the prototypes can be seen in Figure 4, which includes the two map designs used in the experiment. The vertical colour map using a qualitative colour scheme was chosen to compare against the floor-plan maps. The floor-plan maps used in the experiment were used at the chosen test building. Two data sets of each of the map type variants were also made. The data sets contained no difference in the information but varied only on the photos and the horizontal location of the friends. Due to the design of floor-plan maps, only the friends at the particular selected floor were shown, as the floor-plan map is not capable of properly rendering information across multiple floors simultaneously. So the participants had to interact with the interface and typically scroll the list of friends, which would also change the displayed floor-plan map accordingly. The size of the stimuli was set to imitate, as close as possible, a modern smartphone. The size was equal in all conditions. The prototype was designed to emulate a modern handheld device to increase the ecological validity of the experiment. The pictures representing the friends were generic pictures of faces varying in gender, age, and ethnicity. Using generic pictures ensures that none of the participants had an a priori advantage by knowing the persons in question. But the ecological validity is somewhat decreased by design, as in a real-life situation, the user will most likely know the pictures of his or her friends displayed in the map. Future studies could increase the ecological validity by paying closer attention to the participants previous knowledge of the symbols used in the map; for instance, by having pictures of famous faces or actual friends of the participants.

3.3. EXPERIMENTAL DESIGN

The experiment was conducted as a between subject design, based on a standard Web study protocol. An adapted Web survey tool was used to manage the experiment. The choice of a between subject Web study was made to maximize the number of participants tested while keeping the estimated completion time low for each participant. Distributing the study on the Web means less administration needed for each participant. The downside is a decrease in experimental control, as well as less experimenter supervision, which theoretically could cause bias introduced from uncontrolled external distractions. A mandatory tutorial to learn the interface and a clear and concise experimental protocol were used to address the limitations of a Web study and to limit the potential bias caused by these limitations.

The experiment used a two-by-two factorial design consisting of four conditions, manipulating two tasks and two map types. Each participant took part in one of the conditions, which were randomly selected by the system automatically to ensure no chance of participating multiple times in one condition. The average time to complete the experiment from start to finish was approximately five minutes. The two manipulated tasks were a short-term memory task and a perception task. The four different conditions were as follows:

1. Floor-plan map in short-term memory task
2. Floor-plan map in perception task
3. Vertical colour map in short-term memory task
4. Vertical colour map in perception task

The independent variables in the experiment were as follows:

- map type: qualitative vertical colour map and floor-plan map
- task type: short-term memory and perception task
- data set: two data sets varying the photos and location of symbols
- familiarity with the building
- gender

The dependent variables in the experiment were as follows:

- proximity question group
- vertical perception question group
- time used to answer all questions

3.4. PROCEDURE

The procedure was identical for all conditions with the exception that steps 3, 4, and 5 (see list of procedural steps below) were presented simultaneously in conditions 2 and 4, which make up the perception tasks. The participants had no time constraints on either of the tasks in either of the conditions; however, the time used by the participants was recorded in the background during the survey at intervals on each step of the survey. An aggregate of the time used for the equivalent steps in the short-term memory condition was used to compare the time used between the conditions. The aggregated time is comparable across conditions, as neither had any enforced time constraints. Further analyses of the time variable are left out of this study. Participants were informed in the task description of the short-term memory condition that they should remember the information in the map. The steps of the procedure are listed below and will be described in the following paragraphs:

1. Introduction, including consent form, privacy statement, and general information
2. Video tutorial showing the functionality of the interface with explanations in text labels
3. Task description instructing the participants to pay close attention to a list of friends with names and pictures
4. Map interface
5. Questions
6. System Usability Scale
7. Participant specific questions

At the start of the experiment, the participants were presented with an information page, a consent form, and a tutorial to the interface. The tutorial included written explanations and a video tutorial with explanations of the different functionalities of the map interface. For all conditions, the task presented to the participants was to pay close attention to the location of four friends who would be shown in the map. The photos of the four relevant friends were shown in the task description (step 3). The participants in the short-term memory condition had to memorize the information in the map before moving to the next step, which contained the questions (step 5). Participants in the perception condition would see both the map interface (step 4) simultaneously with the task description (step 3) and the questions (step 5).

The questions (step 5) consisted of a proximity group and a vertical perception group. Two questions were included in the proximity group. Here, we refer to them as the first and second question for simplicity. In the experiment, the presentation order was randomized. Figure 5 shows a screenshot of the question interface. With the first question, the friends were at the same vertical and horizontal location. With the second question, the friends were at the same horizontal but different vertical location. Four questions were included in the vertical perception group. Each question asked specifically which floors each of the friends were located on the map. Several hypothesis tests were run on different subsets of the data set to test the association between map types and participant responses.

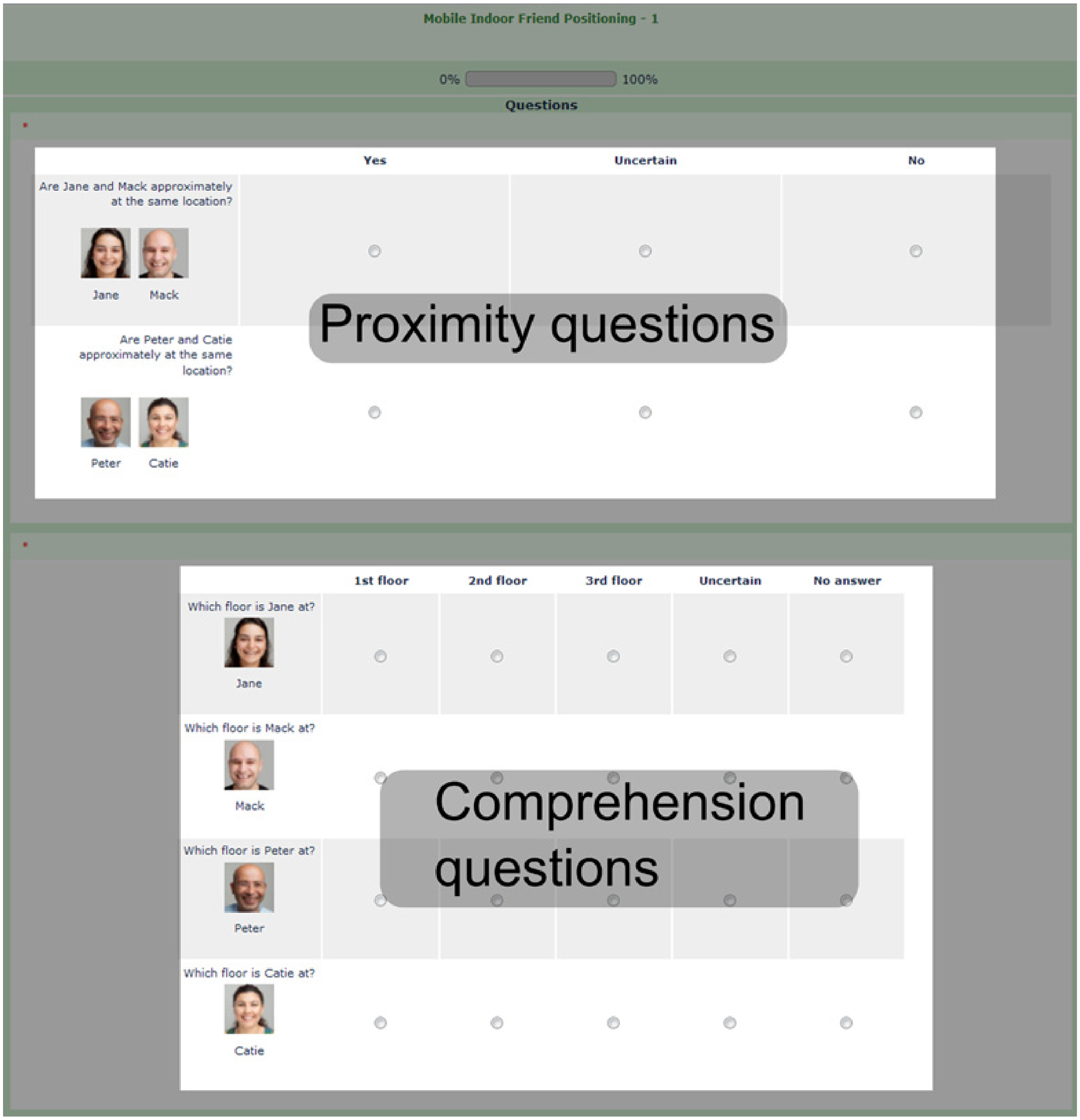

Figure 5. Screenshot of a sample of the questions in the experiment with the two different categories highlighted.

After the task, a System Usability Scale (SUS) (Bangor, Kortum, and Miller 2008) was administered, as well as participant-specific questions. The participant-specific questions were age, gender, familiarity with the building, and familiarity with smartphones. Analysis of the SUS is left for future studies.

4. Results

The primary goal of the experiment was to investigate whether the two map types significantly differed between the conditions and in particular in facilitating the participants in solving the experimental tasks. The answers for one of the map sets in the proximity questions were corrupted and not used in the analysis; the amount was less than 15% of the complete data set.

The overall correctness (percentage of total correct answers) was subjected to a factorial ANOVA having two levels of map type (floor-plan maps and vertical colour maps), two levels of task type (perception task and memory task), and gender. Of greatest interest to the current study, no significant main effect was found for map type,

F (1, 243) = .049, $p > .05$. These findings indicate that similar performance can be obtained using both map displays, results that verify our hypothesis that vertical colour maps are as helpful as floor-plan maps for assisting people with learning and comprehension of multilevel spatial knowledge. A significant difference was observed between tasks, F (1, 243) = 41.710, $p < .001$. Not surprisingly, overall correctness was significantly higher for the perception task (M = 89.3%, SE = 2.7%) than for the memory task (M = 64.2%, SE = 2.8%). There was no significant main effect of gender, F (1, 243) = .543, $p > .05$; however, there was a marginally significant interaction effect of task and gender, F (1, 243) = 3.881, $p = .05$. This interaction indicates that the contribution of task was greater for male participants than for female participants.

Familiarity with the building was expected to have an effect on the answers. But about 86% (216) of the participants stated that they had prior familiarity with the building, which resulted in only around 14% (35) participants not being familiar with the experimental environment. Due to this large difference in the two sample sizes, the familiarity data was analyzed separately. A one-way ANOVA for correctness and familiarity showed that the effect of familiarity was non-significant, F (1,250) = .223, $p > .05$.

The time needed to perform the trials was subjected to a second two-way ANOVA with two levels of map type (floor-plan maps and vertical colour maps) and two levels of task type (perception task and memory task). No significant main effects were observed: map type, F (1, 247) = .001, $p > .05$; task type, F (1, 247) = 1.510, $p > .05$; or the interaction of map and task, F (1, 247) = .162, $p > .05$.

4.1. MAP TYPE DIFFERENCES

The overarching research question in the study was whether the proposed vertical colour map influenced participants' responses to the questions and how performance compared to a regular floor-plan map. The results from the ANOVA indicate that the null hypothesis cannot be rejected at a 95% confidence interval. The null hypothesis states that there is no significant difference between the map type and the percentage of correct answers. In other words, the performance of the vertical colour map, as evaluated in this study, is comparable with the regular floor-plan map.

4.2. GENDER DIFFERENCES

Gender has been found to have an impact in various wayfinding and orientation tasks as well as environmental cognition tasks both in indoor and outdoor environments (Evans 1980; Montello and Pick 1993; Lawton 1996; Jiang and Li 2007). This gives reason to expect that there might be a gender difference in the tasks under investigation in this experiment; however, the results do not support any reliable main effects for gender in the different conditions tested.

4.3. TASK DIFFERENCES

The two manipulated tasks differed only by the way the map stimuli were presented to the participants. The short-term memory task required the participants to memorize the information in the map before answering questions, whereas the perception task allowed participants to see the map and questions simultaneously. The short-term memory task was expected, and designed, to be more demanding than the perception task, which is reflected in the percentage of correct answers between the two tasks. This is a result of the experimental design where the participants needed to memorize the information in the map before they were given the questions. Thus, they relied only on memory to answer the questions. Supporting our hypothesized effect, the results demonstrate that participants yielded significantly poorer performance in terms of percent correct of their answers in the memory task than in the perception task.

4.4. EFFECTS OF BUILDING FAMILIARITY

Familiarity has been shown to have an effect on wayfinding and orientation in indoor environments (Gärling, Lindberg, and Mäntylä 1983; Raubal and Egenhofer 1998). Users of a system similar to the one under consideration in this project could benefit by having previous knowledge of the interior and exterior of the building. This previous knowledge could potentially provide users with greater comprehension of the spatial and relational information being visualized – in this case, friends and their locations. It was expected that familiarity with the building would have a significant effect on participant's responses. In particular, we predicted that familiarity would be an advantage for comprehension of the vertical colour map. The vertical colour map relies on the use of colour on the spatial entities to communicate the vertical dimension, while the interior geometry of the building is excluded; this allows the familiar user to easily get an overview of entities on multiple floors. Unfortunately, out of 251 participants, only 35 (14%) were unfamiliar with the library under investigation. Taking the rest of the tests into account, there is little evidence that familiarity has an effect on the answers in the particular conditions tested here. Future studies should aim at recruiting and designing experiments to the particular investigation of spatial familiarity and its effects on comprehension of the vertical colour map.

4.5. PARTICIPANT COMMENTS

At the end of the study, the participants were asked to provide recommendation and comments on the map system they used during testing. The following comment sums up the general notion from the free text comments which are positive toward the idea of indoor maps in general and specifically the vertical colour map but have concerns on the privacy issues which follows indoor positioning: "This would be an awesome app! Everyone would love it! Although, there should be an option to block certain people from seeing where you are." Around 20 of the free text answers were positive to a system like the one they had tested. On the other hand, there was a similar portion of negative statements that in general revolved around the concern of privacy.

5. Discussion

Facilitating the representation of entities within multi-storey indoor environments is a challenging task. Earlier studies have investigated different aspects of this challenge. Different approaches to various way-finding and orientation tasks have received attention ranging from cognitive aspects of the user, to practical and technological aspects of guiding users through indoor environments (Evans 1980; Passini 1992; Montello and Pick 1993; Lawton 1996; Soeda, Kushiyama, and Ohno 1997; Butz and others 2001; Ciavarella and Paterno 2004; Wiener, Schnee, and Mallot 2004; Jiang and Li 2007; Radoczky 2007; Hölscher and others 2006; Hölscher and others 2009). The vertical dimension is one aspect that differentiates indoor environments from outdoor environments and makes the cognitive integration and practical task of map implementation very different from outdoor environments. Most of the earlier studies have been conducted under the assumption that the interior data are available for the building in question. But this is rarely the case for a significant amount of buildings around the world. The absence of massively available geographic databases of indoor environments can be argued to be one of the reasons for limited implementations of many of the earlier proposed cartographic methods.

Colour is used for many applications in outdoor cartography to depict a wide variety of information ranging from mountain cartography to street maps. Building on this research, the vertical colour map used in this study aims at implementing colour to communicate the vertical dimension in favour of visualizing, or trying to communicate, the interior geography of the building in question. Several different colour scales can be applied for different purposes. The study presented here evaluates one such colour scheme in a simulated mobile environment against the traditional floor-plan map. The evaluation did not consider any vision impairment such as colour blindness or low vision of the users tested (although none self-reported such problems). Vision impaired users may experience problems with the extensive use of colour in the vertical colour map. Using specifically designed colour scales, optimized for vision impaired users would likely greatly aid this demographic. Future studies should focus on the specifics of different colour scales specifically for representing the vertical dimension in different indoor environments and how these parameters might vary for people with different visual abilities.

A simulated mobile environment was used to increase the ecological validity of the experiment and ensure a large sample of participants could be recruited for the study. But the differences from a real-life system were not trivial and could have had an effect on the results in the study. Future studies should aim at implementing a closer to real-life system using real data including real friend icons, familiar to the user, and real-time location data. Observing the use of a system in real life would be very interesting in comparison with the results presented in this initial simulation study. The simulated mobile environment and the chosen ecological validity meant that stacked photos and floor labels were used in addition to colour to render the vertical information, although colour was the only variable which was manipulated while the other techniques remained equal throughout all conditions. In future investigations, isolating colour could potentially yield different results or confirm and strengthen the ones reported here.

Gender and familiarity were hypothesized to affect the results. Earlier studies relating to gender differences and performance differences in way-finding and orientation tasks in indoor environments have demonstrated reliable differences between genders and that familiarity affects the tasks at hand (Evans 1980; Gärling, Lindberg, and Mäntylä 1983; Montello and Pick 1993; Lawton 1996; Raubal and Egenhofer 1998; Jiang and Li 2007). Similar differences were not found in the current study. Gender differences could very well be present between the floor-plan map and vertical colour map and could be further investigated in future studies. The differences in the tasks could have been too small to identify gender differences, or perhaps the question types can be further developed to better suit an investigation of gender differences. Results regarding familiarity are based on an unbalanced data set in favour of familiar participants. Very few people were unfamiliar with the building in question. The effects of familiarity are thus hard to scientifically evaluate with any authority. Another interesting area to investigate further is the potential of social and spatial awareness, where the aim is to facilitate the map user with gaining an increased awareness of both his or her physical and social surroundings. Social surroundings include aspects such as the location, behaviour, and even the schedule of colleagues in real time. Maps facilitating such tasks are hypothesized to have different requirements and designs than maps made solely for way-finding or similar tasks frequently reported in the literature.

6. Conclusion

Location is increasingly being integrated in social media platforms and applications. Mobile, GPS-enabled devices have accelerated this trend. Still, the full potential of location in social media has yet to be explored. Indoor space is one area where a huge potential exists for the full utilization of implementing location-based information in social media; however, GPS-enabled devices are unable to provide position inside buildings. Other kinds of technologies are being developed to fill this gap. Using existing WiFi infrastructure is one very promising solution (Liu and others 2007; Mautz 2009; Curran and others 2011). Currently the accuracy of this technology is very coarse. We believe this will improve in the near future.

Access and availability of geographic data of indoor spaces is another issue. Architectural floor-plan maps are the most common type of data. Initiatives, such as the Building Information Model (BIM) (Eastman and others 2008; Li 2011) and Indoor Open Street Map (OpenStreetMap 2012), are promising techniques and can in the future act as a data source for indoor visualizations. But access to these data sources will most likely be licensed, limited, or in other ways restricted.

Visualization of multistorey buildings needs to not only provide easy access to horizontal orientation but equally well convey knowledge of vertical orientation to facilitate cognitive map development, navigation, and spatial orientation in indoor multistorey environments. The added complexity of the vertical dimension raises new challenges that traditional outdoor maps have not previously had to deal with. Way-finding and navigation, in addition to search and overview tasks, are conceptually similar in indoor and outdoor environments. But the perception, integration, and task solving in three-dimensional indoor spaces are highly different and require visualizations adapted for that use (Giudice and Li 2012).

By using colours to represent the vertical dimension, the vertical colour map represents an alternative to regular floor-plan maps that do not rely on available geographic data and facilitates visualization of the vertical dimension better than floor-plan maps. In this project, the vertical colour map has been implemented in a social location sharing context; however, it could be extended to suit several other applications equally well, such as asset tracking, human resource management, and logistics management. To evaluate the vertical colour map, a human experiment was conducted. In total, 251 participants participated in the study. Results from the study showed that there are very small, statistically non-significant differences between the two compared maps within the different tasks. From these results we can interpret that communicating the vertical information in this context seems to be as equally efficient and intuitive when using the vertical colour map as when using floor-plan maps. But use of the floor-plan map is in many contexts unrealistic due to lack of data availability. While the vertical colour map was shown to communicate the vertical information equally as well as the floor-plan map, it has the advantage of not relying on available interior data and is thus a highly realistic approach to visualizing multistorey indoor environments. The additional benefits of allowing the user to see objects from all floors simultaneously in the vertical colour map also limit the need for interactivity, which is often a requirement for floor-plan maps. The ability to display information from multiple floors simultaneously can be a great advantage in indoor map applications where the user desires overview and rapid reading. By not relying on available geographic building data, the vertical colour map can be implemented with very limited efforts in terms of time and cost associated with data gathering and preparation, which argues in favour of the efficacy of this mapping approach for use in complex buildings. This opens up a new segment of applications in indoor spaces where the geographical data are unavailable.

This study aimed at proposing the vertical colour map as a visualization concept and reported on an initial evaluation of the concept. Future studies should aim at increasing the ecological validity of the experiment. Moving closer to real-life situations and contexts allows for deeper explorations of the limitations of the vertical colour map, in particular the limits on the number of floors and the ideal number of entities displayed in the map. Further investigations are needed to get a deeper understanding of which colour schemes are most appropriate in different situations and for different user groups. In addition, the familiarity variable should be further investigated since the number of unfamiliar users in this study was highly imbalanced compared to familiar users. Privacy issues are another topic not dealt with in this article but are clearly an interesting and highly important issue for such applications. Standards and law practices need to be developed to meet these developing areas.

We conclude that the proposed vertical colour map is a valid alternative to floor-plan maps, in particular for social location sharing where data availability is scarce and user familiarity with the indoor space is good. These results support our view that unavailable map data does not need to be an obstacle when implementing indoor social media maps.

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References

Bangor, Aaron, Philip Kortum, and James Miller. 2008. "An Empirical Evaluation of the System Usability Scale." *International Journal of Human-Computer Interaction* 24 (6): 574–94. http://dx.doi.org/10.1080/10447310802205776

Bertin, Jacques. 1983. *Semiology of Graphics*. Madison: University of Wisconsin Press.

Bertin, Jacques. 2010. *Semiology of Graphics*. Redlands: Esri Press.

Bing Mall Maps. 2011. "Bing Mall Maps." http://www.bing.com/blogs/site_blogs/b/maps/archive/2010/12/07/bing-s-new-mall-maps-get-in-get-out-and-the-avoid-the-crowds.aspx.

Butz, Andreas, Jörg Baus, Antonio Krüger, and Marco Lohse. 2001. "A Hybrid Indoor Navigation System." In *Proceedings of the 6th International Conference on Intelligent User Interfaces – IUI '01*, 25–32. New York: ACM Press. http://dx.doi.org/10.1145/359784.359832

Ciavarella, Carmine, and Fabio Paterno. 2004. "The Design of a Handheld, Location-Aware Guide for Indoor Environments." *Personal and Ubiquitous Computing* 8 (2): 82–91. http://dx.doi.org/10.1007/s00779-004-0265-z

Curran, Kevin, Eoghan Furey, Tom Lunney, Jose Santos, Derek Woods, and Aiden McCaughey. 2011. "An Evaluation of Indoor Location Determination Technologies." *Journal of Location Based Services* 5 (2): 61–78. http://dx.doi.org/10.1080/17489725.2011.562927

Dahl, Yngve, and Dag Svanæs. 2008. "A Comparison of Location and Token-Based Interaction Techniques for Point-of-Care Access to Medical Information." *Personal and Ubiquitous Computing* 12 (6): 459–78. http://dx.doi.org/10.1007/s00779-007-0141-8.

Eastman, Chuck, Paul Teicholz, Rafael Sacks, and Kathleen Liston. 2008. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*. Chichester, UK: Wiley.

Evans, Gary W. 1980. "Environmental Cognition." *Psychological Bulletin* 88 (2): 259–87. http://dx.doi.org/10.1037/0033-2909.88.2.259

Facebook. 2012. "Facebook." facebook.com.

Floorplanmapper. 2012. "Floorplanmapper." http://floorplanmapper.com/.

Foursquare. 2012. "Foursquare." https://foursquare.com/.

Gärling, T., E. Lindberg, and T. Mäntylä. 1983. "Orientation in Buildings: Effects of Familiarity, Visual Access, and Orientation Aids." *Journal of Applied Psychology* 68 (1): 177–86. http://dx.doi.org/10.1037/0021-9010.68.1.177. Medline:6826491

Giudice, Nicholas A., and Hengshan Li. 2012. "The Effects of Visual Granularity on Indoor Spatial Learning Assisted by Mobile 3D Information Displays." In *Spatial Cognition VIII: Lecture Notes in Computer Science* 7463, ed. C. Stachniss, K. Schill, and D. Uttal, 163–72. New York: Springer. http://dx.doi.org/10.1007/978-3-642-32732-2_10

Giudice, Nicholas A., Lisa A. Walton, and Michael Worboys. 2010. "The Informatics of Indoor and Outdoor Space." In *Proceedings of the 2nd ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness – ISA '10*, 47–53. New York: ACM Press. http://dx.doi.org/10.1145/1865885.1865897

Google Latitude. 2012. "Google Latitude." https://www.google.com/latitude/b/0/.

Google Maps. 2011. "Google Maps." http://maps.google.com/.

Harrower, Mark, and Cynthia A. Brewer. 2003. "ColorBrewer.org: An Online Tool for Selecting Colour Schemes for Maps." *Cartographic Journal* 40 (1): 27–37. http://dx.doi.org/10.1179/000870403235002042

Hölscher, Christoph, Simon J. Büchner, Tobias Meilinger, and Gerhard Strube. 2009. "Adaptivity of Wayfinding Strategies in a Multi-building Ensemble: The Effects of Spatial Structure, Task Requirements, and Metric Information." *Journal of Environmental Psychology* 29 (2): 208–19. http://dx.doi.org/10.1016/j.jenvp.2008.05.010

Hölscher, Christoph, Tobias Meilinger, Georg Vrachliotis, Martin Brösamle, and Markus Knauff. 2006. "Up the Down Staircase: Wayfinding Strategies in Multi-Level Buildings." *Journal of Environmental Psychology* 26 (4): 284–99. http://dx.doi.org/10.1016/j.jenvp.2006.09.002

Huang, Haosheng, Georg Gartner, and Felix Ortag. 2009. "A Survey of Mobile Indoor Navigation Systems." In *Cartography in Central and Eastern Europe: Lecture Notes in Geoinformaton and Cartography* 19, ed. Georg Gartner and Felix Ortag, 305–19. Berlin: Springer. http://dx.doi.org/10.1007/978-3-642-03294-3_20

Jiang, Ching-Fen, and Yuan-Shyi Li. 2007. "Virtual Hospital – A Computer-Aided Platform to Evaluate the Sense of Direction." In *Annual International Conference of the IEEE Engineering in Medicine and Biology Society: IEEE Engineering in Medicine and Biology Society Conference*, 2361–64. Lyon: IEEE. http://dx.doi.org/10.1109/IEMBS.2007.4352801

Klippel, Alexander, Christian Freksa, and Stephan Winter. 2006. "You-Are-Here Maps in Emergencies The Danger of Getting Lost." *Journal of Spatial Science* 51 (1): 117–31. http://dx.doi.org/10.1080/14498596.2006.9635068

Klippel, Alexander, Stephen Hirtle, and Clare Davies. 2010. "You-Are-Here Maps: Creating Spatial Awareness Through Map-Like Representations." *Spatial Cognition and Computation* 10: 82–93. http://dx.doi.org/10.1080/13875861003770625

Lawton, C.A. 1996. "Strategies for Indoor Wayfinding: The Role of Orientation." *Journal of Environmental Psychology* 16 (2): 137–45. http://dx.doi.org/10.1006/jevp.1996.0011

Li, Yuan. 2011. "Building Information Model for 3D Indoor Navigation in Emergency Response." *Advanced Materials Research* 368–373: 3837–40. http://dx.doi.org/10.4028/www.scientific.net/AMR.368-373.3837

Liu, Hui, Houshang Darabi, Pat Banerjee, and Jing Liu. 2007. "Survey of Wireless Indoor Positioning Techniques and Systems." *IEEE Transactions on Systems, Man and Cybernetics. Part C, Applications and Reviews* 37 (6): 1067–80. http://dx.doi.org/10.1109/TSMCC.2007.905750

Mautz, Rainer. 2009. "Overview of Current Indoor Positioning Systems." *Geodesy and Cartography* 35 (1): 18–22. http://dx.doi.org/10.3846/1392-1541.2009.35.18-22

Mok, Esmond, and Günther Retscher. 2007. "Location Determination Using WiFi Fingerprinting Versus WiFi Trilateration." *Journal of Location Based Services* 1 (2): 145–59. http://dx.doi.org/10.1080/17489720701781905

Montello, Daniel R., and Herbert L. Pick. 1993. "Integrating Knowledge of Vertically Aligned Large-Scale Spaces." *Environment and Behavior* 25 (3): 457–84. http://dx.doi.org/10.1177/0013916593253002

My Way. 2011. "My Way Aeroports de Paris." https://market.android.com/details?id=fr.aeroportsdeparis.myway.

Nossum, Alexander Salveson. 2011. "IndoorTubes A Novel Design for Indoor Maps." *Cartography and Geographic Information Science* 38 (2): 192–200. http://dx.doi.org/10.1559/15230406382192

OpenStreetMap. 2012. "Indoor Mapping – OpenStreetMap." http://wiki.openstreetmap.org/wiki/Indoor_Mapping.

Pakanen, Minna, Jussi Huhtala, and Jonna Häkkilä. 2011. "Location Visualization in Social Media Applications." In *Proceedings of the 2011 Annual Conference on Human Factors in Computing Systems – CHI '11*, 2439–48. New York: ACM Press. http://dx.doi.org/10.1145/1978942.1979298

Passini, Romedi. 1992. *Wayfinding in Architecture*. New York: Van Nostrand Reinhold.

Point Inside. 2011. "Point Inside Shopping and Travel." https://market.android.com/details?id=com.pointinside.android.app.

Puikkonen, Arto, Ari-Heikki Sarjanoja, Merja Haveri, Jussi Huhtala, and Jonna Häkkilä. 2009. "Towards Designing Better Maps for Indoor Navigation." In *Proceedings of the 8th International Conference on Mobile and Ubiquitous Multimedia – MUM '09*, 1–4. New York: ACM Press. http://dx.doi.org/10.1145/1658550.1658566

Radoczky, Verena. 2007. "How to Design a Pedestrian Navigation System for Indoor and Outdoor Environments." In *Location Based Services and TeleCartography*, 301–16. Berlin: Springer. http://dx.doi.org/10.1007/978-3-540-36728-4_23

Raubal, Martin and M. Egenhofer. 1998. "Comparing the Complexity of Wayfinding Tasks in Built Environments." *Environment and Planning B* 25 (6): 895–913. http://dx.doi.org/10.1068/b250895

Richardson, Anthony E., Daniel R. Montello, and Mary Hegarty. 1999. "Spatial Knowledge Acquisition from Maps and from Navigation in Real and Virtual Environments." *Memory & Cognition* 27 (4): 741–50. http://dx.doi.org/10.3758/BF03211566. Medline:10479831

Schrooyen, Frederik, Isabel Baert, Steven Truijen, Luc Pieters, Tim Denis, Koen Williame, and Maarten Weyn. 2006. "Real Time Location System over WiFi in a Healthcare Environment." *Journal on Information Technology in Healthcare* 4 (6): 401–16.

Soeda, Masashi, Noriko Kushiyama, and Ryuzo Ohno. 1997. "Wayfinding in Cases with Vertical Motion." In *Proceedings of the Conference on Environment-Behaviour Studies*, 559–64.

Spence, Robert. 2007. *Information Visualization: Design for Interaction*, 2nd ed. Harlow, UK: Pearson Education.

Twitter. 2012. "Twitter." twitter.com.

US EPA/Office of Air and Radiation. 2012. *Indoor Air Quality: Publications and Resources: The Inside Story: A Guide to Indoor Air Quality.*

Ware, Colin. 2012. *Information Visualization: Perception for Design (Interactive Technologies).* San Francisco: Morgan Kaufmann.

Wiener, Jan M., Alexander Schnee, and Hanspeter A. Mallot. 2004. "Use and Interaction of Navigation Strategies in Regionalized Environments." *Journal of Environmental Psychology* 24 (4): 475–93. http://dx.doi.org/10.1016/j.jenvp.2004.09.006

Yang, Bo, Yajun Xu, Jianjun Luo, and Yong Bao. 2007. "Indoor Positioning Performance of Galileo Signal." In *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, vol. 6795. Wuhan, China: SPIE. http://dx.doi.org/10.1117/12.775456