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Master thesis

Development of a Tool for Visual Comparison of
multi-faceted Data by Juxtaposed Map Views

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Master Thesis

Development of a tool for visual comparison of multi-faceted data by juxtaposed map views

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DECLARATION OF AUTHORSHIP

I declare that the submitted master's thesis entitled "***Development of a tool for visual comparison of multi-faceted data by juxtaposed map views***" is my thesis. To the best of my knowledge, it does not contain previously published, substantially overlapping material submitted for the award of another degree at another institution, except as noted in the text.

Dresden, November 23rd 2021

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ABSTRACT

Social media data is a popular source of information for scientists and planners. Among all social media, Flickr provides multi-faceted data for scientific research. A well-developed visual analysis tool is required to obtain targeted information through data visualization and comparison. This research focuses on developing a tool for visual comparison of multi-faceted data through side-by-side map views. Flickr data from 2007 to 2018 for the city of Dresden were processed and compared using the developed prototype. Flickr posts related to four activities (e.g., aesthetic appreciation, cultural events, sports, and outdoor recreation) were included in this study. A case study titled "Monitoring the urban green spaces (UGSs) utilization pattern changes among the visitors." was considered to evaluate the comparability of the developed prototypes. Two measures were calculated to solve the problems related to the case study. These measures are expectation and popularity. To achieve the research objectives, two side-by-side map views were developed. The unlinked map view was the first prototype where the data can be compared side by side, but the measures related to activities and year must be selected separately. On the other hand, the linked map views were the second prototype, where the background map, foreground map, and data were linked. Several JavaScript-based libraries were used to develop both prototypes. The libraries used are web-based GIS frameworks - Airship, Highcharts, and Leaflet. In addition, a certain number of interaction methods were selected through the literature review based on the taxonomy to simplify the comparison tasks for both map views. A well-designed survey was conducted to evaluate the developed prototypes. The ability to compare the data and solve the tasks related to the case study was the main focus of this survey. The total number of clicks was used as a measure of the evaluation process. Finally, it was found that linked map views could compare data faster than unlinked map views. Moreover, the designed tasks could be solved very conveniently using the interaction methods. Therefore, the developed prototypes are presented as a powerful and functional means for comparing Flickr data in the scientific domain. The developed prototypes can be usefully applied by urban landscape planners and also in other cities.

Keywords: Information visualization, comparison, juxtaposition, map, interaction, visual analytics

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CHAPTER 1: INTRODUCTION

1.1 Motivation and Problem Statement

Generally, visual analytics is the science of analytical reasoning facilitated by interactive visual interfaces (Andrienko et al., 2017). It is essential to data exploration with visualisation, interaction, and data mining techniques (Chen et al., 2017). Besides, it refers to a visual representation that supports primary forms of analysis of problems and aids decision-making through interactive visualisations and automated data processing. Multiple visual analytics tools support user interactions to enhance data exploration. The supported interactions can be general like data filtering, zooming, changing colours, linking or more task-oriented like dragging items next to each other or making them transparent to reveal the occluded information. Nowadays, data analysis is mainly involved in the comparison of different information. Consequently, demand for visual analytical systems is growing to compare the data with the ever-increasing amounts of the complexity of data. Gradually, information visualisation tools support such comparisons explicitly, beyond merely allowing a viewer to examine each object individually (Gleicher et al., 2011). Maps are one of the many forms of visual representation used in visual analytics. Therefore, interactive maps are more user-friendly and getting popularity where more data can be represented with various interactive functionalities.

In general, the comparison is often considered as a sub-task of data exploration in visual analysis. The main visual comparison methods are juxtaposition, superimposition, and explicit encoding of differences (relationships), with various combinations possible between them (Gleicher et al., 2011). Among these methods, juxtaposing interactive visualisation enables gathering more information in less time (Nazemi & Burkhardt, 2019). In addition to visual comparison methods, the existing visual analytics tools and data exploration dashboards often implement user interactions to make the data analysis more

profound. Generally, juxtaposition works best when visual processing can easily match objects, allowing for repeated patterns and differences to be noticed (Gleicher et al., 2011).

1.2 Research Identification

The visual comparison with various interactive functionalities has become a valuable means for exploring and analysing multi-faceted social media data. Social media data contain different facets that provide meaningful information. The common facets are generally spatial, temporal, social and thematic (Dunkel, 2015). Over the past decade, mobile smartphone subscriptions have grown dramatically, from 723 million in 2011 to 6.4 billion in 2021(ericsson.com, n.d.). The recent emergence of social media creates exciting alternative possibilities to assess how people use and respond to nature and other cues for recreation and tourism(Wood et al., 2013). This research will be conducted on the case study of “Monitoring the urban green spaces (UGSs) utilization pattern changes among the visitors.” through the interactive juxtaposed map views based on geolocated Flickr data. The local comparison of data will be considered for Dresden city’s UGSs as a study area. The study will focus on developing a tool for visual comparison of geolocated social media data by juxtaposed views. This tool will allow comparing the urban green spaces of Dresden city in terms of visitation and utilization patterns by exploring the spatial, thematic, and temporal facets.

1.3 Research Objectives

The research objectives are:

1. To identify and select interactions that support and enhance the visual comparison of multi-faceted data by using juxtaposed map views.
2. To develop a tool that implements interactions with juxtaposed map views to support and facilitate the comparison of geolocated social media data.

1.4 Research questions

Based on the research objectives, the research questions are:

1. Which interaction techniques to use in visual comparison of juxtaposed map views for exploring the spatial, thematic, and temporal facets of social media?
2. How can the interactive juxtaposed map views facilitate the exploration of the spatial, thematic, and temporal facets of social media data?
3. Which juxtaposed map (unlinked map views or linked map views) is the most applicable for the data comparison tasks?

1.5 Thesis Structure

Eight main chapters are in this thesis. The current chapter is the introduction of the thesis and presents the research objectives and questions. Chapter 2 discusses the relevant literature review, while Chapter 3 presents the methodology used to answer the research questions. Next, the main work of the thesis is presented, with chapter 4 focusing on prototype design and development, where the data visualization and interactive data comparison are discussed. Chapter 5 focuses on the usability test, user study design to evaluate the design prototype, and the case study discussion of how the designed visual analytics compare different facets of data. A discussion of the usability test result and the associated benefits and limitations are discussed in detail in chapter 6. Finally, chapter 7 concludes the thesis and discusses future recommendations.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews the relevant research on interactive data comparison methods. In addition, this chapter answer the first research question and relate with the first research objective through identifying and describing the standard practices and the predominant interaction techniques for visual comparison of the different data dimensions.

2.1 Different facets of multi-faceted social media data

Social media is the technological platform where users create and share media content such as photos or videos and other types of content through virtual communities and social networks (Chen et al., 2017). Recently, the increasing availability of online social networks and media sharing services such as Facebook, Foursquare, Flickr, and Instagram has led to large amounts of social media data. Generally, social media users create data by posting and reposting messages that contain time, text, media, and location-related data. This data is extensive and contains information about people's observations and experiences on various topics (Huang et al., 2013). Social media data contain different facets that provide meaningful information. The common facets are generally spatial, temporal, social and thematic. However, not all social media data contains geo-information. Usually, social media data contains two types of geolocation (Habeeb & Al-A'araji, 2016). The first is explicit geolocation, which directly mentions the user's profile such as country, city or full address. Another type is implicit location, where the location data is extracted based on several attributes or objects associated with the user and the message.

The location information of data represents spatial facets, while the posts creation date represents the temporal data. Moreover, thematic facets identify common themes, topics and ideas that can give meaningful information. For example, Heikinheimo et al. (2020) used spatial, temporal, and thematic facets to understand the use of UGSs using social media data from Helsinki, Finland. Furthermore, Dunkel (2015) visualised the peoples' perceptual responses to landscape as a thematic facet from Flickr data. In his study, he focused on how people interact with the natural environment and perceive their surroundings. To visualise hot spots, he represented the spatial aspects of social media data through clusters of user locations.

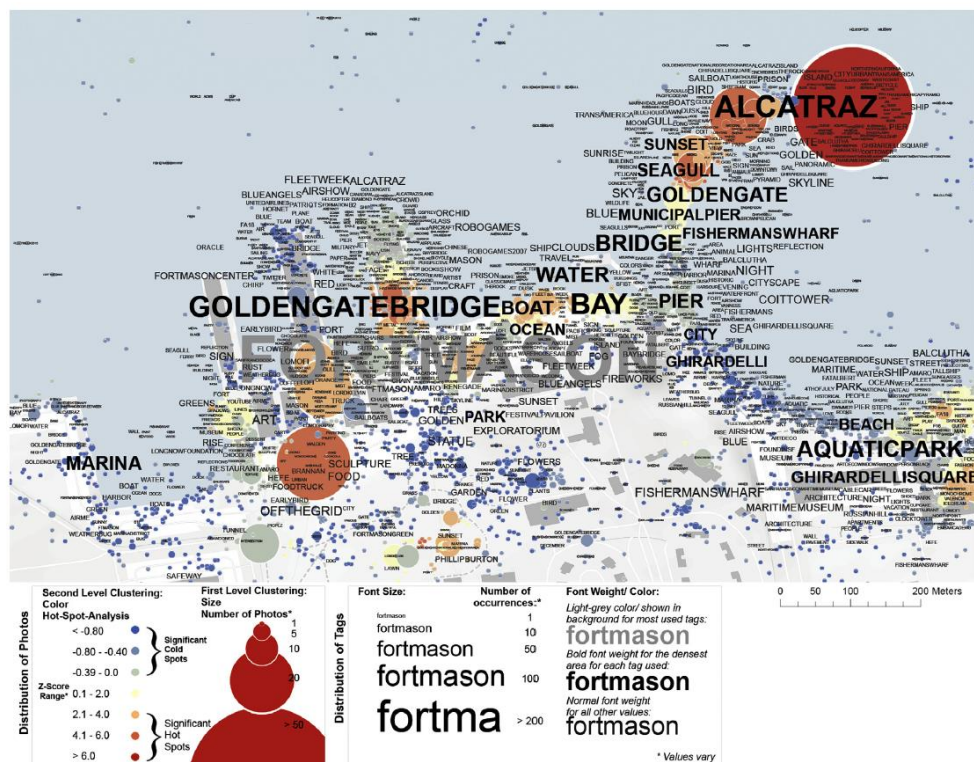


Figure 1. Mapping the thematic facet of Flickr data by analysing the unique tags (Dunkel, 2015).

Hollenstein & Purves(2010) used the spatial facet of Flickr data to explore the place that aimed to gain insights into how people describe urban spaces. The spatial facet of Flickr data is used to model city centre and thematic facet's perceived boundaries to model people's affective responses towards environments (Huang et al., 2013).

2.2 Visual comparison

This subchapter discusses the existing visual data comparison methods for information visualisation. In general, data analysis often involves comparisons of complex objects. Information visualisation tools increasingly support such comparisons allowing the viewer to examine each object individually. Moreover, the comparison is not a single task but a series of tasks that the observer must perform when given several related objects. Many fundamental tasks can be mentioned, such as finding similarities, differences, and trends, finding outliers or determining the causality of changes.

The taxonomy divides the comparative design space into three general categories based on how the relationship between the related parts of different objects is coded (Gleicher et al., 2011). These three major categories are:

- Juxtaposition
- Superposition and
- Explicit encodings

2.2.1 Juxtaposition

In general, comparisons are performed in two ways. First, the comparison between variables and second, the comparison of subsets of data (Nazemi & Burkhardt, 2019). The Juxtaposition method specifies the objects to be compared individually (Figure 2, a). This separation can be both temporal and spatial. It is usually done in space (placing different views next to each other). This can also be referred to as a double view or side-by-side view.

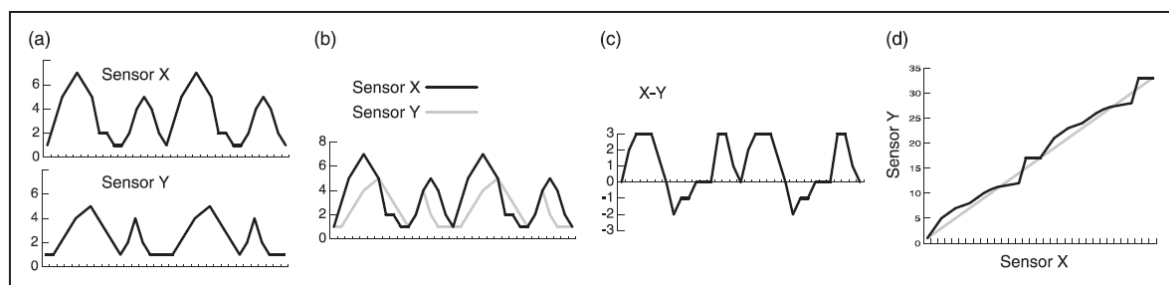


Figure 2. A simple example of comparative visualisations: (a) juxtaposition, (b) superposition, (c,d) explicit coding of relationships (Gleicher et al., 2011).

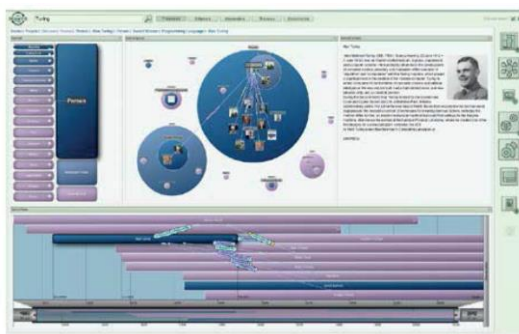
A well designed juxtaposed visual layout is very significant for analytical tasks. Nazemi & Burkhardt (2018) introduced a model juxtaposing visual layouts as visual interfaces with the main difference that several databases can be visualized simultaneously and enables analytical comparison tasks. In this context, they outlined that the following six perspectives give a helpful starting point for more complex visual tasks:

- i. perspective view
- ii. perspective comparative view
- iii. comparative view on level-of-detail

- iv. comparative view on data sub-sets
- v. comparative view on data
- vi. non-linked view

i. Perspective View

The perspective view allows the user to explore the subset of queried data from different perspectives using different visual layouts. The layouts are linked together, and the user can navigate through the different visual layouts and retrieve the desired information from the visual layouts.



(a) Perspective view



(b) Perspective-comparative view

Figure 3. Different juxtaposed visual layouts (Nazemi & Burkhardt, 2018).

ii. Perspective Comparative View

The perspective-comparative view allows solving comparative tasks by freely choosing visual layouts for different data subsets from the same database (Nazemi & Burkhardt, 2018). The results for each subset of data are linked, while the visual layouts are linked only by the data. Thus, only those visual layouts that visualize the same data subsets respond to the interaction when a user interacts with a visual layout.

iii. Comparative View on Level-of-Detail

A low-level comparative view provides a detailed level comparative view. This view allows visualizing the same data with the same visual layouts but different parameterization to get an overview and a detailed view (Nazemi & Burkhardt, 2018). Parameterization of specific visual layouts allows controlling the level of

detail in the context of zooming. The zoom levels can vary from visual zoom to semantic zoom with semantic-based filtering.

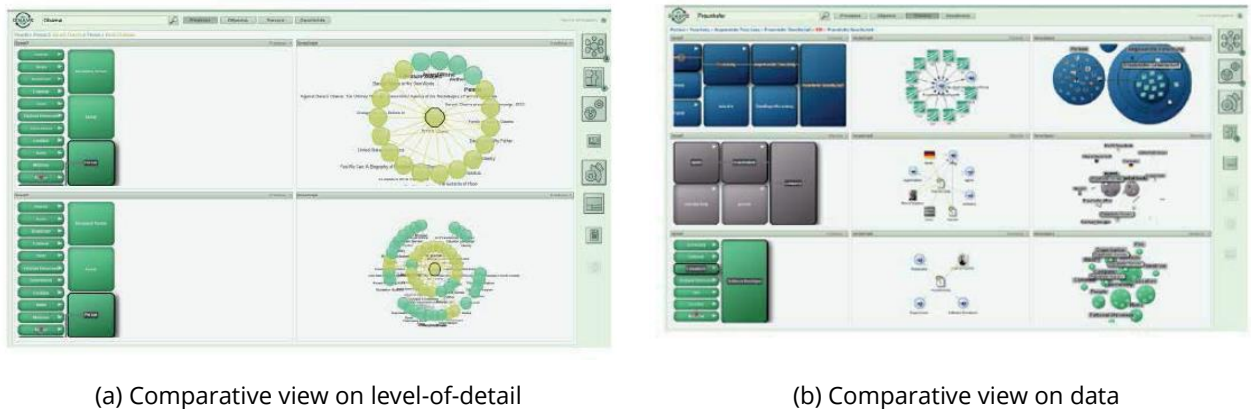


Figure 4. Different juxtaposed visual layouts with the level of details (Nazemi & Burkhardt, 2018).

iv. Comparative View on Data Sub-Sets

This view allows visualization of different search or interaction results using the same visual layouts, often superimposed (Nazemi & Burkhardt, 2018). Using the same visual layout supports the comparison and analysis process, creating a direct visual correlation. Thus, visual layouts that visualize the same content or search result are linked, while visual layouts that visualize a different subset are not affected.

v. Comparative View on Data

This view visualizes different databases with the same visual layouts (Nazemi & Burkhardt, 2018). Thus, this comparative view on data allows analysis tasks without querying different databases and changes the view. Furthermore, it has the advantage that all databases' results are visualized in the same way, allowing easy comparison.

vi. Non-Linked View

The unlinked view has no limits. It allows visualizing data from different databases with different visual layouts (Nazemi & Burkhardt, 2018). It provides an unconstrained view for the suggested more profound exploratory search steps.

This method allows the freedom to retrieve the search results from different perspectives.

2.2.2 Superposition

The superimposition pattern shows the objects to be compared in the same space. Such a pattern can be called an overlay pattern because it usually involves overlaying one object with another (Figure 2-(b)). This taxonomy can be as simple as making one object semi-transparent or even having one object partially obscure another. Usually, the different objects are displayed symmetrically but in slightly different ways.

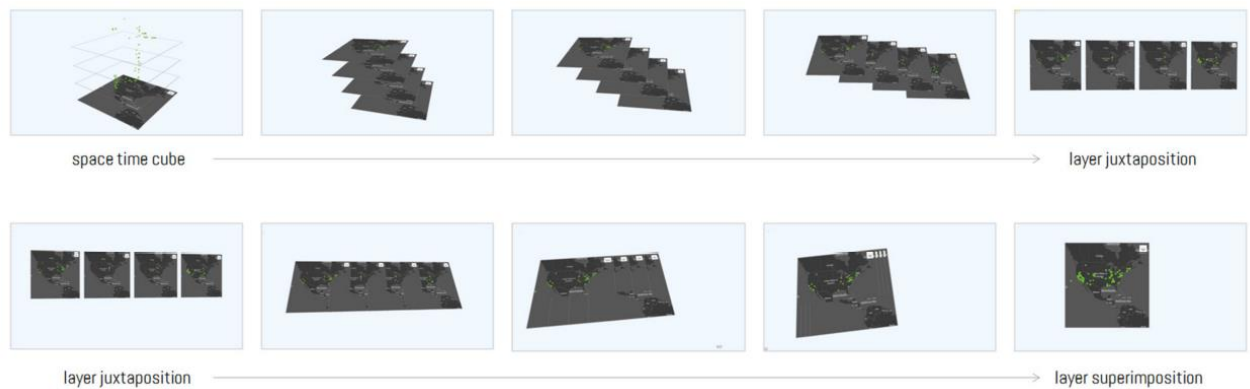


Figure 5. Juxtaposition and superposition view in a single display (Mayr & Windhager, 2018).

2.2.3 Explicit encoding of relationships

The category of explicit coding includes designs that explicitly represent the relationships between objects (Figure 2-(c,d)). Such a design assumes that the relationships between objects are known. In addition, this technique requires assumptions about which relationships might be of interest and a mechanism to calculate them explicitly (Gleicher et al., 2011).

2.3 Interaction techniques for information visualization

This section discusses various interactive functionalities that make the data visualisation and comparison task more user friendly. As the amount of available data increases, the need for comparison tools is also increasing. Data visualisation

is an efficient way to show the distribution and structure of data sets and to reveal hidden patterns in the data (Chen et al., 2015). Many developed visual tools support comparison tasks. Chen et al.(2015) and Sobral et al.(2019) explained the important technological frameworks and programming languages used to develop various interactive functionalities to simplify visualisation and comparison tasks. For example, Java, JavaScript, HTML, C++, PostgreSQL, Open GL, ColdFusion, Flex, Processing and D3.js. The interaction is a core element of visual analytics design that connects users and systems. It helps the environment compensate for the indispensable deficits that arise when displayed on a computer screen. It allows the identification of unclear patterns in the data (Edsall et al., 1995). Zooming, panning, re-centring, and re-projecting are used to compensate for essential deficiencies. Revealing unobvious patterns in data, the commonly used functionalities are altering representation type and altering symbolisation, as suggested by Heidmann (2013). Sedig & Parsons (2013) classified interactive action patterns into unipolar and bipolar based on their characteristics. The categorization is illustrated in the table 1.

Unipolar	Bipolar
Annotating	Accelerating/ Decelerating
Blending	Animating/ Freezing
Drilling	Collapsing/ Expanding
Filtering	Composing/ Decomposing
Navigating	Gathering/ Discarding
Searching	Inserting/ Removing
Selecting	Linking/ Unlinking
Transforming	Storing/ Retrieving
Translating	

Tab 1. Interactive Action Patterns (Sedig & Parsons, 2013).

Unipolar action patterns are actions where an action is performed in one direction, and there is no natural counteraction. For example, after performing

such an action, the user can usually only undo it by performing an undo action. On the other hand, there are some patterns where the action is executed in one direction, and there is no natural opposite. This is called a bipolar action pattern. After investigating the Information visualization system (InfoVis) and its interactive possibilities, Yi et al. (2007) proposed seven general categories of widely used interaction techniques.

Techniques	Uses
1) Selecting,	marking something as interesting
2) Exploring	showing something else
3) Reconfigure	displaying a different arrangement
4) Encoding	showing a different representation
5) Abstracting / Exploring	screening more or details
6) Filtering	showing something conditionally
7) Connect	viewing related items

Table 2. Interactive techniques (Yi et al., 2007)

• Selection

Selection acts to focus on or choose the elements. It can perform as a grouping function on a visual analytic system (Sedig & Parsons, 2013). By visually distinguishing the item of interest, the user can easily track it even in large data sets and when changes are made to the display.

• Exploring

Exploration interaction techniques allow users to explore different subsets of data cases. When users look at data in visual analytics, they can often only see a limited number of data items at once because there are several large combinations of data sets. The most common explore interaction technique is panning (Yi et al., 2007). It refers to changing the focus area or moving the scene while the camera is still. It is often achieved through a special mode where the user moves the scene

with the mouse or changes the view using the scroll bar. Analytical tasks usually begin with an exploratory search task necessary to compare the selected variables or objects. The main goal is to reduce the amount of visualized data or focus only on interest targets. Various disciplines provide technologies, systems, and approaches to enable information retrieval. Nazemi & Burkhardt (2018) divided the methods into two to simplify the study of these approaches.

- a) Bottom-up and
- b) Top-down approach

a) Bottom-up approach

This approach attempts to formalize a three-step query model (Nazemi & Burkhardt, 2018). This model assumes that search begins with the formulation of a known knowledge query. Then, during the search process, the subject gets more knowledge about a specific topic to refine the query and gather more knowledge about a particular topic.

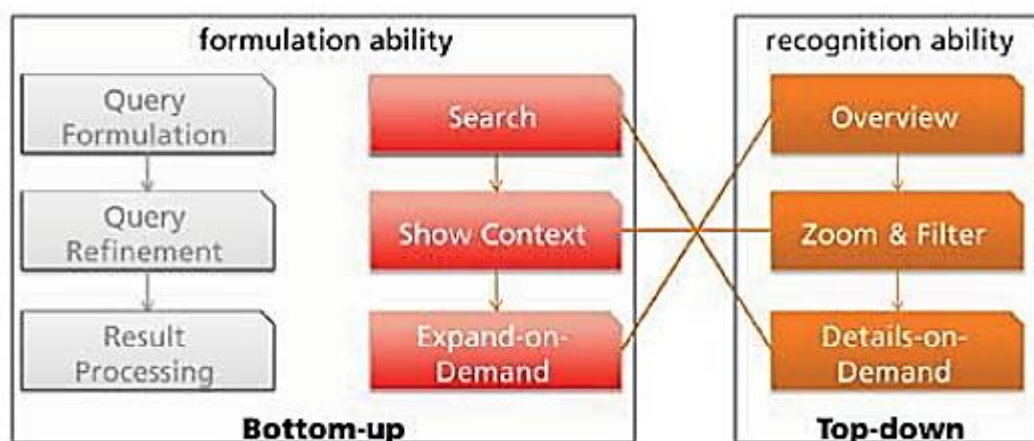


Figure 6. Top-down and bottom-up search approaches (Nazemi & Burkhardt, 2018).

b) Top-down approach

This model represents the opposite of the bottom-up approach and is designed for visual information search (Nazemi & Burkhardt, 2018). The three-stage model involves first getting an overview of the data, then zooming in and filtering the relevant parts, and finally capturing details as needed.

- **Encode**

Encoding techniques allow users to change the essential visual representation of data, including the visual appearance (e.g., colour, size, shape) of individual data elements (Yi et al., 2007). For example, by changing the visualisation style (sequential or divergence colour) of the map, users can better identify information (e.g., thematic information) without changing the spatial settings of the map. Moreover, semantic zoom is also an encoding technique as the data representation can change when the zoom scale changes. For example, interactive point data clustering works at different zoom levels.

- **Filtering**

Filter interaction techniques allow the user to change the set of data items displayed based on certain conditions (Figure 8). In this type of interaction, the user defines a range or condition to display only data items that meet these criteria (Yi et al., 2007).

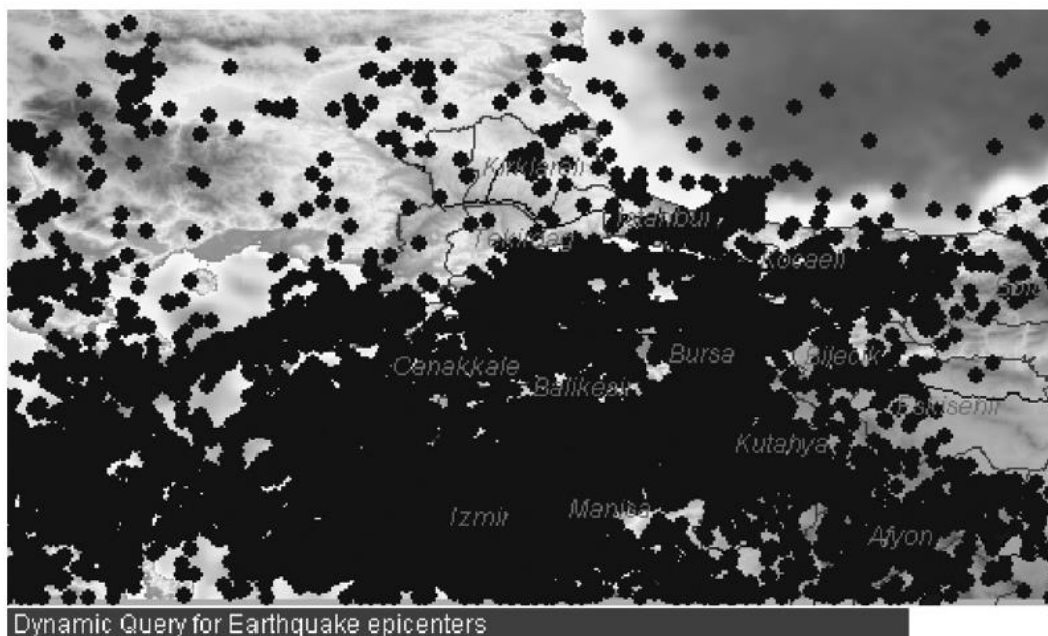


Figure 7. Distribution of Earthquake related data (Edsall et al., 2008).

It allows users to exclude some of the sub-systems of representations from view. Usually, sliders, drop-down menus, or other graphical interface tools are used to

query attributes on individual variables to display. It reduces the amount of data displayed by only showing records that meet certain conditions.

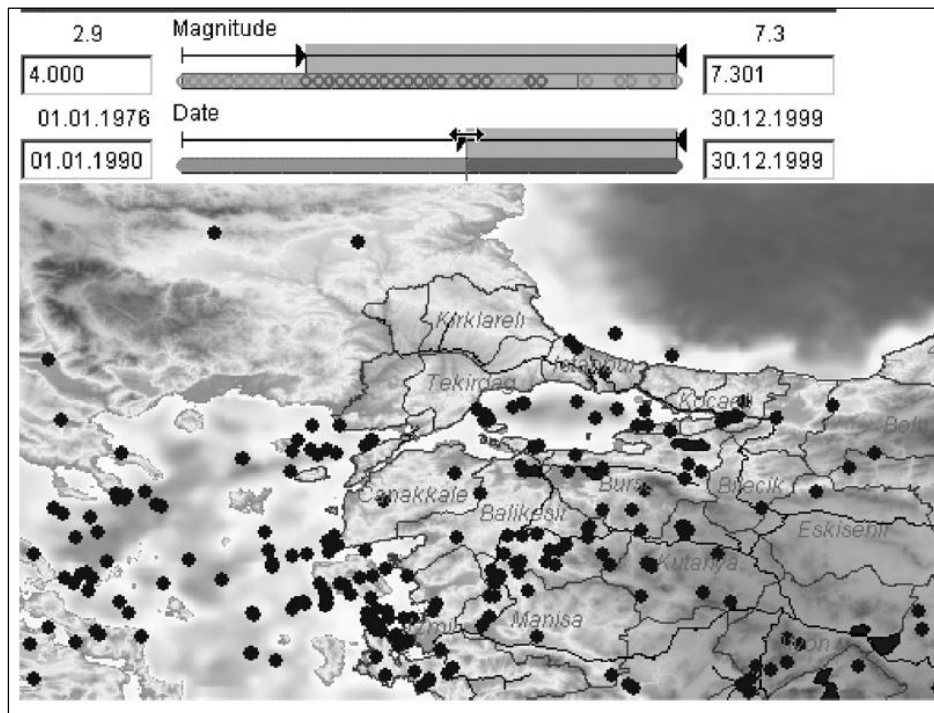


Figure 8. Data filtering is based on specific magnitude and date (Edsall et al., 2008)

• Connect

Connection refers to the interaction technique used to draw relationships and connections between data items already presented. Also, it displays data relevant to an element. Some features of connects are:

- Connect interactions can also be applied to situations that affect a single view. For example, when the mouse pointer moves over a polygon and shows the desired variables.
- The linking interaction technique also makes related data elements visible that were not initially displayed. For example, a double/single click on a polygon causes the bar chart or data table to expand.

There are several taxonomies of interaction methods (Yi et al., 2007). Moreover, the role of interaction in visual data comparison is significant. These interaction techniques make the comparison tasks significantly simplified and

comprehensible to the users. However, research focusing specifically on the visual comparison of data is limited. Therefore, it is necessary to identify and implement suitable interactive methods for developing and implementing juxtaposed map views.

Chapter 3: Methodology

This chapter will explain the methodology used to achieve the completion of this thesis. The first stage of the thesis is the descriptive literature review. The literature review was conducted to identify the existing visual comparison methods and interactive methods or functionalities for visual data comparison. Therefore, relevant scientific visual analytics tools that support the visual comparison task were revised to select the potential interaction and comparison methods.

3.1 Data

Flickr is a photo-sharing website where people share media content in photos with associated tags (keywords) and coordinates. Recently, analysis of the distribution of Flickr photos and selected topics has become an essential resource in this research area. Researchers have used Flickr in the context of landscapes, for example, to extract descriptions of places, characterize landscapes from the public's perspective, or examine the value of cultural landscapes (Wartmann & Mackaness, 2020). The Flickr dataset and UGSs data were used for this study. In this study, the Flickr data was provided by the Institute of Cartography (TUD), which is explicitly geolocated as each post is associated with coordinates. In this study, Flickr data's spatial, temporal, and thematic facets have been considered for the comparison task. The details of the dataset are described below.

• Urban Green Spaces (UGSs)

The dataset containing all publicly accessible green spaces in Dresden was provided by the Leibniz-Institut für ökologische Raumentwicklung e. V. (IÖR) as a

JSON file on the mCloud data portal of the Federal Ministry of Transport and Digital Infrastructure (BMVI) of Germany (mCLOUD, n.d.). This dataset is part of the central data basis for evaluating green spaces according to criteria or suitability for certain activities using the meinGrün app (meinGRÜNapp, n.d.). Furthermore, the provided UGSs data was in .json format. Therefore, the attributes which were relevant to this study were considered. The considerable attributes are OBJECTID, TARGET_nam, TARGET_typ and TARGET_ARE (A dataset preview is given in Tab. 3). The target name in this dataset refers to the name of the particular green area of Dresden, and the target type refers to the category of the land use (e.g., playground, forest, park).

	OBJECTID_1 ▲	TARGET_nam	TARGET_typ	TARGET_ARE
1	1	Rhönweg 23 (H...	playground	578.780177510...
2	2	Maulbeerenstra...	playground	4195.32270070...
3	3	Florian-Geyer-St...	playground	825.414228407...
4	4	Richard-Wagner...	playground	11386.7701415...
5	5	Alemannenstraß...	playground	2083.47284512...
6	6	Hainbuchenstra...	playground	12040.8709180...
7	7	Wormser Straße...	playground	3915.72781996...
8	8	Blasewitzer Stra...	playground	3124.71155515...
9	9	Wormser Straße...	playground	6034.24341205...
10	10	Alemannenstraß...	playground	446.573489248...

Tab. 3 Format of the UGSs dataset used

• Flickr Dataset

The Flickr data provided was related to the urban area of Dresden, to which visitors from all over the world contributed by posting photographs on Flickr. The provided dataset was retrieved using the Flickr API based on bounding boxes for Dresden, Germany. It consists of 23308 geotagged social media posts shared on Flickr under the Creative Commons Attribution 2.0 Generic (CC-BY-2.0) license. The data was retrieved for the period between January 2007 and November 2018 using

the available API. Furthermore, to tackle some of the privacy issues that social media generally raises, some measures were taken, and the following methods were used to ensure increased privacy for the users:

- Global Unique Identifiers (GUIDs), such as UserIDs, PlaceIDs, PostIDs, were hashed with the encryption method sha256 with the purpose that original IDs cannot be obtained from these Hashes without significant effort.
- Only information that was explicitly made public by users were provided.
- Other identifiers and private information such as usernames, biography and others were removed.

The provided dataset was further pre-processed. The geotagged Flickr posts were classified according to four topics representing different activities undertaken in UGSs: aesthetic appreciation, wildlife recreation, cultural events, and sports. The geotagged social media posts classification was carried out based on an unsupervised text classification methodology that implements state-of-the-art NLP techniques and relies on the computation of semantic similarity between word embeddings and was developed by the Institute of Cartography within the mFUND project meinGrün (meinGRÜN, n.d.).

	latitude	longitude	post_creat	aesthetic_	wildlife_r	sports	cultural_e ▼
1	51.032647000000	13.765413000000	2018-10-02	1	1	0	1
2	51.077280000000	13.714788000000	2014-02-11	1	1	0	1
3	51.072036000000	13.722888000000	2014-02-11	1	1	0	1
4	51.058633000000	13.735399000000	2014-02-11	1	1	0	1
5	51.053629000000	13.737330000000	2009-09-27	0	0	0	1
6	51.053170000000	13.733639000000	2009-09-27	0	0	0	1
7	51.052613000000	13.722625000000	2018-08-26	0	0	0	1
8	51.052613000000	13.722625000000	2018-08-26	0	0	0	1
9	51.052613000000	13.722625000000	2018-08-26	0	0	0	1
10	51.052613000000	13.722625000000	2018-08-26	0	0	0	1

Tab. 4 Format of the Flickr dataset used

The provided Flickr data was in .csv format. The essential attributes which are taken into account are; latitude, longitude, post creation date, aesthetic appreciation, cultural events, sports and wildlife recreation (A preview of the dataset table are presented in Table 4). In this dataset, post_create_date was the date on which the photo shared by the user was taken. The post could have been created later to share the photographs. In addition, activities are categorical columns that indicate if a Flickr post is classified as related to that specific activity (1) or not (0).

3.2 Data Processing

The data processing was done by following sequential steps. A summary of these sequential steps is given in figure 9. The data processing tasks were performed by using ArcGIS Pro, version 2.8.3 software and QGIS Desktop, version 3.14.0.

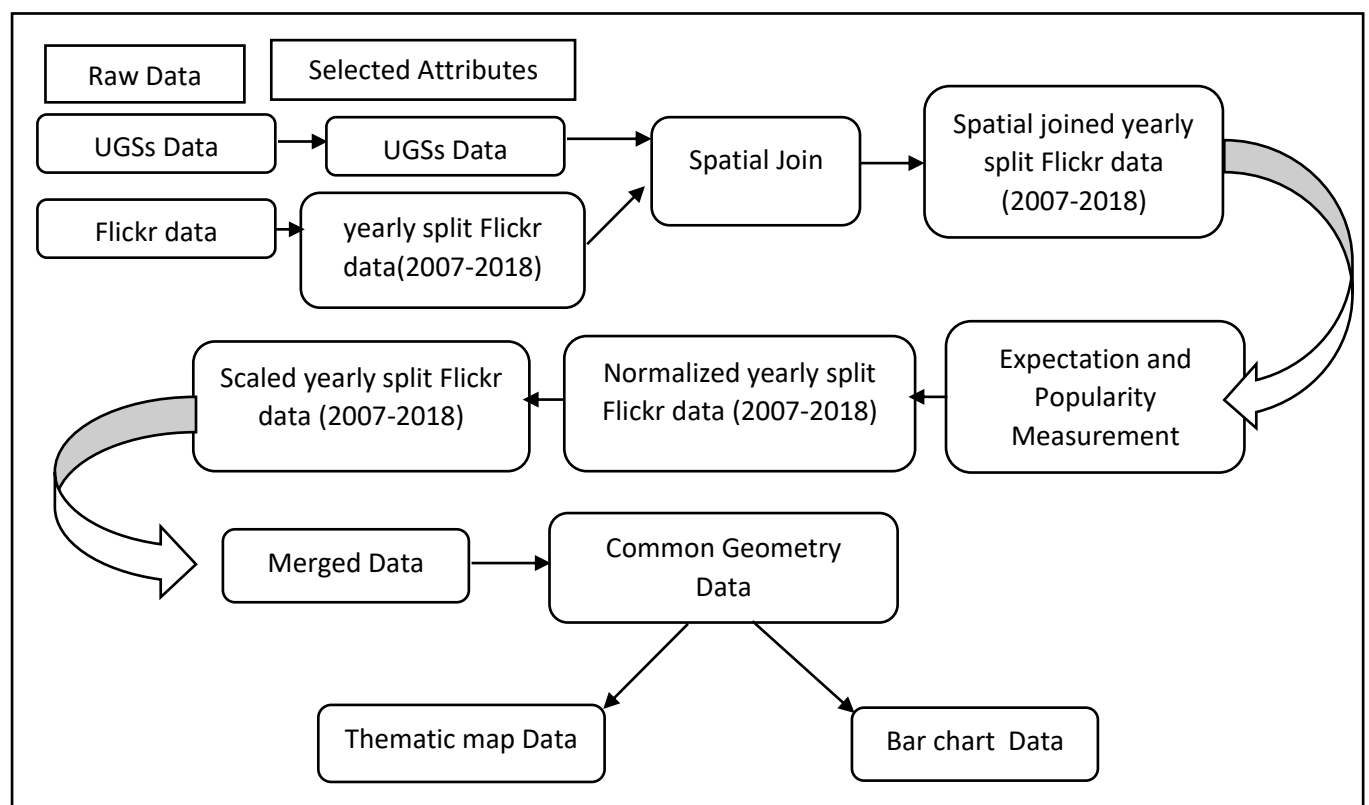


Figure 9. The Sequential data processing steps followed in this study

The Flickr dataset was first split into different subsets for each year (2007 to 2018) by using QGIS and then a spatial join was performed between each subset and

the UGSs dataset to calculate the number of posts for each activity within each polygon by using ArcGIS Pro. After spatial joining, a new shapefile was created with a new field called "total post" that represents the total number of posts (classified and unclassified) in each green area (i.e., polygon).

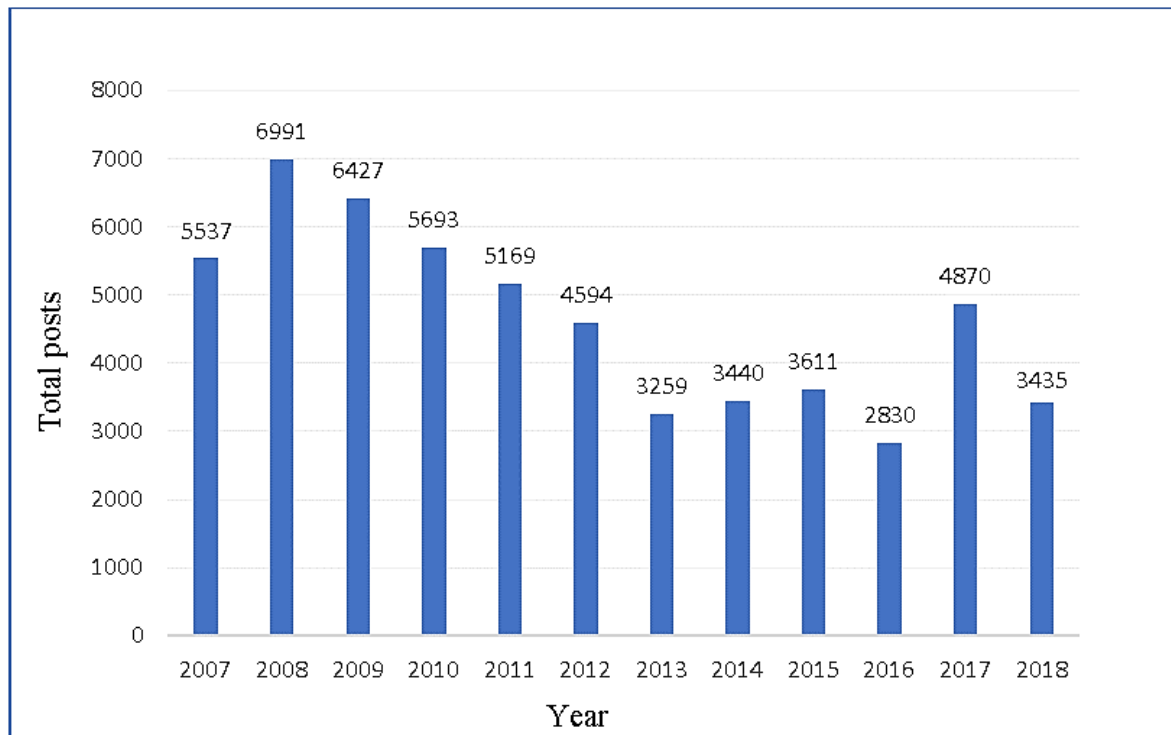


Figure 10. A yearly summary of total (classified and unclassified) Flickr posts for Dresden (2007 to 2018).

A summary of the spatial joined datasets was then calculated for each year. An annual overview of the total number of posts is shown in figure 10, where it is shown that the yearly distribution of the total posts varies. Figure 11 shows the annual total number of Flickr posts for Dresden, along with a distribution of the posts classified into the four activities of interest. The distribution of posts shows that 2007 has the highest number of classified posts, and visitors posted photos related to cultural events and aesthetic appreciation. In addition, the number of classified posts varies for each year, which means that these data have comparable characteristics. These data variation is very significant for the juxtaposed map views where the differences will be compared.

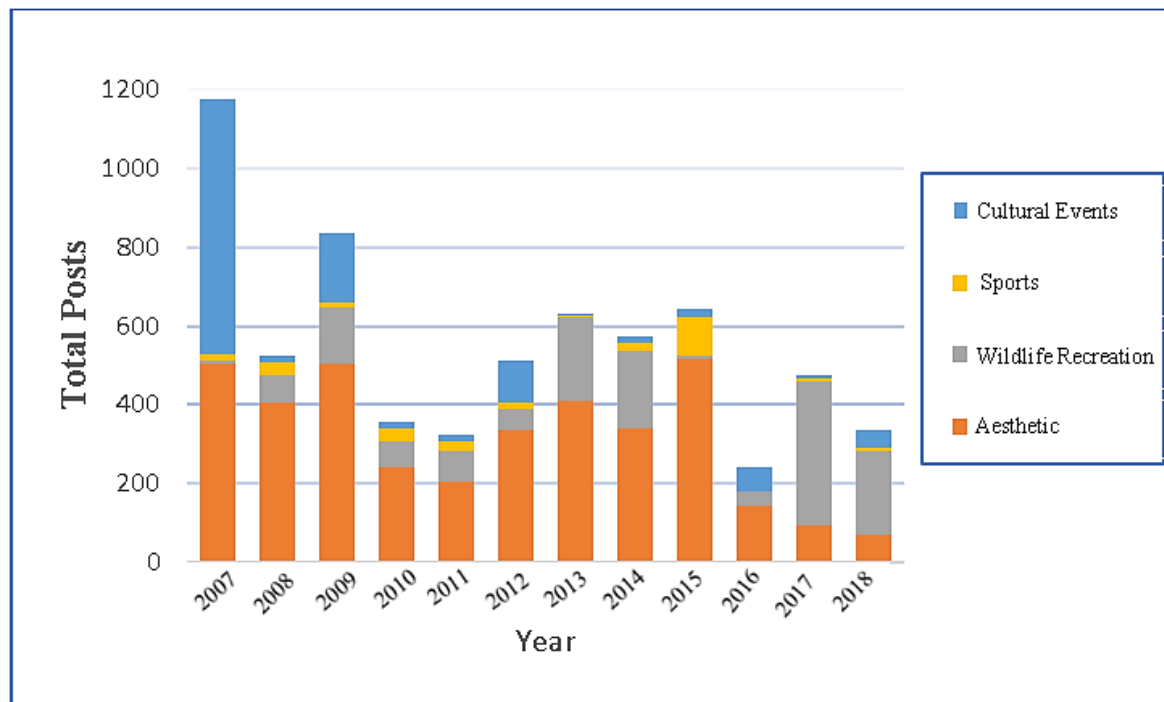


Figure 11. A yearly summary of classified - Flickr posts on four targeted activities in Dresden (2007 to 2018).

The following steps were performed for further data processing to visualize the data for comparison. These steps are elaborately described in below.

• Data Normalization

The data normalization step was performed by ArcGIS pro. Two parameters (expectation and popularity) for each activity (for each polygon) were calculated to compare the data. The expectation measurement is based on Hollenstein & Purves(2010) and Wartmann & Mackaness(2020) research. Hollenstein & Purves(2010) used this measurement for exploring place through user-generated content using Flickr data to describe city cores. Likewise, Wartmann & Mackaness(2020) calculated the exact measurement describing and mapping where people experience tranquillity based on interviews and Flickr photographs. The expectation measurement (χ) represents how unexpected an observed distribution of Flickr posts in a green space is (e.g., only posts related to wildlife recreation activity), as compared to the distribution of all Flickr posts in the same green area (the expected distribution). This measurement tells how activity in a

polygon relates to the overall distribution of the same activity over the whole study area. It will allow comparing different polygons. For this study, the formula for calculating expectations and the description of the variables used are described below.

n_a: no. of posts related to an activity per polygon in one year (e.g., aesthetic appreciation)

n_p: total no. of posts in a polygon for all activities in one year (e.g., total posts)

N_a: total no. of posts related to an activity in the whole study area (all polygons) in one year (e.g., \sum aesthetic appreciation)

N_p – total no. of posts in the whole study area for all activities in one year (\sum total posts)

$$\chi = \frac{\text{observed} - \text{expected}}{\sqrt{\text{expected}}} = \frac{n_a \times \frac{N_p}{N_a} - n_p}{\sqrt{n_p}}$$

Formula 1: The equation for the expectation measurement

As for the popularity measurement (P), this reflects the relative frequency of Flickr posts related to one of the four activities studied in a green space (n_a/n_p), which was normalized by multiplying it by the total number of Flickr posts in the study area divided by the total number of Flickr posts in the data set that are related to the same activity (N_p/N_a). This normalization factor was used by Wartmann & Mackaness(2020) in their work. In this formula, P tells how an activity in a polygon relates to other activities within the same polygon. It will enable the comparison of different activities within the same polygon.

$$P = \frac{n_a \times N_p}{n_p \times N_a}$$

Formula 2: The equation for the popularity measurement

After measuring expectations and popularity for each activity, four new columns for expectations and four new columns for popularity were added to the yearly separated feature class. A preview of these eight columns is given in table 5. In table 5, expect_a means expectation measurement for aesthetic, pop_a means popularity measurement for aesthetic, expect_w means expectation measurement for wildlife, pop_w for popularity measurement for wildlife, expect_sp for expectation measurement for sports, pop_sp means popularity measurement for sports, expect_c means expectation measurement for culture and pop_c refers popularity measurement for culture.

	cultural_e	p_year	expect_a	pop_a	expect_w	pop_w	expect_sp	pop_sp	expect_c	pop_c
1	0	2007	-1.7320...	0	-2	0	-2	0	-2	0
2	0	2007	0	0	0	0	0	0	0	0
3	0	2007	0	0	0	0	0	0	0	0
4	0	2007	0	0	0	0	0	0	0	0
5	0	2007	0	0	0	0	0	0	0	0
6	0	2007	0	0	0	0	0	0	0	0
7	0	2007	0	0	0	0	0	0	0	0
8	0	2007	0	0	0	0	0	0	0	0
9	0	2007	0	0	0	0	0	0	0	0
10	0	2007	-1.7320...	0	-2	0	-2	0	-2	0

Tab. 5 Format of measured expectation and popularity for each activity in 2007

• Data Classification

A new scaling was needed to find a common classification for the two measures (expectation and popularity). This standard classification helps to compare the data more effectively in the juxtaposed map views. Therefore, the expectation and popularity data were scaled from 0 to 100 values. The data for polygons that were zero (i.e., no data was available) was assigned the value -1 to distinguish them from the available data and parameters that were calculated and scaled between 0 and 100. The assignment of the value -1 was done in order to be able to visualize

separately these polygons with no data. To perform this rescaling, the minimum-maximum method was selected, which preserves the relationships among the original data values while converting the values to a scale between a user-specified minimum and maximum values (ArcGIS Pro, n.d.). This min-max normalization or rescaling was performed using the Standardized Field (Data Management) tool in ArcGIS Pro that automatically calculates it based on the selected column and inserted range. The following formula was used to perform this rescaling. Where x' is the standardized value, x is the original value, $\min(x)$ is the minimum of the data, $\max(x)$ is the maximum of the data, a is the user-defined minimum, and b is the user-defined maximum. In order to map the expectation and popularity for four activities and the different years, a standard classification scheme needed to be identified.

$$x' = a + \frac{(x - \min(x))(b - a)}{\max(x) - \min(x)}$$

Formula 3: The equation for the minimum-maximum normalization

The normalized data for each activity for each year has a significant variation in data. Additionally, yearly split data for each activity has a significant data variation shown in figures 10 & 11. Moreover, each activity (expectation and popularity) had shown separate data classes by following any data classification method.

Classes	Data Ranges	Meaning	Explanation
1	-1	No data	UGSs for which the expectation and popularity has not been calculated since there were no Flickr posts available (total posts = 0)
2	0-15	Very low	significantly less than expected / highly unpopular
3	>15-45	Low	expected value is low / low popularity
4	>45-65	Average	average expected value / average popularity
5	>65-85	High	significantly high than expected / high popularity
6	>85-100	Very high	significantly more than expected / highly popular

Tab.6 Data classification scheme used for the data visualization.

Therefore, it was a challenge to make a common data classification by following a standard data classification method (e.g., natural breaks, equal interval, quantiles classification). Finally, a manual data classification method was selected for this study. This classification helped to define classes, to add class breaks, and to specify class ranges manually that are appropriate for the data (Camponovo, 2021). Then again, the data classes can be customized as needed after selecting one of the classification schemes. The manual data classification is described in table 6. Finally, new eight columns were added to the dataset with new field names. A preview of the classified dataset is given in table 7.

In table 7, exp_a refers to expectation measurement for aesthetic, popl_a means popularity measurement for aesthetic, exp_w means expectation measurement for wildlife, popl_w means popularity measurement for wildlife, exp_sp means expectation measurement for sports, popl_sp means popularity measurement for sports, exp_c means expectation measurement for culture and popl_c refers popularity measurement for culture.

exp_a	popl_a	exp_w	popl_w	exp_sp	popl_sp	exp_c	popl_c
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0
40.01519239140	100.0000000000...	2.70793036750	0	3.28282828283	0	15.55555555560	0

Tab.7 Format of classified expectation and popularity values for each activity in 2007

- **Merge features**

All year separated features were combined into one feature by using ArcGIS Pro, with 70056 polygons containing all values for the different attributes. Finally, all

polygons were converted into a standard geometry where 5838 common polygons were found. This process of standard geometry was performed to account for the difficulty of programming tasks and to reduce the loading time of data on interactive maps. Then, two separate datasets were created from the combined geometry dataset. The first was prepared for the thematic choropleth map and the second for the bar chart. Initially, both thematic data files were in the shapefile (.shp) format and the bar chart data file was in comma-separated values (.csv) format. Later, these two files were converted to GeoJSON format by using QGIS to work on the Visual Studio code platform to develop side-by-side map views.

3.3 Comparison methods

Among the three most common comparison methods described in the literature review chapter, the juxtaposed map view was chosen to compare the data in this study. This method offers several advantages for data comparison tasks. In general, this design facilitates comparative exploration because the maps are arranged side by side (Cherukuru & Scheitlin, 2020). This design is more suitable in cases where the displayed data include sufficient context switching between views (e.g., left map view, right map view). Therefore, the user does not need to store the memory of the entire dataset or a particular variable for an extended period. This allows users to make connections between multiple views easily. It is easier to detect differences by juxtaposition when the visualizations (e.g., choropleth maps, bar chart) are very different, and the dataset has comparable features.

Nazemi & Burkhardt (2018) introduced several models juxtaposing visual layouts as visual interfaces with the main difference that can visualize several databases simultaneously and enables analytical comparison tasks. Among their introduced six visual layouts, the perspective view was selected to explore and compare the dataset. In this layout, data can be linked together, and the user can navigate

through the visual layouts and retrieve the desired information from the visual layouts. To compare the data side by side, spatial, thematic, and temporal facets of the dataset are considered in this study. The spatial distribution of Flickr posts are the spatial facets, the yearly distribution of the posts are the temporal facets, and the posts related to the four activities are the main thematic facets that are compared alongside.

3.4 Taxonomy of used interaction methods

Based on the literature review on interaction methods, a taxonomy was prepared with selecting the various interaction methods. A brief of different interaction methods and how these methods are being implemented in this study is illustrated in table 8. First of all, two higher-order interactive tasks were selected. These were linking map views and unlinking map views which set up a relationship or association between different activities, or oppositely, dissociate them and disconnect their relationships.

3.5 Visualization style

To make the visual layout in the user interface more user-friendly, different types of background maps were selected. The selected base maps are satellites, open road maps, Mapbox basemap, maps (dark mode) and maps (light mode). In addition, the choropleth map was chosen as the foreground map visualization to consider the data structure and the spatial distribution. An important goal of choropleth maps is the visual perception of spatial patterns such as the detection of hotspots or extreme values (Schiewe, 2019). In Figure 12, the sample choropleth map shows the number of supermarkets per 100,000 population using the sequential colour scheme and five data classes.

• Interacting with the background map			
Category	Tasks	Interaction	Implementation
Locating	overview	zooming, panning, scrolling, re-centring	gain an overview of the entire collection
	zoom		zoom in on a specific area of interest
	navigating		move on, though, and around on the background map. Selected areas bookmark navigation will easily guide readers to select the area of interest.
• Interacting with the foreground visualization(s) (e.g., user activities)			
Comparison	select	clicking, dragging, scrolling, panning, zooming	choose different activities and parameters from the expand and collapsible menu
	explore		show a different subset of visualized data
	relate		view relationships among the activities
	abstract / elaborate	mouse hover	pop-ups enable users to compare the attributes of the different polygons
	filter	brushing as conditioning / sectioning, database query	define year or area of interest from the dataset
	connect		provide a visual connection between the same year data for different activities on separate views
• Interactions with the temporal component of the data			
Associating	Making comparisons	mouse hover, clicking, linking the views	arranging bar chart side by side in the same window or separate window

Tab. 8 A taxonomy with different interactive analytical tasks

A sequential colour scheme was selected by following the data classification to visualise the foreground choropleth map. Generally, diverging colours provide better colour contrast for non-colour-blind people, but sequential colours provide better lightness contrast to colour-blind people (Harrower & Brewer, 2003). Nevertheless, colour-blind people will see the difference between two values of the same colour (i.e., if the difference is significant enough) whatever the colour is.

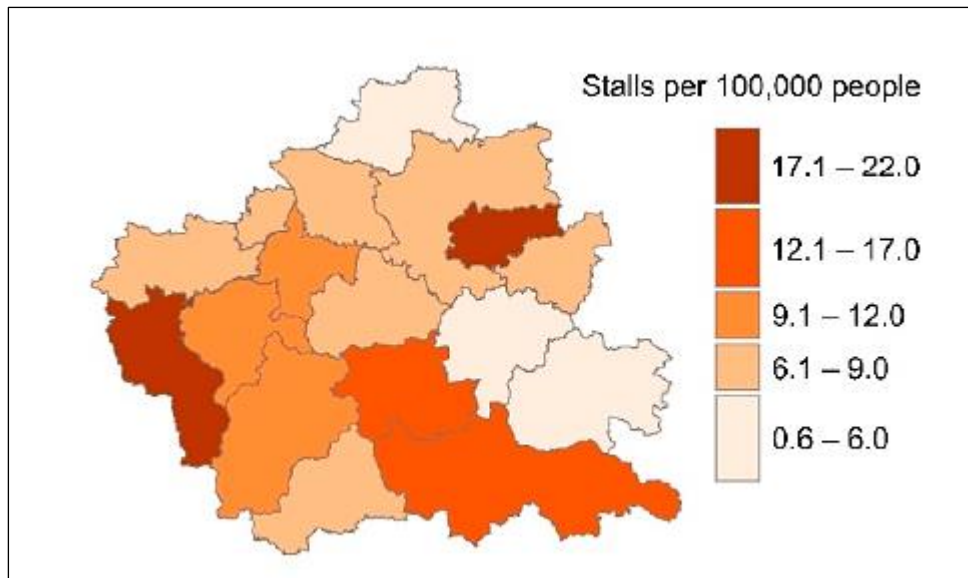


Figure 12. Thematic data visualisation with sequential colour scheme (Słomska-Przech & Gołębiowska, 2021)

In this study, the used data do not usually have a critical midpoint value but consist of a range of values. Therefore, the diverging colour scheme was ignored.

3.6 Software

This thesis data processing steps were done in ArcGIS Pro, version 2.8.3 and QGIS Desktop, version 3.14.0. Splitting the data into different years and converting the data to GeoJSON format were done using QGIS. In addition, ArcGIS pro was used for spatial joining, data normalization, data scaling, merging the data, and creating a common geometry. Moreover, Visual studio code, version 1.62 was used to write, edit the codes, and Brackets, version 1.14.2 was used to test the designed maps. Mainly, the visual comparison tool in this thesis was developed using the web-based GIS framework Airship, Leaflet and HighCharts accessibility module, which are based on JavaScript. In addition, the TopoJSON extension was used to read the GeoJSON files and eliminate redundancies of spatial data that related geometries to be stored efficiently in the same file. It is an extension of GeoJSON that encodes the topology(TopoJSON, n.d.). Furthermore, Bootstrap was used to create typography, forms, buttons, tables, HTML and CSS based navigation for responsive design creation.

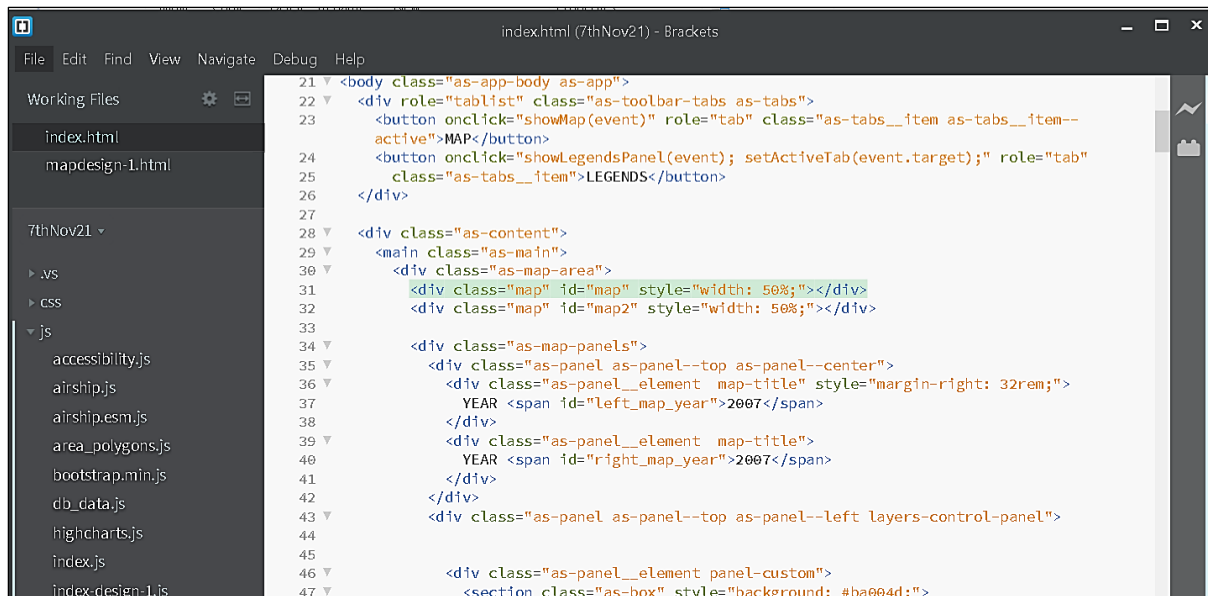


Figure 13. Interface preview of the code editor Brackets

In this study, Bootstrap version v5.1.3 was used. A short description of used major libraries is given below.

- **Airship**

Airship is a JavaScript-based front-end component library. This library was used to visualize the spatial data in this study. It is a set of tools designed to facilitate the use of location intelligence by providing layouts, templates, templates, CSS classes, components, widgets, and more (CARTO, n.d.). It is mainly responsible for the user interface of the application. After adding a map, Airship was used to create a sidebar and a map legend. In general, it helped to create toolbars, tabs, contents, map fields and footers.

- **Highcharts**

Highcharts is a purely JavaScript-based chart library designed to add interactive charting capabilities to web applications. (HIGHCHARTS, n.d.) It offers a variety of graphics. Line charts, spline charts, area charts, bar charts and pie charts are included. To create interactive bar charts to view and compare the thematic aspects, Highcharts was used in this study.

- **Leaflet**

The technological framework used to visualise spatial data as a choropleth map was Leaflet. Leaflet is the leading open-source JavaScript library for mobile-friendly interactive maps(Leaflet, n.d.). This is very useful for creating interactive, colourful choropleth maps.

This study was focused on the development of tools for visual comparison of multi-faceted data with side-by-side map views. Therefore, it was very significant to choose the proper comparison method and technological framework for developing this tool. Correspondingly, the selected JavaScript-based libraries were used to implement the interaction methods according to the taxonomy. In order to achieve the research objectives and answer the research questions, a brief discussion of the designed prototype, usability testing, and the application of this designed prototype to the case study are presented in the following chapters.

Chapter 4: Prototype Design and Development

This chapter comprises the central part of the thesis, which deals with data visualization, comparative taxonomy, interactive methods, and the overall development of linked and unlinked map views. In the following subsections, a brief description of the developed tool for visual comparison of multi-faceted data through side-by-side map views is presented.

4.1 Data Visualization

In this study, two side-by-side prototypes were developed. The first prototype is an unlinked map views, and the second prototype is a linked map views. Both prototypes were developed using the same dataset but with different interaction methods. The unlinked map views follow the unlinked interaction, while the linked map views follow the linking interaction method. In the linked map views, the background map and foreground data are linked, and the user can control the selection of variables of interest from the left map. In the data comparison method, the focus of the developed prototype is on side-by-side data comparison.

Therefore, both prototypes have a left and a right map view. Figure 14 shows a preview of the unlinked map views, where both maps (left and right map) have their own menu, with the right map view containing the dynamic legend which is valid for both map views. However, both map views have icons for basemap, bookmark, zoom in, a default map view, and zoom out.

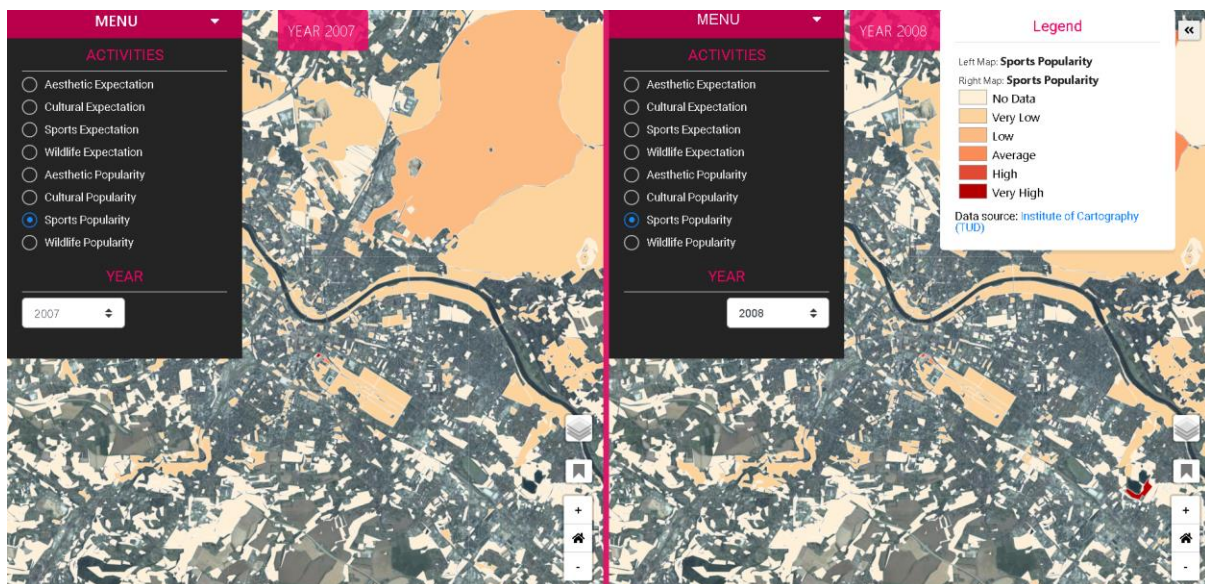


Figure 14. A preview of the designed unlinked map views.

In addition, figure 15 shows a preview of the linked map, with the left map view containing the menu for both map views and the right map view containing the dynamic legend for both map views.

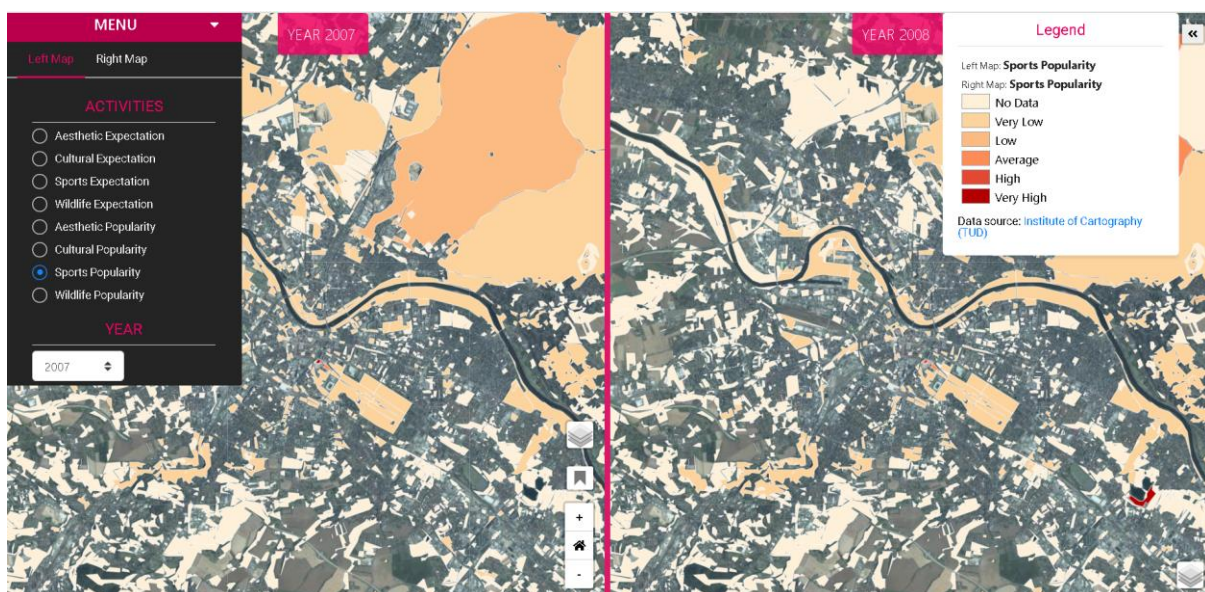
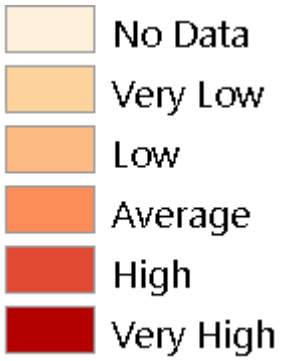


Figure 15. A preview of the designed linked map views.

In this developed prototype, the visualization style includes the colour generated to visualize the Flickr dataset in a meaningful way. To make the designed map more understandable to the user, a manual data classification with a sequential colour scheme was implemented (Table 9). In this developed prototype, specific colours were chosen that stand out well from the base maps. The colour used is hexadecimal (HEX) and the HEX colour values used are sequentially: #fef0d9, #fdd49e, #fdbb84, #fc8d59, #e34a33, #b30000. During zooming dynamically, the pixel sizes on the screen remain unchanged, and the visualization becomes more visible. This sequential colour scheme is differentiable from the five base maps used. However, the colour scheme is more visible in the dark basemap and the satellite basemap but less visible in the light basemap.

Visualization Style	Visual variable	Colour Scheme
Color(Sequential)	Color	

Tab. 9 The visualization style used in the developed prototype

4.1.1 Spatial aggregates (map views)

A selection menu allows users to interactively select activities across the annual spatial aggregates for the left and right map views. This allows for dynamic visualization of the level of detail and selection of any variable of interest for the comparison tasks. There are two types of calculated measures used to visualize the data in these developed prototypes. One is the expectation, and the other is popularity. These two measurements are related to four different activities, and

the user can select any measurement related to any activity and compare them for different time periods or different green areas in the city of Dresden. Figure 16 and figure 17 show a preview of the dynamic choropleth map used in the unlinked map views, showing the aesthetic expectation for green areas in Dresden for years 2007 and 2008.

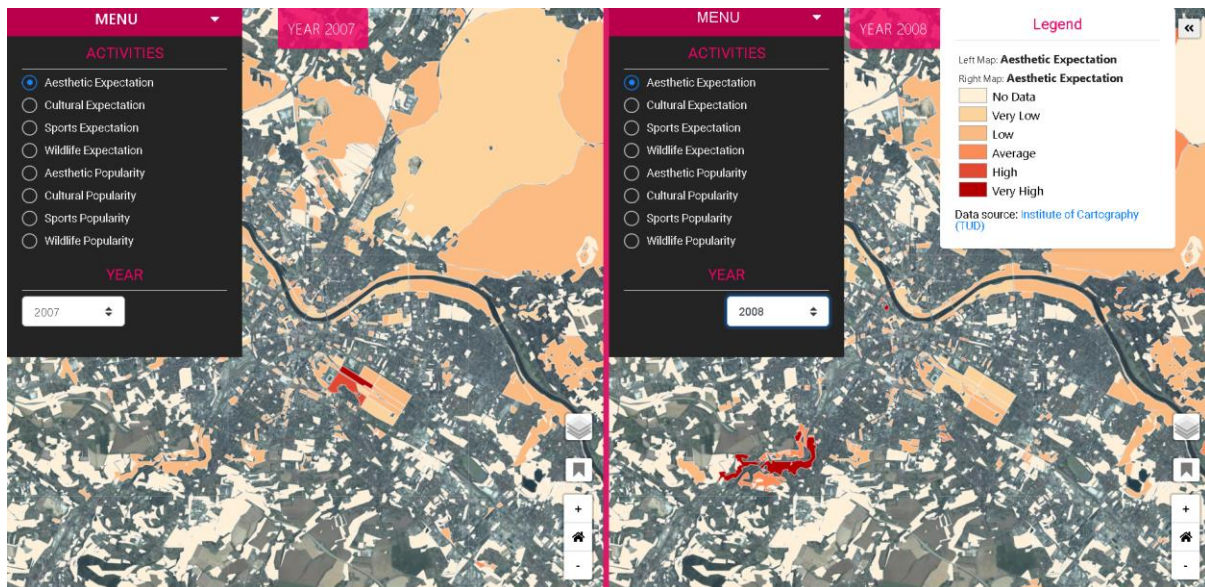


Figure 16. Spatial view of aesthetic expectation for 2007(left map) and 2008(right map).

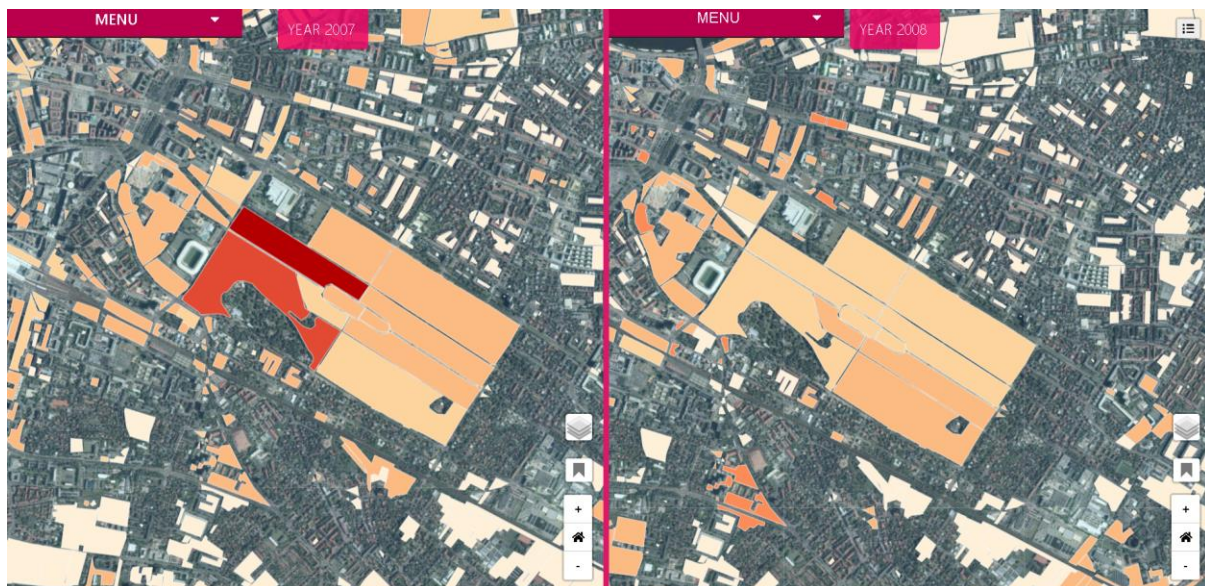


Figure 17. Spatial view of aesthetic expectation for 2007(left map) and 2008(right map) in a moderate zoom level.

4.1.2 Temporal aggregates (Bar charts)

The Flickr posts related to Dresden city has a timespan from 2007 to 2018. Therefore, to visualize the number of posts related to each polygon, the bar chart was implemented. The bar charts represent the number of posts in a polygon that have been classified as one of the four targeted activities. Therefore, the bar charts simply show the number of posts. This allows the user to understand how the visualized expectation or popularity relates to the actual number of posts. In addition, the user can always select a specific year through the YEAR selector to change the spatial view to identify low and high values for further spatial exploration. Table 10 shows a detailed description of the bar chart, including what the chart title mentions, what the chart view shows, and how the data is retrieved.

Temporal aggregate	Bar Chart view shows
Yearly	Name and area of the polygon, total posts within a polygon and the total number of posts for each activity.

Tab. 10 Details of temporal dataset and bar chart view

Additionally, figure 18 shows the bar chart for two different polygons and different years in the unlinked map views. These bar charts show the details of a particular target area for the left and right maps.

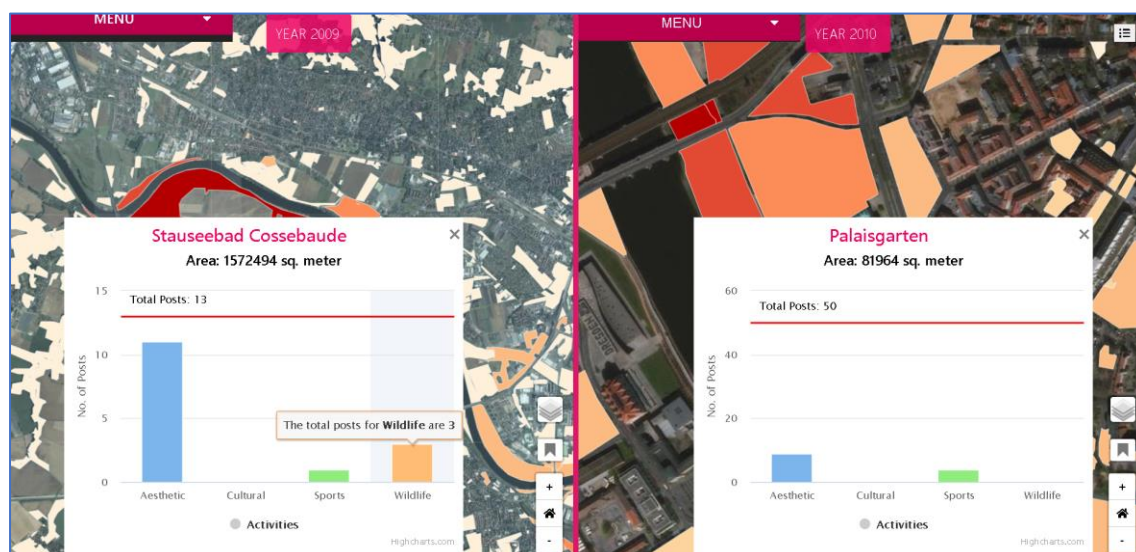


Figure 18. Bar chart view of the developed unlinked map views. An Interactive pop-up over the bar chart on hover can also be seen.

It is very significant to compare two different polygons or identical polygons in a side-by-side view. Therefore, the hover tool is of great use to get more details about the total number of posts for a particular activity. To distinguish the activities in the bar chart, different colours and textual description of bars are used.

4.1.3 Base map

A basemap button is visible separately on both maps (left and right), where the user can select any basemap. There are five basemaps integrated into these developed prototypes. These are the satellite, the Open Street Map, the Mapbox ap (dark), the Mapbox map (light mode) and the Mapbox basemap.

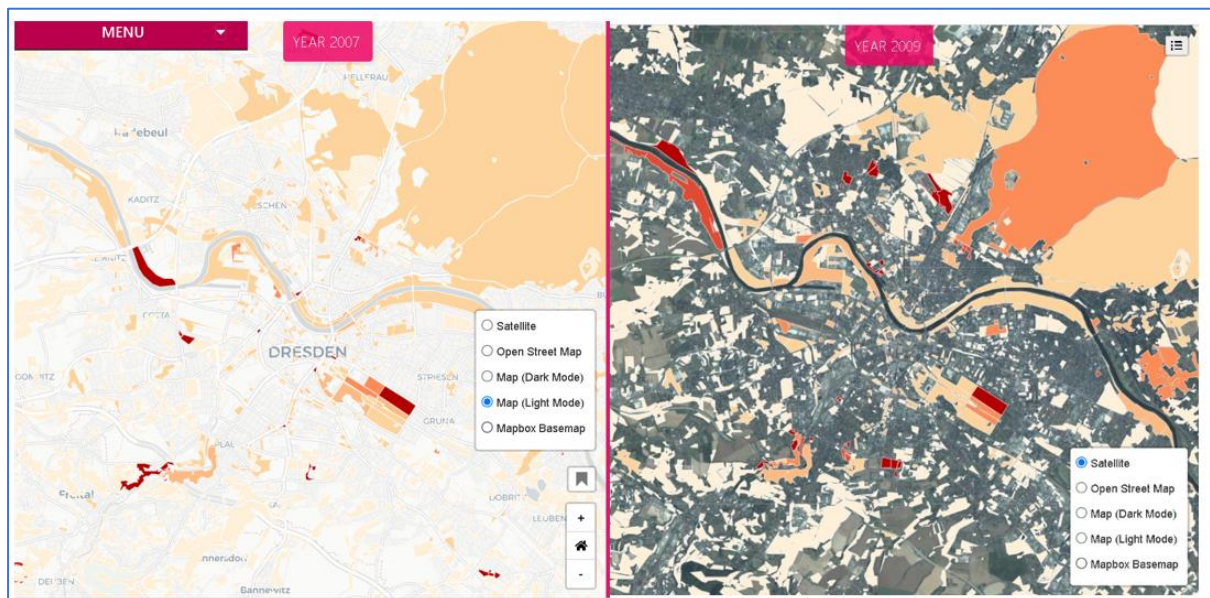


Figure 19. An overview of the incorporated satellite map in the liked map view. The basemap button helps to select any base map for the left and right maps.

These basemaps are included in the visualization because they provide a good contrast with the data. The Mapbox base map is monochromatic and allows for a dark or light background where map labels are visible at higher zoom levels, and surrounding map labels are also clearly visible. The satellite basemap is suitable for general data visualization, while the light basemap is excellent for identifying darker data values (higher popularity or expected value). The "satellite" basemap also allows the user to overlay satellite imagery under the choropleth map. This basemap is

especially useful for identifying land use and land cover features besides comparing the Flickr data.

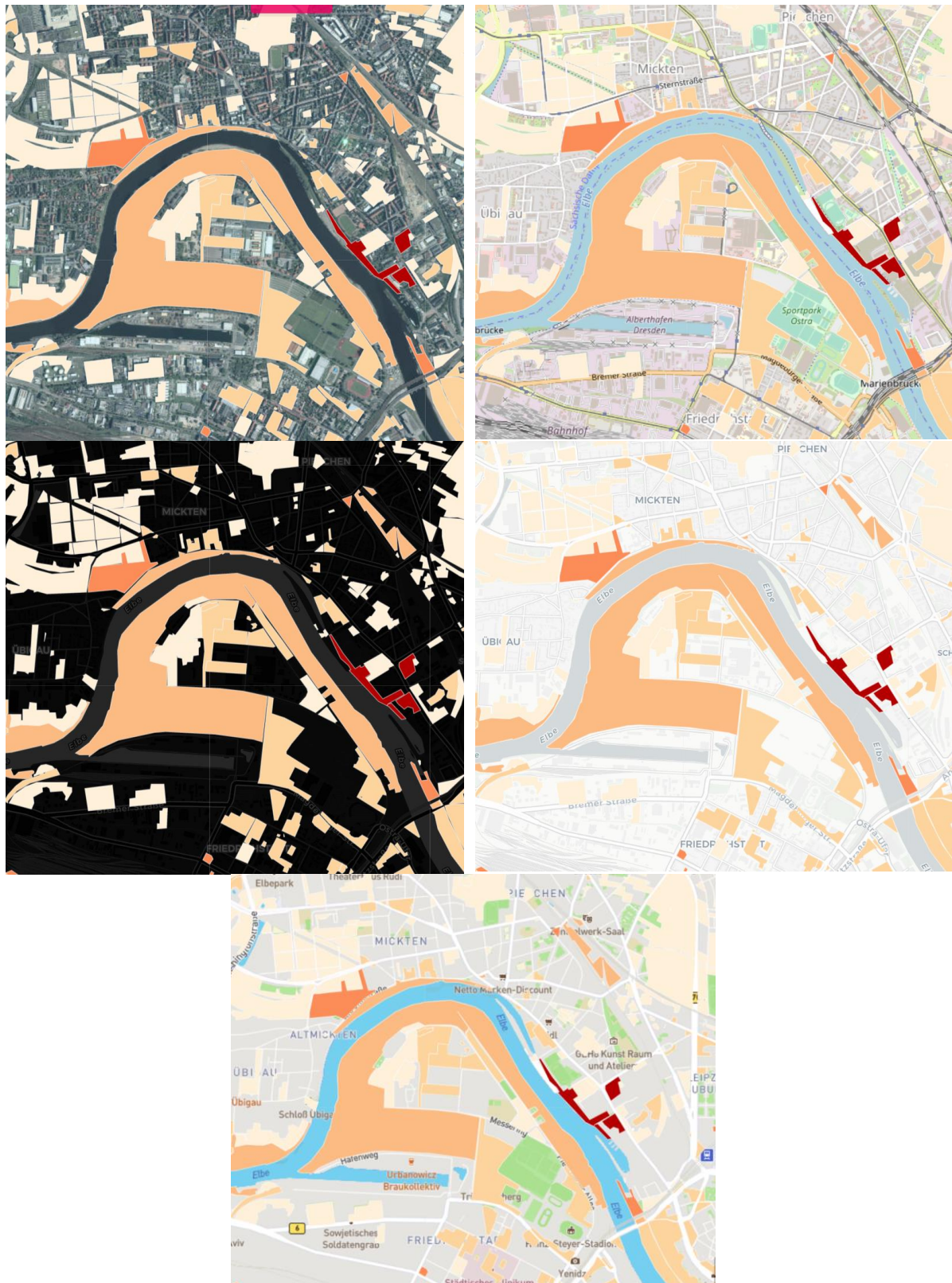
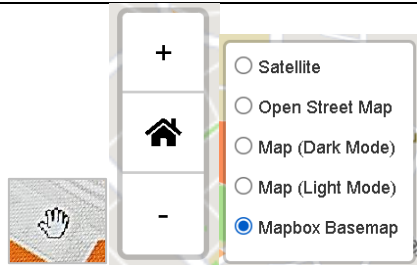
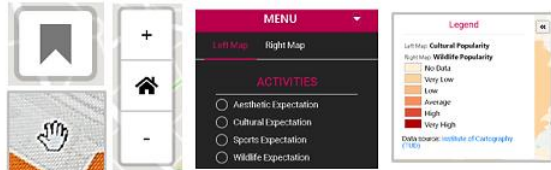

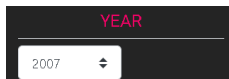

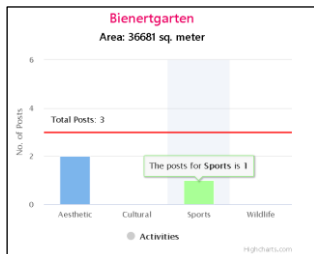


Figure 20. Basemaps used in the design prototype. Satellite basemap (top left), open street basemap (top right), dark basemap (middle left), light basemap (middle right) and Mapbox basemap(bottom).

Furthermore, the Mapbox basemap and the Open Street Map are typical coloured base maps and therefore useful for the user to first make an orientation within the city area. In addition, the basemap in dark mode also shows the area labels, but these are visible at different zoom levels. For example, figure 20 shows a bounding box where the area of interest is the banks of the Elbe River. The area is shown with different basemaps.

4.2 Interaction methods

Based on the taxonomy of interaction described in the methodology, selected interactive methods were implemented in the developed prototypes.

Interacting with the background map													
Category	Tasks	Interaction	Snapshot from the designed prototype										
Locating	overview	zooming, panning, scrolling, re-centring											
	zoom												
	Default map view												
	navigating												
	Basemap selection												
Interacting with the foreground visualization													
Comparison	select	clicking, scrolling, panning, zooming, collapsing and expanding											
	explore												
	relate												
	Default map view												
	bookmarks												
	abstract / elaborate	mouse hover											
filter	brushing as conditioning												
connect													
Interactions with the temporal component of the data													
Associating	filter	brushing as conditioning, mouse hover, clicking, linking the views											
	connect												
	making comparisons		 <table><caption>Bienergarten</caption><thead><tr><th>Activities</th><th>No. of Posts</th></tr></thead><tbody><tr><td>Aesthetic</td><td>2</td></tr><tr><td>Cultural</td><td>0</td></tr><tr><td>Sports</td><td>1</td></tr><tr><td>Wildlife</td><td>0</td></tr><tr><td>Total Posts</td><td>3</td></tr></tbody></table>	Activities	No. of Posts	Aesthetic	2	Cultural	0	Sports	1	Wildlife	0
Activities	No. of Posts												
Aesthetic	2												
Cultural	0												
Sports	1												
Wildlife	0												
Total Posts	3												

Tab. 11 Interactive functionalities in the designed prototype.

These interactive elements allow users to interact with the visualization and compare of Flickr data on a map. Table 11 shows a comprehensive summary with screenshots of the interactive elements, their interaction type, the functionality provided, and a user interface snapshot.

4.3 Prototype summary

In sections 3.3 to 3.5, the design concept used in the development of the prototype was comprehensively presented. The data files used are the property of the Institute of Cartography (TUD), and the data structure is explained in sections 3.1 and 3.2 in Table 3, Table 4, Table 5, and Table 7. The dataset for thematic map and bar chart data are stored in GeoJSON format for convenient application in this designed prototype. The spatially aggregated thematic map data are used for a leaflet-based choropleth map, where a pop-up window displays the name of the area and the land use pattern. In addition, an interactive bar chart with Highcharts (JavaScript library) is implemented using the bar chart dataset. In this study, two prototypes were developed, the first prototype is an unlinked map views, and the second prototype is a linked map views. Both prototypes developed are the concept of juxtaposed map views. There are separate menus, base maps, bookmarks, default map views, zoom in and zoom out buttons for the left and right map views in the unlinked map views. However, the right map view contains the legend. On the other hand, in the linked map, there is only one selecting menu in the left map view with left and right map tabs. In addition, both prototypes contain bar charts. In the unlinked map views, the bar charts must be opened separately with more than one clicks. In contrast, the bar charts can be opened with a single click in the linked map views, where the hover tool displays the pop-up. Figure 21 shows a brief description of the interface of the developed prototype (unlinked map views). It also illustrates the use of integrated buttons and page panels.

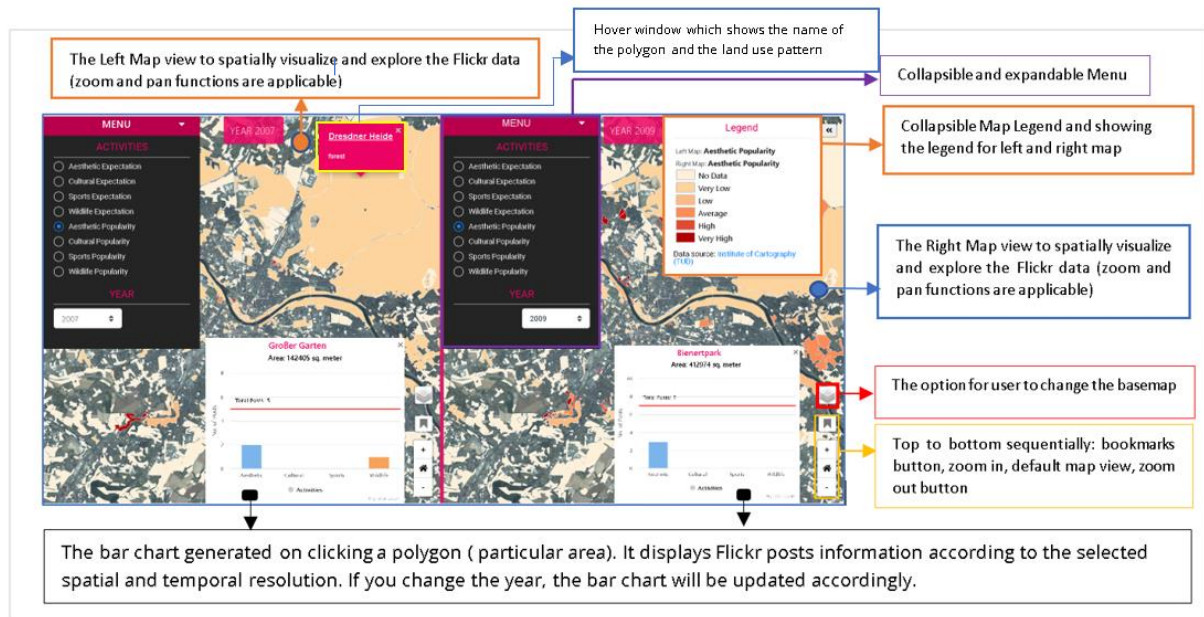


Figure 21. The designed prototype for the comparison of Flickr data on unlinked map views.

Figure 21 is also used as an introduction to the usability testing. In the following chapters, usability testing, case study and discussion part are presented in detail. In addition, the following chapters focus on the usability of the developed prototypes, the comparability of the data, and the advantages and limitations of the two developed prototypes.

Chapter 5: Usability Testing

This section is significant to answer the research question 2 & 3. The capability of exploration and comparison of the spatial, thematic, and temporal facets of Flickr data for the developed prototypes will be evaluated through the usability testing. In this chapter, the subsections 5.1 presents a demonstration about the measures for evaluating usability, relevant tasks and user study design. Additionally, subsection 5.2 presents a discussion on implementation of the usability test to take into consideration the case study.

5.1 Measures for evaluating usability

The comparability of the two prototypes was evaluated using a single measure. This measure is the total number of clicks. The main reason for choosing these measures is the interaction methods. The first prototype is an unlinked map view, where the user has to click more or less to find the target area for the left and right maps and even open the bar chart. The second prototype is a linked map view where background and foreground interactions are linked. Therefore, the total number of clicks to compare facets may vary.

5.1.1 Tasks for a user study

The focus of the user study is on data comparison. The comparison tasks were demonstrated using the spatial, temporal, and thematic facets of the data set. Table 12 provides a summary of how the comparison tasks were demonstrated for the user study.

Facets of dataset	Comparable topics/issues
Spatial facet	targeted area identification based on the spatial distribution
Temporal facet	year identification
Thematic facet	identify any place based on the value of any activity

Tab. 12 Tasks classification for the user study.

5.1.2 User study design

For the design of this survey, the case study titled "Monitoring the urban green spaces (UGSs) utilization pattern changes among the visitors." was considered. Therefore, the tasks were related to this case study. The survey design consisted of two parts. The first part is the "selection of tools" used to identify the interface and interaction. There were six tasks that were not scored. The second part is the central part of the survey, in which all tasks were related to the comparison of the three facets. There were 12 tasks. The first five tasks were related to the comparison of the spatial facet, the second 4 tasks were related to the comparison of the temporal facet, and the last three tasks were related to the comparison of

the thematic facet. Each task consisted of two sections, the first section for the unlinked map views and the second section for the linked map views. The instructions were similar for both prototypes, but the years were different. The different years had the task of evaluating the design prototypes separately. While solving the tasks with both developed map views, it was instructed to note the total clicks to facilitate the evaluation. The survey questionnaire tasks are listed in the Appendix I.

5.2 Implementation of the usability test

This usability test was conducted for both developed prototypes. During the survey, the results were noted. The results of the survey are presented in the following sections.

5.2.1 Comparison of spatial facet

Spatial patterns could be used to explore if a particular area of the city gets very high or high value for any measures for any activities or to compare a targeted area for the different years. This task required exploration of the data over year by following the spatial distribution. There were five designed tasks (tasks 1 to 5) to evaluate the spatial comparison capability of the designed prototypes. The first task was to find out if there were any green spaces highly frequented by Flickr users for aesthetic appreciation and wildlife recreation activities. The year 2013 was selected for unlinked map views and 2009 for linked map views to solve this task separately. Figure 22 (a) shows the spatial distribution for both activities in the unlinked map views where it is very convenient to identify five green areas with high or very high aesthetic popularity, (b) shows the identified polygon which was equally famous for wildlife recreation after side-by-side comparison. The result for task one in the linked view is shown in figure 22(c). This task required a total of 11 clicks, with the menu and legend collapsed for unlinked map views. In contrast, a total of 9 clicks were required for linked map views, with the menu and legend collapsed.

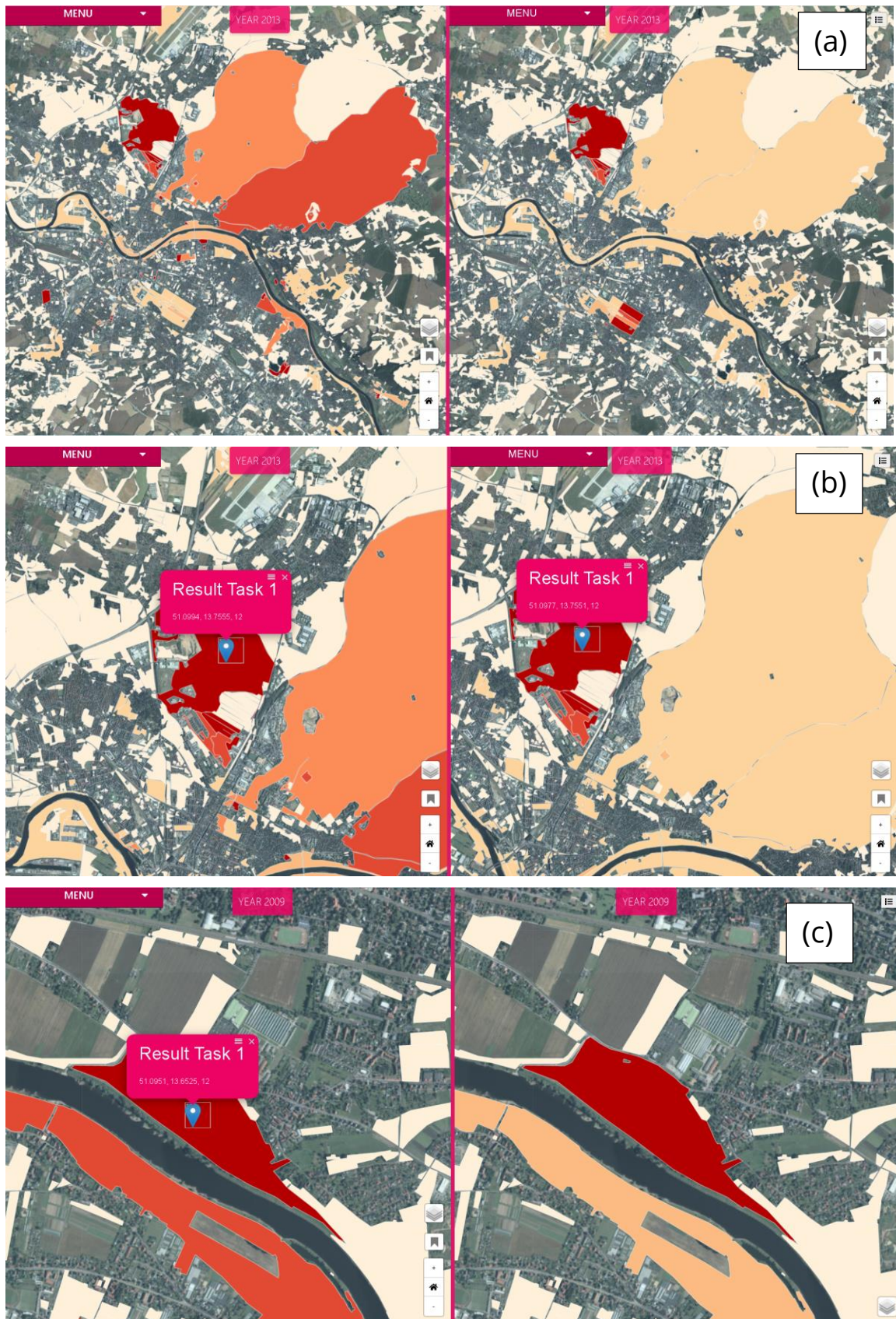


Figure 22. Comparison of spatial facet in developed prototypes

The task two was asked to identify if there were any green spaces where Flickr users equally visited for wildlife recreation. The expectation measure for wildlife recreation was taken into consideration for the years 2012 and 2013 for the unlinked map views.

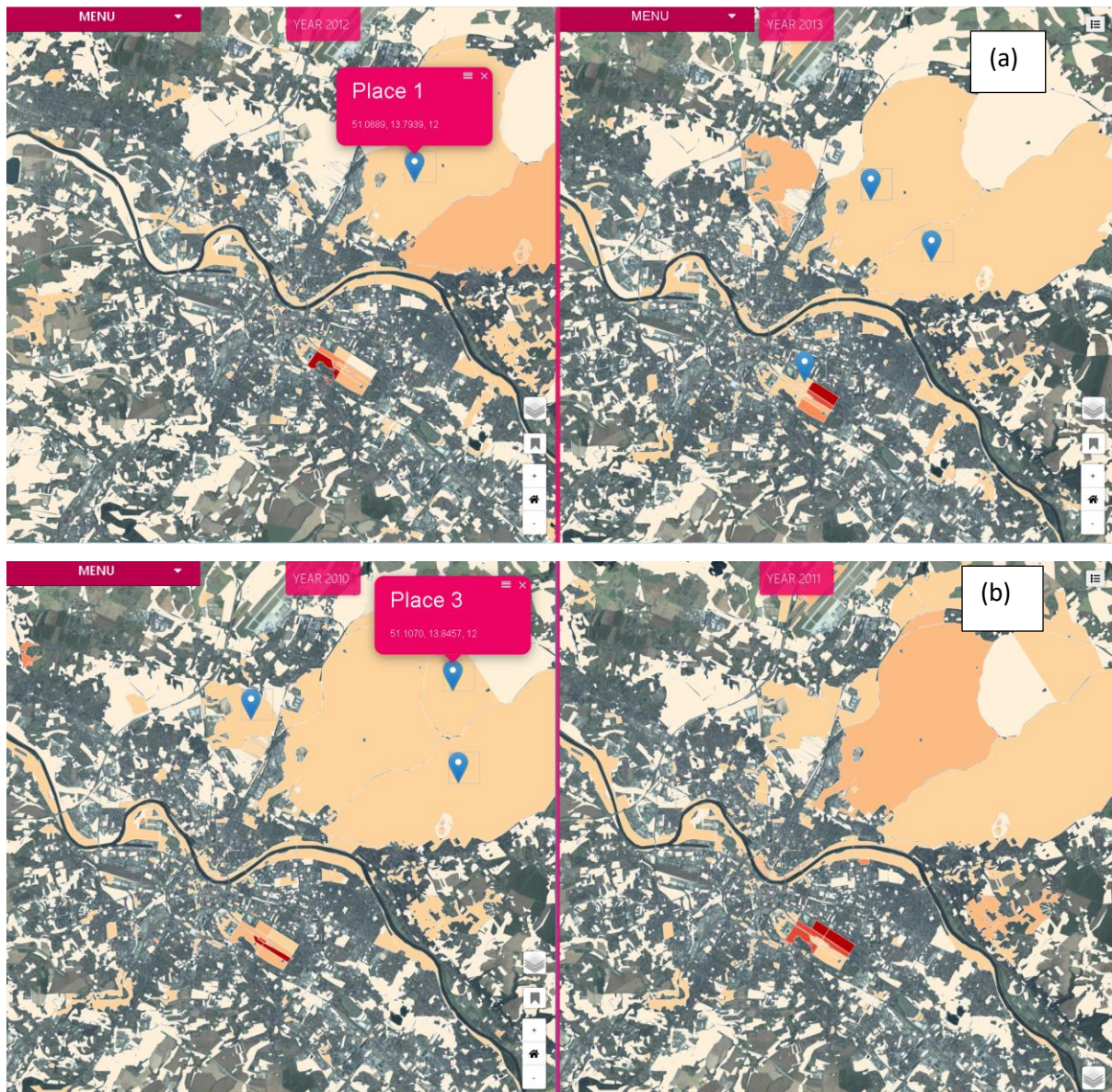


Figure 23. Comparison of spatial facet in developed prototypes to identify the equally visited places.

Figure 23 (a) shows the places by comparing the low values. It has shown that the identified place for year 2012 was visited by very low number of Flickr users. Furthermore, the three places in the right map view also visited equally by the Flickr users in 2013. This task required a total of 7 clicks, with the menu and legend

collapsed for unlinked map views. Additionally, 12 clicks needed to add these identified places in the bookmarks. To solve this task in linked map view, a place was identified in right map view and 3 places were identified in left map view where all places were equally visited by the Flickr visitors. In contrast, a total of 7 clicks were required for linked map views, with the menu and legend collapsed. In addition, 9 additional clicks needed to bookmark the identified places in the left map view. The identified places are shown in figure 23 (b).

The bookmark is available in the left map view in the linked map views prototype. This option facilitates to bookmark the places with linked view. For example, if a user bookmarks a place on the left map user can see the same place on both views. Therefore, no need to book mark the same place twice in both views.

5.2.2 Comparison of temporal facet

This task also represents a significant phenomenon in Flickr data visualization and comparison. Yearly spatial joined data were considered for this study. Therefore, it was comparable to any activities between two years and identified any one year. Tasks 6 to 9 are designed to compare the temporal facet of Flickr data. These tasks were focused mainly on exploration and then comparison. For example, task 9 was to identify a year between two given years in which the urban green spaces near the riverbank were highly visited for aesthetic appreciation by Flickr users. The given years were 2015 and 2016 for the aesthetic expectation measure for the unlinked map views and years 2011 and 2018 for the linked map views. Figure 24(a) shows clearly that in the year 2015, for aesthetic appreciation, the riverbanks were visited mainly by Flickr users compared to the year 2016 in the unlinked map views. In contrast, Flickr users mostly visited the riverbank in 2011 compared to the year 2018 shown in figure 24(b) in linked map views. To solve this task total of 7 clicks were required with collapsing the menu and legend for unlinked map views. On the other hand, linked map views took equal clicks with collapsing the menu and legend.

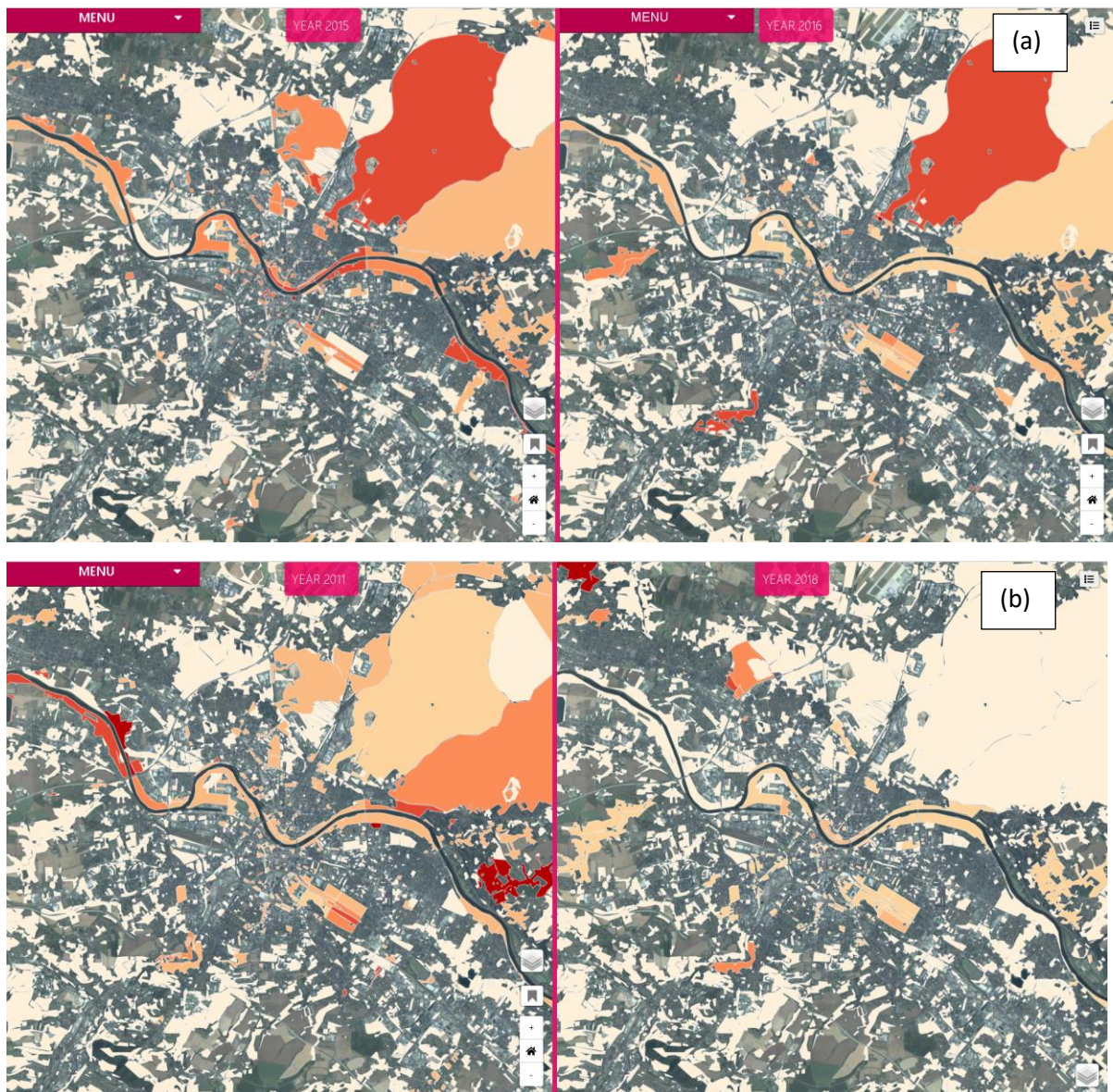


Figure 24. Comparison of temporal facet in developed prototypes.

5.2.3 Comparison of thematic facet

To compare the thematic facet choropleth map was incorporated for both developed prototypes. Three tasks (task 10 to 12) were demonstrated in the survey to evaluate the developed prototypes. For example, task 11 was asked to find out two places (one place for each year) that were mostly visited for aesthetic appreciation and compare both places activities by opening the bar charts. Finally, identify which place was visited by Flickr users for at least two activities. To solve this task, the measurement was the aesthetic expectation and the years 2007 and

2009. Figure 25(a) shows, at first two places, were identified and then figure 25(b) shows, the bar charts were compared separately, side by side. Finally, the result for task 11 was place two, which place was visited for more than two activities by Flickr users in 2009. To solve the same task but for two different years were assigned for the linked views.

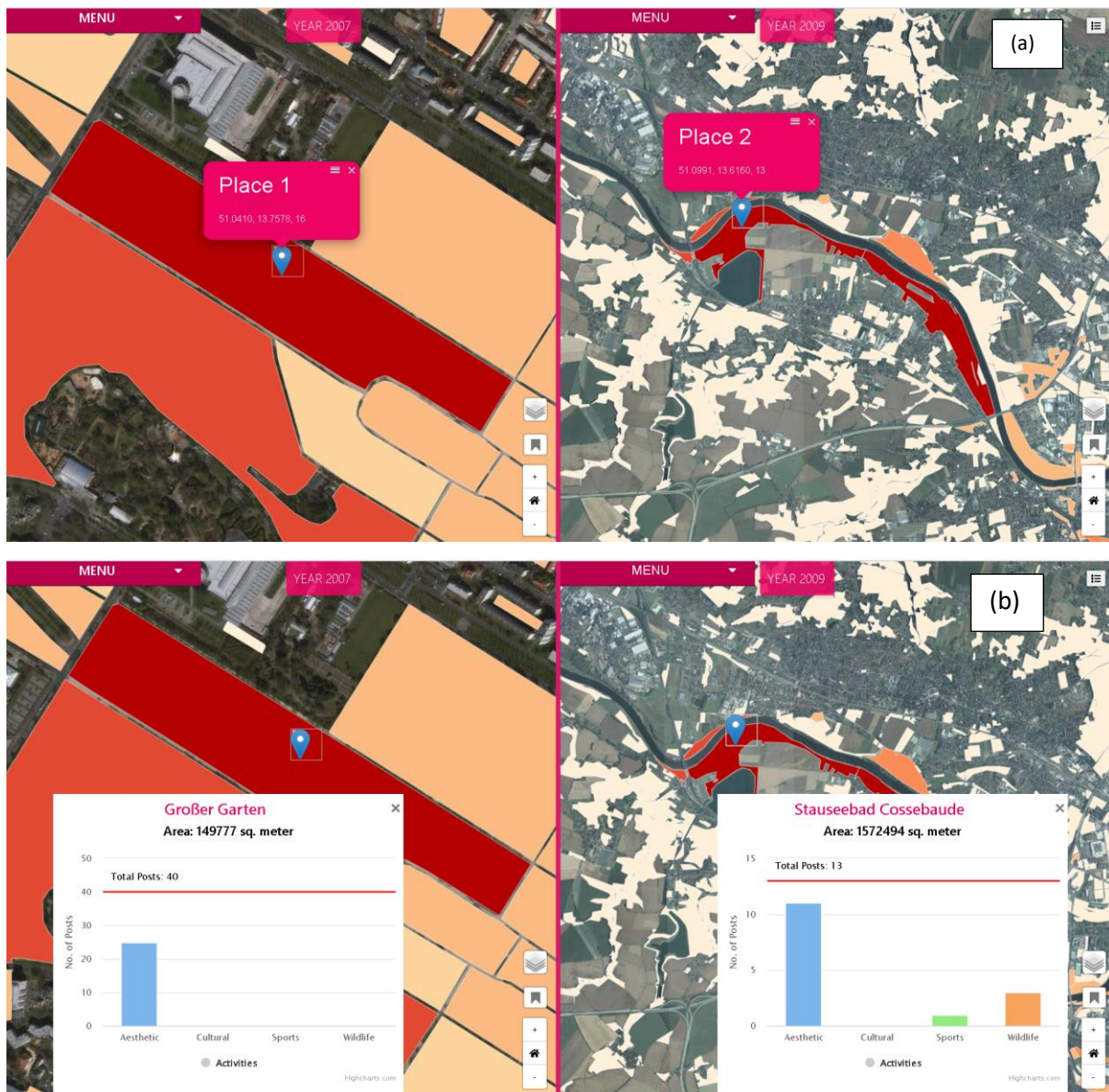


Figure 25. Comparison of thematic facet in developed prototypes in unlinked map views.

Instead of the years 2007 and 2009, the selected years were 2011 and 2013. The background map is linked in this map views. Therefore, separately two places were identified and examined their bar charts. Finally, it was found that both places were visited for two activities, but the total number of posts were higher

for the second place. Figure 26(a) shows the first place on the left map. In addition, figure 26 (b) shows the second place on the right map with the bar chart. The first place on the left map was visited for aesthetic appreciation and wildlife recreation, while the second place on the right map for the year 2009 was visited for aesthetic appreciation and sports. To solve this task total of 13 clicks were required with collapsing the menu and legend for unlinked map views. On the other hand, linked map views took nine clicks with collapsing the menu and legend without bookmarks. This is because linked map views offer only bookmark several places in liked ways for both views.

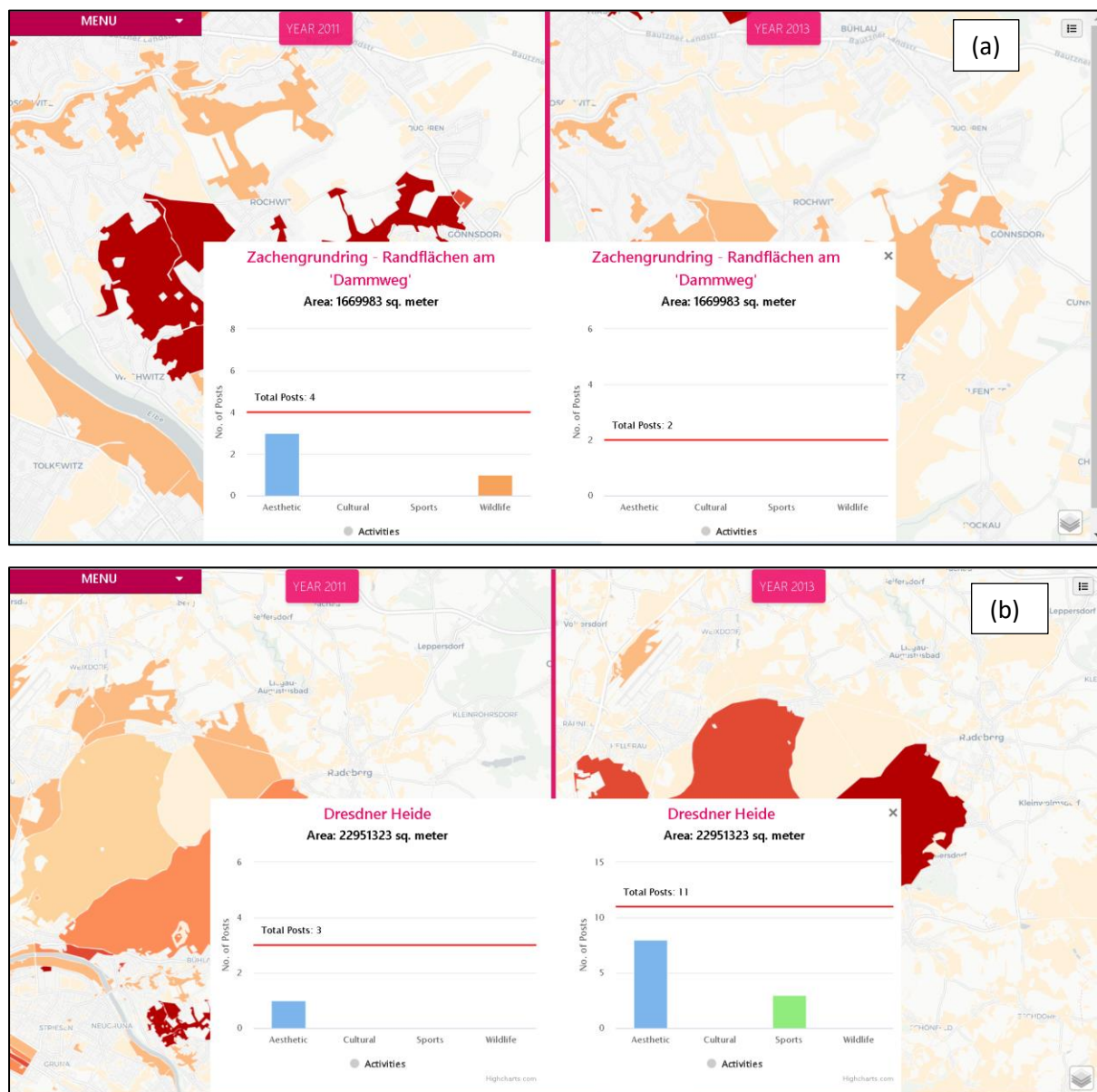


Figure 26. Comparison of thematic facet in developed prototypes in linked map views.

Task 12 was intended to find out one place which place was mostly visited for wildlife recreation and compare these places activities for two different years by opening the bar charts. Finally, find out which place had higher total numbers of posts for wildlife recreation. The parameters were the wildlife popularity from very high or high for 2016 and 2018 for the unlinked map views.



Figure 27. Comparison of bar charts in the developed prototypes.

Instead of the years 2016 and 2018, the years were 2013 and 2014 for the linked map views. Figure 27 (a) shows two places were identified from high categories, and the result was the identified place in the right map with 50 posts for wildlife

recreation. On the other hand, the result shown in figure 27(b) for the linked map views was the place in the right map with 106 wildlife recreation posts. Therefore, to compare the number of posts for wildlife activities, the same place was selected from the very high categories.

To solve this task total of 13 clicks were required with collapsing the menu and legend for unlinked map views. It was also possible to solve this task with a total of 7 clicks without bookmarks. On the other hand, linked map views took eight clicks with collapsing the menu and legend. To accomplish this task, the basemap (light mode) was previously selected for both developed prototypes to identify the very high and high value. In the next chapter, the developed prototypes will be evaluated based on the survey result. Additionally, the limitation and the advantages of both prototypes will be elaborately discussed.

Chapter 6: Discussion

This section covers the last part of the thesis related to research question 3 (i.e., the evaluation of the developed prototypes). This chapter will be discussed and evaluated the developed prototypes based on the result of the survey. A detailed description is presented below with two subchapters; where first sub-chapter will critically evaluate the data comparison capability, assessment of the interactive elements for the developed prototypes. In addition, the second sub-chapter will elaborately point out the advantages and the limitations of each developed prototypes.

6.1 Evaluation from usability test

Three facets of Flickr data were compared in the developed prototypes to accomplish the 12 tasks. Among all of the tasks, the most relevant tasks were presented and discussed in chapter 5. In the following sections, the developed prototypes were evaluated, and a description was presented.

6.1.1 Multi-faceted data attributes

Both developed prototypes were developed to use the same datasets for the data exploration and the comparison tasks. Therefore, the attributes played a significant role to complete the data comparison tasks. There were eight attributes grouped into two measures (e.g., expectation, popularity). In addition, there was freedom to select any year from 2007 to 2018. Two measures helped in the survey to complete the specific tasks. Each activity's expectation measures helped to know how activity in a polygon relates to the overall distribution of the same activity over the whole study area. On the other hand, popularity helped to understand how activity in a polygon relates to other activities within the same polygon. Additionally, it compares different activities for the same year and the same polygon or the same activity for the exact location but different years. The popularity measures for aesthetic appreciation and wildlife recreation were used to identify the highly visited green spaces for both activities. Moreover, the expectation measurements were used to compare the spatial distribution of Flickr data in task 9 to identify the year in which Flickr users mostly visited the riverbank green areas. It is clearly evident that the multi-faceted data attributes of the Flickr dataset are capable of solving the questions or issues related to the case study.

6.1.2 Capability to data comparison

The primary purpose of the developed tools was the data comparison in a side-by-side view. To review the tasks explained in chapter 5, the developed prototypes are capable of comparing the Flickr data. The comparison tasks were performed for the spatial, temporal and thematic facets. Although, the comparison capability of each developed prototypes is not the same. In section 5.2.1, to compare the spatial facet (i.e., through task 1), the linked view took two clicks less than the unlinked map views. The linked map views and the unlinked map views were performed equally to compare the temporal facet, which was done through task 9. In addition, to solve tasks 11 & 12, unlinked map views were required 13 clicks

while linked map views were performed the same comparison task with a total of 9 and 8 clicks sequentially. In the developed prototypes, the background and the foreground map are linked together. Therefore, the linked map views are performing faster than the unlinked map views.

6.1.3 Evaluation of interactive elements

Different types of interaction methods were incorporated into the developed prototypes to consider the data comparison task. A detailed description was presented in chapter 3 and also in chapter 4, with a screenshot following the taxonomy. To evaluate the performance of linked map views, it was evident that the linking interaction helps to compare the data faster. Additionally, the linking bar charts view facilitated a faster comparison between the same polygon attributes for the different years. Figure 26(b) shows the comparison of a specific place attributed through the linking bar chart for the years 2013 and 2014.

Moreover, the interaction with the hover tool makes the comparison task easier to know the data insight for both developed prototypes. The collapsible and expandible menu and legend present a significant role to view the map widely. Besides, the bookmark, panning, zooming and default map view offer to locate any specific place (figure 24) precisely.

6.1.4 Overall user experience

Lastly, based on the performed tasks in the survey, it can precisely provide an overall user experience for both developed prototypes. The total number of clicks shows how the developed prototypes' overall comparative capability to solve a task. Although, for each task, the linked map views showed faster performance than the unlinked map views. However, this was still a positive way out, showing that new and innovative features were used in the prototype. Since the developed prototypes were extensive and had many options and selections, the user interfaces could solve the designed task related to the case study through the survey.

6.2 Advantages and limitations

The designed prototypes are capable of comparing the spatial, temporal and thematic facets of Flickr data used. However, there are several limitations of both developed prototypes. The advantages and the limitations are explained below based on the existing developed prototypes.

- **Advantages of Unlinked Map Views**

- more freedom to choose random places for the left and right map view
- separate bookmark options to locate arbitrary places for both map views
- more opportunities to explore, compare and to know the insight data for the random places

- **Limitation of Unlinked Map Views**

- select the attributes from a separate menu
- one more click need to collapse the menu during the comparison task
- open the bar charts separately require one more click for a specific place
- locating or navigating a particular place needs to do separately
- need more clicks to compare the data
- time-consuming for the data exploration and comparison

- **Advantages of linked Map Views**

- faster data comparison
- less time and click required for the data exploration and the comparison
- navigating a specific location for both views is incredibly faster
- linked bar charts make the comparison task very rapidly
- only one click is necessary to collapse the menu

- **Limitation of linked Map Views**

- can not compare two different polygons bar charts together
- linked bookmarks can only bookmark in one side view (left map view)
- still needs separate hovering to see the data insight in the bar chars
- the left and right tab in the menu requires two clicks more to select the variables.
- years need to select separately for both views, but the year could be linked

Chapter 7: Conclusion

The conclusion of this thesis is presented following the research objectives and questions proposed in sections 1.3 and 1.4. The first research objective was to identify and select interactions that support and enhance the visual comparison of multi-faceted data through the use of side-by-side map views, which were discussed in detail in chapter 2. In addition, the second objective is to develop a tool that implements interactions with side-by-side map views to facilitate the comparison of geolocated social media data. The second research objective focused mainly on the design concepts to be integrated to develop a web GIS-based prototype for the data comparison tasks. Flickr data from TU Dresden for the city of Dresden was used and post-processed in this study. The expectation and popularity measures were beneficial for identifying very highly, highly, or averagely visited locations for the four activities in different years (discussed in section 5.2). The methodology for developing these prototypes is described in detail in chapter 3. Consequently, two separate prototypes were developed for data comparison. The first is the unlinked map views, and the second is the linked map views. The evaluation of the developed prototypes was done with research objective 2 in mind.

Since Flickr data were inherently multi-faceted, these data were studied using spatial, temporal, and thematic visualizations and comparisons. To answer research question 1, the advantages and limitations of the interaction methods were discussed in sections 2.3 and 3.4. Sections 4.1 and 5.1 provided a brief explanation of research question 2. The prototype's ability to compare data in side-by-side views was detailed in chapter 5. In addition, Section 5.2 and chapter 6 discussed the task of evaluating the developed prototypes to answer the research question 3. Finally, the developed prototype was evaluated using a survey. In the survey, the measure evaluated the prototypes ability to perform different comparative tasks (i.e., the total number of clicks).

The overall purpose of this work was how concepts for side-by-side map views could be used to compare Flickr data. The prototype developed used Flickr data from Dresden city. However, the concept behind the developed prototype was to present design concepts for a new and innovative way to develop unlinked and linked map views. Although the linked map views showed faster performance in comparing the three facets of Flickr data than the unlinked map views, there are still limitations. The measures used (i.e., expectation and popularity) help solve the task related to the case study. In addition, various interactions facilitated the comparison task for both developed prototypes. Such an application will help landscape planners and tourism authorities as it can assist them in monitoring urban green spaces and making decisions. This kind of developed application can be easily adapted to compare social media data also for other cities.

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Appendix I: Survey questionnaire

Survey

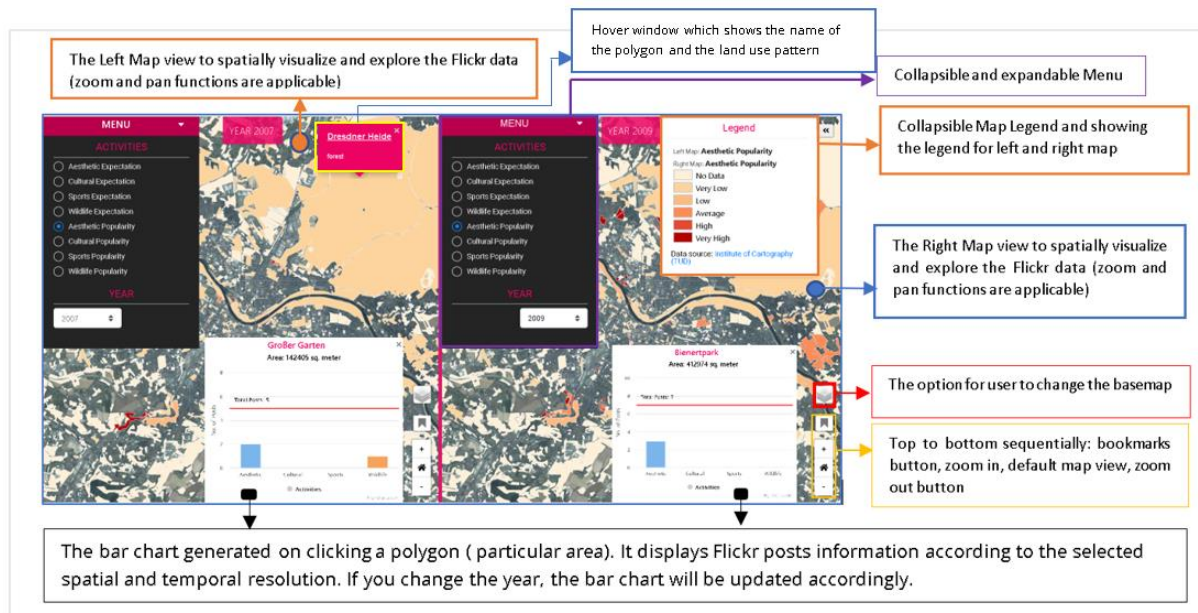
Comparison of juxtaposed map views – linked vs. unlinked map views

Introduction

This usability study is designed to evaluate the capabilities of comparing data between juxtaposed map views. It is part of the master's thesis entitled "Development of a tool for visual comparison of multi-faceted data by juxtaposed map views". This research was conducted on the case study of "Monitoring the urban green spaces (UGSs) utilization pattern changes among the visitors." through the interactive juxtaposed map views based on geolocated Flickr data (2007 to 2018). Moreover, the Flickr posts were related to four targeted activities (e.g., aesthetic appreciation, cultural events, sports and wildlife recreation). The local comparison of data was considered for Dresden city's green spaces as a study area. These developed prototypes allow comparing the urban green spaces of Dresden city in terms of visitation and utilization patterns by exploring the spatial, thematic, and temporal facets. In these developed tools, each area's expectation and popularity will be compared using the dynamic choropleth map.

For each polygon, two statistical measures are calculated, namely expectation and popularity. The expectation tells how activity in a polygon relates to the overall distribution of the same activity over the whole study area. On the other hand, popularity tells how activity in a polygon relates to other activities within the same polygon. In addition, popularity is used to compare different activities for the same year and the same polygon or the same activity for the exact location but different years. Two prototypes with juxtaposed map views have been developed to compare the data. The first one is unlinked map views, and the second one is linked map views. The study consists of two parts of each task, which are interconnected. The first part is designed to get to know the tools. In the second

part, the spatial, temporal and thematic facets of Flickr posts will be compared through various tasks. An initial screenshot view of the application with a description is given below.



In the menu, different combinations of variables can be selected to be displayed on the maps. The variables that can be visualized are:

Activities- what variables to see?

There are two types of measurements (expectation and popularity) for four activities.

YEAR- What temporal aggregation will be applied to the selected activities?

Part 1: Selection of Tools

In this section, the tasks are related to getting to know the tools for the data exploration and comparison.

1. Try out different interactions that are shown in the screenshot. For example, try out hiding and showing the menu and legend.
2. In this task, use the pan and zoom to locate a specific area and then bookmark this place. Then click on the default map view button to see the overview of the choropleth map again.
3. Select an activity and a targeted year for the left map view from the menu and the same for the right map view.
4. Hover the mouse cursor over a polygon and see the name of the area and land use pattern of this particular area.
5. Click on an area to open the bar chart for left and right map views. Additionally, hover on the different activities bars to see the details.

6. See the screenshot of the map again and click on the basemaps button. You will find five basemaps there. Change the background map into one you prefer most to explore the data considering the colours used in the legend.

Part 2: Comparison with the tools

This part will compare the foreground data by using the unlinked map views and linked map views. For each juxtaposed map view, you will compare data for the left and right maps. Finally, you will solve the tasks, and later you need to evaluate your experience based on the total number of clicks. There are two sections of each task, section “a” for the unlinked map views and section “b” for the linked map views.

1. **Find out if there are any green spaces that were highly frequented by Flickr users for both aesthetic appreciation and wildlife recreation activities.**

(a). To do so, you will compare the popularity of urban green spaces for the aesthetic and wildlife of 2013. First, find five green areas with high or very high aesthetic popularity. Then, out of these five identified areas, are there any that are equally popular for wildlife watching? If so, please add them to bookmarks and for each of them, write down the number of Flickr posts for each activity.

(b). instead of the year 2013, select the year 2009

Please note the total number of clicks to solve this task!

(a)	
(b)	

2. **Identify if there are any green spaces where Flickr users equally visited for wildlife recreation.**

(a). To do so, you will compare the expectation of urban green spaces for wildlife recreation for 2012 and 2013. First, find out 2 to 3 green areas with low wildlife expectations. Then compare the variation for the selected places and write down at least one place name for 2012 and three places names for 2013, which were in the same data class.

(b). instead of the year 2012 and 2013, select years 2010 and 2011

Please note the total number of clicks to solve this task!

(a)	
(b)	

3. **Identity one forest area, which was always famous for aesthetic appreciation to Flickr users.**

(a). select aesthetic popularity for 2015 and aesthetic popularity for 2016. see the very high or high aesthetic popularity. Finally, write down the area name.

(b). you can select any aesthetic popularity, instead of the years 2015 and 2016, select years 2012 and 2014

Please note the total number of clicks to solve this task!

(a)	
(b)	

4. **Find out if there are any green spaces where Flickr users activities were highly visited for aesthetic appreciation.**

(a). To do so, you will compare the expectation of urban green spaces for the aesthetic for the years 2011 and 2017. First, find out one green area with high or very high aesthetic expectations for 2011. Then find out 2 or three areas names for 2017 that represent the equal expectation value as a selected area for 2011.

(b). instead of the years 2011 and 2017, select years 2015 and 2016

Please note the total number of clicks to solve this task!

(a)	
(b)	

5. **Locate any green space where a higher number of Flickr users visited compared to the previous year for the cultural events.**

(a). To see the fluctuation of popularity, you will compare the cultural popularity for 2007 and 2008. Then write down the name of the area and the total number of cultural posts for each year.

(b). instead of the years 2007 and 2008, select years 2011 and 2012

Please note the total number of clicks to solve this task!

(a)	
(b)	

6. **In this task, we want to know if there was any green space where the popularity drop-down by Flickr users compared to the previous year for the wildlife recreation.**

(a). To see the fluctuation of popularity, you will compare the wildlife popularity for 2010 and 2011. Then write down the name of the area and the total number of cultural posts for each year.)

(b). instead of the years 2010 and 2011, select years 2012 and 2013

Please note the total number of clicks to solve this task!

(a)	
(b)	

7. **This section identifies two places that were most popular to Flickr users, for sports for two different years.**

(a). To see the popularity, you will compare the sport's popularity for the years 2013 and 2015. Then write down the name of the area and the total number of sports posts for each year.

(b). instead of the years 2013 and 2015, select years 2011 and 2018

Please note the total number of clicks to solve this task!

(a)	
(b)	

8. **Identity, a year between two given years in which a particular place lost its popularity for the aesthetic appreciation by the Flickr visitors.**

(a). To identify the year, you will compare the aesthetic popularity for 2013 and 2009. Then write down the name of the area and the total number of aesthetic posts for each year.

(b). (b). instead of the years 2013 and 2015, select years 2011 and 2018

Please note the total number of clicks to solve this task!

(a)	
(b)	

9. **Identify a year between two given years in which the urban green spaces near the riverbank were highly visited for aesthetic appreciation by Flickr users.**

(a). To select the year, you will select the aesthetic expectation for 2015 and 2016. Then compare the aesthetic expectation values distribution near the riverbank area.

(b). instead of the years 2015 and 2016, select years 2011 and 2018

Please note the total number of clicks to solve this task!

(a)	
(b)	

10. **Identify 2 to 3 areas in which areas were highly visited by Flickr users for the cultural events.**

(a). to compare the cultural expectation, the select cultural expectation for 2012 and 2013 and explore the very high, high and average cultural expectations. Then write the names of 3 identified places for both years.

(b). instead of the years 2012 and 2013, select years 2015 and 2016

Please note the total number of clicks to solve this task!

(a)	
(b)	

11. **In this task, find out two places (one place for each year) and bookmark them which places were mostly visited for aesthetic appreciation and compare both places activities by opening the bar chats. Finally, identify which place was visited by Flickr users for at least two activities.**

(a). you will select the aesthetic expectation for 2007 and 2009. Then compare the aesthetic expectation values very high or high.

(b). instead of the years 2007 and 2009, select years 2011 and 2013

Please note the total number of clicks to solve this task!

(a)	
(b)	

12. **In this task, find out one place which place was mostly visited for wildlife recreation and compare these places activities for two different years by opening the bar charts. Finally, find out in which year this place had higher total numbers of posts for wildlife recreation.**

(a). select the wildlife popularity from very high or high for 2016 and 2018.

(b). instead of the years 2016 and 2018, select the years 2013 and 2014.

Please note the total number of clicks to solve this task!

(a)	
(b)	

Thank You for completing this survey!