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Research Paper

Visualizing the perceived environment using crowdsourced photo geodata

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HIGHLIGHTS

- Visualizing perceptual responses to landscape through crowdsourced spatial content.
- Description of the overall process, allowing project specific adaption.
- Three novel types of visualizations presented.
- Basis for establishing a counterbalance offsetting expert landscape assessments.

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ABSTRACT

Assessing information on aspects of identification, perception, emotion, and social interaction with respect to the environment is of particular importance to the fields of natural resource management. Our ability to visualize this type of information has rapidly improved with the proliferation of social media sites throughout the Internet in recent years. While many methods to extract information on human behavior from crowdsourced geodata already exist, this paper focuses on visualizing landscape perception for application to the fields of landscape and urban planning. Visualization of peoples' perceptual responses to landscape is demonstrated with crowdsourced photo geodata from Flickr, a popular photo sharing community. A basic, general method to map, visualize, and evaluate perception and perceptual values is proposed. The approach utilizes common tools for spatial knowledge discovery and builds on existing research, but is specifically designed for implementation within the context of landscape perception analysis and particularly suited as a base for further evaluation in multiple scenarios. To demonstrate the process in application, three novel types of visualizations are presented: the mapping of sightlines in Yosemite Valley, the assessment of landscape change in the area surrounding the High Line in Manhattan, and individual location analysis for Coit Tower in San Francisco. The results suggest that analyzing crowdsourced data may contribute to a more balanced assessment of the perceived landscape, which provides a basis for a better integration of public values into planning processes.
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1. Introduction

Perception is the process of understanding the environment through visual, olfactory, and acoustic information. The human brain is continually predicting, simplifying, associating, and comparing what the various senses transmit, taking into account not only the actual physical world but also personal preferences, emotions, and memories. For this reason, evaluating perceived values of places and landscapes remains a challenging task. Yet, it is important to know how the public perceives the environment, particularly in landscape planning, management, and design (De Groot, Alkemade, Braat, Hein, & Willemen, 2010). The European Landscape Convention, for example, defines landscape "as a zone or area as perceived by local people or visitors" (ELC art. 1, para. 38). But, despite the fact that significant advances have been made in studying the perceptual and cognitive abilities of individuals, only limited knowledge is available on the "generalized mental picture" (Lynch, 1960, p. 4) formed by *many* people.

Here, crowdsourced data offers to fill an important gap. Compared to traditional data sources, such as census data made available by governments, *crowdsourced geodata* provides an otherwise unavailable perspective on the complex connections between space, identity, and personal perception. The spatial traces of people's decisions embedded in crowdsourced geodata can be used

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to study perception and cognition of the *crowd* itself. The crowd in this case could mean large numbers of Internet users. This opens up new possibilities for planners to understand how people interact with the real environment and perceive their surroundings. Furthermore, incorporating the views of many becomes increasingly more relevant in all disciplines of natural resource management (Brody, 2004; Lynam, De Jong, Sheil, Kusumanto, & Evans, 2007). The demand for public participation is growing and numbers of stakeholders are constantly rising. Accessing this knowledge is an alternative way to traditional survey research used to "measure attributes such as opinions, attitudes, beliefs, values, norms, and preferences" (Brown, 2005, p. 1). Crowdsourced geodata containing measurable sociocultural values may help particularly with the difficult task of weighting contrary views and conflicting interests and, by supplementing single expert views, promises "results that are seen to be more legitimate or fairer" (Erickson, 2011, p. 1).

Many methods already exist to explore important aspects of landscapes using this data source such as the evaluation of attractive areas, places of interest, landmarks, or user travel preferences. However, in landscape and urban planning, assessing perceived qualities encompasses a diverse field of tasks. This work seeks to provide planners with the necessary knowledge to personally explore, visualize, and interpret this data. The complete process of data retrieval, processing and analysis is outlined with the example of crowdsourced photo geodata from *Flickr*. The development of novel visualizations is briefly demonstrated, which highlights specific perceptual patterns. Finally, the evaluation of quality and accuracy of results is addressed. However, such assessment is understood as an open process of data validation, highly depend on the particular problem context and data sources. There exist different degrees of suitability for specific purposes, and this paper includes several examples of applications. Given that there is no easy way to evaluate the open-ended opportunities being illustrated here, these examples are limited to areas where results can be backed up by additional data such as the planner's personal on-site evaluation, authoritative data, or traditional methods.

2. Literature review and conceptual framework

Urban planner Kevin Lynch was among the first to study, on a conceptual basis, how individuals perceive and navigate through the rural and urban landscape. In his influential book "The Image of the City" (Lynch, 1960), he spanned the theoretical discussion from cognition to visual processing, mental maps and pattern recognition. At the same time, the anthropologist John Collier (1967) first used photography as a tool for studying human perception. In the context of photography, Susan Sontag (1977) identified numerous relationships between the subject (physical space) and the photographer's identity and subjective perception of the environment. In the 1980s, photography-based methods gained popularity in landscape perception analysis to compensate for the inadequate levels of precision, reliability and validity of expert landscape assessments (Daniel, 2001). Either handing out cameras to participants (participant or *self-directed photography*, Dakin, 2003; Markwell, 2000) or obtaining responses to a set of photos (Kaplan, 1985; Shafer & Richards, 1974) became generally accepted techniques for assessing the perceived landscape. However, the application of self-directed photography was restricted due to its costs (acquiring participants, providing cameras) and the acquisition of observer ratings from photographs has been criticized by environmental-behavior researchers and psychologists as to their limited suitability for evaluating contextual behavior, interaction, and landscape meaning (Scott & Canter, 1997; Zube, Sell, & Taylor, 1982). In practice, landscape perception analysis remained largely based on conventional expert assessments (Daniel, 2001; Palmer & Hoffman, 2001).

More recently, environmental psychologists and planners have both begun to concentrate on the study of public participation. Planners have found the need to understand individual decision-making processes, and psychologists have likewise become confronted with the macrolevel of human behavior (Churchman, 2002, p. 192). Furthermore, electronic participation has become a new research domain (Kingston, 2011). Due to the increased volume of people and communication involved, however, planners have faced new challenges. Crowdsourcing the participation process, from a technology design perspective, is seen as a possible solution (Brabham, 2009). The effect known as "the wisdom of the crowds" describes situations where valuable knowledge for problem solving or decision making is provided by many people rather than single experts (Surowiecki, 2005).

Instead of collecting people's knowledge directly, the approach described in the following aims at utilizing the phenomenon for aggregating people's knowledge *as inferred from their behavior*. Crowdsourced geodata provides the opportunity for "tapping the perceptual, cognitive, or enactive abilities of many people" (Erickson, 2011, p. 1). In philosophy and cognitive sciences, this source of knowledge is described as *distributed cognition* (Dror & Harnad, 2008). It reflects an attempt to reassess the meaning of "culture, context, history and emotion" (Hutchins, 2000, p. 10) in cognitive sciences. Distributed cognition provides important conceptual links for understanding interactions among groups of people, technologies, and their environment. However, it does not necessarily rely on today's computers, networks, or the Internet. Rather, these developments have created a situation or an *interface* to facilitate and access distributed cognition. Masses of data on how people interact with the real environment and perceive their surroundings are today available on the Internet as *crowdsourced geodata*.

Current terms and definitions to describe this type of data are very diverse and continue to be a matter of controversy (Cinnamon & Schuurman, 2012; Sui, Elwood, & Goodchild, 2013, p. 31). Often, crowdsourced data is misleadingly equated with *volunteered geographic information* (VGI). This implies an active role in supplying information, which is not always the case (see also Antoniou, Morley, & Haklay, 2010; Gorman, 2010). The same applies to the term *collaborative*, if it is not the primary intention of the user to actively collaborate but to personally share information. The term *citizen sensors*, on the other hand, implies that people do not know their data is being used, which is not always the case and may be ethically questionable. All of the above named terms (see Elwood, 2008; Goodchild, 2007; Krumm, Davies, & Narayanaswami, 2008; Matyas, 2007 for definitions) can be categorized under *user-generated content* (UGC). These terms do not adequately describe the specific group of crowdsourced data containing information on people's interaction with the environment that are passively transmitted, that is not transmitted for the explicit purpose of being used in a bigger project or for collaboratively acquiring data.

For the purposes of this paper, I am using crowdsourced data as an umbrella term to describe both the shared data obtained from larger groups of people on the web and the process of utilizing this data for problem solving. It is noted that this definition lies at the opposite, wider end of a continuum of possible crowdsourcing definitions (see Doan, Ramakrishnan, & Halevy, 2011).

2.1. Related research

Despite the availability of crowdsourced geodata being a relatively new phenomenon, the amount of research conducted around it is fairly substantial. Methods to visualize specific behavioral and perceptual patterns have been proposed for crowdsourced geodata from web services such as *Twitter*, *Panoramio*, *Flickr*, and

Foursquare. For example, Frias-Martinez, Soto, Hohwald, and Frias-Martinez (2012) used geolocated Twitter messages to identify urban land uses (Business, Leisure/Weekend, Nightlife, Residential) based on typical temporal and spatial patterns of activity. Alivand and Hochmair (2013) demonstrated the extraction of scenic routes using geotagged photos from Panoramio. A number of researchers have looked at the question whether such data can help describe and locate geographically vague places (Jones, Purves, Clough, & Joho, 2008; Twaroch, Jones, & Abdelmoty, 2008). Others have focused on understanding tourist dynamics (Girardin, Fiore, Ratti, & Blat, 2008), the extraction of representative images for landmark discovery (Kennedy & Naaman, 2008), or the interactive exploration of attractive areas using Google Earth (Kisilevich, Andrienko, Krstajic, Keim, & Andrienko, 2010).

The photo-sharing community of Flickr received special attention in the context of user behavior analysis. Antoniou et al. (2010) classified Flickr as a source of geographic information that is particularly suited for analyzing user behavior. The rationale is that the functionality for georeferencing photos on Flickr is additional, and not the primary motivation of users. Furthermore, Nov, Naaman, and Ye (2010) identified a broad range of motivational factors for contributing and participating in Flickr. Interestingly, a survey from 2008 revealed a comparatively wide range of contributing user groups (Cox, Clough, & Marlow, 2008).

Finally, georeferenced photos with attached, personal descriptors (captions or *tags*) proved suitable for generating place semantics based on general human perception (Rattenbury & Naaman, 2009). Purves and Edwardes (2008) collected half a million photographs and descriptive captions from over 5000 users and found that the frequency of terms can be used to explore relationships between landscape features such as "hill" and activities (climbing, skiing, holidays, observation, sitting, walking), elements (fort, top, summit, horizon, ridge), or qualities (steep, distant, wooded, black, rough). The potential for using common *tag clouds* within a spatial context to visualize semantics from crowdsourced data was demonstrated, among other uses, by Dahinden, Eggert, Mondzech, and Paelke (2010) and Nguyen, Tominski, Schumann, and Ta (2011). This approach was first introduced by Kennedy, Naaman, Ahern, Nair, and Rattenbury (2007) and used by Yahoo Research Berkeley to generate maps similar to the ones presented in this research.

However, existing approaches were found to be not entirely suited for visualizing and evaluating the subtle characteristics of environmental perception. For instance, while Kennedy et al. (2007) presented a complex algorithm to identify representative tags and landmarks, the generated visuals exclude the majority of descriptive tags of lesser importance. Without this information, it is not possible to evaluate the diversity of relevant aspects with which a place may be characterized or assess the relative importance of a single aspect compared to others. Furthermore, the method focuses on visual features while ignoring tags that relate to spatially characteristic associations, emotions, or interactions. Also, approaches described above either investigate important but singular aspects of the process or remain at a conceptual, theoretical level. In order to be applicable within the fields of landscape and urban planning, it is necessary to devote more attention to the entire process beginning with creation of data, to interface questions (encompassing data input, alterations during processing and storage, as well as retrieval from databases), and finally graphical visualization.

In summary, while the following method may not be seen as fundamentally different compared to other research, it is aimed at a more practical, visual level. The computational process is comparatively less complex and specifically designed for implementation within the presented context. Thus, the contributions of this work are multifaceted but focus on the generation of novel visualizations, utilizing common GIS software (ESRI ArcGIS), and the description of the overall process supporting project specific adaption.

3. Material and methods

3.1. Software architecture

Within this section, I am providing a brief description of the software architecture used to retrieve, process, and visualize data. The key steps for creating final visualizations are more precisely portrayed in Section 3.4 (Data analysis). In general, the utilization of existing, common software was preferred over creating new software. However, due to the amount of data, all steps are automated using multiple programming languages depending on the investigated part of the process. The software can be assigned to four stages: data retrieval, quantity analysis, spatial analysis, and visualization. A schematic overview is provided as supplementary online material (App. VI).

Data was collected for three world regions and 12 study areas using the Flickr API (*application programming interface*, used to automatically access data) and a toolset written in *VB.Net* (App. VII). The tool recursively queries available data for a given location going backwards in time (the time photos were taken) until all data is retrieved or a specified maximum is reached. If not otherwise specified, the queried period ranged from 2007 to 2012. Only photo data with the highest accuracy of location information ("street level accuracy", see Girardin et al., 2008) was retrieved. A summary of the data is provided in Table 1. The resulting data consists of a location identifier (the *geotag*, i.e. latitude/longitude), a specific time (time of photo taking or upload time) and further attachments such as user-added semantics (the *metadata*, e.g. *title, tags, descriptions*) and the user name (i.e. the owner of the photo). While titles and descriptions are not used in the following they may serve as supplementary data for study areas with low data density. Further information is optionally requested. For example, the current location provided by some of the users is retrieved to study their origin. In this context, the *geocoding* process (i.e. the conversion of information to coordinates) is implemented by using the *Bing Maps* API. The photo itself is not retrieved but can be manually reached using the attached *URL* (a weblink to the photo on Flickr). The data is then imported into a database (*Microsoft Access* using *MySQL*) for quantity analysis (e.g. total number of photos, total number of tags, total number of unique tags, the most used tags, number of users). The spatial analysis (density of photos, spatial distribution of tags) is performed in *ESRI ArcGIS* by utilizing available options for automation (e.g. the *Modelbuilder* for tag clustering as shown in Fig. 5, or statistical tools such as the *Getis-Ord GI-Star statistic*).

Finally, visualizations are created using common functions for defining display rules and parameters (e.g. the *Maplex Render Engine* for label priority ranking, *Phyton* and *VB* for calculation of final font sizes). Additional information, such as roads and buildings from Openstreetmap or elevation information from the U.S. Geological Survey, is placed in the background as a simple reference. An online mapping interface and service was created for interactively exploring maps (Dunkel, 2014). A sample dataset that was used for both the generation of the map for the state of Baden-Württemberg and the related user origin analysis (App. V, Section 4.3) is attached to this work (App. VIII). Information that is relevant to privacy is removed from this dataset.

3.2. Dataset characteristics

A number of basic, global characteristics of data distribution can be observed without any further processing. Most of the data is located on the western hemisphere, in particular the United States,

Table 1
Summary of examined study areas and available data.

Study area	Berkeley	Coit Tower	Fort Mason	Bay Area, CA	State of California	Yosemite	Highline, NY	Germany	State of Saxony	City of Dresden	B.-Wuerttemberg (2007–2014)	Σ
Num. of photos	121,456	8280	41,777	1,150,954	2,981,319	36,520	39,541	2,821,268	209,323	10,828	376,906	5.8 M
Num. of tags	630,093	40,245	38,696	3,959,748	15,440,753	164,985	218,718	2,291,886	1,207,830	58,063	345,028	18.1 M
Num. of users	5100	1497	5002	27,049	53,977	2461	3776	84,028	7929	901	10,467	0.14 M

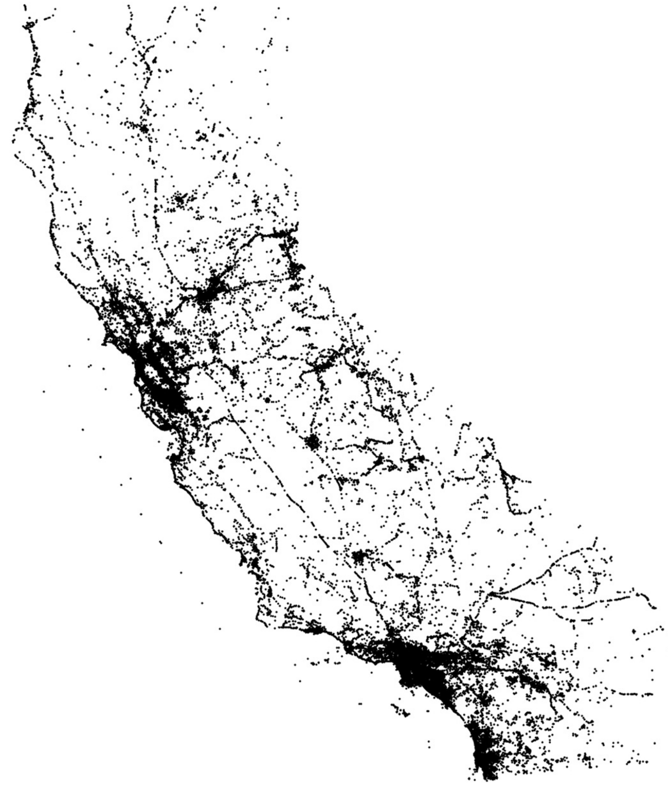

Fig. 1. Mapping of the Flickr data for the state of California with 2.8 million photos taken between 2009 and 2011.

Canada and parts of Europe and Asia (see visualization by Fischer, 2011). For the state of California, Fig. 1 demonstrates how data density peaks in urban areas, as well as in highly frequented places (National Parks, along highways), but is nearly absent in unfrequented rural areas.

Not surprisingly, data availability is also highly time dependent. The animation of photos taken each month from 2009 to 2011 in California (see Fig. 2 and attached media file) allows interpretation of basic temporal characteristics. Urban areas are hot spots throughout the year, whereas other spots peak only during certain times a year: Lake Tahoe in winter (frequented winter sports

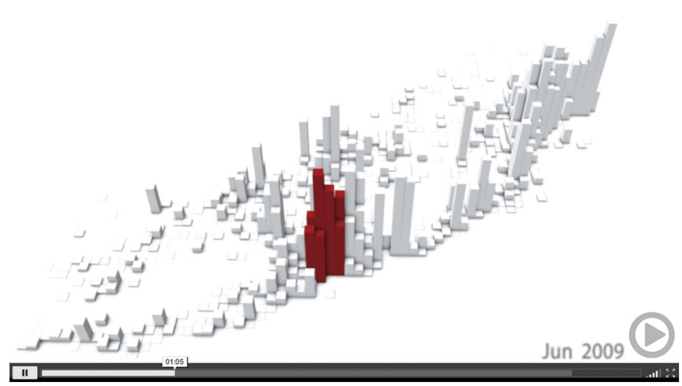

Fig. 2. Animation of the amount of photos taken between 2009 and 2011 in California. Height of bars was calculated using Natural Breaks algorithm, which means super dense hot spots like San Francisco downtown (red) appear less dominant than they are whereas areas with a small amount of photos appear bigger. (The media file is available as supplementary online material; for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

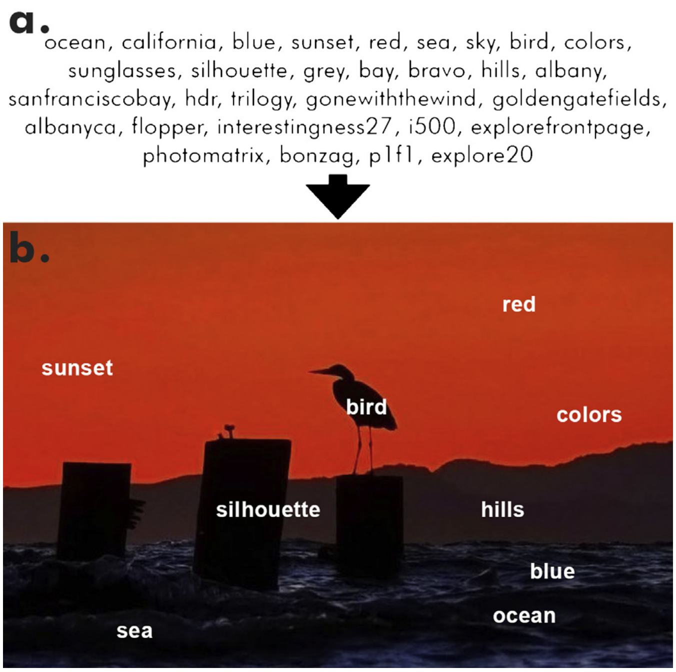

Fig. 3. Example photo with total available tags (a), including those of only personal relevancy, and the selection of tags (b) relevant for describing visual aspects of the photo.
"Bird In Bay" ©Sean Duan.

destination), or Yosemite Valley in spring and summer (scenic and natural attractions, seasonal accessibility). To interpret the temporal and spatial patterns, it is necessary to look at the underlying behavioral and motivational factors of Flickr's specific group of users.

3.3. User behavior and motivational factors

As Nov et al. (2010) note, photo data from Flickr is created in two separate steps: the content-creation process (taking photos) and the contribution process (sharing photos and adding information).

First, taking a photo of something requires an active decision. Lynch proposed "[. . .] the generalized mental picture of the exterior physical world that is held by an individual [. . .] is the product both of immediate sensation and of the memory of past experience, and it is used to interpret information and to guide action" (Lynch, 1960, p. 4). In summary of the findings from Collier (1967), Sontag (1977), and others (Dakin, 2003; Scott & Canter, 1997), the action of taking a photo is recognized as not only being triggered by the immediate environment but by all aspects of cognition: personal preferences, memories, opinions, and more. Here, the need of being in situ for creating spatial content (i.e. taking a photo) is crucial. As a result, the photograph that someone takes of a place, and the photographs they choose to upload may both reflect, in some way, their perceptions of the place.

Second, the subsequent, optional act of *tagging* photos is used by photographers (and occasionally by other Flickr users) to describe the important aspects of a picture for purposes of self-organization and communication (Ames & Naaman, 2007; Hollenstein & Purves, 2010). Tags are a list of words encompassing not only physically visual elements but also conceptualized information of the environment (see Crandall, Backstrom, Huttenlocher, & Kleinberg, 2009; Fig. 3). Tagging involves several mental processes. Contrary to direct perception, tags are assigned at a later time, based on the photo itself and the photographer's memory of the scene. Even if tags relate to potentially visible elements, they may also describe associated aspects (e.g. "sunglasses" in Fig. 3). If we accept this characteristic, there is no right or wrong in tagging photos: even uncommon words or unique descriptors may, from the user's perspective, relate to (personally) relevant aspects of the photo and the memorized scene. Specifically because of this undirected nature, tags can function as artifacts of the user's personal conceptualization and abstraction of the world (Dror & Harnad, 2008, p. 93).

The conclusion relevant to the analysis in this work is the following. If multiple people take photographs at a location, the photographs might be linked to a specific visible or associated characteristic (or absence of characteristics) that initiates the same decision process for that place or area. The more people that follow this pattern, the more significant might be the underlying characteristic. The same applies to tags as semantic descriptors of the abstracted, memorized scene. Repeatedly used tags in an area may relate to similar perceptual or cognitive processes triggered in groups or sub-groups of people by the environment. Thus, it can be said that *tag maps* generated from crowdsourced photo geodata visualize perception and cognition based decision processes. An important characteristic follows: there is no known dimension that can be assigned directly to values. Therefore, it is of higher importance to visualize relative meaning rather than absolute numbers.

3.4. Data analysis

The primary goals of further analysis are finding and characterizing individual locations. This requires different steps of aggregating photo locations and tag data for a given area. Based on the conclusions drawn in the previous section, photo taking and tagging are seen as two separate behavioral processes relating to different aspects of perception. Thus, both types of data are analyzed sequentially. Final maps (Fig. 6) are created in two steps.

First, photo locations (Fig. 4a) are aggregated and analyzed regarding their spatial distribution. Similar to the considerations of Kennedy et al. (2007), measures are necessary to prevent graphics from being biased toward a single photographer who is frequenting a location very often. Therefore, photo locations of each unique user in the data set are dissolved by a specified distance dependent on the scale of analysis. In other words, within a radius of 10 meters,

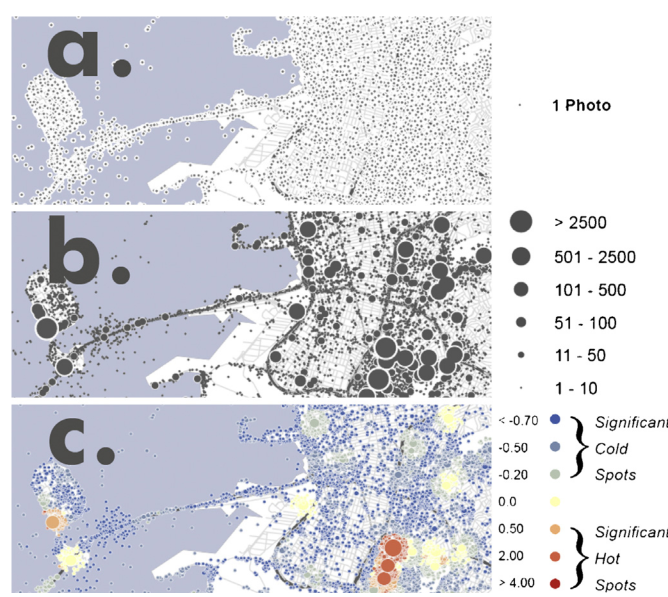

Fig. 4. Processing of photo location data: (a) Each dot represents a single photo, (b) First Level Clustering: combining multiple photos to clusters, dots represent locations of photo taking, and (c) Second Level Clustering: statistical calculation to visualize significant cold and significant hot spots.

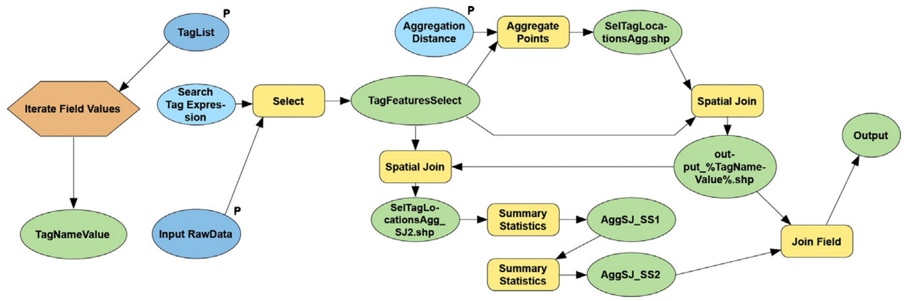

Fig. 5. Model diagram for clustering of tag location data (*ESRI ArcGIS Model Builder*).

all photo locations of a single photographer are collapsed to a single, arithmetically centered point. First Level Clustering (Fig. 4b) is calculated by combining the resulting photo locations to clusters. This is done by using the *aggregate points* tool and performing a *spatial join* for counting the number of photographs at each location. Second Level Clustering (Fig. 4c) is calculated using the Getis-Ord GI-Star statistic, which evaluates the data (number of photos taken at each location) by comparing the local mean to the global mean and then determining whether the difference is statistically significant. The *distance band threshold* (used for conceptualization of spatial relationships within the statistical analysis) is chosen using *incremental spatial autocorrelation.* The tool helps in identifying a characteristic distance for the analyzed scale where the clustering of photo locations is most pronounced. The results are displayed with dots of different size and in different color variations: red for hot spots where significantly more pictures were taken compared to the overall area of investigation and blue for cold spots for areas that do not get as much attention.

Second, available *tags* for each photo are evaluated to label certain areas. Similarly to the clustering of photo locations, measures are necessary to prevent a single photographer's tags from dominating the final graphics. Here however, we are interested in users that are consciously tagging photos (i.e. tagging each photo separately, instead of just copying tags). Thus, data is prepared by first aggregating photos with the same sequence of tags for each owner. Afterwards, the overall number of occurrences is calculated for each distinct tag. Based on this, a preselection is made by choosing tags which were used by a minimal number of photographers (e.g. five) and a minimum total number of times (e.g. ten). The central process of clustering tags is illustrated in Fig. 5. All occurrences of a certain tag are aggregated based on a distance dependent on the scale and desired accuracy of analysis. For each cluster, the number of users and tag occurrences is counted (i.e. by applying *spatial join* and *summary statistics* operations, Fig. 5). This type of clustering belongs to the group of comparatively less complex, single-link fixed-cluster methods. Here, the minimum distance used to link clusters is likewise applied as the clustering stopping criteria. In contrast to other papers, the aggregation does not utilize *mean shift* clustering (Crandall et al., 2009). A sufficient aggregation for the purposes of this paper is still possible because tag locations are already highly clustered in the first place. Furthermore, this relatively simple form of clustering generates spatial extents for each tag. In the following, these extents are used as a boundary for offsetting labels in dense areas.

The importance of a tag is determined by calculating weights proportional to the inverse squared number of tags in each cluster per user. Thus, reoccurring tags of the same user in the same area are weighted less than those of unique photographers. The process of generating weights has significant influence on final maps. For specific project needs, linear weighting may be used to direct more attention toward users who often frequent areas. In final maps, weights are symbolized by font size descending from higher to lower importance. The process of labeling is implemented by defining the following rules for *label priority ranking*. The most used tags are placed first as *background* labels. Afterwards the single densest cluster of each unique tag is placed (written *bold).* Finally all other labels are placed according to their importance for the area (i.e. the number of times a tag was used). This way, tags that were only used by a minority of photographers appear small on the map, whereas often used tags appear bigger (Fig. 6). Each tag is treated as an equally correct descriptor. Thus, in the example of the UC Berkeley Campus (App. II), *tower*, *campanile* and *sathertower* are each correct collective descriptors of a sub-group of people referring to the same object and are placed according to their significance on the map. The resulting maps are *spatio-temporal tag clouds* (or *tag maps*) and can be best described as statistically weighted maps of what is influencing people's perception in certain areas.

4. Results

4.1. Map characteristics and initial interpretation

Data processing and map creation is done automatically and was tested for various scales, ranging from local to state scales as well as for different rural and urban areas in California, the United States, and Germany (see Table 1 and Appendices I–V). While the graphics of all maps are similar, they feature unique characteristics bound to the examined location. There exist several reasons for providing such a large base of figures and appendices. As noted earlier, the data from Flickr is neither created by a homogeneous set of rules nor a consistent group of trained experts. Both the participating users and contribution patterns are unevenly spatially distributed and continually change over time. Furthermore, because of cultural differences, the transferability or generalizability of knowledge obtained for one region to another is limited. Therefore, the demonstration of techniques for a diverse set of locations was prioritized over closely evaluating a single area. The following discussion is aimed at providing an overview of map characteristics with initial interpretation based on personal on-site evaluation.

In the example map of Fort Mason (Fig. 6, App. I), a former army base which was converted into a cultural center along the Bay Promenade in San Francisco, people photograph primarily from along the waterfront, the three Fort Mason piers, and up on a little hill within the park. The most popular vantage point of the area is at the end of the pier extending from Van Ness Avenue. The most popular subject at this place is clearly Alcatraz Island, a former prison and now legendary tourist attraction. The word clouds visualize not only what was *seen* by people throughout the area but more importantly what was collectively labeled as significant aspects of the scene. The aspects of the scene are combinations of known places and landmarks (the Golden Gate Bridge, Coit Tower, the Marina, Fisherman's Wharf and Ghirardelli Square) as well as characteristic elements of the Bay and the waterfront (*water*, *seagull*, *fog*, *boat*, *sailboat*, *beach*), temporal or cyclic events (the annual Robogames and

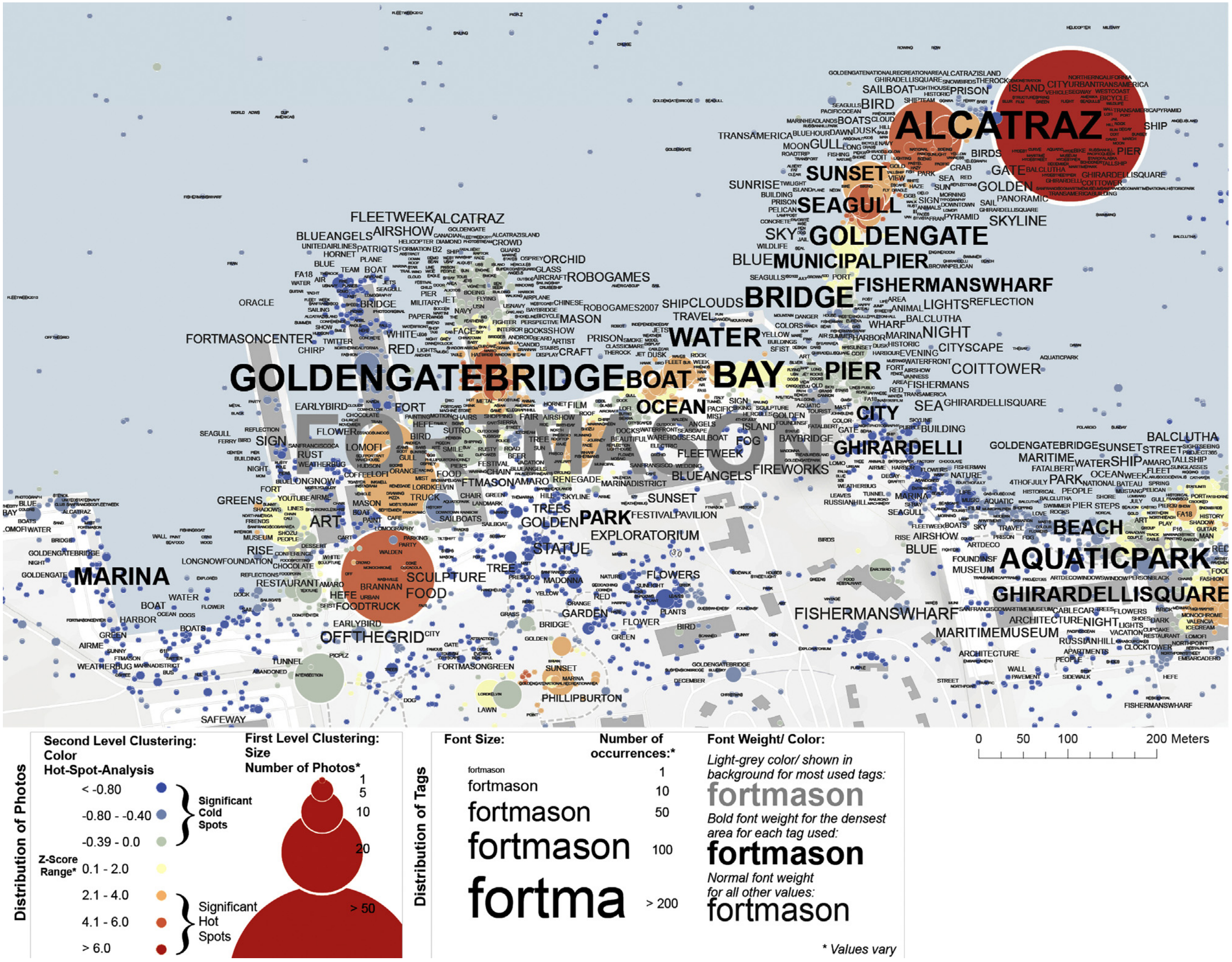

Fig. 6. Mapping of the Fort Mason area based on 41,777 photos taken by 5002 distinct photographers between 2007 and 2012, with 6897 unique tags and a total number of 38,696 available tags.

Fleet Week Air Show, -or the sunset), and to a much lesser extent, verbs describing actions (*shopping*, *running*, *biking*) and aspects that can mostly be felt (*wind*, *hot*, *beautiful*).

The main difference compared to traditional maps is that labels occur in different places compared to where the actual 'object' is located. For example, the Golden Gate Bridge, while it exists only once, influences people's perception in a number of different locations throughout the Bay Area. This characteristic becomes obvious at Treasure Island, a man-made island in the middle of the San Francisco Bay with relatively few attractions itself. The perception of the environment within this area is dominated by aspects from the nearby city of San Francisco and the surrounding bay. A major spot for perceiving the *skyline* of San Francisco is, among other places, a well-known vantage point located at the entry of Treasure Island (Fig. 7/1).

The size of labels is an indicator of the perception and its intensity for a given place and the specific group of visiting Flickr users. Although the skyline of San Francisco is most dominant, other relating aspects are similarly influencing this group's perception: San Francisco *downtown*, the *cityscape*, and the *urban* scenery with the characteristic *fog* (Fig. 7/1–3). Infrequent or cyclic events, such as the New Year's Eve *firework* or the sun setting down behind the Golden Gate Bridge (Fig. 7/1 and 3), are equally relevant for people's identification with the island. Furthermore, perception changes on a small scale. Although the skyline of San Francisco is still visible, the majority of photographers seem to look easterly at the south-eastern edge of Treasure Island and other subjects, such as the (in the meantime completed) construction of the new span of the Bay Bridge, become visually dominant (Fig. 7/4).

For other areas, maps reflect how spatial and perceptual behavior is shaped by characteristics of the place itself. At the Berkeley Marina, along the eastern side of the San Francisco Bay, the 1 km long pier dominates the majority of photographers' perception when they first enter it (Fig. 8/1), whereas toward the end of the pier the focus starts to shift to various visual elements, like seagulls (Fig. 8/2), the skyline of San Francisco (Fig. 8/3), or the Golden Gate Bridge (Fig. 8/4).

4.2. Application to planning

These maps are useful as a supplementary set of data for a variety of applications in landscape and urban planning. For example, while conducting a field survey for England's Landscape Character Assessment program, planners need to provide information on the esthetic and perceptual aspects and the perceived character of landscapes. In preparation for this task, the presented type of maps could be used to study the relative importance of features within an area. Later, during on-site evaluation, personal comparison may either confirm findings or proof as to whether the maps accurately reflect the perception of a sub-group of people. Similarly, Germany's Environmental Impact Assessment program requires

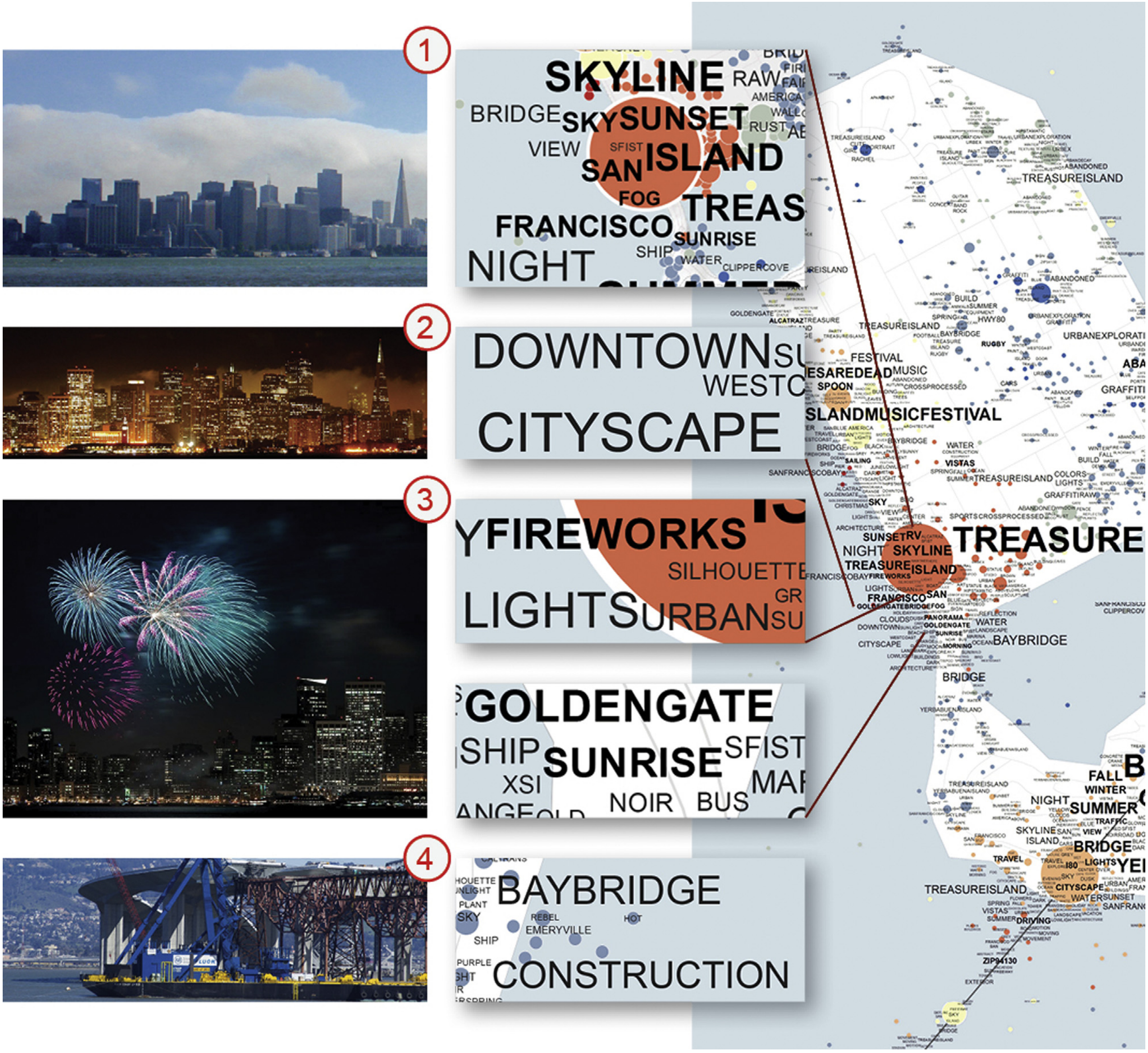

Fig. 7. Example map of Treasure Island (San Francisco) and selective characteristic patterns of photo taking.
Photo by author; "The Lights of San Francisco", ©Thomas Hawk, CC BY-NC 2.0; "Fireworks*San Francisco's 2009 New Years Eve", ©Ron Lowe; "New Bay Bridge viewed from Treasure Island", ©a200/a77Wells", CC BY 2.0.

planners to estimate perceived project or plan impacts. These maps provide the opportunity to quantify aspects of the perceived landscape character and thus may help in more accurately assessing a projects consequences. Often, however, it will be the case that additional questions need to be explored based on the specific context of a project. Here, the clustered data generated in the first step is a suitable base for further analysis. The following experimental visualizations are merely brief examples of additional and relatively simple exploration of specific questions.

For planners, for example, the comparison of maps generated for different timespans opens up possibilities to track the impact of projects, analyze the way perception of landscapes changes over time, and react to unwanted developments or trends. This technique is demonstrated in Fig. 9 for the Highline, a former elevated freight railroad spur that was turned into an accessible greenway in Manhattan, NY. The mapping of data from before and after the opening of the High Line offers strong evidence for how a single project can transform the way people perceive a neighborhood. Although data availability has risen in recent years through the proliferation of geotagging, smart phones, and photo-sharing, the concentration of growth is clearly along the path of the High Line. The accessible greenway gave opportunity to the public to walk separated from street level and perceive the neighborhood district of Chelsea in a different way. Not only did this project provide new usage of the Highline itself, but it also improved the perception of the whole area surrounding it.

Another example is the analysis of sightlines or visual axes, which is an important subject of study in urban and landscape planning. By connecting all low clusters of a tag with the single densest cluster of the same tag (e.g. by using the *spider diagram tool*), it is possible to create visualizations similar to sightlines. The technique was explored in Yosemite National Park for Half Dome, a dominant granite dome visible from a number of places in the valley (Fig. 10, App. III).

Similarly, by preselecting and connecting all dominant photographed aspects in an area with merged low clusters and joined number of sightings, it is possible to visualize the relative importance of a location as a subject compared to its importance as a

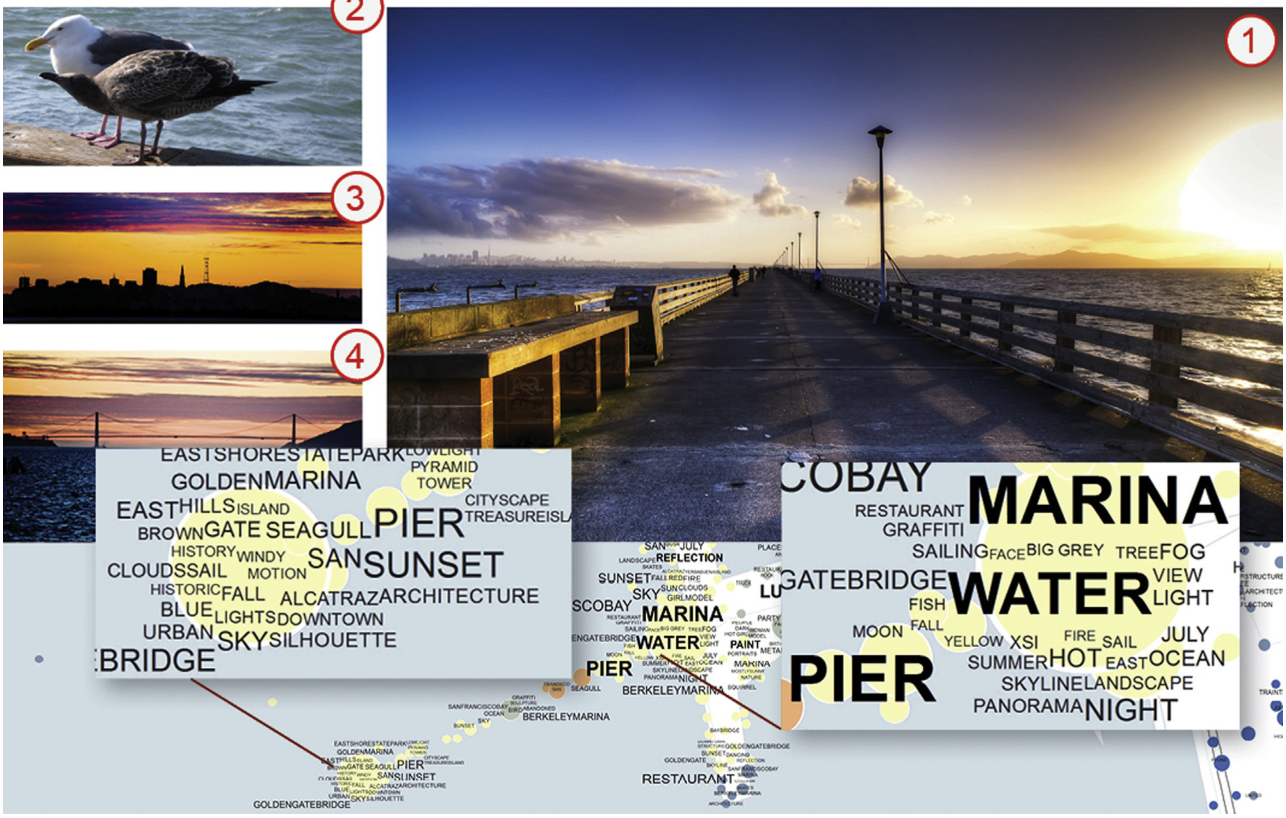

Fig. 8. Example map of Berkeley Marina (San Francisco Bay Area) and selective characteristic patterns of photo taking.
"Berkeley Marina Pier", ©Ryel Kestano; "Pictures from family trip", ©Erik Eckel, CC BY-NC-SA 2.0; "San Francisco Skyline", ©Thomas Hawk, CC BY-NC 2.0; "Sunset on the Golden Gate", ©Thomas Hawk, CC BY-NC 2.0.

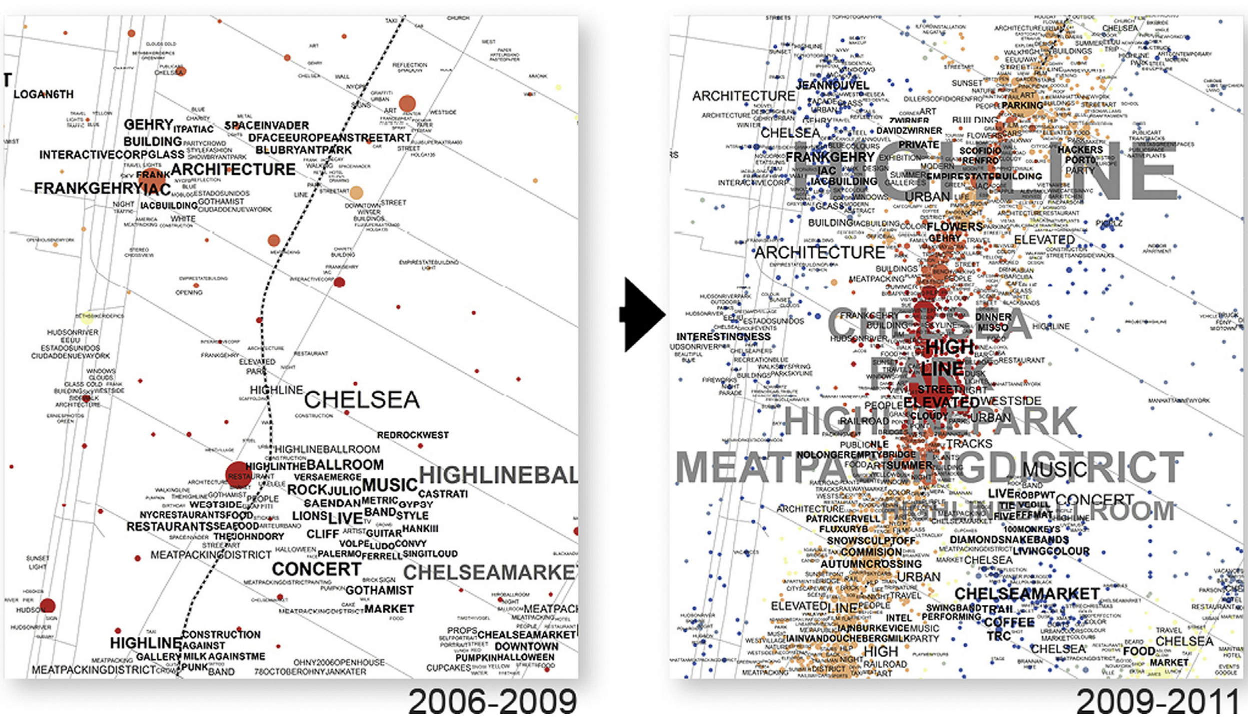

Fig. 9. Map for the district of Chelsea (NY), with data from before the opening of the High Line (left) and afterwards (right).

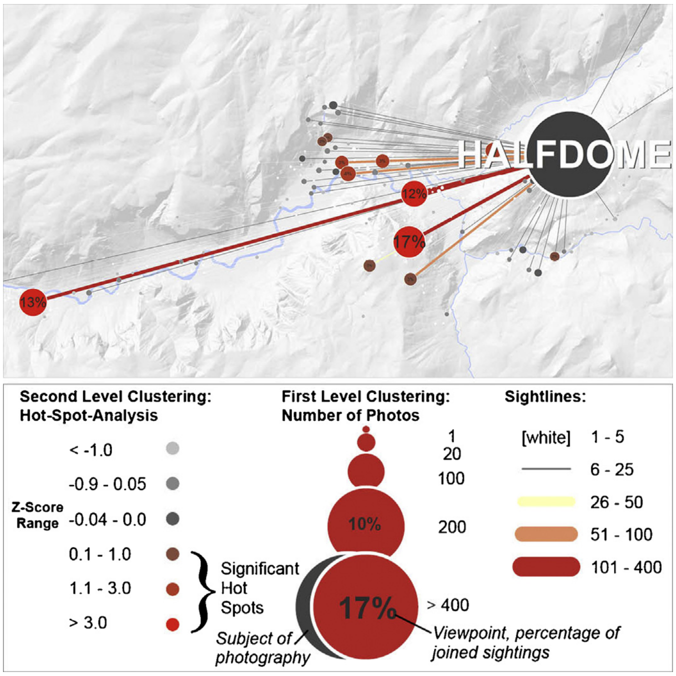

Fig. 10. Visual sightlines for 'Halfdome' in Yosemite Valley.

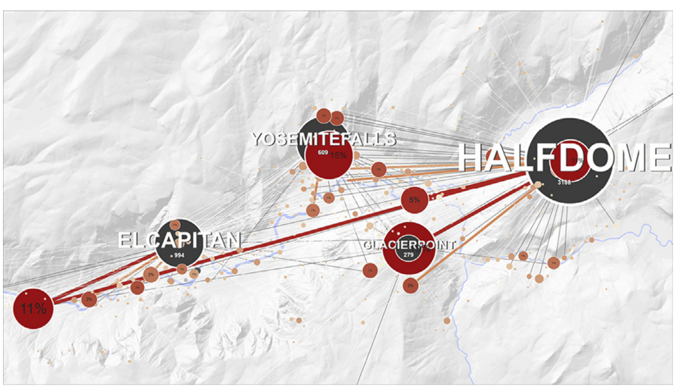

Fig. 11. Important visual connections in Yosemite Valley.

vantage point. In Yosemite Valley this method was used to determine statistically important visual connections for Glacier Point, Yosemite Falls, El Capitan, and Half Dome (Fig. 11). The granite cliff face of El Capitan (Fig. 12a) is the subject of many photographs but hard to reach as a vantage point. The opposite can be said for the point on the valleys entrance (called Valley View, symbolized on the lower left part of Fig. 11), which became famous as a vantage point

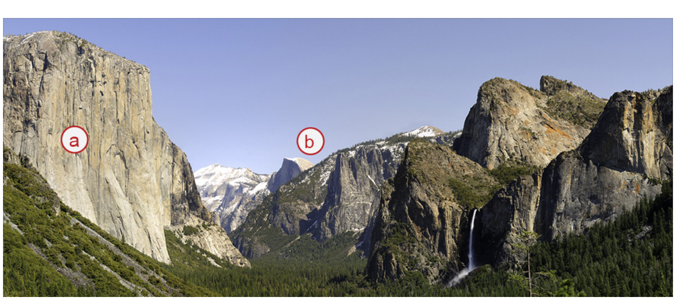

Fig. 12. View of Yosemite Valley as photographed from 'Valley View', a frequented vantage point for perceiving El Capitan (a) and Half Dome (b).
Photo by author.

by photographer Ansel Adams. Still far in the distance, Half Dome also has significant influence on the perception of many people at this place (Fig. 12b).

Unlike other visualizations, these maps are based on people's individual abilities for perceptual and mental processing, including memories and preferences and also accessibility factors and temporal characteristics. For planners, as a supplement to theoretical viewsheds computed from digital elevation models, this method can reveal which vantage points are highly frequented and why. Conversely, maps can unveil underutilized places and areas, with the need to examine reasons and guide action. Analyzing photos from specific time periods (Winter/Summer, Night/Day) could also demonstrate how preferences for certain vantage points/subjects change.

Furthermore, experimental visualization techniques can be used to study perception within a specific location. One example of individual location analysis is shown in Fig. 13. Coit Tower in San Francisco is a frequented vantage point as well as subject of photography itself. The graphic was calculated with the purpose of symbolizing characteristic patterns at Coit Tower. The *Golden Gate Bridge*, *Alcatraz Island* and the *Bay Bridge* are the most influential elements (Fig. 13a). By using the photographs timestamp in addition to the number of photographs, a popular time to visit Coit Tower throughout the day seems to be around *3pm* and *7pm* and the month with the highest frequency of visits is May (Fig. 13b). Also, counting occurrences of tags helps identifying people's associations and associative values with this place (Fig. 13c). The location information provided by photographers can serve as an additional source for information on the origin of visiting users (Fig. 13d). In the fields of landscape and urban planning, this data may help better understand the unique characteristics of a certain place, to protect and develop specific characteristics, or to propose action for changing negative influences.

4.3. Quality and accuracy of results

The integration of results into a planning process depends to a large degree on the quality and accuracy of the provided information. The main criteria for quality of data, with respect to its application in planning, are validity and reliability.

Reliability means the extent to which the planner can rely on the source of the data and, therefore, the data itself. The main measure for reliability is consistency. A suitable example is the apparent dominance of the Black Forest national park ("blackforest" and "schwarzwald") in the map of Baden-Württemberg in southern Germany (App. V). The size of labels is indicating a high importance. But is this information reliable? The sample of data may contain biases toward a narrow, specific group of users who particularly frequent this area and use these tags. Or, numbers may be undercounted. A planner can seek corroboration by using a wider range of measures and compare the consistency across results. For example, users can be classified into different groups based on their origin. If a consistent amount of users from culturally diverse groups share a similar amount of interest in the Black Forest, the information can be regarded as more reliable. An initial user analysis for the state of Baden-Württemberg shows that 4006 (38%) of overall 10,467 photographers provide information on their current location. Of this group, 825 (about 21%) have their location set to a place in Baden-Württemberg. The remaining majority (2401 users, 60%) specify a place located within Europe. Based on this, users can be classified into three groups: visitors from Europe (A), visitors from outside Europe (B), and local population (C). In the example, a mean proportion of 18% from group A, and 14% from group B frequent the area of the Black Forest during their stay in Baden-Württemberg (Table 2). A slightly higher percentage of about 20% of the local population frequent and photograph the Black Forest National Park

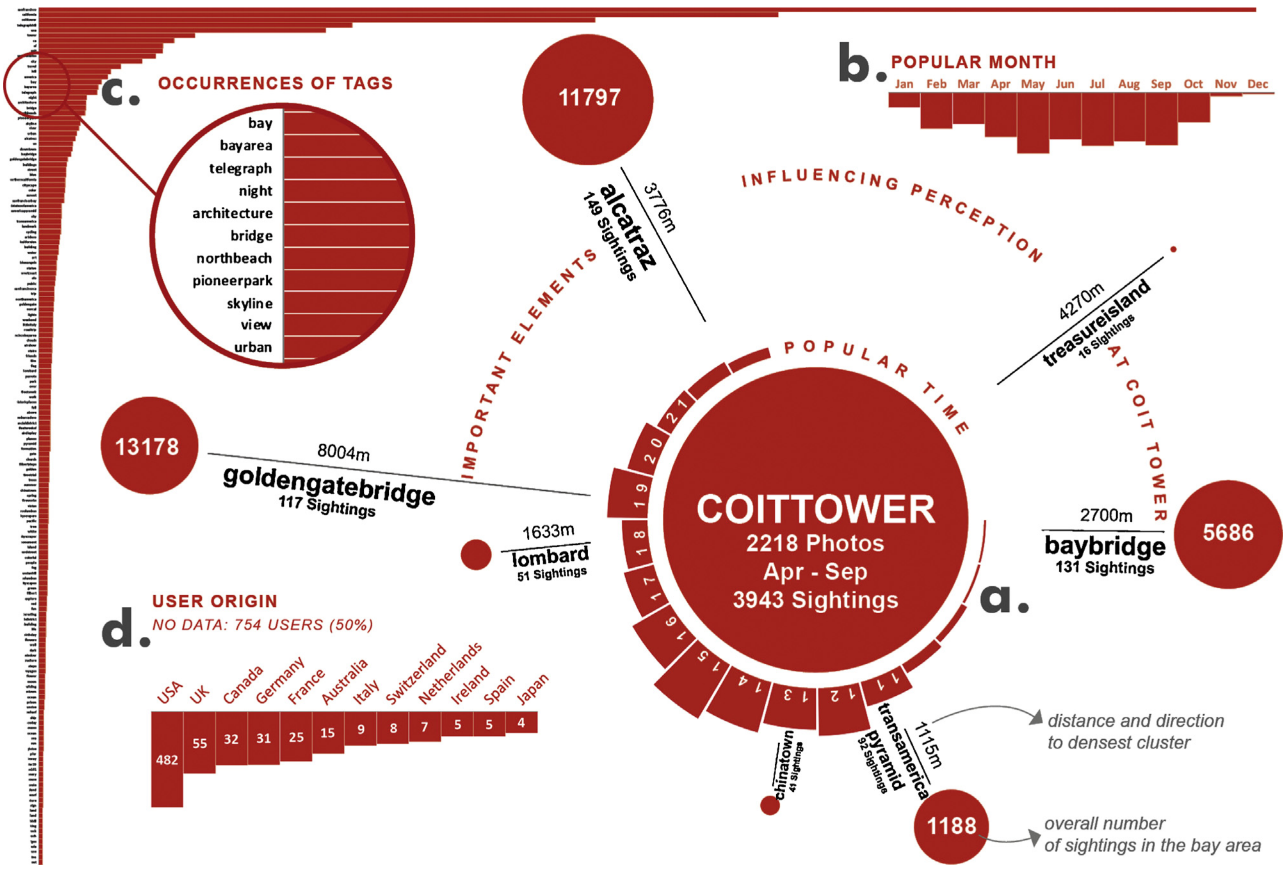

Fig. 13. Individual photo location analysis with temporal and spatial patterns for Coit Tower, a frequented landmark as well as vantage point in San Francisco.

(Group C, Table 2). While the numbers are not equal, they reflect a comparatively consistent distribution of data across culturally diverse groups. As we might expect, the amount of users with interest in the Black Forest is slightly decreasing with the distance traveled.

But, is it actually valid to equate the frequency of visits with "interest", or, equate the amount of tags people apply to their photographs with "perceptual responses"? The answer could be 'to some extent'. Validity relates to the relevancy and appropriateness of the information to the research question. Particularly

Table 2
Summary of user origin with photo locations in the State of Baden-Württemberg (BW) and within the Black Forest National Park for different groups of users.

Group	Origin	Σ Users with photo locations in BW	Σ Users with photo locations in the Black Forest National Park	%
A	Germany	1.196	183	15%
	UK	236	47	20%
	Switzerland	211	50	24%
	France	138	24	17%
	Netherlands	118	32	27%
	Italy	112	16	14%
	Spain	102	22	22%
	Belgium	39	10	26%
	Austria	37	4	11%
	Russia	26	2	8%
			Mean:	**18%**
B	USA	376	51	14%
	Canada	55	11	20%
	Australia	48	9	19%
	Japan	38	6	16%
	Brazil	23	1	4%
	Taiwan	23	6	26%
	China	21	2	10%
	Turkey	13	0	0%
	India	12	3	25%
	Singapore	12	1	8%
			Mean:	**14%**
C	BW	825	161	20%
			Overall mean:	**16%**

in landscape perception analysis planners will often have to use data whose validity appears weak because no other information is available. While this does not invalidate results, it means that the planner has to be carefully in processing data, interpreting results, and drawing conclusions. An example of limited validity is evident in the visualization of sightlines for Yosemite Valley (Figs. 10 and 12). As noted earlier, the connection between the tag and photo is not always based on visual sightings. We do not know whether people who tagged *halfdome* actually visually perceived the rock formation or refer to their trip's hiking destination (even if Half Dome may be visible in the photo). An elevation model can be used to pre-select theoretically possible photo locations to increase accuracy. In the example, about 13% (325 out of 2362) of the photos tagged with *halfdome* lie outside the theoretical viewshed which was calculated using the elevation model. About 58% (188) of these are located along the path leading up to Half Dome (possibly indicating people's hiking destination). Despite this imprecision for separating visual features, the technique may provide essential information on the significance of locations compared to other locations for perceiving a single aspect in the landscape.

5. Discussion

The amount of available crowdsourced geodata has grown in a very short time to reach an extent that covers almost all urban areas in the western hemisphere. Furthermore, the growth of this data is expected to rise exponentially in the future. Relative to the goals herein, the physical presence required for generating crowdsourced spatial content makes it especially suited to collect information on aspects of identification, perception, emotion, and social interaction with respect to the environment. Understanding these processes is vital for designers and planners. As Lynch stated, "it is equally important to analyze the way in which the area is perceived by its people, since perception is a two-way process" and further emphasized, "[. . .] the visual character of a place, and its evaluations, is impossible to analyze if divorced from the people who see it" (Lynch, Banerjee, & Southworth, 1990, p. 279). Jack Nasar, whose work built up on Lynch's, wrote, "to improve community appearance, planners need to know how the public evaluates the cityscape" (1990, p. 1). Despite this importance, it is difficult for designers to obtain an unfiltered view on the public's way of perceiving a place or an area. The Kaplans argued that "[. . .] landscape architects and other natural resource specialists are among the most sensitive and knowledgeable observers of landscapes, but their design training may have also led them to perceive landscapes in ways that differ from the general public's" (cited in Bell, 2001, p. 38).

The potential application of this data is obvious. With thousands of individual personal experiences available, the public's *Image of the Environment* (Lynch, 1960, p. 1) increasingly manifests itself on the Internet. Richter and Winter (2011) describe that it is "the people's mental conceptualization of the environment they are living in" (p. 446). On various web blogs, twitter tweets, social networks, and photo sharing communities, this *Image* is already partially visible. Analyzing the hidden patterns of these data streams enables us to access this knowledge. The vision that is taking shape is to incorporate the unfiltered general public perception of the environment in planning and design processes.

The techniques demonstrated in this paper provide a basis for applying this source of information in landscape perception analysis. The assumptions herein are similar to those made in traditional participant photography or photo-interviewing. Photographing and labeling photographs are forms of attributing meaning to the environment. However, the process of evaluation differs significantly due to the different sources of data. Characteristically, the evaluation of meaning in landscape perception analysis is a tedious process of interviewing or manually describing photographs that have been actively acquired from participants. In such a manual process, several studies found that the research setup, the way of questioning or instructing participants, and the personal authority of the researcher may fundamentally influence results (Kaplan, 1985; Palmer & Hoffman, 2001; Zube et al., 1982). In contrast, the techniques presented in this work utilize data that is available without the need for interaction between the researcher and its subjects. Data is generated by photographers as part of typical activities carried out in the environment. As the photographers are not aware of the particular contribution to landscape perception analysis, the generated data is a better approximation of their unfiltered, unaffected, and, to a large degree, *unconscious* landscape experience. This objectivity is further reinforced by examining the *location* of photos instead of examining the photographs itself. While the latter technique is suited to evaluate *preferences* for certain types of landscapes (Shafer & Richards, 1974), research from Scott and Canter (1997) indicates that it is only limitedly suited for inferring the actual *experience* of the place pictured in the photo. The approach demonstrated herein may fill in this gap. Furthermore, through the benefits of reduced costs, increased volume of data, and larger number of participants, the approach described in this work may also be of help in establishing a practical counterbalance offsetting expert landscape assessments, which currently dominates in practice.

Notwithstanding the many ways in which this data could be analyzed and applied, the method described herein constitutes an integrated approach with limited consideration of related computational methods, and it was only tested on one specific data set. It would be interesting, for example, to expand the source of data beyond the extent of photo taking. Another direction could be to use more advanced methods for tag categorization and classification such as those presented by Jung, Park, Maeng, and Han (2012) or Purves and Edwardes (2008). Incorporating methods to reduce noise or to detect more precisely the accurateness of the provided location information (Zielstra & Hochmair, 2013) may help in further improving map quality.

Finally, one of the most significant questions that need to be addressed in future research is related to the limited group of people on which this analysis and these visualizations are based. In the example of Flickr, maps are biased toward a specific group of photographers and are therefore not universally representative. Thus, the integration of maps into planning remains problematic. It is an open question whether we can self-create data streams with people volunteering photo data. We must further consider how these applications should be designed to facilitate perception analysis. Addressing these questions may help in widening the group of people on which this analysis is based.

Application of this knowledge also requires us to discuss the wider implications and consequences. At the same time this data is publicly available, it is highly sensitive. In this view, the users' explicit understanding of what is contributed and how data is used takes on a central role. Analysis and application within our profession can be justified based on the responsibility for designing and planning for the public. If a fraction of our daily generated data can be used to improve "community appearance" (Nasar, 1990, p. 1) without compromising privacy, the potential is high that the virtual counterpart of the *Image of the Environment* will continue to develop.

6. Conclusions

Crowdsourcing is a completely new form of information retrieval and increasingly relevant in the spatial domain. This article highlights the broad potential of crowdsourced data for environmental perception analysis in landscape and urban planning. In particular, crowdsourced photo geodata is seen as an important supplemental source of information with an otherwise unavailable perspective on the perception of the environment by the general public.

While limitations apply, the presented experimental visualizations already provide a comprehensive basis for evaluating a variety of the perceived characteristics of places or areas. On a conceptual, methodological level, the article provides a foundation for further research. Before wider application can happen, a number of issues need to be addressed including questions of copyright, defining ethical standards within the profession, and protecting the individual people's privacy. From a wider point of view, opportunities are seen for designers and planners not only to integrate this new source of data to enhance work flows but also to exploit the phenomenon's essential nature of increased interconnectivity for communication with clients, participants, and the public. Such integration will better address specific user needs and build more focused solutions. It will also allow the public to participate in a small but essential part of design and planning processes and finally result in broader acceptance of built projects.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2015.02.022.

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