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Evaluating the Use of Gazetteer Data for Locating Former Concentration Camp Subcamps

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Abstract

How can researchers use available gazetteer data to determine and assess the locations of former Nazi concentration camps and their subcamps? Often these places are known only by the names of the towns, villages, or areas of cities where the subcamps were (possibly) located. In this paper, we consider the challenges of using digital gazetteer data to help identify the actual locations of the camps. We assess the accuracy of the locations we can establish, comparing these to the locations of the subcamps available from the Buchenwald Memorial Foundation. Researchers can exploit gazetteer location data using GIS or online mapping tools. Using publicly available GIS methods and various geo-statistical techniques, we compare place names associated with concentration camp subcamps with historical and contemporary digital gazetteer information. The results suggest that gazetteer data can help to map larger areas, but are often ill-suited for precise identification of sites of remembrance. This lack of certainty points to the need for further information and to the complexities of reliably establishing locations using geographic information from geomedia.

Keywords:

Geocoding, remembrance sites, Holocaust, positional accuracy

1 Finding sites of remembrance

To locate sites of remembrance known only by place name, perhaps only the name of a town, researchers and interested people can turn to various technologies using geomedia, such as GIS, GPS, and offline- and online-mapping applications. The emphasis on historical memory is greatest in historical research and in relation to mourning connected to specific places. People remember places even if they cannot be located accurately. In this contribution, our focus is on the technological aspects of connecting places of memory (concentration camps' subcamps) with the actual locations of the subcamps. We consider the geographical accuracy that various types of digital gazetteers and place names can achieve for locating subcamps reliably. The information in such sources is frequently collected as volunteered geographic information and as such may not always be 100% accurate. This type of geospatial data is exemplified by GPS-data collections and institutional gazetteer data. We use digital data for the locations of subcamps (Aussenlager) of the Buchenwald Concentration Camp which were made available by the Buchenwald/Mittelbau-Dora Memorials Foundation. The geographical and thematic focus of our article speaks to the possibilities and challenges of using geomedia for place-based remembrance. In particular, we are concerned with limitations in accurately finding specific places from sparse historical information and the challenges this poses. We show that using information from multiple sources provides reliable ways to understand the discrepancies between data on subcamp locations and gazetteer data and possibly to find ways to improve accuracy in pinpointing sites.

The United States Holocaust Memorial Museum Encyclopaedia 2009 identified 20,000 camps, subcamps and ghettos. That was updated in 2013 to 40,000, and in 2016 to 42,500 (Megargee, 2009–2018). Still, locating specific sites of concentration camp subcamps can be a challenge. Roz Vara and Charlie Hoffman located 158 camps but did not give their geographical coordinates (Knowles, Cole and Giordano, 2014). Benjamin Perry Blackshear improved the geographical accuracy of other camp locations. He triangulated latitude and longitude by comparing the geographical description of locations from an encyclopaedia with the locational data from digital gazetteers, satellite imagery and online maps (using Google Maps' Latitude Longitude popup information), and getlatlon.com (Knowles, Cole and Giordano, 2014).

To illustrate the possibilities and challenges of identifying the discrepancies referred to above, we compare subcamp locations with some currently available digital gazetteer information. We have not been exhaustive in considering all possible information sources, for example analog records from researchers and remembrance organizations (e.g. the European Historical Research Institute (EHRI)).

The remainder of our contribution is divided into three sections. The next section covers the possibilities and challenges of locating sites of remembrance as a form of geocoding that uses specific historical data sources. The following section presents an analysis of positional accuracy which we conducted by contrasting the locations of subcamps of the Buchenwald concentration camp using two digital gazetteers, GeoNames and Google Earth. The concluding section provides a summary and vital points for using historical data and digital gazetteer data to find sites of remembrance.

Throughout, we use the generic term 'populated places', as found in censuses and gazetteers, to refer to sites of persistent human inhabitation. These include larger communities such as cities, towns and villages.

2 Potentials and Challenges of locating sites of remembrance

This section covers the possibilities and challenges of locating sites of remembrance as a form of geocoding that uses specific historical data sources. Generic issues of geocoding in locating places or sites from names or from address information are further complicated by the complex, often imprecise, and possibly also obscured geographical information. The essence of the geocoding process is understanding how information about place can be most accurately connected to specific locations for the intended purpose. It involves complex space/time challenges with similar methodological challenges which, when diligently pursued, open up significant possibilities for deepening historical and geographic understanding. Our focus here is on connecting places to locations, which can be mapped using widely available applications. These can be simple online mapping of locations as a series of steps, or more complex GIS-based geovisualizations that involve cartographic and geographic information transformations. (How to use different mapping packages is outside the scope of this article.)

3 Potentials and Challenges of Geocoding

Geocoding, the process of connecting a place with geospatial information (coordinates), helped GIS become a success in the 1990s: it was now possible to take historical place descriptions, connect them to locations, and analyse geographical relationships. GIS became an essential part of many digital or spatial humanities research projects (Bodenhamer, Corrigan and Harris, 2010), and was used for any amount of data, large or small. The locations where individual letters were written (The Valley Project, no date) or thousands of records from ship logs (Farrington, Lubker, Radok and Woodruff, 1998) could now be visualized and digitized, and used, for example, for the analysis of wartime movements or in research into global changes. Successful geocoding was also the gateway to carrying out more complex spatial analysis (Chrisman, 1997) and using spatial statistics (O'Sullivan and Unwin, 2003). In contrast to digitization, which was the primary way to create digital data for GIS, geocoding has continued to be an effective method for transforming place information into locational data.

It is worth reminding readers of some of the subtle but impactful geodetic complexities that can bedevil geocoding, for instance, datums (i.e. coordinates). As the earth moves through the solar system, tectonic forces, both subtle and dramatic, lead to changes in the shape of the earth, as do the movements of magnetic fields and poles. These changes mean that locations become 'displaced', and thus specific datums need to be updated. People mapping at different times may knowingly or unknowingly use different datums for the same location. It is thus possible that the same site will appear in different places in a mapping geovisualization. To this challenge are added those of map projections, which map a two-dimension coordinate system on to the roughly spherical shape of the earth. Even avoiding projections by working with degrees (for example using GPS degrees, minutes, seconds (DMS) constraints), or by limiting the number of decimal places recorded with the data, may significantly impact accuracy or precision (Chapman, 2005).

For many people working with geographic information, these technical issues often appear obscure, presented in very technical language. Wieczorek et al. (2004), however, make a significant contribution to discussion of issues that influence positional accuracy when transforming place names into mappable location data, pointing to six sources of uncertainty that impact geocoding:

1) extent of the locality
2) unknown datum
3) imprecision in distance measurements
4) imprecision in direction measurements
5) imprecision in coordinate measurements
6) map scale.

Using these elements, it is possible to break down the complexity of location information. While some of these sources of uncertainty are unlikely to be relevant for some uses of data for locating sites of remembrance, all are likely to be inherent in the description of places. They serve to remind us that detailed locational data is not by itself accurate, but understanding the limitations can help us assess the data accuracy for a specific (intended) purpose (the fitness for use paradigm) (Chrisman, 1982).

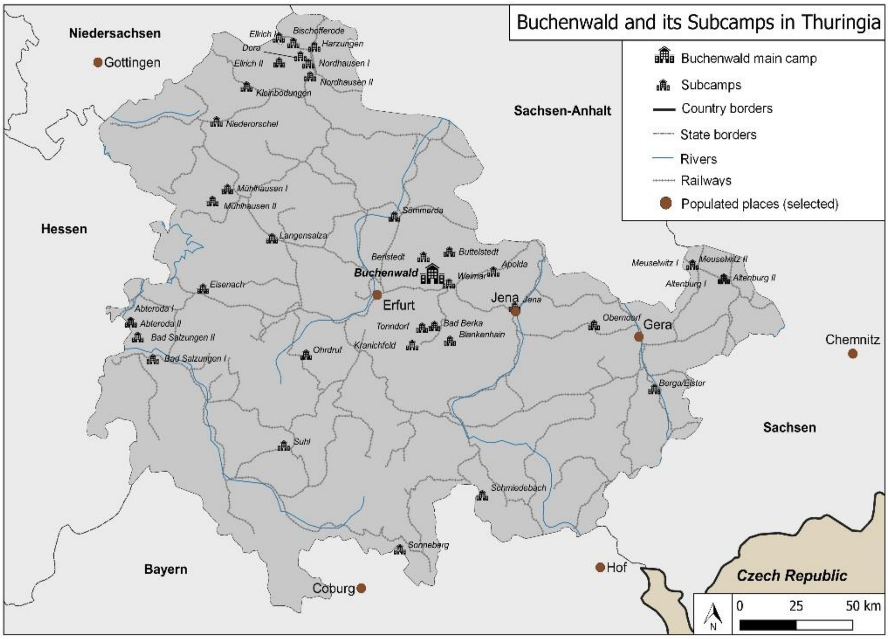

Figure 1: Location of the subcamps of Buchenwald and Dora(-Mittelbau) concentration camps in the present state (Bundesland) of Thuringia

4 Using digital gazetteers to locate former concentration camp subcamps

It is regrettably not possible in the scope of this study to assess all six aspects of data accuracy as defined by Wieczorek et al. (2004). Instead, we address a more straightforward question: what differences are there between the locations of places that historically or currently bear names associated with particular subcamps, and the Memorial Foundation's locations of the those same Buchenwald concentration camp subcamps (e.g., subcamps Altenburg I and Altenburg town)?

5 Background

One website showing locations of the Dora(-Mittelbau) subcamps, http://www.aussenlager.dora.de/l/de/home/map, and information in five languages offers much specific information. Spatial and temporal issues described on the website impact how accurately we can determine the location of the subcamps. As the notes for individual sites explain, the exact location of a subcamp may be unknown; what we have by way of evidence is only the name of the populated place of the same name, and when the name was first used. Subcamps may also have been used only periodically, or only for a limited period. Because of missing documents, it may not be possible to ascertain the precise facility or the exact location of a subcamp. We assume for this analysis that the Buchenwald Foundation data is accurate and verified.

6 Analysis

In the following, the analysis steps are described (see Figure 2). The 37 Buchenwald subcamps, all of which were in what is now the German state (Bundesland) of Thuringia, were identified for us as point locations, as shown in the Appendix (Table 1). We created a table, with coordinates from the PDFs provided to us, showing the location and other information for each subcamp. After collecting the gazetteer data, we extracted locational data for the place names of subcamps from four data sources: GeoNames (one of the most widely-used digital gazetteers); GoogleMaps; and two historical sources (the Amtliches Ortsverzeichnis (1944) and the Post-Taschen-Atlas (1917)) which we digitized. A GIS neighbourhood analysis was used to detect the place closest to the location of each subcamp, as defined in the data from Buchenwald concentration camp. Of course, the localization was possible only when spatial coordinates were available, which was not the case for historical gazetteer data. It was very important to consider not only modern data but also historical data, in order to avoid misinterpretation of the results due to the temporal gap between the Holocaust-related and modern spatial data, and of the possible inaccuracies in the datums, as described earlier.

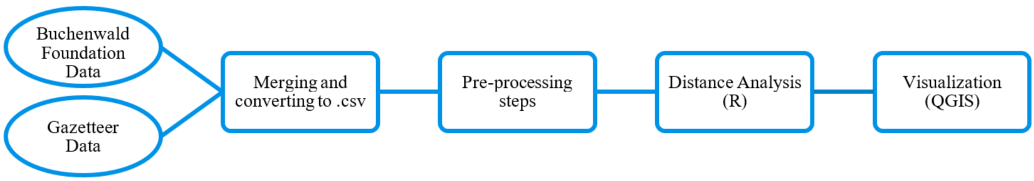

Figure 2: Workflow of the analysis

A text-string distance function was used to detect the closest possible corresponding place names in the two historical sources. Textual distance functions map two strings and return a value of difference, which is small if words (or in our case toponyms) are similar, and larger the more they differ. An important part of distance functions is considering so-called 'edit distances', which measure the hypothetical costs of converting one word to another (Cohen et al., 2003). Because the goal is to detect difference between words, the Levenshtein edit distance was selected as the best-documented and most widely used for linguistic research (Kessler, 1995; Angelis et al., 2017). The algorithm finds the 'cheapest' way of converting one word into another, checking all possible combinations. The words (or names) are matched against each other and the minimum cost is calculated. The cost consists of three operations (deletions/insertions/substitutions of individual letters, and a value of 1 is given to each operation performed. After that, the values are summed, resulting in the Levenshtein distance between two strings (see Figure 3).

String 1		k	r	y	s	z	b	o	r	k	
String 2	c	h	r	i	s	t	b	u	r	g	
Costs of conversion	1(i)	1(s)		1(s)		1(s)		1(s)		1(s)	= 6

Figure 3: Example of the Levenshtein distance calculation (s – substitution; i – insertion)

After the textual pre-processing, a spatial multi-source place-name database was created, consisting of the subcamp names, names of reference populated places, and spatial coordinates. This data was used for the analysis of locations of subcamps and corresponding populated places, and for the analysis of the exact textual and spatial discrepancies between the names from the data sources (discussed below). First, the text string-distance was measured, using the Levenshtein distance function, and stored in the form of a matrix, with the names of subcamps on the y-axis and names of sources on the x-axis. The minimum distance was 0, if there was no difference between names (for example, Abteroda and Abteroda); the maximum difference was 17 (between Oberndorf and Bad Klosterlausnitz). Some pre-processing was done to reduce the detection of unnecessary string elements, such as additional geographical information in brackets (for example, 'Provinz Sachsen' was deleted as it was not a part of the name itself). However, numbers (in names of subcamps like Altenburg I or Altenburg II) were preserved, because they serve to differentiate subcamps. Finally, the spaces between elements in composite names (e.g. in Bad Salzungen) were deleted.

Secondly, the spatial distance between subcamps and the locations of similarly- or identically-named populated places was measured using the 'geosphere' package. The package is used for spherical trigonometry for geographic applications. It computes distances and the latitude and longitude of locations. The package's distHaversine function was used to retrieve the shortest distance (the 'great-circle-distance' or 'as the crow flies') in metres between two points. This method assumes a spherical earth, ignoring ellipsoidal effects (Hijmans, 2019). Because of the lack of coordinates in the historical data, the possibility of working directly with the database, and the effort required to support open-access data, only toponyms found in GeoNames were covered in this part of the analysis.

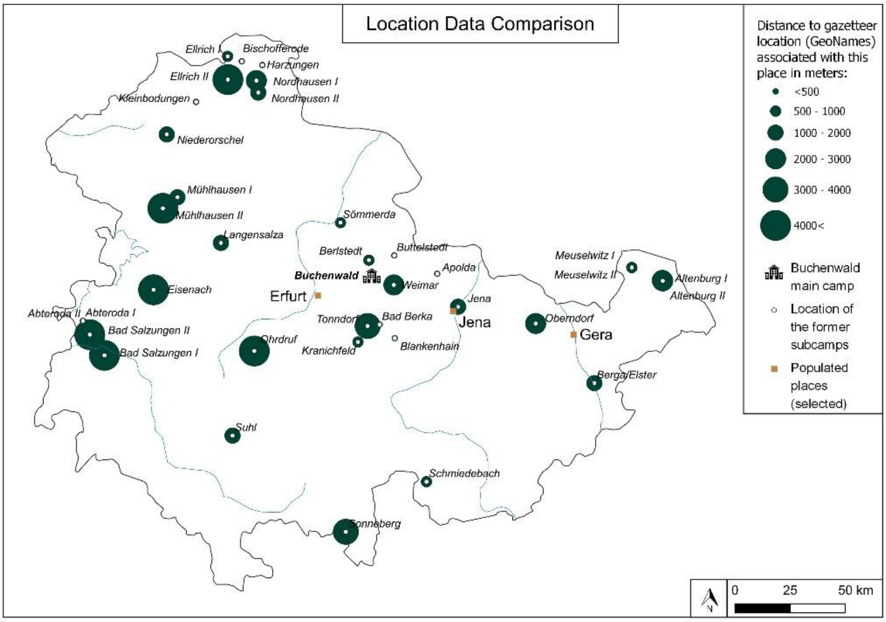

Figure 1: Distances between the Buchenwald concentration camps and subcamps, and corresponding places from the GeoNames gazetteer for the present state (Bundesland) of Thuringia

Figure 4 shows the spatial differences in metres between the subcamp locations (data from the Buchenwald memorial site) and GeoNames. Five of the 37 subcamps' actual locations are more than 4 km from the corresponding GeoNames locations. Discrepancies for the majority of the other subcamp locations are between 500 and 2,000 metres.

The larger discrepancy still allows GeoNames-based locations to be used for making maps of the region. However, with such a large discrepancy, it is not possible to zoom in on the maps. For online browsing, zooming in to a specific town may lead to erroneous conclusions regarding the site of the subcamp. The five sites with a difference of more than 4,000 metres from GeoNames would be unsuitable even for many regional maps; clear information regarding the inaccuracy of their locations would assist map readers in assessing the suitability of particular maps. In one case, the distance is over 16 km. Research into the sources (following Wieczorek et al.'s criteria) of the locational discrepancy would be helpful for understanding it.

Using string-distances, it was possible to detect text-based discrepancies, because all sources used provide names of places. Figure 5 shows the differences between the names from the gazetteer in question and those provided by the memorial site. It is notable that the most significant differences are between place names from modern sources (Google-Maps and GeoNames) and the memorial sites' data. Furthermore, a significant difference was also detected for the 'Post-Taschen-Atlas', which was published almost 20 years before the first of the subcamps researched here was built. In contrast, the smallest distance was detected for 'Amtliches Ortsverzeichnis', which was published in 1944 and is thus the closest source, temporally speaking, to the time when the places became subcamps and received their names.

One could observe here a correspondence between the string distance and the temporal remoteness of a source from which a place name was derived. Subcamps received official names, which often but not always (as we can see in current work) corresponded to some extent to names of neighbouring places, which were in a particular administrative unit. It could be, then, that over time administrative units changed, which then affected the association of place with subcamp location. So using data from historical gazetteers could produce erroneous results or be a source of uncertainty. This temporal relationship requires further research, using additional sources.

The present research, however, is only our first attempt to perform this analysis. The limitations we faced are also relevant, as they may reflect more general issues for research into subcamps. The actual data (place names) were derived from sources which do not necessarily reflect the official historical names, but rather are place names used by gazetteer makers at the time. Consequently, the results show textual and spatial relationships between names of Buchenwald subcamps and places from non-official sources. To understand how far or close the official place names were in relation to the subcamp names, one has to work with primary sources such as acts and documents rather than with gazetteer data. Unfortunately, the gazetteer data, especially the historical data, often reflect subjective perspectives and interpretations.

Second, the spatial resolution of the data in the gazetteers is an important issue. Historical sources, unlike modern ones, cannot provide detailed information for locations, as they do not have, e.g., a zooming function. This is why information from many sources is only approximate, and a subcamp, for example, might be associated with a larger or more important populated place, and not necessarily with the nearest one.

Third, Thuringia as a region did not exist at all in 1917, the year when the first of our sources was published, although the spatial dimension of the research does appear to coincide with the extent of Thuringia's modern-day borders. To avoid a certain amount of data processing, one has to consider either (a) using a different geographic area and focusing exclusively on the entire Buchenwald camp system, or (b) using only those sources which are applicable for present-day Thuringia. But even in this case the borders can be open to doubt, because they have not been stable over the period from when the subcamp was built to the present day.

Fourth, the methodology to detect the places that correspond most closely in textual and spatial senses should be refined with the addition not only of buffer and intersection tools, but also of statistical approaches such as Nearest Neighbour Analysis to provide statistically more reliable results. Finally, as already mentioned, additional sources are needed, which could reveal trends and relationships which cannot be detected using our 4 sources, only 2 of which have spatial coordinates.

Fifth, the techniques used to detect textual difference do not always reflect how place names may (or may not) differ from each other. As we know, language is not just written, but also pronounced or spoken. The perspective taken in the current work tends to understand language only as something written, and distances measured are based only on different spellings and not on a comparison of their phonetic forms. With the help of the Soundex algorithm, for example, one can detect the differences between words as they are *pronounced*, like the Levenshtein algorithm does with regard to spelling.

As both parts of our analysis show, associations of subcamp locations with populated places can lead in some cases to erroneous conclusions. One might think that subcamps were located close to the places which bear the same names as the camps, but this is not true in all cases. This analysis may serve as the starting point for deeper historiographical research exploring how people see the sites of former concentration camps, and just how they can be located.

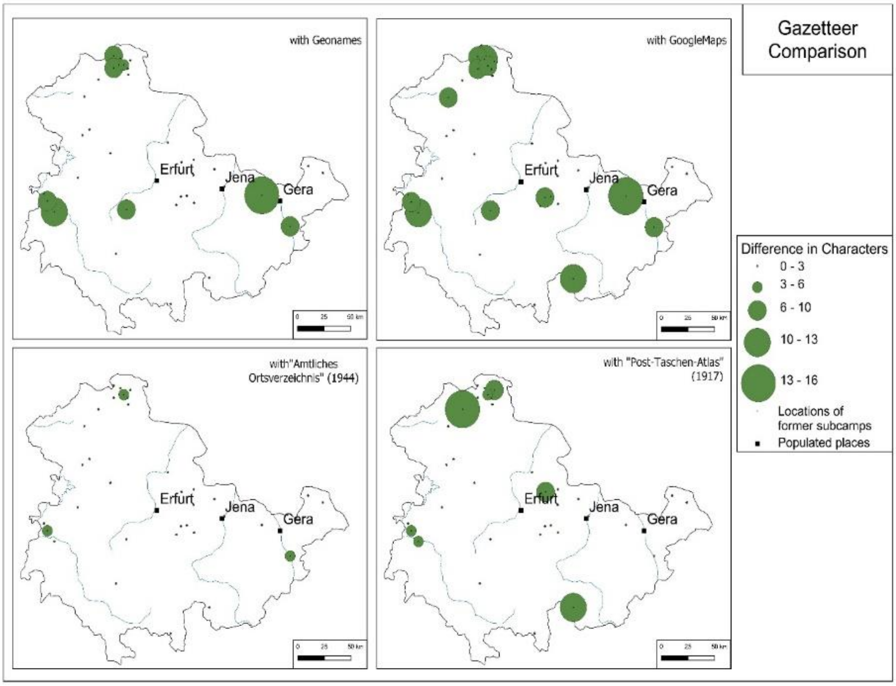

Figure 5: Differences in number of characters for the names of subcamps considered in this paper.

7 Conclusion

What this analysis shows is that the locational accuracy for subcamps is in many cases uncertain to a significant degree. The digital and historical gazetteer data we utilized is frequently not sufficiently reliable to connect a place of remembrance with the actual location of events. For most uses, the accuracy is still generally sufficient for larger areas (maps of, e.g., regions). However, for research using locational data available) in geomedia, adequate information on metadata and the presentation of data should be offered. Possibly, even, the display of data for smaller areas should be limited (in order to avoid overloading maps visually). This latter point is relevant also to assessing the accuracy of geocoding for volunteered data collections (Goodchild, 2007) and newer forms of data integration that digital geoinformation makes possible, e.g. collaborative geocoding.

To conclude, we can highlight several points from the analysis that also suggest some directions for further research. First, the discrepancies in distances between gazetteer locations and data from the Buchenwald memorial suggest that while for the most part the gazetteer-based locations would be sufficient for mapping sites at regional or national scales, the differences limit the use of the gazetteer data for detailed mapping (e.g., to show sites accurately on a local map) (see Figure 5). Second, knowing the purpose of the mapping is essential to assess the desirable degree of locational accuracy. Using Wieczorek et al.'s list of factors for geocoding would provide valuable information to guide the assessment of locational accuracy. Third, also following Wieczorek et al. (2004), using and presenting subcamp locational data should come with clear information about its accuracy and documentation on how the data was collected.

As pointed out in the introduction, locating places of remembrance is complicated. The place remembered is difficult to connect to the location of specific events. This is a significant research area for historians and geographers, and more recently for those working in digital humanities. Looking at degrees of linguistic similarity among toponyms for Buchenwald subcamps in Thuringia suggests that transliteration and other linguistic differences should be taken into account **(**Bodenhamer, Harris and Corrigan, 2013). In this analysis, we compared simply the number of characters used in different data sources. While this gave some interesting results, they need further interpretation, and a method is required that can be used to identify differences between toponyms for the same places in extensive data collections (Figure 4).

While this article makes only a small contribution to the challenges of locating and mapping sites of remembrance, hopefully its consideration of locational data points for concentration camp subcamps gives an indication of essential issues and geocoding guidelines that can help historical researchers using gazetteer data better to associate places with the locations of events. Explaining the issues that can arise from using information in gazetteers will hopefully aid future research in locating additional places of remembrance, and in locating them more accurately.

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Present and Absent: Exploring the Holocaust of Jews in Prague Using a Mobile Application

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Abstract

This paper discusses the goals, methodology and experience gained in the project ‘Integration and Segregation in Cityspace: The History of the Holocaust in Prague Through a Web Application’, funded by the Technology Agency of the Czech Republic. Using a mobile application, the project aims to overlay the current cityscape with extensive datasets on the Holocaust victims who were living in Prague before their deportation. By giving insights into working with the data, and by presenting the digitized material used and the technical development of the web application, the paper also hopes to contribute to future approaches for archival and educational GIS-based applications. Following an introduction to the spatial history of Jews in Prague, the article analyses the challenges at the crossroads of documentation and digitization, technology and user interface, as well as user interaction with data.

Keywords:

Holocaust, Prague, mobile application

1 Introduction

Due to the rapid exclusion, disenfranchisement and expulsion of Austrian Jews following the Anschluss of Austria to the German Reich, Ernst (Arnošt) Löwit, an Austrian bank assistant born in 1889, was forced to flee from Vienna to Prague in July 1938. He rented a room in Čermákova 9 in Královské Vinohrady / Königliche Weinberge, a middle-class neighbourhood, and became dependent on the support of the Jewish Community in Prague. Following the occupation of Czechoslovakia in March 1939, he tried in vain to prepare his further emigration to Shanghai. In 1941, he received a summons for a transport from Prague. Ernst Löwit was arrested on 18 October 1941 in a café on Charles Square in Prague: he had removed his Star of David to meet his non-Jewish fiancée Ludmilla Klimt and bid her farewell. Showing the intricacy of the day-to-day interactions in the city, he was found and punished after being denounced anonymously to the Czech police[1].

After two weeks in prison, on 30 November 1941 he was transported to the ghetto in Terezín (Theresienstadt)[2]. A month later, several inmates in the camp were arrested, Ernst Löwit included, for illegally sending letters out of Terezín (Adler, 1960, p. 86). In an exemplary punishment, the SS hanged him together with eight other inmates on 10 January 1942, a mass execution unique in the history of the Terezín Ghetto[3].

The story of Ernst Löwit underlines how the persecution of Jews under the Nazi regime began in the space of everyday life in cities: in private homes, public spaces or workplaces. In education and public history projects, persecution during the Holocaust is easier to communicate using historical places of exclusion and extermination, which are often separated from the spaces of everyday life. However, mobile maps and the constant accessibility of information, as well as more experimental technologies such as augmented reality, are changing our perception of the present as we move around these public spaces. As pointed out in recent studies, historical geo-apps can function as an interface between the user and information on the real/virtual space (Bollini et al., 2014).

In recent decades, Holocaust-related research institutions have seen a massive shift in the nature of their work due to the 'digital turn': the digitization of large quantities of Holocaust-related archival material has made it possible for archival content to be connected with individual entries in victim databases. In various countries, local digital projects are currently experimenting with ways of making data on persecution available in the public space via web and mobile technology, using new approaches to the numerous large and small datasets that document names of Holocaust victims created by Holocaust archives and memorial institutions.

This trend was also clearly demonstrated by an international workshop, 'It happened here! Digital and shared: Holocaust history in public space', organized by the European Holocaust Research Infrastructure (EHRI) in April 2019[4]. The call to critically explore how digital approaches contribute to the social construction of space resulted in a surprising number of proposals and highlighted how topical such research and projects are. The growing application of spatial studies to Holocaust research provides a framework that leads historians to ask new research questions and to deploy geographic visualizations of the Holocaust (Cole, 2016; Knowles et al., 2014). Studies on the user experience of spatial mobile apps containing historical information have already shown the importance of the user's own vicinity. This underlines the need to expand user-testing methodologies to include the use of prototypes directly in the field (Bollini et al., 2014). The application for educational work in the field of

[1] National Archives Prague (NA), Policejní ředitelství v Praze (Police Headquarters Prague, PP), 1941–1950, call number L 1507/3 Löwit Arnošt.

[2] NA Prag, PP, 1931–1940, call number D 391/51 Deutsch Oskar, Verhaftungsprotokoll.

[3] Jewish Museum in Prague (JMP), call number SHOAH/T/2/A/2d/071b/001, Verzeichnisse inhaftierter Ghettoinsassen in Theresienstadt.

[4] See https://vwi.ac.at/index.php/veranstaltungen/icalrepeat.detail/2019/04/01/263/-/it-happened-here-digital-and-shared-holocaust-history-in-public-space (30.1.2020) for workshop programme.

Holocaust research is still in its infancy, however, making the experiences of earlier similar projects even more important.

This paper gives insights into the questions and methodologies of one of these projects: 'Integration and Segregation in Cityspace: The History of the Holocaust in Prague Through a Web Application', funded by the Technology Agency of the Czech Republic, which projects data from the database of victims into the present cityscape of Prague, using a mobile application. For its implementation, an interdisciplinary team joined forces: the Terezín Initiative Institute (TII), a documentation and educational institution; the Masaryk Institute and Archive of the Czech Academy of Sciences, a research institution; the Multicultural Centre Prague, an educational institute; and Deep Vision, the technological partner institution. Drawing on experience from similar projects, it contributes to the exploration of how historical data on individuals, locations and events can mobilize local knowledge and participation. It works closely with the online application 'Memento Vienna' (Schellenbacher, 2017), which currently makes available data on more than 55,000 victims of the Nazi regime in Vienna and is based on the database of victims of the Documentation Centre of Austrian Resistance[5]. Using a map of the city, the mobile website makes visible the last-known addresses of those murdered, and connects the people and places with archival documents and photographs.

This paper discusses both the challenges of developing a mobile application mapping the persecution of the Jewish residents of Prague after 1939, and fresh approaches to the development of the application. By giving insights into working with the data, the digitized material used and the technical development of the web application, the paper also aims to contribute to future approaches for archival and educational GIS-based applications. Following a short introduction to the history of Jews in Prague (Section 2), the article analyses the challenges at the crossroads of documentation and digitization, technology and user interface, as well as user interaction with data.

2 Jews in Prague: A spatial history

The emancipation of Jews, as well as its violent reversal during WWII, was an inherently spatial process. While Prague's Jewish community could be proud of its continuity of settlement from the early Middle Ages (occasional and short-term expulsions notwithstanding), during the 19th and 20th centuries the patterns of Jewish presence underwent profound transformations, as did the city as a whole. These changes included the recoding of spaces, the development of new urban spaces, and increasing migration and mobility within the city.

The Prague Jewish Town, or the former ghetto, became a regular city neighbourhood in 1850. The fifth administrative district, also called Josefov after the Emperor Joseph II who started the emancipation of Jews in the 1780s, was home to an increasingly diverse and mostly impoverished population. By 1890, only one third of the 11,535 inhabitants of the fifth district were Jews, and the historian Cathleen Giustino has described the transition of Josefov into a 'slum' (Giustino, 2003b, pp. 89–114, 172; 2003a). In 1896, however, Prague City Council

[5] See www.memento.wien, current status July 2020.

launched a long-prepared urban reconstruction programme known as 'asanace' or 'Assanierung' ('sanitization'). With the exception of selected synagogues and most of the Old Jewish Cemetery, by the outbreak of WWI the former ghetto had been torn down, and the neighbourhood was rebuilt in the fashionable, middle-class styles of the day (Giustino, 2003b; Hrůza, 1993).

While older Jewish spaces were in decline, new neighbourhoods gave Jews possibilities to integrate and flourish. The new sprawling suburb of Královské Vinohrady (Königliche Weinberge in German) invited the migration of Jews from smaller towns in Bohemia as well as from Prague's former Jewish Town. The impressive Vinohrady synagogue, built in the fashionable Moorish style and opened in 1897, became one of Prague's most visible landmarks – so much so that Czech anti-Semites perceived it as a symbol of Jewish dominance over Czechs and Christians (Šmok, 2015). Vinohrady offered ample spaces for middle-class social life in its parks, cafés and theatres. As the city grew, the Jewish population migrated to the new neighbourhoods. Especially in the public sphere and in professional life, Jews increasingly interacted with non-Jews (Koeltzsch, 2012). But as the historian Gary Cohen has calculated, while Jews and non-Jews shared the public space, they still gravitated towards the same residential spaces in their private lives (Cohen, 1977).

Jews co-produced the modern cityscape of Prague. For instance, Jiří (Georg) Kosta described in his memoires how in 1927 his grandfather, developing his artificial-flower business, built a modern functionalist house at the bottom of Václavské náměstí (Wenceslaus Square, one of the main squares and public spaces in Prague), next to the Bat'a shoe store, the celebrated symbol of the economic success of inter-war Czechoslovakia. To this day, the house is named after his grandfather (Lindtův dům). A passageway connects the highly frequented spaces of the Václavské náměstí with Jungmannovo náměstí (Jungmann Square) (Kosta, 2001, p. 18). Yet this presence in the public space, which was sometimes prominent, was not uncontested. The position of the Jewish population was subject to a double conflict: over their presence in middle-class spaces such as cafés, parks, theatres or public transport, and over language and national coding of space. With the growing intensity of the Czech–German nationality conflict, public spaces and the public use of languages became subjects of a bitter struggle. Prague Jews, many of whom spoke German or were bilingual (like Jiří Kosta), were often accused of 'Germanizing' (that is of spreading German loyalties among themselves and others (see e.g. Cohen, 1981). The same accusation was often directed against German-Jewish refugees from Nazi Germany who found a temporary and insecure refuge in Prague. Some lived in overcrowded homes on the outskirts; some – not allowed to work – spent their time walking the streets or sipping the same cup of coffee for hours in a café in the city centre (Čapková & Frankl, 2012).

After the occupation by Nazi Germany in March 1939 and the creation of the Protectorate of Bohemia and Moravia, Jewish spaces rapidly shrank, often by order of the local authorities, from municipal councils to Czech 'autonomous' ministries (Adler, 1960; Gruner, 2016; Kárný, 1991). For instance, on 17 May 1940, just as the time for enjoying spring and summer strolls arrived, Jews were prohibited by the Prague police from entering public parks and gardens; mothers instead took their children to Jewish cemeteries, the only green spaces they were allowed to enter. Jews were prohibited from certain streets or riverbanks and had to move to overcrowded apartments. Synagogues were closed and turned into storage spaces for confiscated goods. With the ongoing revocation of rights, Jewish life underwent a spatial re-centring: even those who were not particularly religious or who were 'Jews by race' (i.e. people who had converted to Christianity) were now increasingly dependent on Jewish communal institutions for emigration and social or health care (Bondy, 1989; Krejčová et al., 1997).

At the same time, new geographies of persecution emerged. For instance, the Nazi Zentralstelle für jüdische Auswanderung (Central Office for Jewish Emigration) in Prague-Střešovice became a place of humiliation and terror (Černý, 1997; Milotová, 1997). On 16 October 1941, the first mass transport of Jews left Prague for the ghetto in Łódź (Lodz); soon transports departed on a regular basis to the newly established ghetto in Terezín (Theresienstadt), and from there to other ghettos and extermination camps. The systematic deportations produced a new geography: an internment camp was established in the grounds of an industrial exhibition area in Prague-Holešovice, from where approximately 45,000 deportees were led to the nearby Bubny railway station. Local inhabitants would see families with heavy suitcases containing the permitted 50kg of personal belongings moving to the exhibition ground and then being marched to the station. Jews who were still allowed to live in their city, mostly those from 'mixed' families, were excluded from much of its space, and towards the end of the war many were interned at Hagibor, a Jewish sports club which had been turned into a forced labour camp.

Holocaust survivors returning from camps or from emigration found a changing city and shifting political climate. In 1946–47, the Jewish community counted 7,422 Jews defined by their religion, and 3,145 others considered Jewish by the Nazis under the Nuremberg Laws, who were still supported by the Jewish community. After the war and after the suppression of the Prague Spring in 1968, many Jews emigrated. As a result, the current official Jewish community has fewer than two thousand members.

Until the fall of state socialism in 1989, Holocaust memorials were largely confined to Jewish spaces such as cemeteries and synagogues. In the 1950s, the State Jewish Museum inscribed the names of approximately 80,000 Bohemian and Moravian Jews on the walls of the Pinkas Synagogue in Prague. However, the memorial was closed in 1968 and only reopened in 1996, once the museum was returned to the Jewish community. Because the Prague synagogues and most other Jewish sites were not physically destroyed in the 'Reichskristallnacht', the Jewish Museum became a major tourist attraction, symbolizing the void, but also representing what was labelled 'virtual Judaism' (Gruber, 2002; Veselská, 2012). Until recently, the places related to deportations were insufficiently marked and remembered. Thanks to an initiative by survivors, a memorial plaque was installed in 1989 close to the original collection point, and became a location for annual commemorations. Recently, as part of the general redevelopment of an extensive brownfield site, Bubny railway station began its transformation into a museum. Other memorials have also been unveiled, for instance a number of Stolpersteine set into the pavements in Prague by a local initiative.

3 Database of the Holocaust victims

Building on the unique database of the Holocaust victims managed by the TII, this project aims to unlock the potential of a large dataset through bringing it into the public space via maps and a mobile application. Similar to other projects documenting the names and fates of Holocaust victims, the database is the result of long-term coordinated research that began in the early 1990s, which itself built on earlier documentation activities. The first public outputs were a list, published in 1993, of 218 children who survived deportation to Terezín (Kárná, 1993); in 1995, the Terezín Memorial Book listing all deportees from Bohemia and Moravia followed (Kárný, 1995; Terezín Memorial Book, 1996). The book contains information on approximately 80,000 people deported from the Protectorate to Terezín, Minsk, Lodz and other ghettos and camps. In 2000 and 2005, the Terezín Memorial Books for prisoners from Germany and Austria respectively were published (Theresienstädter Gedenkbuch, 2000; Theresienstädter Gedenkbuch, 2005).

The core sources were lists of prisoners who died in Terezín or who were deported to extermination camps, compiled between 1968 and 1972 by the Jewish Committee for Terezín; the lists of survivors in Terezín published in 1945 for repatriation purposes (Spilka, 1945). This data was supplemented by information from transport lists to and from Terezín, card files of prisoners (held in the National Archives in Prague and at the Federation of Jewish Communities in the Czech Republic), as well as other archival sources, memorial books, personal testimonies and memoirs. The database is continuously updated and currently contains more than 170,000 individual records of which approximately 35,000 will be used for the Prague mobile application. In 2008, the victim database was published online as part of the holocaust.cz educational portal (Plzáková & Štěpková, 2015).

The original database contained only personal data and no documents or photographs. In 2005, the TII embarked on an extensive digitization project, the Terezín Album, which aims to – symbolically – give faces to the victims and to open up a trove of documents to further research. While some documents and photos of the victims are from individual donors, this project focuses on the systematic processing of collections stored in Czech archives. Until 2012, the TII digitized personal files of the Police Directorate in Prague, held in the National Archives in Prague, and all the death certificates from the Terezín Ghetto, part of the Jewish Registers Collection. During this phase of the project, around 180,000 documents (more than 370,000 single pages and about 50,000 photographs) were scanned. Since 2013, the project has continued with a focus on communities outside Prague. The database is still person-centred and now allows for investigation into the lives of Holocaust victims in much greater detail.

4 From data to social practice

The purpose of the application is not purely commemorative. Starting from an awareness of the social construction of space, it builds on the data in the database of victims to establish a connection between the familiar space of the city and the complex history of encounters and conflicts in the multi-ethnic city of Prague. The application measures and tests the social impacts of data, and is an intervention in the public space designed to catalyse thinking about the mechanisms of inclusion and exclusion in everyday life. Using the application is understood as a social practice which affects not only users' knowledge, but also their perception of the places and spaces they frequent. To achieve this, and beyond what many similar applications offer, the project places particular emphasis on data which enrich the spatial experience and on awareness of the shared and disputed space.

In doing this, the project aims to relocate where and how users (including residents, students and tourists) experience 'Jewish' Prague and the history of the Holocaust of Prague Jews. Hopefully, it will extend the geography of 'Jewish Prague' beyond the Jewish Town itself (where the Jewish Museum provides access to a number of sites and exhibitions). Moreover, by looking at tensions in the public space, it aims to reach beyond the usual commemorative function of projects locating Holocaust victims in their pre-war places of residence.

To connect the Holocaust victims to the city space, the team used the addresses listed during the registration of Jews which began in the autumn of 1941, just as mass deportations were launched. These addresses were checked, corrected and unified by adding the current street names to the historical German and Czech names from the 1940s. They were also automatically geocoded via BatchGeo, a software powered by Google Maps. In doing this, the project built on the experiences from the mobile web application 'Memento Vienna', but aimed for a more automated workflow combining data enrichment services with manual finalization. The digitized police files, such as passport and ID card applications containing photographs as well as residence permits and other types of routine documents, often allow for a reconstruction of information about an individual's residence, changes over time, employment, education, social and economic status, and family ties. In the application, these documents and photographs provide a possibility to (at least partially) reconstruct the victims' everyday life before 1939 and during the occupation.

The project team focused on what it called 'incidents', such as the arrest of Ernst Löwit, and invested time and resources in identifying documents that demonstrate interactions between Jews and non-Jews, as well as ordinary people and authorities in the city space. Even though this information is derived from the police archives and is necessarily one-sided, it can reveal details of social life before and during the occupation, the day-to-day enforcement of anti-Jewish decrees, and transgressions of them. At the same time, spaces of tension are revealed – those where exclusion ran most dramatically against pre-war social practices. Unlike the deportations, which were decided on by the occupying authorities, the involvement of the local population and of Czech authorities are disputed subjects, disrupting the idealized picture of Czech national history. Documents on arrests and criminal cases provide unique data about the exclusion of Jews from society, and the spaces and situations of transgression. They include, for instance, investigations of Jews who entered spaces prohibited to them or did their shopping at times reserved for 'Aryans', as well as of Jews who were caught not wearing the obligatory Star of David or whose ID cards were not marked with the letter 'J'. At the time of writing, the team has identified and catalogued around 1,000 such 'incidents' which will be marked with a special icon in the application and, we hope, have a disruptive effect, making users think critically about public space and the participation of Czech society in the exclusion of a minority.

In the next phase, the team plans to add data on places of interest. While some of these may be tourist sites, the information will differ from standard tourist information by starting from the function of the location during the Holocaust. For instance, the history of a synagogue might point to its war-time use for storing 'aryanized' objects and the destruction of its community, rather than its long history and unique architecture. The project aims to map, at least partially, spaces prohibited to Jews, the sites of the Jewish community, major places of persecution and deportation, as well as selected places of memory.

Importantly for turning data into an application, the space is not understood as a static phenomenon. Combining the map with a timeline allows a dynamic picture of presence and absence to emerge. Users will be able to move along the timeline to see the shrinking Jewish space, the points of conflict, and the vanishing Jewish life. The preliminary idea, still to be tested, is that objects on the map which symbolize people as well as points of interest will change colour as a result of persecution, exclusion and confiscation. For instance, an icon of a person will change to grey after deportation, and a synagogue, too, after being turned into a storage space. Visualizing absence is an essential ambition of the application.

5 Challenges of technology

To build an application which represents a rich and extensive dataset in space and time that is optimized for use by end-users as they move through the same space brings significant challenges. The project team decided to prioritize the building of native mobile applications for Android and iOS, rather than the originally planned responsive web application (which will only be created as a fall-back option). This decision was taken mainly in view of the technological advantages: access to the operating system's kernel, and the possibility of reading data from navigation sensors or the gyroscope. Implementing such features on a web platform is much more complicated and the solutions tend to be unstable. Given the large number of records and documents and their ongoing updating, the application will require an internet connection. The software stack used consists of Node.js as the server application layer, Nginx as the web server, GraphQL as the communication language, and React.native for building mobile applications. (The choice of the database server is discussed below, in this section.) The application code will be open source, with documentation regarding the data structure and import formats, so that it can be customized for similar projects elsewhere or those addressing other historical topics.

The resulting application will be centred around the representation of space and time, or a map and a timeline, in which we locate people (victims of the Holocaust), events (arrests or other incidents) and points of interest. The final version will also offer predefined guided tours. Two aspects of the technical development turned out to be particularly challenging – and interesting: the choice of the right database and data model, and the work with maps. (We discuss these further below.)

How to represent the complex data and provide smooth and effective access was a key question. The application needs to retrieve data from a large database based on connections between people, locations and events, and other supporting data types, and to display them in real time as end-users move through the streets. Although the project originally tested modelling data in a conventional relational database, it ultimately opted for a hybrid graph database. While relatively novel, graph databases have become more popular in recent years because of their flexibility and ability to retrieve information by following the relationships between data objects. A hybrid graph database proved an elegant solution for modelling a data structure which captures the local history of the Holocaust. A graph database, specifically ArrangoDB, allows for a better, more logical and effective data structure.

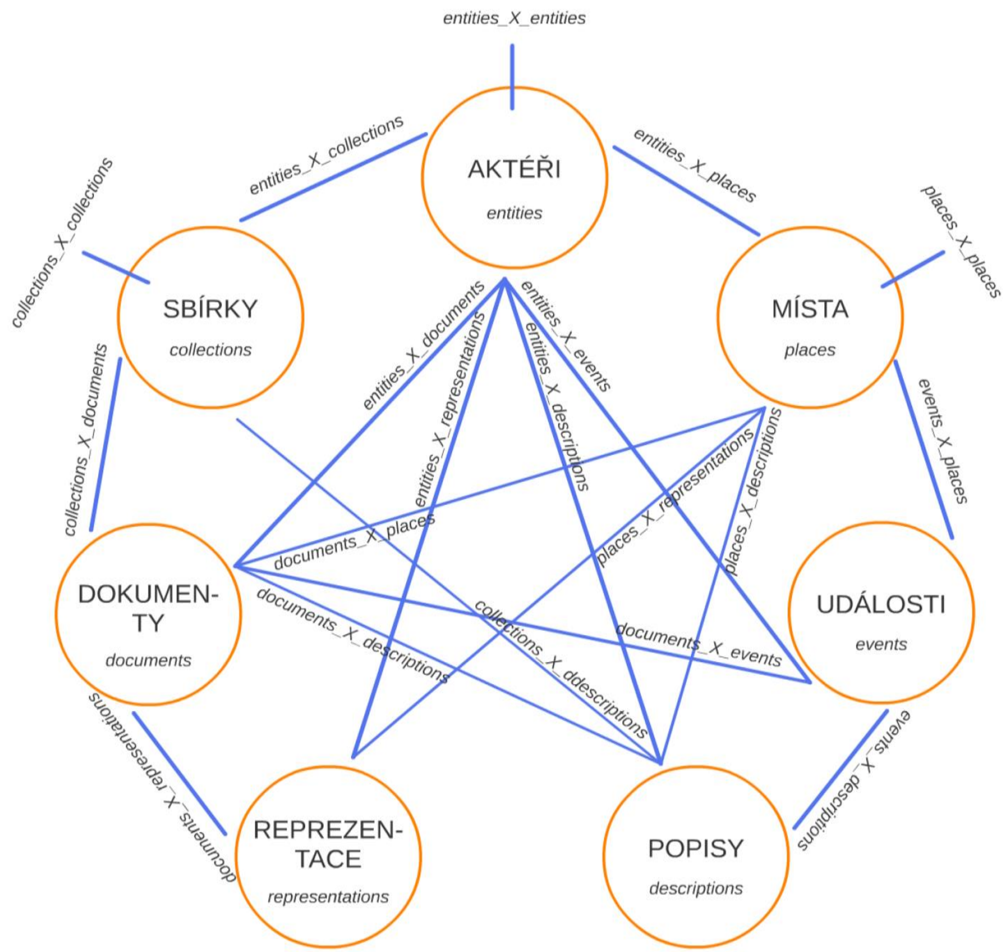

Figure 1: Schema of the data structure

The project opted for a generic data model applicable to any set of historical knowledge about people in space and time, thus making it useful for encoding not only the history of persecution, but also human agency. The core data elements (vertices) are people (Holocaust victims who lived in Prague before deportation), locations (places of residence, historical sites, places of interest etc.) and events (incidents involving the victims of the Holocaust, transports and other data). The sources of information are encoded as documents and collections, and the model is further extended by support data types of descriptions and representations. Most information, however, is located in the edges connecting the vertices, which allows the representation of a dynamic network of named relationships. The cost, however, is that the more generic model might be more difficult to adopt by projects with lower data expertise and technical capacity.

The application projects historical data into the present space. Hence mapping is a crucial element of its functionality. Since users are navigating through the current cityscape while accessing the information, the core map had to be based on the current street plan and includes current street and place names. The project team discussed the two standard possible solutions, OpenStreetMap and Google Maps, and eventually decided on the latter. While OpenStreetMap is free and the base map is often richer, its implementation would be more complicated, most likely requiring a dedicated map server. Google Maps, despite requiring fees based on the amount of access, offers good configuration of the user interface and rich possibilities for styling.

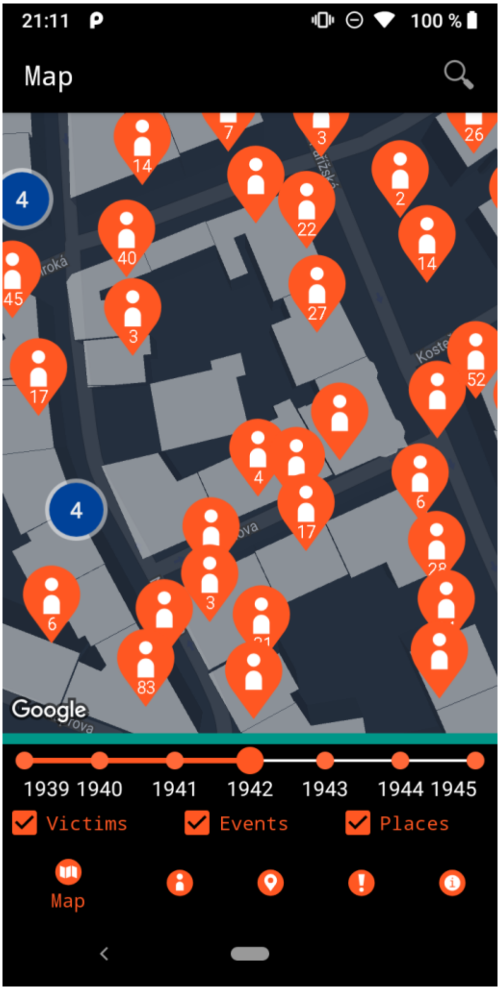

Figure 2: Development version of the application, showing map view with timeline

Implementing Google Maps, however, brought its own challenges, which were partly related to the focus of its standard layout on driving rather than walking, visually under-representing public spaces (such as squares) as a result. Moreover, the designers suggested a powerful dark graphic style which reduced the amount of detail and the readability of the map. Based on user feedback (discussed in Section 6) and a detailed exploration of the possibilities of the Google Map API, the map style in the application was upgraded to address these issues. The application may in the future overlay the Google Maps layer with a historical map layer; more research and testing are needed to better understand how users would navigate in the present space while using an historical map.

Early in the project, to allow for user testing and internal discussion by the project team, we first developed a test application which used just a very small subset of data and a conventional relational database. The next round of testing will be based on a new and feature-complete application using the full dataset (which was delivered as this paper was being finalized).

6 Testing user experience

While technology introduces its own challenges, the main challenge is the real-life interaction of end-users in the physical space of the city. In fact, we know very little about how students, residents or tourists use mobile devices to engage with history, especially when a large amount of data is made available. User testing and feedback from different groups of potential users are therefore essential aspects of the project. Before the development of the application itself began, the interaction of users with archival documents was examined, and testing continued after the release of every beta version of the application. The testing so far has been based on a partial dataset only and has lacked most of the data on 'incidents' and points of interest, as well as the visualization of absence.

The testing was conducted with small groups of users, and therefore qualitative research methods, especially participative observation, semi-structured interviews and focus groups, were used. (See for instance Lichtman, 2012; Delamont, 2012; Denzin & Lincoln, 2011.) According to this methodology, the researcher must respond to ongoing results and circumstances and adapt the research plan accordingly. Researchers took notes during participative observation and analysed them in combination with interview transcripts, photographs and video recordings. We used rules and methods of qualitative questioning during semi-structured interviews, and moderated discussions in focus groups. Predetermined response formulations or categories were not provided to respondents, and a neutral stance was expressed in the questions. Each testing was conducted with a specific group of pre-selected participants: team members and external collaborators, children of Holocaust survivors, students of an IT school, and students in third grade at the Jewish grammar school in Prague (the Lauder School, itself located in a former Jewish orphanage, not far from where Ernst Löwit first found refuge in Prague).

Participants were given basic information about the project, and about the main goals and research methods. In the case of the Lauder School, cooperation was negotiated in advance and integrated in school activities. The testing with students at the Lauder School also used the peer research method (sometimes called user-focused research), a form of research steered and conducted by people with a lived experience of the issue under study. In each group of students, one acted as a 'researcher', taking pictures, videos and leading short interviews.

Although very different in terms of age, family background and emotional engagement, the respondents generally identified easily with the main functions of the application, as they understood them: to commemorate Holocaust victims in public space and to relate their stories and faces to specific locations. All groups also wished to add guided routes to the application, to provide a more detailed insight into the life stories of specific individuals and historical context. All were attracted by the visual material – the historical photographs of houses and streets, and portraits of Holocaust victims. They suggested that in the absence of a personal photograph, an icon visually indicating gender should be used.

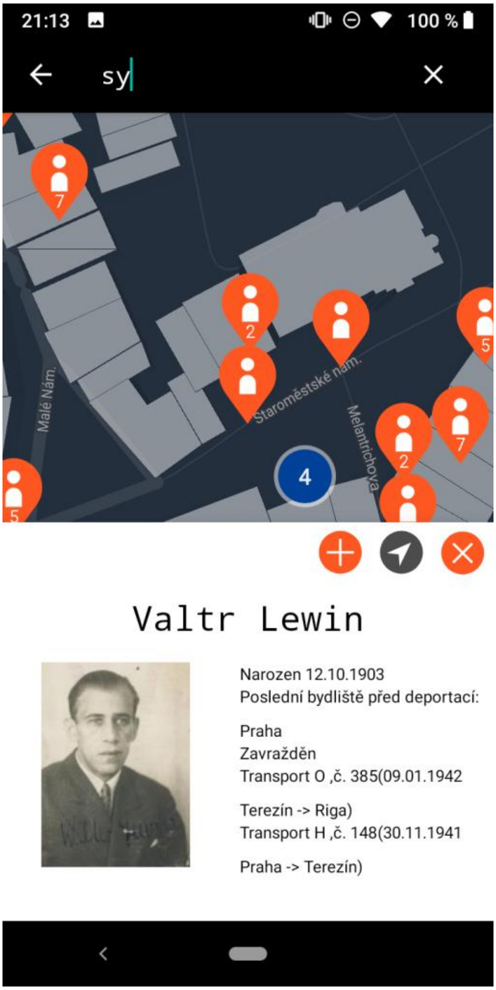

Figure 3: Development version of the application, showing map with personal information

Users asked for greater clarity and comprehensibility of the map base. They pointed out the need to display house numbers, and to show street names and landmark buildings, even the non-Jewish ones, clearly. Some expressed concern that the map showing the contemporary street plan and names is confusing, especially for users from outside Prague. Students from both schools, used to working with mobile applications, asked questions about data consumption or the possibility to download application data via Wi-Fi and then work offline. Useful comments also related to the application functionality: the possibility of selecting a particular time span on the timeline was requested, as were colour differentiation for the points or people already visited, and the option to collapse the toolbar and show a full-screen map. Children of Holocaust survivors reflected primarily on the connection to their family history and emphasized ethical aspects of publishing photographs of people with living relatives. They also expressed their concern about possible anti-Semitic reactions.

In the future, more testing will be required regarding the use of archival documents on mobile devices and in space. Reading can be made difficult by the presentation of handwritten texts, in German or other languages, or insufficient understanding of bureaucratic procedure and administrative jargon from the period. In the next phase, the testing process will focus on the tension encoded in the history of the public space in Prague, and the shifting between presence and absence of Jewish life.

7 Going forward

Cooperation in the interdisciplinary team proved to be a challenging yet enriching learning process. Following an agile development pattern, the work did not follow a straightforward, linear design but rather one in which all aspects regarding data and functionality needed to be revisited regularly based on user testing, further evaluation and discussion.

The project work has been delayed by the Covid-19 pandemic, making not only the development, but also (and mainly) testing difficult. This article was finished just as a new test version of the application, with the full dataset and upgraded functionality, became available. In the near future, the team will re-evaluate the effects on the user's perception of space and any critical reflection on its social construction. Ideally, after the final release of the application in 2021, students, residents and tourists in Prague will be able not only to commemorate Prague's Jews who were deported and murdered, but also to reflect on the history of the shared and contested space of Prague.

In the longer term, the project team will focus on the sustainability of the software and extending its functionality for the Prague application, as well as on its possible deployment in other spaces. Discussions will also be held with EHRI and its future national nodes to assess how this and similar projects may be supported by providing data services or in other ways.

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Passport for Life

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Abstract

For Tal Yaar-Waisel, finding her great-grandmother's passport was a shocking experience. The 'Deutsches Reich' passport, stamped with the Nazi seal, allowed Karoline Bloch (Dr Yaar-Waisel's great-grandmother) to leave Vienna just two days before Kristallnacht, 9 November 1938, saving her life and enabling her to join her daughter's family in Nesher, in Mandatory Palestine.

This study intertwines Karoline's story, history, research and experimental pedagogy. The personal story of Karoline Bloch, a Holocaust survivor from Vienna, is discussed against the background of the persecution of Austrian Jews and the destruction of their community. Her passport reflects her personal suffering and salvation, and is discussed in relation to immigration policies at the time. From the research point of view, the study deals with geomedia as working tools that can be used to widen the interdisciplinary dimensions of passports. The authors used the passport as the basis for inquiry-based teaching of the broader historical subject. The combination of a personal story, historical background, and facilitating students to work as geomedia researchers, asking questions and finding answers, generated the students' interest and rendered them capable of thinking about the meaning of the subject for themselves.

Keywords:

passport, Austrian Jewry, geomedia, primary sources, inquiry-based teaching, multidisciplinary teaching, immigration

1 Introduction

A single document or picture is sometimes an 'historical treasure' through which we can experience a direct encounter with the past, in which a meaningful experience is created that leads to valuable learning. Such 'pearls' are not found only in museums; sometimes they are literally within our reach, just waiting for us to find and recognize them. In 2012, Tal Yaar-Waisel was sorting out photographs and documents in her parents' home, and came across the passport of her great-grandmother, Karoline Bloch, which was issued in Vienna in 1938. Finding the passport was thrilling.

The ‘Deutsches Reich’ passport, stamped with the Nazi seal, allowed Karoline Bloch (Dr Yaar-Waisel’s great-grandmother) to leave Vienna just two days before Kristallnacht, 9 November 1938, saving her life and enabling her to join her daughter’s family in Nesher, in Mandatory Palestine. Within nine months, after her husband’s death in February 1938, followed by the German annexation of Austria in March, Karoline lost everything she had, and her survival depended on her passport. Miraculously, because her children had left Austria before those tragic events, she could choose between two destinations (Palestine or Brazil) at a time when few people had any choice. The personal story reflects the history and destiny of many millions, Jews and others, who were persecuted and displaced in the 20th century.

After years during which Dr Ben Dor, a senior teacher of history, had taught students about the unification of Germany and Austria and the persecution and expulsion of Austria’s Jews, it was possible to see in the passport, clearly and symbolically, the tragic and human power of these events. Austria was united by force with Germany and the passport is therefore one of Nazi Germany, with the words ‘The German Reich’ emblazoned at the top; under them are the Reich Eagle of Nazi Germany and a swastika. On the left-hand side of the passport, in red ink, is the letter J, showing that the passport’s owner was a Jew (*Jude*). Beside the letter ‘J’, the date 12.10.1938 appears vertically. (See Figure 1.) The passport was issued on 29 September 1938; from October 1938, Jews had to carry special passports which identified them as Jews. The directive derived from a Swiss initiative, which sought to prevent the arrival of a stream of Jewish refugees (Barkai & Mandes-Flor, 2005: 212). Karoline received the passport just before the directive came into force; the letter ‘J’ and the date (12.10.38) were added later. The passport is written in German, but it also includes words in English, Portuguese and French.

Figure 1: Evidence of the ‘Anschluss’ in Karolyne’s passport

2 Passports as historical documents

The uniqueness of Jews as a separate collective, but one lacking territorial sovereignty while being transnational in nature, stands in contrast to the increased importance of passports in the nation states of Europe after World War I. Between the two world wars, a passport becomes a means of differentiation and exclusion (Keshavarz, 2018). The nation states established after the disintegration of the empires used passports as a device for limiting the freedom of movement of all those who had lost their citizenship and become refugees. For many Jews, holding a passport was one of the first steps to ensuring their survival. But as a nation without a state, Jews suffered. The inability to solve the problem of refugees on the eve of World War II merged with the inability of nation states to deal with the question of Jewish existence. After the Nazi regime came to power, the risks faced by Jews increased, from expulsion to genocide (Jean, 2011).

The renowned Austrian-Jewish, anti-Nazi writer Stephan Zweig (1881–1942), a refugee in Brazil, in his autobiographical book The World of Yesterday (1942), records the tragedy of the German and Austrian Jewish intellectuals who were forced to live as wandering Jews. Zweig and his wife, out of despair at their status as refugees and the catastrophic situation of Jews in Europe, committed suicide immediately after he had finished writing his book. Many other Austrian Jews likewise took their own lives (The National Library of Israel) (Gulddal & Charlton, 2017).

For Zweig, the introduction of passports after the First World War symbolized an attack on individual liberty. People travelling had to deal with bureaucrats who blocked international borders. Zweig's memoirs document his own trauma when his passport became null and void after the annexation of Austria in 1938 (Zweig, 1964: 408–411).

The internet can serve as a tool in the search for complementary information to personal stories and illustrations of the wider historical context, as can be illustrated with reference to Felix Nussbaum (1904–1944), a German-born Jewish artist who was murdered in Auschwitz. In his paintings, he expressed the despair of Jews as displaced and rejected human beings. In 'The Refugee' (1939), we see a man sitting with his back bent, holding his head in his hands; on a table is a globe, symbolizing how the entire world is closed for the Jews. In another painting, from 1943, 'Self Portrait with a Passport'[1], Nussbaum depicts himself holding a passport that bears no visible country name and wearing the yellow Star of David that identified Jews (Yad Vashem, 2020).

The passport not only grants free movement, but also validates the personal history, identity, and connection to place and community of its holder; removing or denying a passport also removes any foundation of personal status (Gulddal & Charlton, 2017).

A passport is one of the most basic personal documents of the modern era (Keshavarz, 2018), and archives contain numerous examples which tell the personal stories of survivors and victims of the Holocaust. For example, the Yad Vashem Archives in Jerusalem have more than 2,000 passports, and over 4,000 are stored in the US Holocaust Museum in Washington. The ready availability of passports creates an opportunity for instruction in the context of History

[1] The interested reader will be able to find reproductions of both works online.

and Geography education in schools. Using the data, stamps and symbols found in a passport, it becomes possible to trace a personal story and its wider connections. On the one hand, the passport itself was always, and remains today, a document designed to help the traveller; but the passport system has become increasingly used to block unwanted immigrants, and to protect the state and its citizens from threats, real or imagined. Therefore, the passport is relevant to several key contemporary debates concerning internal and international relations (Keshavarz, 2018; Torpey, 2000).

3 Geomedia and passports

Geomedia enable the visualization of digital information from various geographic and historical sources. The digitization of geographical information of all kinds allows bridges between citizens and efforts to solve global problems by connecting social media participants. Geomedia also create learning opportunities that can empower students and lead to flexible, personalized, learning based on critical thinking. Their use can also promote complex multidisciplinary approaches to issues (Donert, 2014: 9–10; Fast et al., 2018).

Nowadays, when virtually every student has, or has access to, a mobile phone, tablet or computer, geomedia can help students to develop their spatial understanding of the world, for example in Project Based Learning, as demonstrated in this study. Vienna in the 1930s can be studied through maps and photographs, and the historical city can be compared to current satellite and photographic imagery. It is possible to identify the sites where Karoline's life was conducted during the 1930s, and the locations of Jewish community institutions at that time.

The use of geomedia helps students and researchers to decipher the course of life during World War II. Students can research a relative’s or another person's passport. For example, the German passport (issued on 9 March 1935) of Alfred David Les, a distant relative of one of the authors of this study, who was born in Schwedt on the Oder River (now located on the German border with Poland), allows us to follow his way to ‘Palestina’. Alfred was sixteen at that time. On 19 June, the passport was stamped at the British Consulate in Berlin with a B3 visa for Palestine, a type of visa intended for students who had been admitted to higher education, usually with some scholarship. On 25 June, he crossed the border into Trieste, which was under the control of Italy; the next day he boarded a ship, and on 1 July 1935 his passport was stamped when he arrived in the port of Haifa. The passport saved him from Nazi persecutions, but his family did not survive. Alfred enlisted in the British army in World War II and fought against the German army in Italy with the Jewish Brigade.

As illustrated by the case of Alfred David Les, the internet serves as a tool in the search for complementary information to a personal story.

4 Persecution of Jews in Austria and destruction of the community

Persecution of Jews in Germany and the restriction of their movements began immediately after Hitler’s rise to power in 1933. The Nuremberg Laws (1935) voided their German citizenship and made them outcasts. In 1938 there was a sharp turn for the worse when on 12

March German military units annexed Austria to Germany in the ‘Anschluss’. At that time, there were around 185,000 Jews in Austria, of whom about 170,00 were in Vienna (Rosenkratz, 1990: 24). Pogroms against the Jews of Vienna had begun even before the entry of German soldiers, with Germany seeking to implement in the city all the methods of the persecution of the Jews in Germany, as carried out from 1933 onwards. However, within a short time their anti-Jewish policy became even more far-reaching and brutal than in the ‘Old Reich’ (Bata, 2002). Teachers and leaders of the Jewish community in Vienna were sent to Dachau concentration camp. Jewish property was confiscated in the framework of accelerated ‘Aryanization’. On 20 August 1938, leading Nazi Adolph Eichmann moved into Vienna and took over other sites in Vienna, acting rapidly, with the enthusiastic help of friends in the Austrian Nazi party, to dispossess and deport the Jews. His staff humiliated, beat and robbed Jews who came to arrange the necessary forms (Barley, 2007: 322–323). During September 1938, when blackout was enforced in preparation for aerial bombings, Jews were thrown under the wheels of tram cars; synagogues in Vienna were attacked on Yom Kippur, and Torah scrolls and religious books were burned in the street.

Before the outbreak of the war, more than two-thirds of Austria’s Jewish population (around 128,500) had emigrated to 89 countries. The main destinations were Britain (30,850), North America (28,700), China (18,124), Central and South America (11,580) and Palestine (9,195). More than one-third (more than 65,000) died in the ghettos and camps in eastern Europe. At the end of the war, about 1,000 Jews survived in Vienna, one-third of them in hiding. The rest were employed by the Gestapo to sort the tremendous quantities of property confiscated from Jews (Rosenkratz, 1990: 27–28).

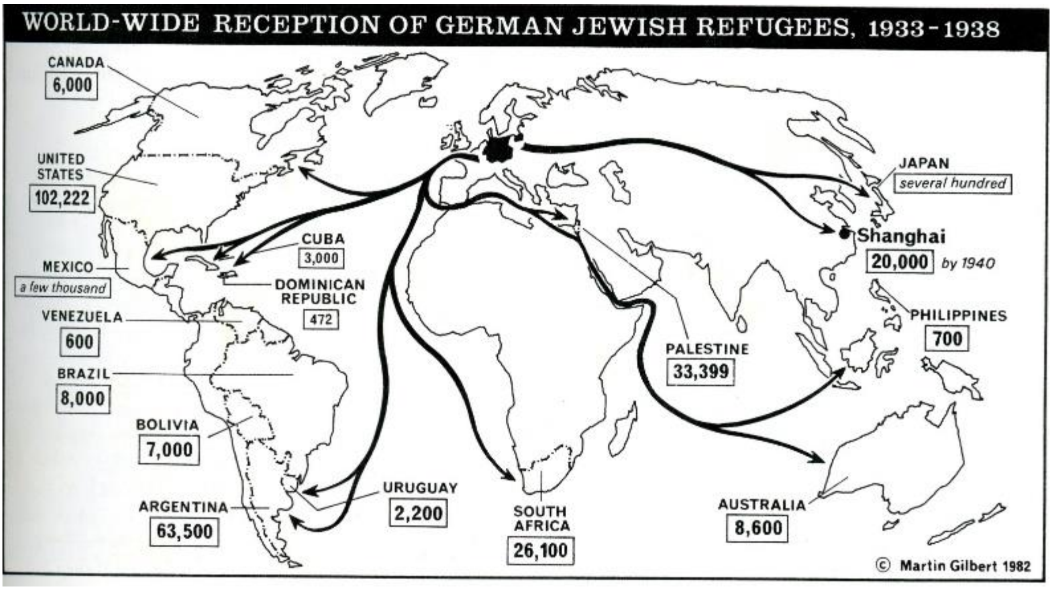

Figure 2: Worldwide diaspora of German (including Austrian) Jewish refugees, 1933–1938 (Gilbert, 1982: 23)

5 Immigration Policy in the 1930s and 1940s

Jewish people in particular were especially vulnerable to immigration policy, which was regulated heavily by using passports as well as other means. The USA was particularly severe in its restrictions on immigration from Germany and Austria, while most of those who applied for a visa were Jews. In 1939, for example, 24,000 applicants received visas while 241,000 (Yad Vashem) remained on the waiting list. Many of them could have been saved by a more generous immigration policy. Karolyn Bloch herself fell foul of this policy: in 1940, when she was already in Palestine, her application for an American visa to join her son was refused by the American consul.

Karolyn was also affected personally by the immigration policies of both the British Mandate in Palestine and Brazil.

From the early 1920s, the British Mandate in Palestine defined seven categories of immigrants, indicated by the letters A to G. The British preferred immigrants who held property and who exercised necessary professions (category A). Between them and the Jewish Agency (the representative organization of the Jewish community in the British Mandate), there was constant disagreement about immigrants from category C – workers who lacked property according to the British definition and who were ‘pioneers’ according to the Zionist definition. Karoline’s visa was of category D – ‘women, children, and others, who depend on the residents of the land’ (Shavit & Biger, 1982: 101). In addition, the Jewish Agency provided Karoline, through its Chamber of Immigration in Vienna, with an immigration certificate. This printed document, in Hebrew, was like the passport of the as-yet non-existent Jewish state and was given to all legal immigrants to the British Mandate.

In the years 1929–1939, about a quarter of a million Jews immigrated to the Land of Israel in the context of the ‘Fifth Aliya’, or wave of immigration. Jews from central and eastern Europe were prominent, and included Jews from Germany and Austria who were fleeing Nazi persecution. In part, this was illegal immigration, as the British had limited the immigration to the Land of Israel of Jewish refugees from Europe since 1934. Their numbers doubled after Germany’s annexation of Austria, which led to the Évian Conference in July 1938, the outcome of which was that not a single country (with the exception of the Dominican Republic) was willing to accept Jews in large numbers. In 1939, the Jewish community in Mandatory Palestine reached 450,000. Gradually, Britain neglected its obligation to the realization of Zionism, and in May 1939 in the Third ‘White Book’ (British government policy document), it restricted the immigration quota to just 75,000 Jews over five years. Throughout World War II, the British rigidly prevented Jewish immigration to the Land of Israel, and in 1940–1944 immigration was even below what was permitted by the White Book. The gates to the Land of Israel were locked at the very time that the Holocaust occurred in Europe.

As mentioned, one of Caroline's three sons emigrated to Brazil and settled in Sao Paulo. In Brazil, in the 1930s, the elites were hostile to Jews and considered them a Communist threat. As a result, Brazil restricted immigration quotas, and on 7 June 1937 the Brazilian Foreign Ministry secretly forbade representatives of Brazil in Europe to grant entry visas to Jews (Ben-Dror, 2002). Following this directive, the number of Jews who immigrated to Brazil declined by 75%, although some officials ignored the explicit instructions they received. The Brazilian ambassador to France, for example, continued to grant visas during 1940–1941.

Such diplomats, who were recognized later by Yad Vashem as 'Righteous Among the Nations', acted courageously, succeeding in saving thousands of Jews. Other prominent examples include Sempo Sugihara, the general consul of Japan in Kovno, Lithuania, who issued 3,500 Japanese transit visas to Jewish refugees in the summer of 1940, and Raoul Wallenberg, a Swedish diplomat in Budapest, who provided thousands of Jews with Swedish passports (Righteous Among the Nations – Yad Vashem Website).

6 Karoline Bloch's life was saved

Karoline Bloch was born in 1877. When she was 19 years old, in 1896, she married Moritz (Moshe), and the couple had three sons, Heinrich, Rudolph and Alfred, and a daughter, Gertrude. Two of the boys served in the Austrian army in World War I.

Figure 3: The Bloch family, Vienna, 1909

At the start of the 1930s, the boys emigrated from Austria: Heinrich to the United States, Rudolph to Sao Paolo, Brazil, and Alfred to England. In 1934, a year after Adolph Hitler came to power in Germany, their daughter Gertrude and her husband, Dr Rudolph Steinhertz, reached the conclusion that there was no future for Jews in Europe, and they immigrated to the Land of Israel, along with their daughter, the infant Zuzanna. They settled in Nesher, a working-class neighbourhood in the south of Haifa, beside the Nesher Cement Factory. Rudolph, a chemist by profession, established the laboratory at the factory, which was the main source of livelihood of the area's residents.

The parents, Moritz and Karoline Bloch, stayed in Vienna. On 13 February 1938, when he was about 70, Moritz died, and Karoline, who was then aged 61, remained alone.

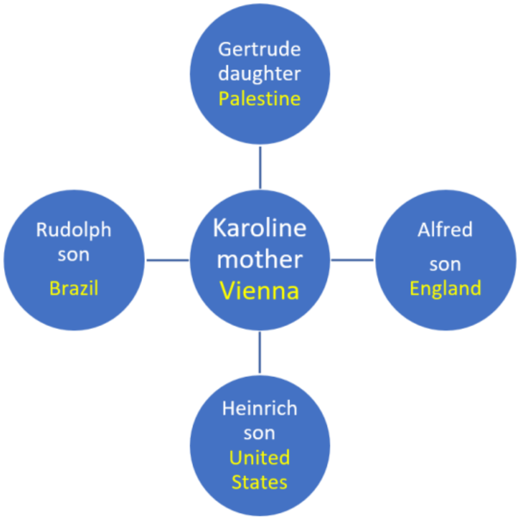

Figure 4: The dispersal of the Bloch family, March 1938

After the 'Anschluss' (just a month later), Karoline's children asked her to make haste and leave Vienna. Thanks to them, she had two good (and rare) options for that time: her son, who had emigrated to Brazil, obtained a visa for her to go to Brazil; her daughter, who had emigrated to the British Mandate in Palestine, obtained a certificate enabling Karoline to immigrate to the Land of Israel. One of the pages of Karoline's passport states in Portuguese that her son is legally in Brazil. On October 27, she was thus able to obtain a visa for Brazil, signed by the deputy consul of Brazil in Vienna. On another page there is a visa for Palestine, issued by the British passport office in Vienna on 15 October. This visa allowed a single journey only and was valid until 30 November 1938. The visa's recipient, it was written, was entitled to remain permanently in the land with the status of immigrant. The visa which enabled Karoline to immigrate to the Land of Israel was issued about five months before the third 'White Book'; the visa for Brazil was even rarer because of Brazil's objection to the immigration of Jews, as outlined above.

On 27 September 1938, the Immigration Division in Haifa informed Rudolph Steinhertz, Karoline's son-in-law, that Karoline had received a type-D certificate – that is, approval for immigration to Palestine following Steinhertz's request of 16 August 1938. In addition to the certificate, the immigrant was required to bring a passport and any other document proving their identity and suitability for immigration. On arriving in Palestine, the immigrant was supposed to give the document to the immigration authorities at the port or border crossing. Karoline was also asked to provide a medical certificate stating that she did not suffer from any serious mental or physical illnesses. Accordingly, on 13 October she went to a licensed physician and obtained the certificate.

Figure 5: The Brazilian visa

On 7 November, Karoline left Vienna by train for the Italian port of Trieste, where she waited for a ship. Two days later, on the night of 9–10 of November, Kristallnacht occurred. On November 18 she boarded the *Marco Polo*, a passenger ship of the Italian shipping company Adriatica (Haaretz, 25 November 1938); on 24 November she reached the Port of Haifa, from where she went to her daughter's family in Nesher. Page 9 of her passport illustrates with simplicity the miracle that Karoline Bloch experienced: on the upper part of the page is the symbol of Germany with a swastika and the date she left Vienna (7 November), and under it is the seal of the Immigration Division of the Palestine government, stamped at the Port of Haifa by the inspector of immigration, with the words, in English: 'permitted to remain permanently in Palestine as an immigrant'.

Archival materials for the Adriatica shipping company, including photographs, can be found at: https://adriatica.altervista.org/?id=1&lang=it.

It could have been hoped that Karoline Bloch's arrival in Palestine would end her hardships, but while she joined her daughter, son-in-law and granddaughter, she never again saw her three sons. These were the days of World War II, the financial situation in the Land of Israel was difficult; bombings by Italian planes and fears of a German occupation marked the years 1940–1942. Gradually, news of the large-scale murders of the Jews in Europe became partly known and people in Palestine were deeply worried.

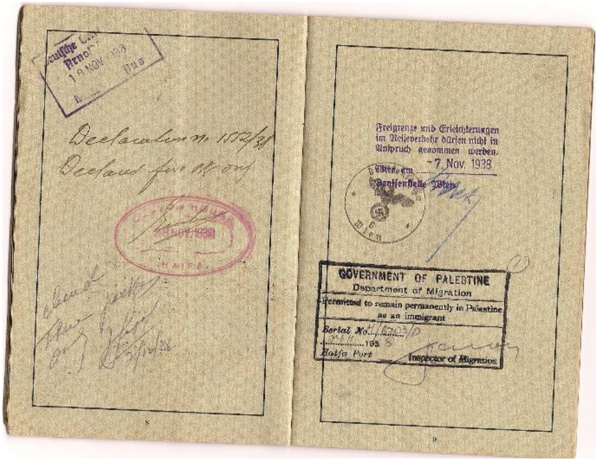

Figure 6: The passage from Nazi Germany to Palestine

Karoline's personal economic situation was difficult. On 2 April 1940, the Mukhtar (the local representative of Nesher-Yagur, a sub-district of the Haifa District) produced a certificate stating that Mrs Karoline Bloch, who had been living in the community of Nesher since 24 November 1938, was a widow with no income, who therefore needed regular financial assistance from her son, Rudolph Bloch, in Sao Paolo, Brazil. In 1940, Karoline attempted to obtain a visa to the United States, which had not yet entered the war, where her son Heinrich lived with his family. On 3 May 1940, the American consul in Jerusalem informed Karoline that her request had been rejected and would not be discussed again in the coming years.

Karoline Bloch died in 1943 and was buried in Haifa. Her daughter and granddaughter often noted that 'it was good that she died without knowing the true scope of the disaster suffered by the Jewry of Europe'.

7 The interdisciplinary dimension of passport research

A passport can be a tool for interdisciplinary study. It connects to wider aspects of knowledge: geopolitics, cultural geography, historical geography and geomedia.

In terms of geopolitics, a passport reflects borders as central in shaping foreign policy and immigration. For example, Karoline Bloch's passport reflects Austria's becoming part of Nazi Germany in 1938. In terms of cultural geography, much can be learned about the Nazi regime and the persecution of Jews in Austria from the symbols and stamps in the passport. In terms of historical geography, researchers and students can explore the ways in which overland or marine routes functioned. Further, Karoline's passport reflects the influence of dominant ideologies in the 1930s in shaping state boundaries, and the possibilities for movement and emigration of different ethnic groups.

A passport can serve as a starting point for research. We can look online, for example for the historical sites and buildings that remain today from when Karoline made her journey from

Vienna, through the port of Trieste, to Haifa, and from there to the working-class Nesher neighbourhood in Mandatory Palestine.

A breakthrough in the research of the geographical history of Vienna was achieved lately with the new website Memento Vienna. This is an online tool that connects archival documents and photographs of victims of the Nazi regime in Vienna to specific locations in the city. Among other things, the app enables the user to explore the last known addresses of those murdered. The process of exclusion, deportation and murder of Austrian Jews becomes retraceable and visible in the city's streets themselves (https://www.memento.wien).

Interpreting the passport is aided by documents preserved by Karoline's descendants, and these too can be expanded by further archival research. Increasing digitization of archives will facilitate such research. Here, we examine connections between the micro-history (Nora, 1989; Ginzburg, 2005) of Mrs Bloch and her family and the wider historical context of 1930s Europe and Palestine. In addition, using passports as primary historical sources allows for the integration of history, geography, art, literature, economics, international relations, international law, political science, genealogy, transportation, communication, sociology and anthropology.

Figure 7: The interdisciplinary dimension of passport research

8 Using a Document as a Primary Source in Teaching

A passport, as a document to be used in specific circumstances, is a primary source: the symbols and the texts in it indicate political organizations, and reflect specific policies and how they were implemented by state officials. Such symbols and texts can also give indications of the bearer's fate.

Through research based on a primary document, unlike the study of history through textbooks, the student acts as a historian, draws conclusions and comes to understand history (Kobrin, 1996). Working with primary sources enables students to construct their own understandings of the past. The process involves them making links between a source and things they already know, making their prior knowledge and the primary source relevant to them. After the research, students provide feedback and describe the significance of their learning.

In recent years in History and Geography education, there has been a broad move to the identification, examination and critical evaluation of primary sources as a central part of the curricula. In Britain, for example, students are required to know how primary sources can reveal knowledge of the past, and they learn how to classify, interpret and evaluate sources in a critical manner. In France, the student is supposed to attain mastery in the reading of different types of source material, to learn how to differentiate between primary and secondary sources, and to identify historical information in sources of all types (Wolf, 2008). This move to the use of primary sources is reflected in the 'Teaching with Primary Sources Partner Program' at the Library of Congress in Washington, which encourages teachers to develop approaches that exploit the primary sources available in the library (https://www.loc.gov/programs/teachers/about-this-program/teaching-with-primary-sources-partner-program/).

In the Internet era, the potential has been created to produce added value for primary sources, through the collection of knowledge from other sources and establishing relationships between people and/or resources. Historical research has been strengthened through the addition of testimonies, which until recently were unknown (Orbach-Natanson, 2007).

9 Inquiry-based teaching: a case study

The model for Inquiry-based teaching developed and published by Woyshner (Woyshner, 2010) comprises six stages: connect, wonder, investigate, construct, express, and reflect/feedback (and back to connect). The author describes activities for each of the stages.

We used this particular model to teach this chapter of history. The first goal is for students to understand through the passport the complexity of the process of emigration for Austrian Jews on the eve of World War II and to reach their own conclusions about the long-term implications of this process. The student who is examining the historical document, in this case Karoline Bloch's passport, must ask questions, research the family's history, formulate hypotheses about the family's history, and others about the choices they made. After reflecting on their own inquiry work, the students then formulate new questions and search for deeper understanding of the specific historical context.

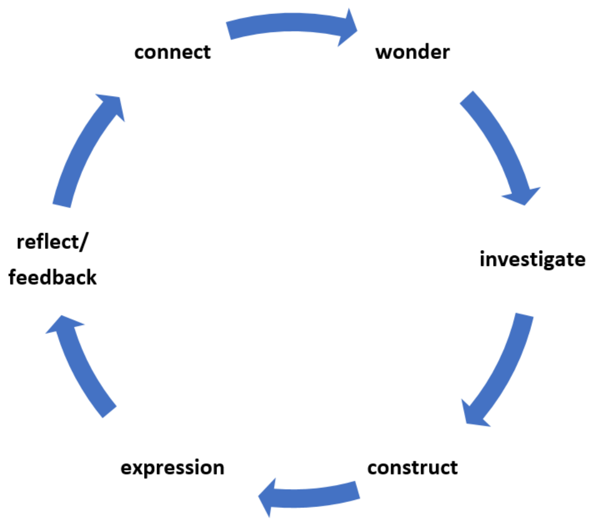

Figure 8: Model for Inquiry-based teaching (simplified from Woyshner, 2010)

Our project was undertaken with student teachers at Oranim Academic College of Education, in the context of one particular course that teaches Project-Based Learning. The project required clarification of basic concepts that were unfamiliar to some students, because of their young ages, and technological changes. For example, postcards, which were widely used by soldiers at the front during World War I, are almost out of use today, in the age of social media.

The story-based approach, which was accompanied by pictures of the actual boxes in which the photographs and passport were discovered, and the findings themselves caused excitement and curiosity. For example, the marking of the letter 'J' in red ink on the passport sparked great interest.

The entwining of the personal story with historical events gave rise to questions and requests for clarifications: the rise of Nazism to power in Germany; the annexation of Austria to the German Reich; the 'Anschluss'; 'Kristallnacht'; the British Mandate; illegal immigration to Palestine. Students asked in particular for clarification of 'Palestine – Land of Israel', which was not familiar to them.

Personal photographs showing the everyday life of the Bloch family before the war allowed students to identify with the Blochs, such that they wanted to know what happened to the members of the family. The frequent transitions between the personal story and the historical story succeeded in motivating students to learn about historical processes.

The students cooperated actively in the investigation stage. They were asked to ask questions; on average, they wrote about four questions each. Most of these addressed the particular chapter in history; a third concerned the personal story. The questions show how the lesson prompted students to think 'beyond' the story, for instance: 'My grandmother immigrated to Israel from Poland, my grandfather from Romania, another grandmother from Egypt – what did they experience?'; 'Is the number of immigrants from Europe to Israel during the Second World War identical to the number of immigrants today?'; 'Why do we (and the Ministry of

Education) teach about the destruction of the community and not emphasize the glory of these communities in Europe?'; 'Does the story of an individual teach about the whole? Is it exceptional?'. Additional questions addressed the Israeli reality after World War II, for instance 'Many Palestinian Arabs underwent the same process as Mrs Bloch did. What is your opinion on the topic? As somebody who experienced similar difficulties and transitions, how would she have addressed them? How would she have behaved?'.

At the 'insights' stage, the students said some very interesting things. 'This was a story lesson – there was a personal story in which there was historical knowledge. You get into the story. This is an experiment because of the integration between knowledge and the personal. A discussion develops: this is the transfer of knowledge from a primary source.'; 'We did not learn only history. We learned some geography, and there were all sorts of topics that were learned through history. In my opinion, this was not a lesson in history.'

The use of primary documents such as certificates and photographs led the students to learn voluntarily and to draw conclusions. For the students, who were largely unfamiliar with the particular chapter of history related to the passport, it was important to understand the processes that accompanied the personal story. Lessons of this type spark curiosity and motivate the student for inquiry-based learning, whether into the history of his/her family or something else. Because of the personal character of the document and the person's individual fate, the learning inspires identification and the ability to understand human distress.

Such a lesson has added value also for the teacher, creating a feeling of mission and responsibility, the desire to stimulate interest, and to combine the personal story with a universal one. This type of teaching enables teachers to create meaningful dialogue with students and to renew their passion for teaching.

10 Epilogue

Karoline Bloch's passport illustrates, more than anything else, the destruction of Austrian Jewry under the Nazi regime. However, the passport also provides a wonderful illustration of the fate of one individual and enables us, by using its historical contexts, to see how Karoline succeeded, at the last moment, in leaving Austria, two days before Kristallnacht.

Karoline's descendants kept the passports and other documents, making it possible for future generations to confront painful questions raised by the past. It should be noted that the documentation of this era in history, including the gathering of documents and testimonies, started while the tragic events themselves were still taking place. After the war, wherever Jewish community life emerged, survivors initiated documentation of and research into the Holocaust on a grand scale (Cohen ,2003). The efforts were private ones, carried out by survivors and organized according to cities, areas or countries. Historical commissions were also established. One of the main motives of the survivor-historians was to confront the moral dilemmas that the Holocaust raised. This motive has practical and educational implications. The challenge is to renew faith in the ability of the individual and of society to act in a moral fashion. Research into the Holocaust is thus a matter not simply of the past but also of the present and the future (Cohen, 2003). This is the approach we adopted in educational activities to connect the family history with wider history and geography, using the passport as a trigger to generate discussion of moral dilemmas with past and present connections.

In this study, we used the digital databases of the Ghetto Fighters' House Archive and enriched the archive with our own findings. Passport research was made possible by examining World War II passports that can be found on the Web. Teaching methods that guide students to independent research, asking questions and finding answers to them, rely on the resources of the Internet. Above all, we found that students are happy to explore historical issues independently and enjoy using digital tools to do so.

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A Mobile Application to Visualize Historic Land Use along Hiking Trails in Southern Germany

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Abstract

Land-use and land-cover change is a global phenomenon that poses great challenges to people, who often oppose changes in the familiar landscape (Foley et al., 2005). However, it needs to be recognized that humans have continuously shaped and intensively intervened in the landscape throughout history, creating the 'Kulturlandschaft' (cultural landscape) we see today, and leading to the scientific preoccupation with the 'Anthropocene' (Ellis, 2011). By enriching locations with digital content, this knowledge can be better conveyed, since so-called 'augmented places' not only convey information, but also allow the embodiment of what has been learned through increased immersion (Chang, Hou, Pan, Sung & Chang, 2015). We present an application that combines historical landscape change and the legacies of early mechanization through a mobile WebGIS designed with tourists in mind to convey information about historical land use in a playful way (http://gdi.geographie.uni-tuebingen.de/echaz/map.html). Historical map material for the region of the river Echaz in southwest Germany was digitized and georeferenced, organized in a framework of geoservices, and finally made available together with further content in a web app. Ultimately, the aims are to show alternatives to current land use and to address the variability of the landscape, and thus to achieve participation in and acceptance of landscape planning.

Keywords:

WebGIS, land use, augmented places, Anthropocene

1 Background and motivation

Nearly every landscape on earth is the result of centuries of anthropogenic use and transformation. Accordingly, landscapes are a valuable archive of human activity on the planet. In many parts of the world, historical land use is well documented or can be reconstructed. However, this information is rarely made accessible to the public.

Digitizing historical land use and its organization in a GIS can help to increase understanding of past land-management practices and raise awareness of traditional methods of cultivation and husbandry (Knowles & Hillier, 2008). This has been demonstrated by Bender, Boehmer, Jens & Schumacher (2005), who collected and digitized cadastral maps, land registers and aerial photos dating from 1827 to 2001 to quantify the changes in cultural landscapes in the Bavarian Forest and the Franconian Alb. This information can be used for the restoration of historical habitat aggregates or the development of sustainable land-management plans. Rosner (2000) and Nowatzki & Rosner (2016) analysed century-scale landscape changes in the nearby Schönbuch area using the landscape metrics approach. While geospatial techniques are already increasingly used to integrate historical data in plans for the conservation of natural resources, the aspects of remembrance and cultural heritage are still widely neglected. However, the availability of such data is not the major constraint in most cases, but rather their accessibility for people from outside public administration or without the technical know-how. As one possible solution, Burggraaf et al. designed an online platform for the collection and cartographic representation of cultural heritage sites to assist their preservation and remembrance, as well as their consideration in offi¬cial planning applications (Burggraaff, Knieps, Schulteiß, & Tempel, 2017).

Hasse (1996) recognized that tourism is strongly linked to the human desire for an unspoilt state of the environment and that outdoor-enthusiasts especially show great interest in the stories behind the landscapes through which they hike. Accordingly, the location-based provision of historic land-use information can increase awareness of historical forms of land use, the morphogenesis of landforms, and cultural heritage.

This article proposes a way to prepare and organize, in a user-friendly manner, openly accessible historic land-use data along hiking trails in the Echaz valley in southwest Germany. To further attract people who are not primarily interested in landscape history, this information is enriched with information about land-use changes, and selected socio-cultural content, such as photographs or historical descriptions of administrative divisions and their cultural peculiarities. Consequently, our target group includes all people, from young adults to the elderly, who show an interest in landscape and nature, have at least a minimal affinity for technology, and can handle everyday mobile apps. Using elements from familiar mobile map applications, we augment historical maps and aim to facilitate access to the wider public.

2 Data and methods

2.1 Data and preparation

Local primal cadastral map: *Urflurkarte*

As a starting point of the land-use analysis, we used the earliest cadastral maps ('Urflurkarte') of the kingdom of Württemberg, which were created between 1818 and 1840 by a decree of King Wilhelm I. These maps show parcels of land, landforms, settlements and buildings at the scale 1:2,500 and were made publicly available as a web mapping service (WMS) by the federal archive of the state of Baden-Württemberg (Naumann, 2014).

Historic topographical maps

Topographical maps from 1908, 1936, 1963, 1977, 1987 and 1999 are provided in paper form by the State Office for Land Information and Development, Baden-Württemberg (LGL) at a scale of 1:25,000. They contain the most relevant forms of land use and land cover related to urban areas, traffic, energy, infrastructure, vegetation and topography, and use predominantly consistent legends.

Hiking trails

We selected hiking trails in the area from among those officially designated as such by the municipality of Pfullingen and retrieved them from Open Street Map. The chosen trails stand out for being waymarked, and for having trailside information on nature and culture as well as works of art. Additionally, maps and route descriptions were available on the town's homepage (Stadt Pfullingen, 2020), so that the online map can directly refer to these materials.

Cultural descriptions of communes

As additional content for the online map, the 'Württembergische Oberamtsbeschreibungen' were used. Compiled between 1820 and the early 20th century, these contain descriptions of the historic administrative units, their geographical characteristics, living conditions in the towns and villages, the characteristics and habits of residents, linguistic peculiarities, and various amusing anecdotes (Memminger, 1824). A collection of over 60 texts is available and attracts several thousand page-views per month (Wikisource, 2020). The document dealing with the Reutlingen area dates back to 1824 and includes a topographical map with a scale of 1:100,000. A digital version of a reprint from 1971 is available free on Wikisource (2020).

Historic POIs

Points of interest (POIs) include the historic water mills on the Echaz and other historic buildings, and the artificial Echaz canal. Some of the mills can be traced back to at least the 11th century and are living monuments with functioning equipment. As they were of great importance for the economic development of the region and are also in a good state of repair, the 'water experience path' provides information about them on boards (Pustal, 2018). Parts of the mills are also included in the Milldatabase, which features technical aspects of the milling equipment (Milldatabase, 2020). Further tourism-related information, such as opening hours and entrance fees for museums and lookout towers, was obtained from Pfullingen's homepage (Stadt Pfullingen, 2020).

Processing

The maps were available only in paper form, so topographical maps were georeferenced using the coordinates (Gauß Krüger Zone 3) at the map margin and subsequently reprojected to the current system (UTM Zone 32). In the absence of a usable map margin, the historic maps were georeferenced using persistent buildings (e.g. churches), elevation points and other control points that could be cross-checked with those on modern maps. When inaccurate localizations occurred in the historic maps, these were excluded through an analysis of the residuals. The thin plate spline method proved to be best suited for the transformation process, which was carried out (as was the whole procedure) using the 'Georeferencer' plugin in QGIS 3.8. All land-use information in the maps was digitized and classified into the following harmonized classes: industrial/commercial, mixed, residential, forest, grassland, meadow, cropland, cropland with trees, orchard, garden/park, viticulture, hop cultivation, disposal (Figure 1). The classes meadow ('Heide/Weide'), cropland with trees ('Baumacker'), meadow orchard ('Streuobstwiese') and hop cultivation ('Hopfenanbau') especially have strong cultural connotations, as they are linked to particular periods of German history and traditional forms of cultivation. In the second step, changes in the land-use classes over the period being investigated were identified using a pair-wise approach, as proposed by Herold, Hecht & Meinel (2011). The results show an increase of built-up areas from 34 to 493 hectares between 1820 and today. More importantly, traditional land-management techniques, such as viticulture, or cropland with trees, vanished almost entirely from the area. This underlines the importance of the digital conservation of knowledge of these for hikers in the present landscape. In many cases, remnants of historical land use become visible once pointed out to the viewer, for example the shape and sizes of parcels, characteristic landforms, or the remains or transformations of buildings (Eberle, Eitel, Blümel & Wittmann, 2017; Morrissey, 2015)

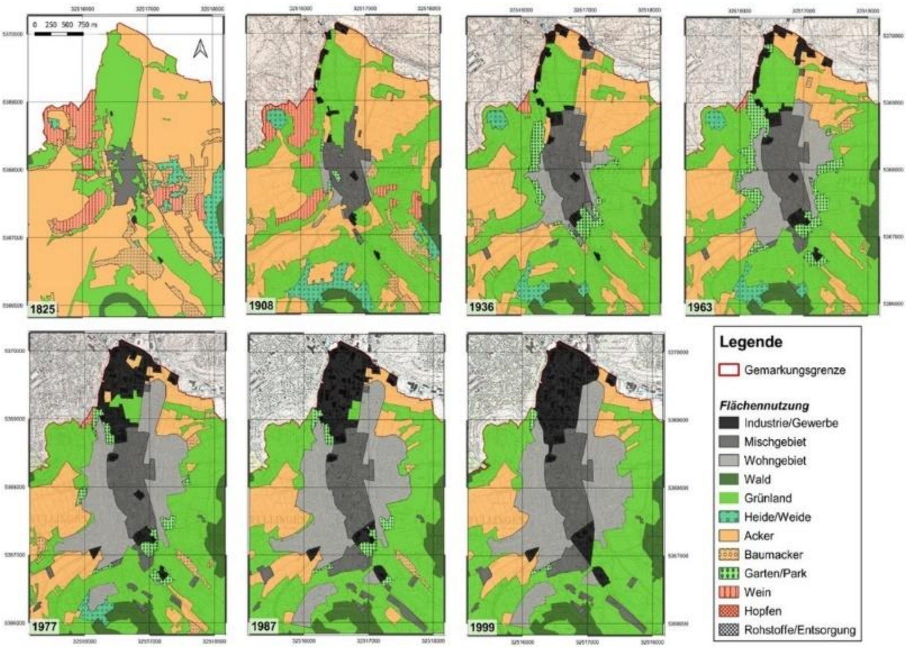

Figure 1: Change in land use in the study area around the city of Pfullingen (Brand, 2019)

2.2 Online Application

The web application is based on a framework of web services, local data and sensor information, which are merged and executed on mobile devices using a JavaScript interface. The background data include geodata from Maps4BW (the freely accessible official map service of the state of Baden-Württemberg) and the map service of the OpenStreetMap project. The two datasets are integrated as interchangeable basemaps via standardized Web Map Services (WMS) or Web Map Tile Services (WMTS), as defined in ISO 19128. Other records are linked via the same standardized interface, but these are self-hosted by a Geoserver instance on a web server of the University of Tübingen (Geoserver, 2020). They include primarily raster data, such as the georeferenced historical maps. The relevant vector layers, such as land-use data, hiking trails and POIs, are kept on the web server together with linked attributes, such as additional information, external web links, or picture URIs, as feature collections in the open format geojson.

All these data sources are bundled, styled and displayed in a WebGIS application based on HTML5, CSS3 and the JavaScript library Leaflet 1.6.0 (Leaflet, 2020). The Leaflet library is an open source software for generating interactive web maps, which, thanks to its responsive design, is particularly suitable for display on both desktop and handheld devices, and is, furthermore, accessible through a broad range of web browsers.

The individual time steps are represented by layer groups that bring together the various geo layers of each time period. Each layer group consists of a contemporary basemap and an overlying land-use layer. Since the geo-referenced basemaps have defined scales and are therefore not freely scalable, several basemaps with varying scales were integrated and only the most suitable one is displayed for each zoom level. For example, the map of the 'Oberamtsbeschreibung', featuring an overview at 1:100,000, is displayed at zoom level 14. This is replaced by the 'Urflurkarte' at higher zoom levels. Finally, the maps are overlaid by an opaque land-use layer in vector format, which is colour-coded for land-use classes. POIs and hiking trails are also symbolized and integrated as a simple overlay layer, on top of all the other layers.

Auxiliary information about the POIs, hiking trails and land-use classes can be called using the pop-up functionality of Leaflet. The additional information is read from the attribute fields of the corresponding geojson files and displayed in an output window. Depending on the layer, external content such as web links or images are included in this output using HTML5 syntax.

The user's precise location is identified by the device's GPS sensor via the HTML5 Geolocation API once the localization of the device has been activated. For reasons of privacy, the user is asked to confirm access to the position, although the application does not track any information about users.

The application's user interface comprises several basic cartographic elements of the Leaflet library, which allows the user to interact with the map. These include an interactive legend, a zoom-dependent scale, and essential gesture control.

3 Results and discussions

3.1 User Interface

In order to make access as barrier-free as possible and to make the software accessible to as many people as possible, the application can be loaded directly into the browser. Navigation in the map, with gestures for pane, zoom and click, is identical to that found in common map applications, so that the user instinctively finds his/her way around. Since some content is integrated via web services, a constant internet connection is required.

If the user opts in to having their GPS location displayed on the map for better orientation, the map can be underlain by recent topographic background maps showing landmarks and walkable paths. Waymarked hiking trails and themed trails with information boards can be displayed as a separate layer; information about trail length, names and further links can be displayed using pop-ups.

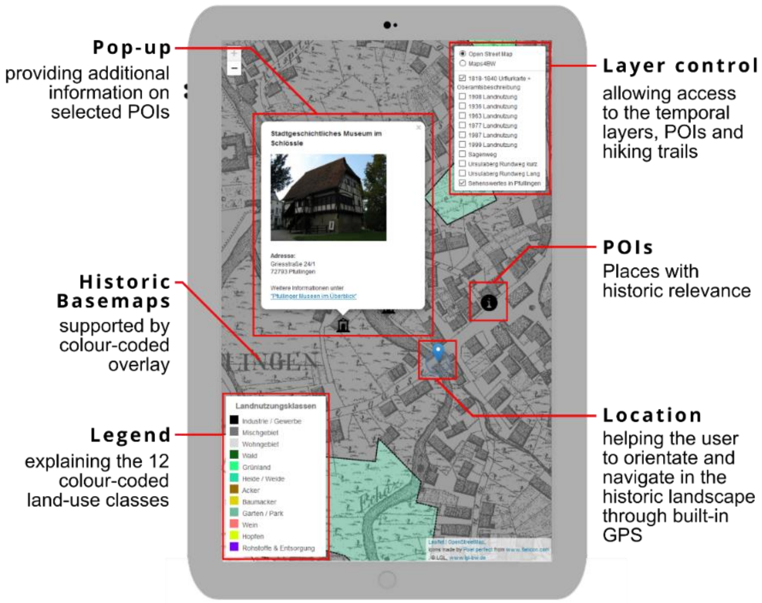

Figure 2: User interface of the mobile application

The historical land use is presented as a contemporary background map that uses colour-coding to distinguish between classes, as the historical symbolism alone is difficult to read. Since the land-use classes are standardized across all time steps, the user can see directly the development of the landscape over time and, for example, experience the growth of the urbanized area. They can also see the replacement of special crops by industrial agriculture and the loss of landscape diversity that goes along with that at concrete locations. At the same time, however, the example of the mills also shows that the landscape was subject to constant change even in historical times and was actively shaped by human activity through intensive interventions.

Displaying contemporary maps is intended to increase immersion, a concept from augmented and virtual reality (Milgram & Colquhoun, 2014), which refers to the ability to translate reality into a non-physical world through various stimuli. In this case, the historical maps represent a visual stimulus, which is the result of the (nowadays unfamiliar) symbology, old-fashioned fonts, and the printing technique of the time. Earlier studies indicate that such location-based access to information fosters embodiment of historical places, not only conveying knowledge but also creating an emotional attitude towards place (Chang, Hou, Pan, Sung & Chang, 2015; Oleksy & Wnuk, 2016)

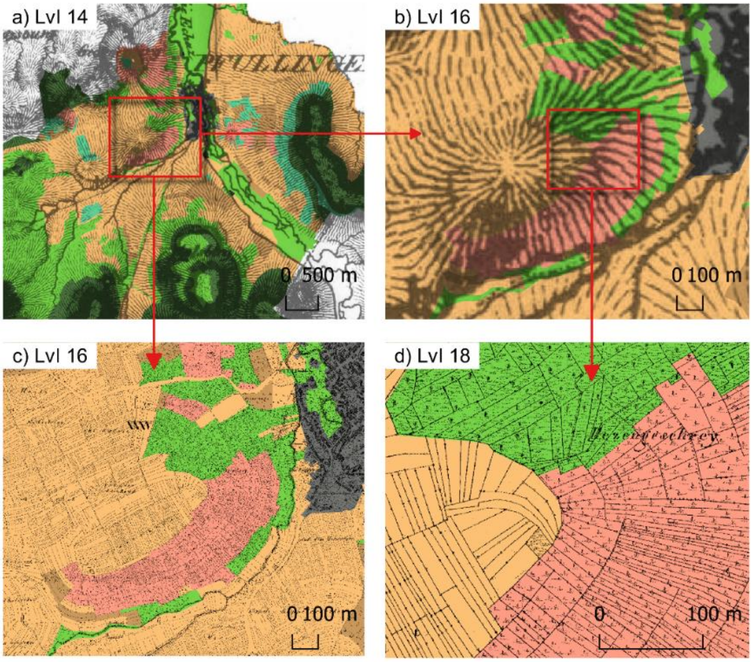

Figure 3: Screenshot of historic land-use maps with colour-coded overlay at different zoom levels. The overview map of 'Oberamtsbeschreibung' serves as background in (a) and (b), while the background map switches to the 'Urflurkarte' (earliest cadastral maps) at the higher zoom level (b). Note that the 'Urflurkarte' was excluded from low zoom levels due to poor readability (c).

3.2 Challenges and Outlook

The project was carried out largely in the context of final dissertations and practical seminars by geography students at the University of Tübingen. The collaborative work on the web map was greatly facilitated by the use of the developer platform GitHub, which enabled planning, programming and code reviews (https://github.com/sommergeo/echaz-histo). Furthermore, the open source programming allows high reproducibility of the mobile application. However, programming skills are required. With regard to the map material, the increasing policy of governmental agencies to make (historical) geodata freely available, partly even as web services, is very much in line with our approach. With the growth of portals like https://www.leo-bw.de, the need to host one's own WMS-Servers will be progressively reduced, so that Web Services can be integrated directly into to the application, thus simplifying portability to other regions or use cases.

The heterogeneity of the input data posed particular challenges – for example the development of a consistent classification for land use, because the topographic maps were created using different scales, surveys, classification systems and mapping techniques.

Since historical symbolism and changes in it over time are difficult for most users, the transparent colour-coded overlay of the harmonized classes has proved to be a good choice. This method of representation corresponds to the thematic maps which are common today and allows for continuity when comparing different points in time, while maintaining the aesthetics and thus the immersion of historical maps.

A further expansion of the application within the scope of student research projects provides for the following modules, each corresponding approximately to the time required for a group term paper:

- The enrichment of additional locations with elements of augmented or virtual reality, such as pictorial representations of buildings or landscape views, which are included in some historical sources (e.g. panoramas in the 'Oberamtsbeschreibung' or contemporaneous copper-plate engravings).
- A stronger link between the physical world and the app. This can be implemented relatively easily using mobile tagging applications on information boards etc.
- The creation of additional content for children. This not only appeals to a new target group, but also involves prospective geography teachers on the development side, bringing them into contact with geomedia in creating educational content.
- The possibility for users to add information themselves and thus increase participation.
- Developing the app further with possible future land uses or planning scenarios, including the expansion of urban development. The app could thus have a positive influence on citizen participation and acceptance of planning measures (Bishop, 2015).

Finally, we aspire to a scientific evaluation of the application and of the educational effect on the user. To date, feedback has been provided mainly by participating and non-participating students and lecturers of geography, who cannot be considered representative of the target group because of their extensive prior knowledge. Feedback could be gathered by means of a questionnaire, for example, which could be accessed directly via the app, or by a personal survey of representative users. It would be particularly interesting to compare users' knowledge about the variability of the landscape before and after using the app, as well as their attitudes towards, and acceptance of, interventions in the landscape.

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Writing Place History, Living Place History: Dimensions of Student Learning in a Geomedia-based Holocaust Education Environment

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Abstract

As contemporary witnesses of the Holocaust in both family and institutional environments disappear, Holocaust Education has to deal with a radical change. A wide variety of digital, sometimes spatially-explicit, learning environments have been developed that could be called 'virtually interactive'. Only a few of these learning environments allow for research-based learning, and even fewer have been evaluated according to the aims of Holocaust Education itself, or with regard to the digital tools used. This contribution presents central aspects of an evaluation of a research- and geomedia-based learning environment. It was tested with students at various schools in Vienna's second district, specifically in the Stuwerviertel, which was a place of widespread deportation during the Nazi regime. In this paper, we concentrate on three domains: (1) the usability of currently available tools, (2) the emotional side of the research-based learning process, and (3) the contributions of the learning environment to the formation of the political subject.

Keywords:

Holocaust Education, geomedia, collaborative mapping, places of remembrance

1 Introduction: Current challenges in Holocaust Education and geomedia

Coincidentally, the first day of our project (see section 2.) happened to be International Holocaust Remembrance Day. The Hashtag '#Weremember' was highly visible in social media. But such widespread awareness could give rise to questions of whom we remember and through which channels and media. These questions on remembrance culture are difficult to answer. Around the globe, there are different approaches to the topic. German memorial sites are described as neutral in tone and objectified (Yair, 2014), which has resulted in a more distant way of history telling. But an essential part of Holocaust Education (including education on other genocides) is the confrontation of emotions and a moral approach on the one hand, with historical correctness and understanding on the other (König, 1998). Looking into memorial and remembrance pedagogy in Yad Vashem (Israel's World Holocaust

Remembrance Centre), one approach is to revive the stories of Holocaust victims from an autobiographical perspective (Mykayton, 2013).

Some 'key educational experiences' are missing in Holocaust remembrance culture (Yair, 2008, p. 92). Notably, interactive learning environments in German-speaking countries are lacking as an opportunity to encourage students' self-discovery. Researching and tracing the history of Jewish deportees in Vienna (Schötz, Jekel & Wöhs, 2020) is one way of allowing students independently to discover the brutality of the Nazi regime, while at the same time questioning the circumstances and discourses leading to it.

Remembrance in educational terms often, if not always, deals with violent and unjust actions (Kansteiner, 2014). The aim of remembrance culture in an educational context is to challenge us emotionally as well as intellectually, to disturb our everyday routines, and to provide narratives of the past. In many cases, proponents aim to 'trigger self-critical reflections about humanity's predilection with self-destruction' (Kansteiner, 2014, p. 403). Current conditions lead – especially in the case of the Holocaust and Nazi terror – to the need to change Holocaust Education both in structure as well as in learning content and experience.

The role of the digital sphere in remembrance culture has been discussed in the literature for quite a while (see for example Geser, 1998; Hess, 2007; Levinger, 2009). The approaches very much reflect what was technically possible at a given time. The roles of digital (geo)media can be manifold, but a few stand out (see Jekel, Schötz & Wöhs, 2020). Increasingly elaborate visualizations, and public, sometimes cartographic, access to databases have become the norm.

The implementation of (geo)media in Holocaust Education is not new (see Fitchett & Good, 2012), but there are no data evaluating the use of geomedia in mapping, tracing and communicating about places of remembrance and genocide. We suggest that a geomedia-based approach to the Holocaust is more relevant than other action-oriented learning environments. One of our key areas of interest are the feelings of secondary-school students as they carry out projects that confront them with sites of the Holocaust, as these feelings may both enhance as well as hinder learning (see Hintermann, 2020). The level of emotionalization, however, is closely related to the appropriation of space, because of how students construct space through their own experiences (Tuan, 1977).

Current geomedia-supported tools for Holocaust Education include, but are not limited to (see Jekel, Schötz & Wöhs, 2020):

1. **Virtual reality tours** of places of the Holocaust, often portraying concentration camps using aesthetics and rhetoric that can seem strange. For example, an Auschwitz virtual reality tour (BBC News, 2015) shows unpopulated spaces, with sedate music and very little text. These virtual realities (in our subjective reading of them) do little to foster remembrance of inhumanity, crime, torture and violence. Instead, they offer a distanced, peaceful impression of the places depicted. Emotionally, the depiction does not necessarily link to the historic events remembered at the specific places, and therefore probably does not support learning.

2. At the same time, **holograms** of survivors were developed, containing extensive interview material that can be used in educational contexts (Kansteiner, 2014; Zalewska, 2016; see also www.erinnern.at). For education and 'interactivity' purposes, these interviews can be divided into answers to hundreds of questions. These questions have to be formulated by learners or

the general public, to generate the impression of interactivity and authenticity. While the activity can contribute to emotional effects, real interactivity with individuals who passed away a considerable time ago cannot of course be achieved, and the effect is very different from dealing with contemporary witnesses in the real sense (Bertram, 2015).

3. Last but not least, information technology has been used to create **address-based databases of victims**. A typical example is the Memento Vienna initiative, which also provides cartographic access to the wider public (Schellenbacher, 2017; see also www.memento.wien). Such initiatives are local, regional or national, and are not currently standardized. The European Holocaust Research Infrastructure (EHRI) is one of the driving forces in both integrating these databases with each other and exploring avenues for their use by the public in public spaces, and in education.

Whereas the hologram approach does not necessarily link into the idea of place-based learning, the other initiatives do. Places of remembrance, however, need to be experienced through all the senses, not audiovisual encounters alone (Hintermann, 2020). The individual exploring a specific place needs to be able to change the angle of view, to smell and feel, to link different aspects of the surroundings which are not available online in order to critically analyse its history. The concept we follow here combines experience of place and the construction of (mainly online) document-based research.

A coherent pedagogy using recent technological advances has still to be developed, but we strongly believe that using places of remembrance to support citizenship education can and will be supported through (geo)media. At the same time, we strongly support the view that an active physical encounter with a place and the traces of history inscribed in it is not to be missed. The real-world encounter allows for a completely different individual construction of that place, and for a variety of learning processes not possible through the sole use of technology, digitized historical sources and narratives. Accordingly, our project (described in Section 2) put this personal encounter with places of remembrance at the centre of the learning environment, with the paradigm of traces (Hard, 1995) being used to construct new places of remembrance. Digital geomedia provided support for finding and documenting locations, and for writing and publishing histories.

2 Writing place history, Living place history: a geomedia and Wiki-based learning environment

At the University of Vienna, all students training to become teachers in Geography and Economics have to participate in the University-Educational Cooperation Project (Vielhaber, 1998), which involves a learning environment that is quite different from the 'ordinary' classroom. Within a very generally-formulated topic, secondary-school students focus on a specific area they are interested in, with trainee teachers in an explicit support role to help them achieve their goals. At least part of the project has to be carried out beyond the school walls. Trainee teachers are typically responsible for two or three secondary-school students during the week-long project; the same trainees consider this course one of the most important experiences of their teacher training in Geography and Economics (source: trainee teachers and student grapevine).

In the project described, because of limits on the data available, topics (writing history through individual biographies) and places (the geographical area of the Stuwerviertel in Vienna's second district) were fixed, and individual deported persons were pre-selected based on recommendations of the DÖW (the Documentation Centre of Austrian Resistance).

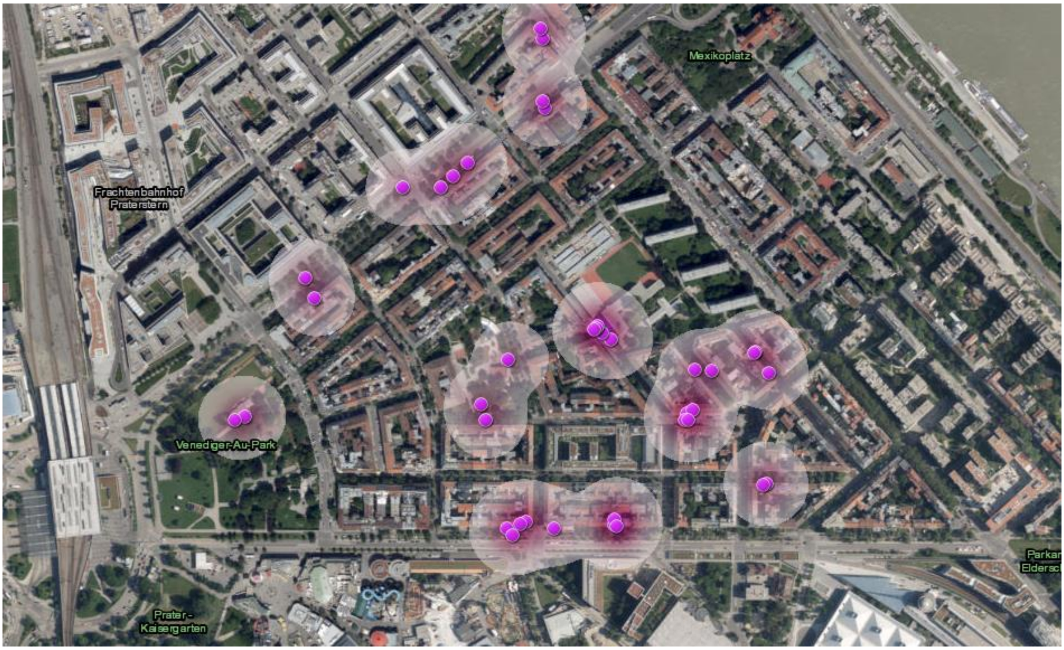


Figure 1: Map of the Stuwerviertel with the locations of traces of past Jewish life (students' work)

The Stuwerviertel (see Figure 1) was selected for several reasons:

- First, the area had a sizeable Jewish population pre-1938. Post WWII, the neighbourhood had a less savoury image, as it included a redlight district and run-down buildings. Currently, minor gentrification tendencies can be identified.
- Second, the area was less well travelled and documented by researchers than other parts of Vienna's second district, allowing students to devise a meaningful contribution.
- Third, the quarter is bordered by three main thoroughfares, is eminently reachable from school, and has light traffic, making it safer and more viable for a school project.

Secondary-school students were from two 6th forms (age approx. 16 years) at the Gymnasium (AHS Heustadlgasse). According to the general curricula, they had at least 3 modules on history and political education: Fascism, nationalism and dictatorship; Holocaust / Shoah, genocide and human rights; and remembrance cultures and remembrance politics (all at the age of 14) (BGBI, 2016). Several general educational principles, none more so than the principle of citizenship education, also allow the inclusion of Holocaust-related topics in a range of other subjects (BMBF, 2015). In addition, there is constant media coverage of Holocaust-related subjects, which are strongly socially embedded, such that the effects of pre-concepts concerning the Holocaust are difficult to determine.

Most of the central research questions were developed by students in a 2-hour pre-project session through a moderated process. The session covered the major topics of identifying traces of Jewish culture in the neighbourhood today, as well as history / Living place history today. The final stages of reporting (a public presentation at the Museum of Vienna's second district) were again fixed, owing to rules of project work both at school and within the University-Educational Cooperation project (Vielhaber, 2003).

In the first phase, students wrote spatial and individual histories based on a single deported person from the neighbourhood. They used the Memento Vienna app (Schellenbacher, 2017) to find specific places of deportation and gather initial data, enriched this data by research using historical sources, then set about writing individual and georeferenced biographies for the Vienna Historical Wiki (see Figure 2; for the materials used, see Schötz, Jekel & Wöhs, 2020). This first phase, which was designed for students to get a feeling for the spatial histories that are lived through today, was pre-set for them. Both the Memento Vienna app and the Vienna Historical Wiki are explicitly geo-referenced, supporting the aim of constructing individual places of remembrance.

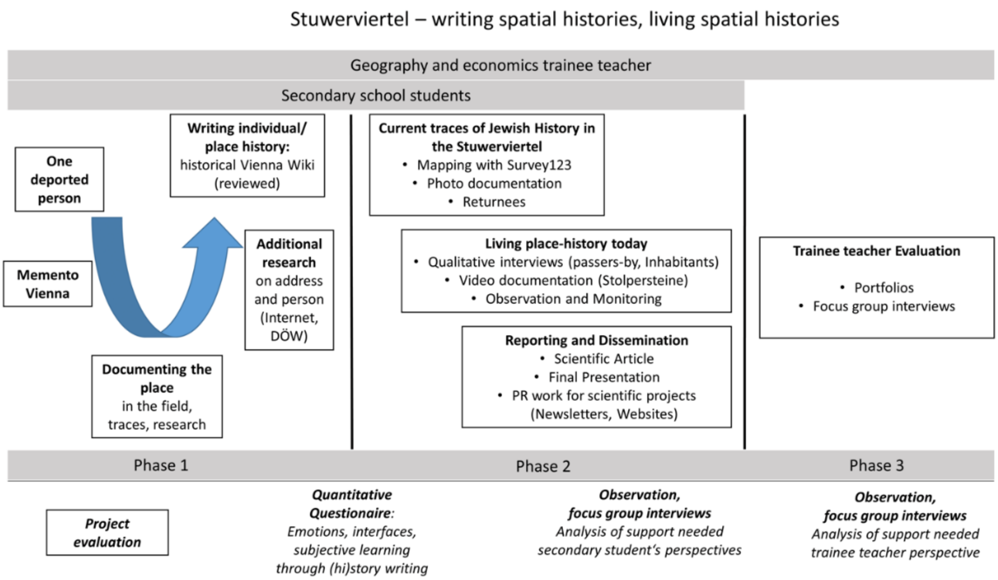


Figure 2: General Project Structure and Dimensions of Evaluation (based on Wöhs, Paulischin-Hovdar & Gatterbauer, 2018, and Jekel, Schötz & Wöhs, 2020).

Figure 3: Secondary students doing field research, looking for traces on site

In the second phase, students attempted to answer their self-developed research questions, again using geomedia for documentation and analysis. It has to be stressed that the students' aim was to make histories accessible in the present and foreseeable futures. This phase also included writing a scientific report, preparing a final public presentation, and doing PR for the project in cooperation with project partners.

The third phase concerned trainee teachers only. It included their reporting and portfolios on the teaching and learning experience of the project, as well as an open discussion of improvements and additions that could be made to the learning environment.

3 Evaluation of the project's learning environment – topics and methods

Within the learning environment, a host of different aims were followed. These were derived from:

- questions concerning the user-friendliness of the technology,
- teaching experiences, gained during the pre-project, regarding the emotional side-effects of place-based learning (Jekel, Schötz & Wöhs, 2020),
- the general aims of Holocaust Education and Education for Spatial Citizenship

The evaluation of the approach was based on 46 students from secondary education and 17 students in teacher training. The school chosen was AHS Heustadelgasse in Vienna, in order to reduce the likelihood of students having prior knowledge of the research area. A mixed-method approach (Creswell & Clark, 2017) was used, combining a questionnaire with quantitative and qualitative questions, observation of student research and learning, and focus-group interviews. In addition, two teachers who had used this specific approach with classes gave their personal impressions of the learning processes with regard to individual secondary students. There were thus many perspectives on the project, allowing not only a triangulation of data sources but also validation of the different methods (Jick, 1979). The quantitative questions were evaluated using a six-point Likert scale (Likert, 1932) to check for tendencies. The qualitative questions and observations were interpreted using Mayring's (2010) inductive method.

The feasibility of using digital approaches to Holocaust Education (Vienna History Wiki and Memento Vienna) was evaluated in comparison to quantitative and qualitative questions formulated by the secondary-school students and the observations made by the students in teacher training.

Measuring the emotional effects of place-based learning, especially in the context of tracing the Jewish deportees' last homes, was preferred over a quantitative evaluation. We used a simplified version of Shaver, Schwartz, Kirson & O'Connor's (1987) approaches to categorize four general emotions: surprise, anger, sadness and fear. In terms of the appropriation of space, these categories can be linked to the informative-significative everyday regionalization (Werlen, 1997, pp. 257 and 381–2; Schreiber, 2017).

To measure the impact of the project regarding the aims of Holocaust and citizenship education, the secondary-school students were asked qualitative questions about their learning success concerning the topic of the Holocaust itself and the digital media and tools.

4 Results

Quantitative and qualitative evaluation data were collected from 35 secondary-school students after the first phase of the project, i.e. after being confronted with the actual places of deportation and writing place-based Wiki entries.

Digital approaches to Holocaust Education, as used in the Vienna History Wiki, Memento Vienna and other online resources, were described mostly positively because of their accessibility and ease of use, fast and various research options, and because the 'internet never forgets' (student, female, 16) regarding the bios of the deported and murdered members of the Jewish population. Communication about places and sharing the history of the people who lived there is an essential part of Spatial Citizenship Education (Gryl & Jekel, 2012), although some secondary students did mention that there was a lack of information and sources online and on site for the person they were examining.

The emotional side-effects of this approach to Holocaust Education were widespread. Many students reported high levels of 'surprise', mentioning the 'huge number of deaths' (student, male, 16) and 'how quickly people [the Jewish deportees] can be forgotten' (student, female, 16).

Mostly the students were shocked and horrified by the annihilation of so many Jewish families in Vienna, as seen in statements like how much the Nazi regime 'despised the Jewish people' (student, male, 16), or how 'this past was a really bad time' (student, female, 16) and 'happened here in Vienna' (student, male, 16).

Such reactions could denote a 'key educational experience' (Yair, 2008, p. 92) in Holocaust Education, because similar responses were obtained when the students were asked what they would 'never forget' about working on the project. The question regarding whether the students felt guilty (a sub-category of sadness) was based on the assumption of collective responsibility. However, they hardly showed any feelings of guilt. The result is similar to that for the group of trainee teachers. This relates to 'coming to terms with the past' ('Vergangenheitsbewältigung'; Maislinger, 2017) and the obligation to remember, and could furthermore correlate with the acceptance in Austria of the 'Opfermythos' ('Austria victim theory', denoting a post-WWII discourse defining Austria as the first victim of Nazi Germany) (Uhl, 2001), but it could also be the result of increasing historical distance from the events concerned.

Students also felt very little sadness, fear or pain. The cross-item correlation shows that this was because of the lack of personal biographical information and traces for some of the deportees. Student groups with sufficient data showed a higher emotional response. It is this emotional response that needs to be transferred to today's discourse and political structures (Lutz, 2013).

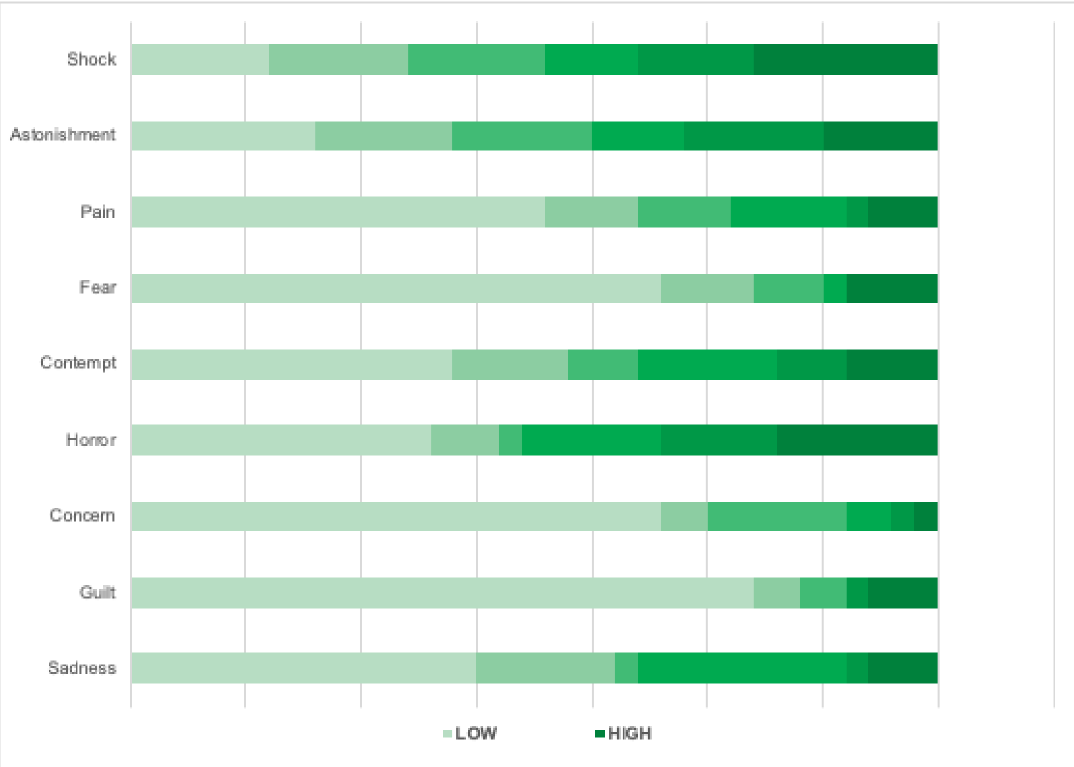


Figure 4: Emotions of secondary-school students experienced while working on the project; n=35 (authors' own Figure).

The significance of Holocaust Education (see Eckmann, 2010; Metthes & Meilhammer, 2015) for Spatial Citizenship Education (see Jekel, Gryl & Donert, 2010; Gryl & Jekel, 2012) was reflected in the students' qualitative answers. Mostly, students said that it is important to prevent such inhuman behaviour (e.g. genocides) and pointed to the extreme brutality ('it was really brutal' (student, female, 15). For the students, the Holocaust is an essential part of Austrian history. Communicating about the Holocaust is therefore an important task, especially for remembering its victims and bringing their stories back to life, as illustrated by this comment: '[This project] was quite cool and it is a nice feeling to participate in the remembrance of people' (student, male, 16). Interestingly, some students were able to instantly link their research work to current discourses characterized by xenophobia and exclusion with regard to specific groups. Overall, the students thought that the part they played in researching, writing and sharing their stories was essential for the remembrance of the Holocaust.

The trainee teachers (n=8) showed a slightly different picture regarding emotions while working on the project. Because of their age and prior knowledge of the subject, they were less surprised by the facts of the Holocaust. However, they were similarly shocked and horrified by people's personal stories. This also showed in relation to sadness: students who had found too little information on site and online felt less connection to the person and were therefore not as sad. But as one trainee teacher (female, 22) stated, 'To find nothing is also an important discovery.'

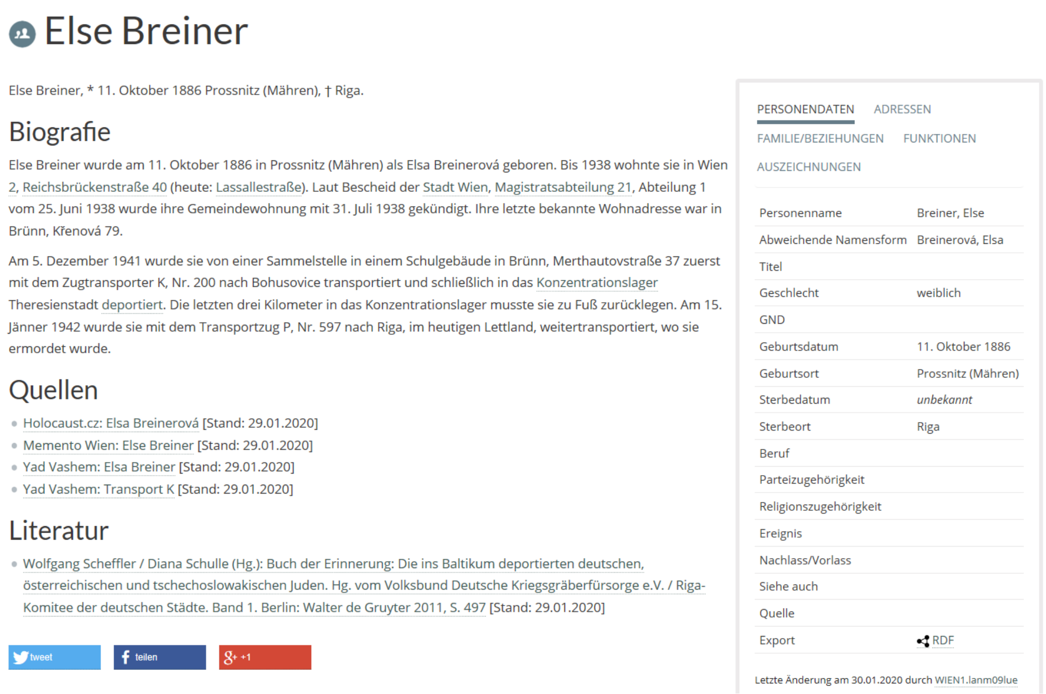
Like the pupils, the student teachers were positive about the accessibility, participatory possibilities, and possibilities for communicating and disseminating information in this mainly digital project. The search for the last places of residence was also given great importance as an empathic but also cognitive-visual approach to Holocaust Education.

The focus-group interviews and the comments of the trainee teachers accompanying the secondary-school students showed further qualitative findings. The focus groups clearly demonstrated that searching for traces on site is of great importance for the project, and memories would be less vivid without this excursion-like approach. As in Schreiber (2017), the identification of the last places of residence of the deportees in combination with the written background information and pictures has contributed to the fact that space no longer represents a purely physical-material construct, but acquires much more significance (Tuan, 1977) and symbolism. Unfortunately, the hoped-for creation of emotions of sadness could not be demonstrated in some groups due to the lack of available traces on site. Pupils were very horrified and shocked as a result of visiting actual locations of deportations. However, the project also showed that the understanding of space by considering the present and past contributes to the initiation of an historical orientation competence (Schreiber, 1997).

Communication about and remembering the places and victims of the Holocaust, and thus the (re-)visualization of stories, were accorded a very high priority in this project. With regard to the education of students as global citizens in view of the Third Reich's injustice and cruelty of dealing with the Jewish population and other minorities, such priorities could result in more tolerant, respectful and anti-racist citizens (UNESCO, 2017). This also shows the potential of Spatial Citizenship approaches in connection with Holocaust Education.

In summary, the overall picture of the emotional focus of the project and the associated challenges is extremely broad, but the project, which was also presented in this form in the district museum at Leopoldstadt, has been very well received by all participants and viewers. The challenges of this learning environment are strongly connected (including in relation to the emotional and empathetic part of Holocaust Education) with the existing information and the information uncovered about the deported Jewish people, or its lack. But not finding traces also means something for the state of the culture of remembrance in the Stuwerviertel. As one student put it: 'I am fascinated how little there was to fascinate me' (student, male, 17), meaning that very few traces were easily visible in the Stuwerviertel area of Vienna.

The focus-group interviews and the evaluation showed that the geomedial and excursion-like aspects of the project had a great influence on students' understanding, participation and motivation, and on the achievement of learning objectives. Although there were no major emotional debates on the topic, far-reaching successes were achieved: the students remembered the Holocaust, researching and writing stories of the victims and their last places of residence in the Stuwerviertel, before sharing them with the world.


Else Breiner

Else Breiner, * 11. Oktober 1886 Prossnitz (Mähren), † Riga.

Biografie

Else Breiner wurde am 11. Oktober 1886 in Prossnitz (Mähren) als Elsa Breinerová geboren. Bis 1938 wohnte sie in Wien 2, Reichsbrückenstraße 40 (heute: Lassallestraße). Laut Bescheid der Stadt Wien, Magistratsabteilung 21, Abteilung 1 vom 25. Juni 1938 wurde ihre Gemeindewohnung mit 31. Juli 1938 gekündigt. Ihre letzte bekannte Wohnadresse war in Brünn, Křenová 79.

Am 5. Dezember 1941 wurde sie von einer Sammelstelle in einem Schulgebäude in Brünn, Merthautovstraße 37 zuerst mit dem Zugtransporter K, Nr. 200 nach Bohusovice transportiert und schließlich in das Konzentrationslager Theresienstadt deportiert. Die letzten drei Kilometer in das Konzentrationslager musste sie zu Fuß zurücklegen. Am 15. Jänner 1942 wurde sie mit dem Transportzug P, Nr. 597 nach Riga, im heutigen Lettland, weitertransportiert, wo sie ermordet wurde.

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- Holocaust.cz: Elsa Breinerová [Stand: 29.01.2020]
- Memento Wien: Else Breiner [Stand: 29.01.2020]
- Yad Vashem: Elsa Breiner [Stand: 29.01.2020]
- Yad Vashem: Transport K [Stand: 29.01.2020]

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PERSONENDATEN ADRESSEN FAMILIE/BEZIEHUNGEN FUNKTIONEN AUSZEICHNUNGEN

Personenname	Breiner, Else
Abweichende Namensform	Breinerová, Elsa
Titel	
Geschlecht	weiblich
GND	
Geburtsdatum	11. Oktober 1886
Geburtsort	Prossnitz (Mähren)
Sterbedatum	*unbekannt*
Sterbeort	Riga
Beruf	
Parteizugehörigkeit	
Religionszugehörigkeit	
Ereignis	
Nachlass/Vorlass	
Siehe auch	
Quelle	
Export	RDF

Letzte Änderung am 30.01.2020 durch WIEN1.lanm09lue

Figure 5: Published Wiki entry for Else Breiner (student work)

5 Outlook

While the project was considered successful by both the students and the teachers, and contributed to the work of social scientists and historians, quite a few open ends remain.

The first is technical in nature and concerns the quality of the Wiki entries made by secondary students. In terms of content, they were considered acceptable by the historians responsible for curating the Wiki. However, their style and syntax had to be edited by professionals. Here, better preparation of students might help. At the same time, the curation by professionals is of course essential due to the sensitivity of the topic. Because of the timeframe of the current project, but also because of the timeframe of school projects in general, the need for professional editing may make the project unusable as a citizen science approach.

The second major topic regards emotions at places of remembrance and any effect on learning that these may have. While we had hoped to show a positive correlation between personal confrontation with this difficult topic (supported by geomedia), emotions and motivation, individual effects could not be traced by the methodology used. Research into this issue would probably need further orientation from psychology and learning theory and is reserved for future projects.

Nevertheless, we do believe that the approach is transferable, in terms of space as well as of the historical period, and suggest that other project-based teaching may make use of the general concept.

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Viral Constructions of Space and Content Knowledge: What Teachers Need to Know

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Abstract

Digital spatial processes have been widely explored and investigated in subject-specific geographic research. So far, however, this research has not been sufficiently reflected in classrooms or teacher education, and remains unconnected to notions of geographical digital literacy. Viral constructions of space – realities shaped in everyday life that are experienced and (re-)produced by students and teachers alike through social media – present an opportunity for Geography education to adapt to the digital society. This paper attempts to connect viral constructions of space, the digital society and the knowledge teachers need to include viral constructions of space in the classroom using Mishra and Koehler's (2006) TPACK model, a well-established means for summarizing teachers' technological, pedagogical and content knowledge for a specific topic. The paper focuses on content knowledge, identifies five sub-types of viral constructions of space, and extracts nine descriptors of teachers' content knowledge. By focusing on content knowledge, the paper presents a starting point for future investigations of pedagogical and technological teacher knowledge as well as their intersections. It also raises awareness of viral constructions of space as both a new essential topic in the Geography classroom and a phenomenon already shaping learning environments for spatial acquisition.

Keywords:

viral constructions of space, digital space, TPACK, teacher education

1 #okboomer…?

Young people responding to a statement by saying or typing #okboomer is a viral phenomenon which started in autumn 2019. Using the hashtag, however, is not limited to online contexts: 'ok boomer' has become part of everyday language as a way for young people to dismiss an older person's 'narrow-minded' or 'old-fashioned' views. The hashtag and phrase are thus part of young people's everyday lives and so demonstrate the blurred lines between 'offline' and 'online' realities. #okboomer is therefore emblematic of a society characterized by the hybridity of 'analog' and 'digital' environments, which, following Stalder (2016: 20), are central to the digital condition beyond digital media themselves. This digital condition is marked out by 'referentiality', 'communality' and 'algorithmicity' (Stalder, 2016: 13) – all of which are illustrated by the rise of #okboomer, which has become validated collectively by the continual on- and offline referencing of it, such that the two words incorporate a whole discourse on intergenerational tension conflict.

That digital phenomena are ingrained in young people's lives and are therefore of exceptional relevance for future didactic considerations can be recognized if we analyse current studies on (social) media use, which suggest that youngsters are almost never offline and use social media and their smartphones on a daily basis (Ofcom, 2019; Rideout & Robb, 2019; Medienpädagogischer Forschungsverbund Südwest, 2018). It is not only the frequency of social media use, however, that demonstrates its relevance for Geography education. Even more relevant is the structure of social media use, which facilitates constructions of space through 'new forms of participation, communication and collaboration' (Kanwischer & Schlottmann, 2017: 60, own translation). In this way, social media enable societal changes to surface (ibid). The rapid spread of these changes and content are referred to as having gone 'viral', prompting Kanwischer and Schlottmann (2017: 61) to coin the term 'viral constructions of space'. Through 'everyday regionalizations' (Werlen, 2009), viral constructions of space acquire efficacy regarding actions and decision making, which subsequently (re-)shape spatial realities (Kanwischer & Schlottmann, 2017; Reithmeier et al., 2016). Consequently, space is constructed through 'everyday virality' and a place's social media representation merges with its 'real-life' version. Navigating these hybrid viral constructions is thus key in spatial action. In summary, viral constructions of space are powerful instruments ingrained in interpersonal communication and thus in the construction of space itself.

If Geography education is to live up to its curriculum-defined claim of connecting 'space' with 'orientation' (DGfG, 2014), the inclusion of viral constructions of space in teaching contexts is vital. Otherwise, both hybrid spaces and their implications for students' acquisition of space would be ignored. The current understanding and presentation of viral constructions of space in a classroom context may be enhanced by studies on teachers' digital competence. While the terms 'digital competence' and 'digital literacy' are occasionally used by different authors to refer to the same idea, two lines of argument dominate the discussion: (1) technology-focused definitions; (2) citizenship-oriented approaches. Both García-Martín and Cantón-Mayo (2019: 203) and López-Belmonte et al. (2019) use 'digital competence' to refer to teachers' ability to navigate specific online contexts and to use specific applications. That implies a focus on technology, with digital innovations as new tools for teaching. On the other hand, Godhe (2019: 27-28), Yue et al. (2019: 101-103) and Krumsvik (2008: 283) combine digitality with societal participation – the central goal of education in a digitalized world. Citizenship thus includes digital competences that go well beyond the use of online applications simply as tools. This second view mirrors notions of the 'actualizing citizen' as summarized by Bennett et al. (2009), who connect citizenship education to interactive online learning focused on informal involvement in flatter hierarchies. This view of citizenship is reflected in the Spatial Citizenship approach (Gryl & Jekel, 2012), a prominent concept in current Geography education that provides insights into reflexive map competences. In contrast to the descriptors developed in this paper however, the all-encompassing digital hybridity is not considered by Gryl & Jekel (2012) as a core or starting point, and the domains of content and pedagogical knowledge are connected. The isolation of content knowledge attempted in this paper is more suited to the TPACK model (see Section 2). (Didactic knowledge is an exclusive area of knowledge not covered in this paper.)

While the inclusion of digital media in the classroom increased significantly between 2013 and 2018, the ICILS report does not find any increase in German 8th graders' digital competence (Eickelmann et al., 2019: 214, 122). This suggests that the increased use of digital devices in the classroom does not make for increased digital competence, which is all the more noteworthy as possession of smartphones with internet access has also increased over recent years (Medienpädagogischer Forschungsverbund Südwest, 2018: 31). The ICILS report suggests, furthermore, that digital media use in German schools focuses on copying information from the internet, as teachers feel competent using online material for lesson planning and believe online information to hold the greatest potential for teaching (Eickelmann et al., 2019: 226, 18). The potential of online environments as facilitators of new teaching challenges and topics is not explored in the ICILS report – which, however, is not to be expected, as only instrumental digital competences are assessed. Viral constructions of space can be assumed not to play a role in German classrooms, as social media – which are powerful tools in viral constructions of space – are barely used (Bos et al., 2014: 206).

The potential of viral constructions of space consequently remains unaddressed, while they consistently shape learners, teachers and school environments in a digitalized world. For Geography education, this is going to prove a missed opportunity for providing socio-spatial orientation. The power of viral constructions of space on students' spatial existence thus needs to be acknowledged.

This paper aims to provide a starting point for discussions in Geography teacher education by examining the following question:

What content knowledge do Geography teachers need for the inclusion of viral constructions of space in the classroom?

In order to answer this, teachers' abilities to include viral constructions of space in the classroom need to be investigated. This is achieved through (in the first step) a normative analysis of the relevant literature by means of the TPACK model (Mishra & Koehler, 2006). Oriented towards classroom-relevant teacher knowledge, in the second step essential content is selected and assigned concrete descriptors. These allow areas of content knowledge of viral constructions of space to be classified. Open questions regarding further teacher knowledge and viral constructions of space are discussed in the conclusion, along with future prospects.

2 The TPACK model

Mishra and Koehler's (2006) TPACK model describes teachers' Technological, Pedagogical and Content Knowledge. Combining these areas of knowledge enables teachers to master the complex task of teaching as technology evolves throughout their career (Mishra & Koehler, 2006: 1020, 1024). While each domain is essential in its own right, this paper focuses on content knowledge as one part of digital competences in the area of viral constructions of space. Content knowledge goes beyond memorized facts to include a subject's 'concepts, theories and procedures' (Mishra & Koehler, 2006: 1026). Therefore, when adapting TPACK for viral constructions of space, related and specific concepts and theories need to be included, while also keeping in mind subject-specific working methods in Geography education.

Various publications demonstrate the adaptability of the TPACK model, which has been used across subjects, with different aims and target audiences (see e.g. Ouyang & Scharber, 2018 or Mouza et al., 2014). A search for the use of TPACK for specific geography topics, carried out on the Web of Science and GoogleScholar, provided only two relevant examples (Hong & Stonier, 2015; Doering et al., 2014). However, both adaptations focus heavily on technological skills – a misinterpretation of TPACK – and cannot therefore serve as useful examples for the present endeavour.

2.1 Scope of the present investigation

Material for comparison and research on teachers' knowledge of viral constructions of space is scarce. However, to investigate here the whole TPACK model would be far too great a task, and this paper focuses specifically on developing a normative model for describing teachers' necessary content knowledge. The challenge of developing accurate descriptors of teachers' content knowledge is to formulate statements that are broad enough to remain valid throughout the shifts of viral environments and specific enough to be empirically verifiable and adaptable.

3 Content Knowledge for Viral Constructions of Space

The subject-specific content knowledge teachers need in order to implement viral constructions of space in the classroom is based on theoretical conceptions of the digital society (see e.g. Jandrić et al., 2018; Stalder, 2016; Leszczynski, 2015). While these cannot be separated from viral constructions of space, they are not of immediate didactic relevance for classroom implementation and are hence not included in the descriptors of teachers' content knowledge. Instead, characteristics of viral spaces essential for teachers are investigated.

As digital geographies have received vast attention in recent years, it is not possible to analyse all available material and publications. For this paper, therefore, I selected authors who represent popular strands of discussion while following the premise of space as a construct by means of the Web of Science database. The ability of individuals to contribute to constructions of space, a concept inherent in viral constructions of space, is consequently maintained.

A subject's concepts and ideas constitute the core of content knowledge (Mishra & Koehler, 2006: 1026) – therefore viral constructions of space are considered in relation to the digital society. The concepts behind the digital society are not made explicit but are at the core of the approach. Central concepts as part of teachers' content knowledge are also important in TPACK (Mishra & Koehler, 2006: 1026). For the present paper, these concepts are viral constructions of space and their characteristics. Teachers' understanding of the theoretical considerations regarding viral constructions of space is essential if they are to integrate viral constructions of space in the classroom pedagogically and technologically.

While in TPACK, subject-specific methods, referred to as 'proceedings', are part of teachers' content knowledge (Mishra & Koehler, 2006: 1026), methods for designing scientific studies are deliberately excluded here as irrelevant for teachers in our specific context. Instead, analysing viral constructions of space in view of their characteristics and implications by means of content analysis is emphasized. This 'excising' of core features contributes to very precise knowledge descriptors and can contribute to teachers' continuously updated content knowledge.

3.1 Viral Constructions of Space

A subject is said to be 'viral' once it has spread rapidly online, is viewed extremely frequently, and inspires reactions that may be positive, negative or mixed (Kanwischer & Schlottmann, 2017). Viral trends include anything from politically charged hashtags, such as #sharphiegate (used to criticize US American president Trump's hand-marked map of hurricane Dorian), to funny cat videos. Hashtags facilitate communication on a subject, as using a specific hashtag links a single post to others published under the same hashtag (Kanwischer & Schlottmann, 2017: 63; Reithmeier et al., 2016: 283). Georeferencing a post or connecting it to a place by means of a hashtag opens up the possibility of this hashtag contributing to a place's construction on social media (Kanwischer & Schlottmann, 2017: 63; Reithmeier et al., 2016: 283). At the same time, this social media portrayal is inseparable from the 'analog' place. Online actions – such as posting a georeferenced comment on a place – can influence 'analog' behaviour, as peoples' perceptions of this place can be influenced positively or negatively, resulting in behaviour that is adjusted accordingly. Individuals may thus decide to favour one place over another 'rival' place. Following these fundamental features of viral constructions of space, teachers need the ability to

(1) Explain the term 'viral constructions of space'.

A basic understanding of the term provides a starting point for looking at different manifestations of viral constructions of space – different aspects of the same phenomenon (explained further in subsections 3.1.1 to 3.1.5 below).

3.1.1 Reproduction of Pre-existing Structures

The connection between social media users and specific urban spaces is investigated by Boy and Uitermark (2017: 613). They explore Instagram users as 'performers' who stage their own personae in connection to the city of Amsterdam. Their orchestration of what they see as a desirable life in the city is manifested in the photos they post, while these postings are based on and refer back to other related posts (ibid.). Boy and Uitermark (ibid.) highlight the reproduction of social inequality and existing power structures, as access to 'desirable' places in the city is limited by financial possibilities. For example, people who cannot afford to go to a particular expensive restaurant are excluded from producing this space online, as they cannot enter it 'offline' either. Popularity indicated by a large following allows particular Instagram users to set (viral) trends, which are subsequently reproduced by their followers (Boy & Uitermark, 2017: 623). These popular users' embellishments of particular places online result in the places being reproduced by further (less popular) users (ibid.). Consequently, the popular users dominate the discourse. This discourse-governing characteristic is also seized on by Butler et al. (2018: 497), who focus on the further marginalization of marginalized groups and minorities whose contributions remain unheard due to popular users dominating discussions. Negative depictions of residential areas by outsiders, but also by residents of the areas themselves who have adopted ascriptions made to their living space, can result in a place's stigmatization while silencing alternative presentations by other residents (Butler et al., 2018:

497). As one result of this practice, Butler et al. (2018: 507) point to the increased cultural and social segmentation of urban spaces.

Part of the effectiveness of viral constructions of space is consequently their reproductive power, which reinforces both existing structures and already existing social and cultural barriers. The teacher whose classroom is situated in a space that is virally constructed in one way or another thus needs to be able to

(2) Analyse viral constructions of space regarding the reproduction of social inequalities and prevailing structures of power, and how these are connected to and visible in the 'real' urban space.

One major aspect of this regards presentations on social media, which, through individuals' reproductions of them, have the power to repeatedly shape life and actions in (urban) spaces. These (re)presentations are ultimately a precondition for broader-scale developments (see (5) below). Furthermore, this self-perpetuating and self-reinforcing aspect of viral constructions of space provides material for the classroom, giving students an opportunity to participate in analysing the online spatial material of which they are both consumers and producers, its connection to spatial decisions, and their awareness of the interweaving of online space with their perceptions of 'offline' spaces as well as of the power structures involved.

3.1.2 Spatio-temporal Segmentation

Segmentation on the spatiotemporal scale is another form of segmentation of the urban space identified by Kovacs-Gyori et al. (2018). They demonstrate how, on Twitter, a single place – in this instance a sports complex – can attract significantly differing allocations of meaning (Kovacs-Gyori et al., 2018: 91). It can be concluded that the value assigned to a place can be extremely flexible and change over time. Viral constructions of space, the results of a mass of individual social media posts, are thus characterized by their fast-changing nature and variability. This requires teachers to use examples in the classroom of open-to-interpretation viral constructions of space that illustrate their spatiotemporal nature and variability. To do this depends on teachers' ability to

(3) Connect viral constructions of space to 'realspace' phenomena and individual actions, and to differentiate between the three.

This enables teachers to contextualize viral constructions of space as unstable results of both 'analog' influences and individual ascriptions.

Kovacs-Gyori et al. (2018) further demonstrate that the same coordinates do not necessarily refer to one homogeneous society over the course of 24 hours. As people move from their home to work or school, visit restaurants, parks or sports clubs, they carry with them their mobile devices, which allow them to continuously consume and produce (georeferenced) social media content. As a result, places are permanently being reproduced as new realities depending on individuals' contributions that depend on spatiotemporal decisions. To do justice to these characteristics, teachers need to be able to

(4) Analyse viral constructions of space in terms of spatiotemporal segmentation.

This is a prerequisite for exploring further interrelations of viral constructions of space and society. As has surfaced above, viral constructions of space can only ever be understood in interplay with social, societal and political development. Hence, teachers need also to be able to

(5) Evaluate the relevance of viral constructions of space in relation to political and societal developments.

This ability, which is also connected to (2), enables teachers to establish viral constructions of space both as teaching content and as variable in classroom discussions.

3.1.3 Conceptions of Space

The mobility of individuals addressed by Kovacs-Gyori et al. (2018) is viewed from another perspective by Shelton et al., who introduce personal online interconnectedness beyond city borders and across the globe as behaviour-influencing factors (Shelton et al., 2015: 200). This illustrates that overemphasizing georeferenced social media posts may lead to establishing unfounded causal relationships between coordinates and those posts: a place could be falsely interpreted as a 'container' pooling different characteristics assigned by posts (ibid.). As a solution, they suggest a more refined socio-spatial classification of posts according to global and/or local contexts. Reducing digital space to its 'container' properties goes against the spatial concepts identified by Wardenga (2002): as digital space is only created through individuals' actions within specific structures, linking posts to their georeferenced places without considering contextual connections violates the property of the digital space being produced only by individuals themselves.

Navigating this area of conflict is a task that teachers have to face constantly when addressing viral constructions of space in the classroom. While they need to be aware of different concepts of space, they also need to be able to

(6) Reflect in terms of spatial concepts on their personal mindset and teaching regarding viral constructions of space.

Thereby, teachers can create a meta-awareness of both their teaching and their own positions, and adjust their teaching accordingly while aiming for the preservation of digital spaces as spaces created and recreated by individuals.

3.1.4 Alternative Images

Rivalling depictions of a single place were addressed in 3.1.1. While these stressed the oppressive power of dominant discourses, creating counter-narratives can also contribute to activist approaches and spark change. This is illustrated by Lundgren and Johansson (2017: 80), who analyse rural areas and their discursive construction on social media in the categories 'alive' or 'dying'. They conclude that some discussions purposely oppose dominating ascriptions and follow activist approaches in order to change public perceptions (Lundgren & Johansson, 2017: 81). Following this, teachers need the ability to

(7) Analyse viral constructions of space in relation to dominant and alternative images.

Through this, teachers acquire a basis for including viral constructions of space and their inherent spectrum of depictions and opinions in the classroom while distinguishing between dominant and less popular voices.

While the introduction of alternative images pluralizes spatial discussions, these alternatives can be as ideologically infused as popular discourses. This is why teachers must be aware of underlying political and societal preconceptions before including viral constructions of space in the classroom. Therefore, they must be able to

(8) Analyse the ideological backgrounds of producers of dominant viral discourses and alternative images.

While this prevents the undesirable manipulation of learners, it also opens up an opportunity to analyse differing basic motivations for participating in viral constructions of space, and emphasizes content-producers in contrast to content itself (as in (2) and (5)).

3.1.5 Participation

Because viral constructions of space derive from the contributions of individuals on social media, social media allow individual spatial participation. As illustrated by Kelley (2013: 182), shared mental images of a place are rendered possible by associating digital presentations with personal experiences and opinions in combination with georeferenced data. Each person is thus both digital consumer and producer (ibid.) – their perception of place and space develops through the entanglement of the two 'roles'. Participation in the construction of space is consequently easy: only access to social media and a smartphone or other device with georeferencing ability are required (Kelley, 2013: 201). Active participation that involves the creation of political and socio-spatial alternatives on social media is also implied by Jekel et al. (2017) and Shelton et al. (2015).

Although the successfulness of participatory endeavours depends heavily on the didactic implementation in the classroom, research demonstrates the potential of social media for fostering participation. Here, teachers must be aware that social media use does not causally determine participation but only facilitates it. Therefore, they must be able to

(9) Reflect on the reciprocal relationship between social media and participation.

This is a continuous challenge for teachers who include viral constructions of space in the classroom: they have to be open to the possibility of students' spatial participation while developing participatory preconditions without suggesting miraculous outcomes.

4 Conclusion and Future Prospects

Using the TPACK model to identify necessary teacher content knowledge has proven beneficial, as it allowed for the separation of content knowledge as a distinct area of knowledge and the identification of other areas of knowledge within viral constructions of space. However, content knowledge is but one essential part of teacher knowledge and is not sufficient in itself to innovate educational processes. Nonetheless, the characteristic domains of viral constructions of space and the related descriptors of teachers' content knowledge cover one central area necessary for future discussions: the identification of appropriate educational approaches to mirror the nature of viral constructions of space as well as the interweaving of human activity and technology that underlies such constructions. The importance of technological knowledge in the field of social media and viral constructions of space has to be addressed, and the role of didactic concepts within Geography needs to be discussed. These can be targeted towards the development of a model for viral constructions of space in Geography didactics, while opening up interdisciplinary approaches to society's overarching characteristics mirrored in viral constructions of space.

Because this paper has used a normative approach, the results need to be transferred into a research design suitable for the empirical assessment of educators' content knowledge of viral constructions of space. Seminars for student teachers or continued professional development for in-service teachers could serve as frames for empirical investigations. Subsequently, pupils could be included in empirical considerations. Just how teachers can integrate viral constructions of space into the curriculum also has to be explored further, as do the ways in which curricular limitations currently hinder viral constructions of space from becoming fruitful orientation-content in the classroom.

Finally, the question posed at the beginning of this paper, 'What content knowledge do Geography teachers need for the inclusion of viral constructions of space in the classroom?', was answered in detail through concrete descriptors of teacher knowledge. However, the relevance of viral constructions of space and how to include them in the classroom have only just begun to be illustrated. Future discussions and analyses need to further explore teachers' knowledge so that eventually students can profit from the spatial orientation which Geography education claims to provide.

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The Potential of a Critical Cartography Based on Immanent Critique

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Abstract

This paper argues for the potential of a critical cartography based on immanent critique – or more precisely, a practice for educational contexts that fosters reflexive map-reading based on immanent critique. It starts with a discussion of contrasting approaches based on discourse analysis and immanent critique. This provides first insights into how one can overcome problems based on discourse analytical framings by using an approach rooted in immanent critique. At the same time, it shows how immanent critique can nevertheless benefit from discourse analysis. This interplay fosters a particular practice of reflexive map-reading that offers the potential to foster 'maturity' ('Mündigkeit') (Adorno & Becker, 1971) and the 'political subject' (Mitchell, 2018; Mitchell & Elwood, 2013) in educational contexts.

Keywords:

immanent critique, deconstruction, maturity, education, spatial citizenship, critical cartography, discourse analysis

1 Introduction

Critical Cartography already offers more than three decades of tradition. Glasze (2009), for example, summarizes the developments in cartography using 3 paradigms: (1) the map as an image of reality; (2) the map as an effect of social structure, and (3) the map as a producer of social reality. To illustrate the first paradigm, the Diercke-Dictionary for Geography defined 'cartography', at least until the 2005 edition[1], as a 'true-to-scale image of the earth's surface' (Leser & Broll, 2005; quoted after Glasze, 2009; own translation). In opposition to this paradigm, the development of critical cartography started in the 1980s and early 1990s (Schuurman, 2000). This initial phase is closely linked to the theoretical writings of John Brian Harley (1989; 1988; 1988) (see Crampton & Krygier, 2010).

In his canonical paper 'Deconstructing the Map', Harley (1989) refers to Derrida and Foucault. Using a Derridean perspective, he examines the 'textuality of maps and, in particular, their rhetorical dimension' (p. 2). With this emphasis on their rhetorical dimension, Harley tries to

[1]In its current edition (2017), the Diercke-Dictionary defines 'cartography' as 'a field of art, science and technology for the production and usage of maps […]' (Leser & Broll, 2017; own translation).

overcome the idea of the map as an image of reality and argues for 'an epistemological shift in the way we interpret the nature of cartography' (p. 1). He breaks with the 'realistic paradigm' (paradigm 1) (Glasze, 2009, p. 183), which treats cartography as 'an "objective" form of knowledge creation' (Harley, 1989, p. 1). Based on a Foucauldian perspective, Harley proposes 'to draw a distinction between external [paradigm 2] and internal [paradigm 3] power in cartography' (p. 12). He describes 'external power' as 'power exerted on cartography. Behind most cartographers there is a patron; in innumerable instances the makers of cartographic texts were responding to external needs' (p. 12). Glasze (2009) interprets this idea as the root of paradigm (2), which treats the map as an effect of social structure. Paradigm (3), which treats the map as a producer of social reality, would be rooted in Harley's concept of internal power (see Glasze 2009, 184), which basically claims that 'power is also exercised with cartography' (Harley 1989, 12); see also Wood's 'The power of maps' (1993).

Gryl and Kanwischer (2011) identified a gap concerning reflexive map work in their review of geography education literature. The Spatial Citizenship approach addresses this gap. The approach is well rooted in critical cartography, with a focus on spatial-societal participation through the reflexive use of geomedia, such as (digital) maps (Gryl & Jekel, 2012; Jekel et al., 2015). In this paper, we will follow this tradition and try to further examine the reflexive use of geomedia for educational contexts with the aim of fostering 'maturity' ('Mündigkeit') (Adorno & Becker, 1971), and with that the 'political subject' (Mitchell, 2018; Mitchell & Elwood, 2013).

In particular, we will focus on a specific mode of reflectivity, namely critique. We will start this paper with a discussion of different modes of critique and will try to show that a Foucauldian approach to critical cartography also (along with all its strengths) has significant limitations. In contrast to Foucauldian approaches, as utilized by Harley (1989), we will discuss Jaeggi's approach of *immanent critique* (Jaeggi, 2013). We will argue that this mode offers the potential to overcome the limitations of critical cartography based on discourse analysis, but at the same time it can still benefit from some aspects of Foucault's approaches. In the last section, we will present some initial insights into a potential interplay of discourse analysis *and* immanent critique for critical cartography, and in particular a practice of reflexive map-reading that offers the potential to foster 'maturity' ('Mündigkeit') (Adorno & Becker, 1971) and the 'political subject' (Mitchell, 2018; Mitchell & Elwood, 2013) in educational contexts.

2 Four problems of critical cartography based on discourse analysis

2.1 'The map' as fetish

The first problem we would like to illustrate is closely linked to Harley's (1989) approach of 'Deconstructing the Map'. As this particular paper has already been discussed widely,[2] we will summarize just briefly some potentials and limitations of Harley's approach. As discussed in Lehner et al. (2018), Harley's perspective supports a better 'understanding of the power of cartographic representation' (Harley, 1989, p. 15). However, due to its eclectic framing of

[2]See for example the 2015 special issue of Cartographica celebrating the 25th anniversary of Harley's 'Deconstructing the Map'.

postmodern theories with hermeneutics, Harley limits the critical potential of his approach to the interpretation of maps. This helps to fruitfully criticize maps with a focus on the power of cartographic representation,[3] but shows its limitation in the critique of power relations as such. This leads to the following potentials and limitations:

Table 1: Potentials and limitations of Harley's approach (Lehner et al., 2018)

potentials	limitations
to question the influence of e.g. institutions on the 'map'…	but not the institutions as such;
to understand 'the map' as an instrument of power…	but power relations are treated as a means to an end, …
to question and uncover implied ideologies of the map…	but not power-relations as such.

The point is, as Belina (2013) argues against Harley, that 'maps – like all forms of knowledge – do not have power-effects just by existing, but only if they effect social practices' (p. 152; own translation). Thus, the first problem we would like to illustrate is that a critical cartography that is closely linked to Harley's approach is in danger of exhausting itself in a critique of maps, thus losing the potential to critique social relations (*problem # 1*).

2.2 Unintended discursive effects of critical cartography based on discourse analysis

Crampton and Krygier (2010) tackle the question 'What is critique?' in their introduction to critical cartography. They frame critique as 'a politics of knowledge. First, it examines the grounds of our decision-making knowledges; second it examines the relationship between power and knowledge from a historical perspective; and third it resists, challenges and sometimes overthrows our categories of thought' (Crampton & Krygier, 2010, p. 14). This understanding of critique is clearly inspired by a Foucauldian perspective ('it examines the relationship between power and knowledge'; see Foucault, 2017a).

Foucauldian discourse analysis plays a prominent role in critical cartography not only for Crampton and Krygier (2010). In Glasze's (2009) introduction to critical cartography as well Harley's canonical paper, Foucault's (early) discourse theory – in combination with his concept of power – provides the foundation for a critique of maps. So, one can clearly claim that discourse analysis plays a prominent role in critical cartography, which can be traced back to Harley's 'Deconstructing the Map'.

If we take a closer look at Foucauldian concepts, they are without doubt powerful instruments to question the seemingly normal or natural. Pinder (2003) (based on Harley), for example, discusses four aspects of reflexive map usage inspired by discourse analysis (*hierarchization*:

[3] For example, to criticize the influence of institutions such as 'monarchs, ministers, state institutions, [or] the Church' (Harley, 1989, p. 12) on the map (external power), and beyond that the discursive effect of a map that has been thus influenced (internal power).

What is displayed more prominently?; *concealment*: What is missing?; *geometry*: What kind of projection is used, what is centred?; *symbols*: How is colour used?). Clearly, this is very useful to overcome the concept of the map as 'an "objective" form of knowledge creation' (Harley 1989, 1): the approach offers adequate tools to critically examine maps, including the maps' internal power. Therefore, Harley's mode of critical cartography helps to criticize hierarchizations in maps such as 'the place of the king is more important than the place of a lesser baron, […] a castle is more important than a peasant's house' (Harley 1989, 7). But, is it enough to criticize hierarchizations and marginalization in maps, and with that break the potential discursive and normalization effects of the map ('power exercised *with* cartography' – paradigm 3)?

Even if we delve deeper, using Foucault's concept of the 'episteme' (Foucault, 2017b) as an artefact of hierarchized space, as a mirror to interpret this hierarchization in the map as a trace of deeper social structures (the hierarchical place of the king in the map would represent his hierarchical place within the social order - paradigm 2), the potential critique of the hierarchization in the social order would still be at the level of a single negation of a hegemonic position. Žižek, for example, argues that such modes of critique are not sufficient. He insists that we need a critique 'which opens up a new space outside the hegemonic position *and* its negation' (Žižek, 2012, p. 1007).

It seems that Žižek has a point here: Boltanski and Chiapello (2006) examined different modes of critique of capitalism in a historical-empirical way. One outcome of this exploration is that critique is in danger of fostering what Gramsci calls a 'passive revolution' (L. Becker et al., 2017), a transformation *within* an existing regime, like the transformation from a Fordian mode of production to a neoliberal one. Candeias (2008) follows this argumentation and shows how state criticism of the movements of 1968 was deferred on the terrain of neoliberalism to foster privatizations and a reduction of state control against the movement's intention.

Žižek's point that a single negation of a hegemonic position (as such, and not only within the map) is not enough, finds its echo in these historical developments. The point we are trying to develop here is that the discursive effects of critical interventions of a reflexive map usage based on discourse analysis cannot be assessed in advance. Therefore, it is constantly at risk of being deferred on the terrain of the criticized hegemonic position against its own intention, as happened with the state criticism by the movements of 1968 (*problem # 2*):

Demirović (2008) argues that it is not enough to criticize the circumstances in which people are enslaved and exploited. At the same time, we need to criticize the scales of critique, and to analyse their practical functionalities and the consequences of critique. Demirović basically insists on meta-critical reflections (see 2008, p. 29).

While the Spatial Citizenship approach already implies these thoughts about critique in its theoretical framework with its focus on a combination of reflection *and* reflexivity[4] (Gryl & Jekel, 2012; Jekel et al., 2015), in this paper we are looking for a practice which specifies and applies these thoughts on critique within the Spatial Citizenship approach.

[4]In the context of critical reflexive map usage, reflection implies the performed critique of the map as well as of the social relations to which the map refers; reflexivity implies meta-critical reflections on one's own thinking, acting with the map, and social relations. (See Demirović (2008).)

2.3 The problem of normativity and legitimation

Foucauldian discourse analysis has its anchor point in the thesis of the immanence of power, power which could come from anywhere (Foucault, 2017a, p. 114). With this, Foucault 'de-idealized scientific thought by revealing its intrinsic discursive materiality' (Vighi & Feldner, 2007, p. 151). So, every claim or statement communicated via maps is suspicious of its 'politics of knowledge' (Crampton & Krygier, 2010, p. 14). While this perspective has great potential for a 'thorough denaturalization and dereification of entrenched notions of the social' (Vighi & Feldner, 2007, p. 151), it fails to legitimate critique. Foucault describes critique as 'the movement by which the subject gives himself the right to question truth on its effects of power and question power on its discourse of truth' (Foucault, 2007, p. 47). Linked to this perspective are questions such as: How can we question truth on its effects of power? Is it possible to describe these effects of power objectively? What is the normative viewpoint of the discourse researcher? Do we need a normative dimension to claim that identified power effects are negative? Is there a normative position that is superior, which legitimates this potential normative position?

Foucault tries to avoid normative argumentation and thereby to avoid all problems of the legitimation of normative positions. He basically limits himself to revealing power structures and power effects – without the adaptation of any explicit normative position. For example, Foucault historizes concepts, such as 'madness', which at first sight seem to have no history (Foucault, 1988). He impressively shows that such concepts do indeed have a genealogy and have changed over time, instead of being naturally defined. From this illustration of the history of a criticized concept, it is only one further step to link madness and its institutions to power structures and power effects. The problem is that one could simply turn this argument against itself: What if we turn this strategy of revealing power structures and power effects against discourse researchers, based on a second-order discourse analysis? What power effects come from discourse analysis? What power effects come from the seemingly objective description of power effects?

The point we are trying to develop is that Foucault's avoidance of normative critique leads into an 'infinite regress' (Albert, 2010), a never-ending cycle of legitimation and de-legitimation (see Herzog, 2013; Vighi & Feldner, 2007). While Harley (1989) already implicitly used the normative position of equality in his critique of hierarchization, more recent approaches of critical discourse analysis (CDA) try to avoid the 'infinite regress' by adopting a normative viewpoint as well. For example, van Dijk (2009) links discourse analyses to particular norms and values such as human rights, using concepts such as 'discursive injustice'. However, with this normative framing we simply come back to the problems of the legitimation of normative positions.[5] The question of the legitimation of critique in a critical cartography that is based on discourse analysis remains unanswered – it ends either in the treadmill, or in problems linked to the legitimation of normative positions (*problem # 3*).[6]

[5] We will discuss the problem of the legitimation of normative positions in more depth in section 3.
[6] This is a serious problem. The thinktank of the so-called new right, the Institut für Staatspolitik, has used this argument since at least 2004 and tries to discredit critique as such (Institut für Staatspolitik, 2004).

2.4 The silence of discourse analysis: questioning the obstacle

The fourth – and for us the most important – problem with cartography based on discourse analysis concerns its transformative potential.

Discourse analysis offers great potential in historicizing 'concepts which were thought to have no history' (Vighi & Feldner, 2007, p. 151), which seemed to be natural or objective, as we discussed in relation to the concept of 'madness' (Foucault, 1988). Discourse analysis describes its object of investigation in a new and provocative way, which leads to a change of perspective, to seeing the object or topic in a different light (e.g. the 'modern' system of sanctions (Foucault, 1995)). That said, discourse analysis obviously has subversive potential (Butler, 2016; Saar, 2007, 2016).

As already stated, along with Harley (1989) we can criticize the hierarchization of space (in maps) based on discourse analysis. While we absolutely agree that this is an important task, we think it is also important to show that this mode of critique exhausts itself in identifying the hierarchization. In contrast to immanent critique, it does not ask what the *obstacle* is that prevents change. The identification of hierarchization is one thing, but what *prevents* the change or the abolishment of hierarchization? Historicizing concepts (e.g. madness) is an important task because it offers a hint of the possibility of change. But discourse analysis remains silent with regard to the obstacle; it neither offers an (explicit) reason why what is criticized should be changed, nor does it identify what prevents the change (*problem # 4*). This is exactly where immanent critique shows its strength.

3 Immanent critique

In contrast to Crampton's and Krygier's (2010) understanding of critique, with its Foucauldian framing, Jaeggi (2013) differentiates between external critique, internal critique and immanent critique.

External critique uses criteria 'from the outside' to assess what is being criticized. A critique in this sense is like a normative theory in the form of a judgement. For example, one could use human rights as a scale for measuring an existing position. In this sense, external critique has a transformative potential: one can use a normative theory and contrast what exists with it, even if this perspective from the 'outside' is not yet legitimated in what exists. On the other hand, though, it is difficult to legitimate the position from which the critique is expressed ('outside'), even if we refer to human rights: interventions based on human rights are in danger of becoming so-called 'civilizing missions' with an imperialistic taint (Spivak, 2007; Varela & Dhawan, 2015). The problem with external critique is that the position from which the critique is expressed remains ambiguous (see Jaeggi, 2013, pp. 261ff) (as we discussed with problem # 3).

This problem can be solved by the use of internal critique. Internal critique seeks its scale 'within the criticized itself'. For example, one can blame a staff manager who publicly promotes gender equality if he or she invites applications from male candidates only. Internal critique refers to standards that already exist and criticizes their violation. Internal critique is very convincing – who would like to be accused of violating their own ideals? The problem with internal critique is that it implies a conservative character and lacks transformative potential, because it exhausts itself in the compliance and recovery of the existing (see Jaeggi, 2013, pp. 263–277).

Immanent critique combines the strengths of external and internal critique. It has transformative potential and develops its scales or criteria 'within what is criticized itself'. Immanent critique does not approach what exists with a preconceived ideal. Rather, it tries to reveal immanent contradictions within what exists, by emphasizing the ideals of what exists. Romero (2014, p. 7) claims that immanent critique fosters a self-criticism of existing social relations. One prominent example of immanent critique comes from Marx: the double sense of freedom in bourgeois-liberal societies. Marx argues that the concept of freedom plays an important role in the self-perception of bourgeois-liberal societies. In fact, in contrast to e.g. feudal societies, the choice of labour is free, but at the same time the worker is free from means of production, and as soon as he or she gets hungry, is forced to sell his or her labour power under a capitalist mode of production. Marx argues that there is bondage in seemingly free liberal societies – or in his own words: the 'worker must be free in the double sense that as a free individual he can dispose of his labor-power as his own commodity, and that, on the other hand, he has no other commodity for sale, i.e. he is rid of them, he is free of all the objects needed for the realization of his labor-power' (Marx, 1981, p. 272).

The scale for the critique of the bourgeois-liberal society is found in this Marxian example from 'within the criticized itself' – the ideal that bourgeois-liberal societies are 'free' societies. This reference to standards or ideals that already exist legitimates the position of the critique, as we discussed with internal critique. This solves problem # 3. In contrast to internal critique though, Marx's critique does not exhaust itself in the compliance and recovery of what exists. It has transformative potential because it reveals immanent contradictions within bourgeois-liberal societies: the worker, who is free to choose, is at the same time free from means of production and is therefore forced to sell his or her labour power under the existing conditions. This contradiction cannot be solved under existing conditions, because it is an immanent part of existing relations. At the same time, this mode of critique reveals the obstacle that prevents the change, which solves problem # 4.

This helps to solve problem # 2 as well – the problem of unintended discursive effects – as discussed based on the historical examples of critique of capitalism, which were deferred on the terrain of the criticized hegemonic position. As mentioned, Žižek claims in this regard that we need a critique 'which opens up a new space outside the hegemonic position and its negation' (Žižek, 2012, p. 1007). This is exactly what immanent contradictions offer: 'it surpasses the corrective critique by revealing the systemic difficulties of fulfilling the demands' (Herzog 2026, p. 284). So, the new space outside the hegemonic position and its negation are opened up by revealing specific systemic difficulties of fulfilling the demands, as we see in the Marxian critique of bourgeois-liberal societies: workers are described as free in the double sense. This critique does not simply negate the claim of freedom within bourgeois-liberal societies; it paradoxically reveals a relation between the claim of freedom and its criticized opposite – bondage: as soon one gets hungry, one is forced to sell one's labour power under a capitalistic mode of production, because the worker is free from means of production.

Immanent critique does not describe a new space outside the hegemonic position and its negation as an essentialist utopia, but it opens a way to them. This does not completely eliminate the danger for the critique of being deferred on the terrain of the hegemonic position that is being criticized, but its more precise description of the obstacle should help to avoid unintended discursive effects.

Stahl (2013, own translation) distinguishes between two different types of immanent critique: 'hermeneutic' and 'practice-based' (p. 533). He argues that the 'practice-based model of immanent critique differs from a hermeneutic model insofar as it locates the norms, which the critique employs, within the rules of common social practices, rather than within shared understandings' (ibid.). So, the hermeneutic approach takes its critical norms from a reinterpretation of explicitly acknowledged standards. Stahl criticizes that the hermeneutic approach exhausts itself in 'a new interpretation of the ideals of bourgeois liberty, pointing out some hitherto unacknowledged aspects of their meaning' (ibid., p. 535). He argues that a critique of the cultural meanings of accepted standards in a given community is not enough, and he promotes a focus on the communities' practices and institutions: 'Practice-based immanent criticism thus presupposes that the structures and modes of interaction in a social community contain – beyond the explicit understanding of their participants – immanent normative potentialities upon which a critic can draw' (ibid.). A practice-based form of immanent critique 'demands the change of both the actual practice and the explicitly accepted norms of the community' (ibid.).

This discussion of 'hermeneutic' and 'practice-based' immanent critique brings us back to problem # 1: how critical cartography that is closely linked to Harley's (1989) approach of 'Deconstructing the Map' exhausts itself in a critique or reinterpretation of the map and its normative implications. This approach does not aim to change social practices – at least not in a direct way. Although practices can be seen as 'discursively created, shaped and interpreted by social actors, the primary focus of the analysis required for this type of critique must be practices and not more or less conscious language use' (Herzog, 2016, p. 283).

Belina (2009, 2010, 2011), for example, focuses on practices during the production of crime-maps ('external power'), as well as on the practices fostered by these maps ('internal power'). One central characteristic of the production of maps, Belina argues, is 'abstraction' (Belina, 2010, p. 9). The data for crime-maps usually comes from crime statistics, but what is counted as a crime? Belina describes several requirements ('filters', p. 11) that need to be met for something to count as a crime – questions of the law, of course, but also subjective perception, and complaining to the police. For example, drug-crimes are against the law but are rarely reported to the police by citizens; they usually get into crime statistics based on police control. Belina mentions drug-maps as an example of such abstractions. Such maps suggest that close to the German–Netherlands border, drug-crimes would be higher. However, based on the examination of practices that lead to the production of such maps, it is more likely that these maps are the result of greater police controls at the border, and not necessarily higher numbers of drug-crimes or consumption of illegal drugs. This practice of abstraction may lead to the production of an ideology that could influence the intensity of police control fostered by these maps, leading to a vicious circle or 'self-fulfilling prophecy' (p. 15).

While this example of a practice-based analysis of crime-maps shows the potential of going beyond a critique of the map as such (problem # 1), immanent critique is in addition a critique based on norms that are already accepted – at least within a hegemonic position. These norms are not always obvious and are often only implicitly present in practices (see Herzog, 2016, p. 284). They need to be uncovered somehow, and here discourse analysis can help a critical cartography based on immanent critique. While immanent critique does not offer tools for determining the implicit norms, 'for discourse analysts, revealing the implicit structures of discourses is everyday work and should not be overly complicated' (ibid.).

Table 1: Summary of the central arguments

	Problems of critical cartography based on discourse analysis	**How immanent critique (IC) overcomes this problem**
# 1	'The map' as fetish	IC tries to question social practices and not only implied ideologies of the map
# 2	Unintended discursive effects of critical cartography based on discourse analysis	IC does not describe a new space outside the hegemonic position *and* its negation as an essentialist utopia, but it opens a way to them. This does not completely eliminate the danger for the critique to be deferred on the terrain of the criticized hegemonic position, but its more precise description of the obstacle should help to avoid unintended discursive effects
# 3	The problem of normativity and legitimation	IC finds the scale for the critique 'within the thing criticized itself'
# 4	The silence of discourse analysis: Questioning the obstacle	IC tries to reveal the obstacle as immanent contradiction

4 Critical cartography based on immanent critique *and* discourse analysis

A practice for critical cartography – or more precisely, a practice for reflexive map-reading that fosters 'maturity' ('Mündigkeit') (Adorno & Becker, 1971) and with that the 'political subject' (Mitchell, 2018; Mitchell & Elwood, 2013) in educational contexts – could start with tools derived from discourse analysis. The aim of this first phase is the identification of implied norms derived from textual and non-textual aspects (e.g. practices, institutions) that are linked to the map – as 'discursively created, shaped […or] interpreted' (Herzog, 2016, p. 283). The second phase would be the phase of immanent critique, which would have its starting point in the result of the first phase: the implied norms derived from textual and non-textual aspects linked to the map. To illustrate the potential of such an interplay of discourse analysis and immanent critique, we provide a short example below (see 4.2), but first we outline steps that we think helpful for such a practice.

4.1 Helpful steps for a critical cartography based on immanent critique *and* discourse analysis

The analysis during the **first phase** (based on *discourse analysis*) needs to focus on textual *and* non-textual (e.g. practices, institutions) aspects that influence the production of the map, as well as textual *and* non-textual aspects that are (potentially) influenced by the map produced (as discussed earlier with Harley's concepts of external and internal power and with Belina's critique of crime-maps). Practice could consist of the following steps:

1. first approximation
   - 1.1. general characterization of the map: source and political localization of the source, intended readership, circulation, etc.
   - 1.2. allocation of thematic areas (crime, economy, education, etc.)

2. fine analysis
   - 2.1. What textual *and* non-textual (e.g. practices, institutions) aspects influence the production of the map (related to Harley's concept of external power: What is the specific practice of e.g. data acquisition? What are the rules that permit the statements of the map?)
   - 2.2. How is this map used? (related to Harley's concept of internal power: What is the discursive effect of the map? What are potential practices fostered by these discursive effects?)

3. summary
   - 3.1. How can the discourse strands which influenced the production of the map, as well as those that are influenced by the resulting map, be described?
   - 3.2. What are their implicit norms? What is the most prominent one?
   - 3.3. Finding a corresponding practice: every norm refers to a practice. What is the practice corresponding to the identified norm?

Now that we have identified the implicit norm, it is time for the **second phase**: the analysis regarding an *immanent contradiction*. This could consist of the following steps (see Jaeggi, 2013, pp. 297–298):

4. Examining the relationship between norm and its conflicting practice
   - a) <u>internal critique</u> only criticizes the difference between an accepted norm and its conflicting practice (e.g. promoting gender equality but inviting only male candidates for job interviews)
   - b) <u>immanent critique</u> examines a *relationship* between both, in the sense that *the norm is even constitutive for the practice criticized* (as illustrated by the Marxian example discussed earlier)
   - c) <u>immanent critique</u> analyses whether the norm is *realized* in the practice *deficiently* (in the Marxian example, the norm (freedom) is realized in the practice deficiently in that it became transformed into a type of bondage)

5. Further discussion of the immanent contradiction that has been revealed: Which questions can be asked on the basis of the immanent contradiction? What are the new insights generated by the immanent contradiction?

4.2 Example as Model

We will now put these abstract steps into a specific context to further clarify them, using a map with the title 'equity in education'.

1. First approximation: The map[7] shows the findings of a survey conducted by the Programme for International Student Assessment (PISA). In particular, this map shows the *influence of social background* on what PISA describes as performance or educational success. At country level, the map compares 'equity in education' (OECD, 2018): the deeper the red of the country (e.g. Germany, France), the more influence social background has, which means less educational mobility in comparison to other countries and therefore less 'equity in education'; the richer the green (e.g. Russia, Canada), the less influence social background has, which means more educational mobility in comparison to other countries, and hence more 'equity in education'.

2.1 of the fine analysis: How is the data for this map acquired? This is related to Harley's concept of external power: What is the specific practice of data acquisition? Or, in discourse-analytical jargon: What is the system of possibility for this kind of knowledge? What are the rules that permit such statements? (see Philp, 2000, p. 69). The data for this survey on 'equity in education' comes from so-called context questionnaires. In order to gather contextual information for the knowledge and skills in the main domains being analysed (reading, mathematics and science), PISA uses five additional questionnaires, including the 'Educational career questionnaire' and the 'Parent questionnaire' (OECD, 2018, p. 17). For example, the 'Parent questionnaire' includes questions for parents, such as: 'In the last twelve months, approximately how much have you paid to educational providers for services?' or 'What is your annual household income?' (OECD, 2017). In summary, one can say that statements about 'equity in education' are based on correlations between socio-economic factors and 'educational success' ('educational success' as defined by PISA).

2.2 of the fine analysis: How is this map used? This is related to Harley's concept of internal power: What is the discursive effect of the map? What are potential practices fostered by these discursive effects? While this would need further examination, first insights show that, for example, German-language newspapers which used this map (or variations of it) compared the results of the PISA survey for Germany with those of other countries (see e.g. Pauli, 2016; Schmidt, 2016). One factor for this cross-country comparison could be the national scale of the map – in Germany, the Federal state level plays an important role in regulations in education, and so discussion of this topic at a national level is not obvious. Articles using this map discuss other countries' education systems, which are assessed as being superior in terms of 'equity in education', and derived political demands based on this comparison, such as more resources for pupils with disadvantages based on starting conditions (Schmidt, 2016).

3. Summary of the first phase: How can the discourse strands which influenced the production of the map, as well as those that are influenced by the map produced, be described? What are their implicit norms? What is the most prominent one? What is the practice corresponding to the identified norm? Obviously, one prominent discourse strand concerns 'equity in education'. Its implicit ideal or norm could be called the *effort principle*, and its conflicting

[7] For legal reasons, we cannot provide the map here. Please follow the link: Map of PISA survey: Equity in education (http://www.compareyourcountry.org/pisa/?lg=en).

practice the *performance principle*. While the *performance principle* demands, for example, the same remuneration for the same achievements/performances, the *effort principle* takes into account that individual achievements are also the results of social constellations (e.g. socio-economic background), and therefore some individuals need to spend more effort to achieve the same performance. This should reveal the core of the potential critique of the PISA survey: if an educational system pays less respect to starting conditions, it is closer to the practice of the *performance principle* and further away from the ideal of 'equity in education' with its implicit norm of the *effort principle*, which takes into account that some individuals need to spend more effort to achieve the same performance. Basing its view on the effort principle, the newspaper *TAZ* interprets the PISA map as showing that 'Germany remains unfair' (Pauli, 2016), because there is less effective compensation for different starting conditions based on social inequality. By contrast, the performance principle would demand the same appreciation for the same achievements.

4. Examining the relationship between norm and its conflicting practice: So, what can an immanent critique based on the already quite radical norm, the *effort principle*, offer? In a first step, it would follow this norm of the PISA survey, but in a different way from internal critique: the reaction of internal critique is to demand compensation (as in the example of the newspaper article which demands more resources for pupils with 'deficits' (Schmidt, 2016)). While internal critique tries to dissolve this difference between norm (*effort principle*) and practice (*performance principle*) with different types of compensation, immanent critique paradoxically asks for a relationship between norm and its conflicting practice (see step 4). While this step does not work for every constellation and needs prior analysis and context-knowledge (Jaeggi, 2013, p. 298), it can lead to a completely new perspective, as we will now explain.

The PISA survey opens the perspective that the *performance principle*, which does not consider biographical inequalities when measuring individual performance, is 'unfair' (Pauli, 2016). But the PISA survey, on the other hand, uses the performance principle prominently in the assessments of the main domains (reading, mathematics and science). This leads to a tension, which should reveal the relationship between the norm (*effort principle*) and its conflicting practice (*performance principle*). The PISA survey does not really question the performance principle; it more or less invites us to look for ways to fix the performance principle, in the sense of: How can we compensate for the effect of biographical inequalities while preserving the performance principle?

This becomes clearer if we take a closer look at the map's colour scheme. The colour scheme invites us to compare different practices from different educational systems, which can be easily identified as better or worse. But even the nations with the richest green (e.g. Russia, Canada) use the the performance principle (for Canada, see e.g Mitchell, 2018). We can already find an echo of this framing in the subtitle of a newspaper article: 'PISA shows that socially disadvantaged students tend to do worse in science. But that need not be the case. Individual countries perform well despite major social differences' (Schmidt, 2016; own translation). The problem seems to be revealed now: it appears that the PISA survey offers a critique of 'unfair' conditions – e.g. different starting conditions due to socio-economic inequality. But quite the opposite is the case: *the norm* (effort principle) *is even constitutive for the criticized practice* (*performance principle*), in the sense that it invites us to search for ways to fix the performance principle (e.g.

through compensation) (see steps 4b and 4c in Section 4.1 above). It is not about 'fairness' anymore; it is not about abolishing social inequality; it is about performance: 'Individual countries perform well *despite* (!) major social differences' (ibid; own emphasis).

The immanent contradiction between the norm (*effort principle*) and its conflicting practice (*performance principle*) can be identified now as follows: based on the PISA survey, the performance principle needs to be criticized in contrast to the effort principle, because of the 'unfair' influence of socio-economic factors on performance-based 'educational success'. If we could compensate for socio-economic inaqualities (and not even countries like Canada, which are rated among the 'fairest' in the PISA survey, have achieved this yet (see Mitchell, 2018)), this would fix the problems of the performance principle and could lead to the called-for 'equity in education' *despite* the performance principle. This is what Jackson et al. (2005, p. 27) describe as 'the liberal dream of an education-based meritocracy' – a society whose allocation of privileges is based on 'merits'/performance under 'fair' conditions. The point here: based on 'fair' conditions (e.g. same starting conditions), hierarchies and social inaqualities would become justifiable.[8] This is exactly where the immanent contradiction shows itself: while in the liberal perspective, social inequalities would be justifiable based on 'merits' under 'fair' conditions, these 'fair' conditions can only be created under the condition of social equality. So, the paradoxical point here is that an educational system/a society that is based on 'merits' or performance creates and justifies social inequality, but to create justifiable social inequality it needs social equality – at least as a starting point – as a prerequisite for 'fair' condititons. The practice fostered by this framework of an 'education-based meritocracy' is one of permanent compensation for social inequality (an inequality that is legitimated through this compensation), because it (should) create 'fair' conditions for the performance principle that produces and justifies social inequaltity.

Step 5 further discussion: Immanent critique 'surpasses the corrective critique by revealing the systemic difficulties of fulfilling the demands' (Herzog, 2016, p. 284). This example revealed the permanent, self-perpetuating, compensation for social inequality. Compensation in this context fixes and legitimates the performance principle, which produces and justifies social inequality (social inequality-based starting conditions are in the liberal perspective justifiable), which in turn requires new compensation. So, immanent critique does not argue morally that, for example, social inequality is wrong; it reveals the systemic difficulties of fulfilling the demands of 'fair' social inequality – it reveals dysfunctional aspects of an education-based meritocracy with its central idea of 'fair' social inequalitity. In this sense it is a mode of *negative critique* (see Flügel-Martinsen, 2016) – in contrast to constructive critique, it does not describe better alternatives – but it still has transformative potential, because it identifies the obstacle and its dysfunctional effect, and so offers a new perspective and raises new questions. In our example, it raises questions about performance measurement: while education should help to develop individuals' potentials, an 'education-based meritocracy' also requires some form of *selection*. While one could argue that a test, as an instrument of the performance principle, can

[8] The ideal of an 'education-based meritocracy' consists of the triad 'education, career and income'. If the conditions in education are 'fair', a differentiation in 'educational success' would be justifiable and based on different educational qualifications, different career paths and different income. Finally, this triad of 'education-based meritocracy' justifies social inequality (see R. Becker & Hadjar, 2009, p. 41; Kreckel, 2004). For further critique, see Goldthorpe (1996) and Solga (2013).

serve as helpful feedback for students, in an 'education-based meritocracy' it is also an instrument for selection in the context of the meritocratic triad of education, career and income. This fosters what Goldthope (1996, p. 255) calls 'demonstrated competences', which refers to the need for educational qualifications in the context of an 'education-based meritocracy'. It is not so much about education or competences as such anymore, because the certification of an educational process and its measurement gain in importance. This shift in education leads Hauser to the conclusion that a central critique of meritocracy needs to focus on what he descibes as 'testocracy' (Hauser, 2002, p. 54). This leads to questions such as: What are the social effects of the current testing practice? 'There is more controversy than evidence about the effects of these tests [high school exit exams]. A reasonable speculation is that these exams will encourage early school dropout, especially among African-American and Hispanic youth, and that they will create new barriers to post-secondary education and training and to labor market entry' (ibid, p. 55). Based on the immanent contradiction, a critical examination of social effects of the current testing practice and other instruments for selection could be helpful to reduce the effect of the performance principle that produces and justifies social inequaltity.

5 Conclusion and outlook

Learning environments that are based on a practice such as reflexive map-reading offer the potential to go beyond an affirmation of given conditions, because they lead to points where these current conditions are conflictive or even dysfunctional. In contrast, learning environments that are in agreement with current social practices end in an affirmation of given conditions. Hence such learning environments foster not only integration into these conditions, but also (and mainly) adaptation to them, which can lead to effects of alienation (see Lehner & Gryl, 2019b, pp. 14–15). On the other hand, learning environments that are based on immanent critique lead to social conditions that are conflictive, unfinished and open to change. Such learning environments do not foster adaptation to given conditions; they offer the potential to foster the sense of 'maturity' ('Mündigkeit') (Adorno & Becker, 1971) and are aimed at the 'political subject' (Mitchell, 2018; Mitchell & Elwood, 2013).

Certain questions remain. While this practice of reflexive map-reading based on immanent critique and discourse analysis seems to be promising for maps that cover topics around social practices (e.g. economics, ethnicity, crime, education, etc.), it does not seem to offer much potential for topographical maps (although their design and margins might still be questioned in deconstruction mode). We need also to further examine the method's practicability through practical applications in empirical settings, in order to identify potential problems and challenges. Furthermore, additional intermediate steps could be developed for the suggested two phases of the practice, which might increase its accessibility for a heterogeneous target group.

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Adolescents and the 'Instagramability' of Places – An Explorative Study on Spatial Practices in Social Media

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Abstract

Social media are everyday companions for adolescents, enabling them to communicate and share their experience of the world. With the rise of social media, location has gained importance as an organizing principle of online content. In addition, actions like taking, geotagging and uploading pictures on the go mediate space in a new way. In this article, we explore the production of space through social media, and the emerging receptive processes among young people against the background of a changed allocation of spatial meaning through digitization processes. The ubiquity of software leads to a production of 'coded spaces' and 'code/spaces'. We give an overview of contemporary research within geography that examines the production of space in social media and identify possible ways of thinking about space in social media. In order to analyse young people's spatial practices in social media, we conducted interviews with adolescents regarding their social media habits. Our first analysis reveals several spatial practices that occur on Instagram: youngsters select locations specifically for Instagram, geotag places that they deem exceptional, and edit their photos with filters. Our analysis confirms that software leads to the emergence of new spatial practices. The production and reception of space in the context of digitization raise a series of questions regarding the theoretical conception of space on social media.

Keywords:

social media, spatial practices, adolescents, instragram, digital geographies

1 Introduction

Social media are 'places' where people engage with a variety of topics, articulate opinions, share feelings, and communicate in different forms. Every video, hashtag or post has the potential to go viral. There are countless examples of posts on social media that went viral and entered traditional media, e.g. Greta Thunberg sitting on the floor in an overcrowded German train, sparking a debate about data privacy (Frankfurter Rundschau, 2019), or Donald Trump's infamous tweets leading to further tensions between the USA and Iran (Frankfurter Rundschau, 2020). As Stalder (2018) argued, we are experiencing a cultural transformation in which computer networks are the key infrastructure for all aspects of life – leading to a digital condition. We produce space online and offline everyday through our actions and communication, blurring boundaries between 'online' and 'offline'. Under these conditions, as Leszczynski (2015) puts it, location has become an organizing principle for online content, information services and everyday life – especially on social media.

There are various social media platforms, designed for different purposes and used by different groups. While Facebook and Twitter focus on news distribution, Instagram, Pinterest and Snapchat are used mainly to exchange photos or videos (Highfield & Leaver, 2016). With the proliferation of mobile phones and smartphones, virtually anybody is able to take a quick snapshot and post it online, leading to an increased integration of visual content (Highfield & Leaver, 2016). Not only do photos of food, pets or selfies proliferate online, but places have also gained more and more attention and now play a big role on social media. The European Central Bank Headquarters in Frankfurt, for example, was tagged on 39,918 images on Instagram's explore feature (see Figure 1). It is noticeable not only that the building was photographed from a certain angle, but also that a filter was used to dramatically intensify the colours.

Figure 1: European Central Bank headquarters in Frankfurt 2019
(Source: https://www.instagram.com/p/-Bz1OIL1otKY/)

The photo shows only a fragment of the headquarters and renders the surroundings invisible. On social media – particularly on platforms like Instagram – it is common practice to edit photos. Users produce images of places that are represented in a new aesthetic form. Social media enable users to communicate an experience of space and place online with others, to render invisible spaces visible, to offer image details, and to alter the meaning of places. The European Central Bank Headquarters are located next to the 'Hafenpark', a park on the banks of the Main River which also features a skate park. It is a popular location among young people and a prominent place on Instagram. Social media are everyday companions for adolescents, and the production and consumption of unmoderated constructions of space have an impact on their self-perception and their relation to the world. Although practices and features may vary between platforms, they morph and reappear on other social media platforms (Highfield & Leaver, 2016); 'Stories', for example, originated on Snapchat, but were such a popular feature that they were implemented on Instagram, WhatsApp and the YouTube mobile app.

Adolescents take part in producing space on social media, yet little is known about their spatial practices on Instagram and why they exercise them. To develop a better understanding of how space is reconfigured through social media, and which practices and processes of reception emerge among young people against the background of the changed spatial allocation of meaning through digitization, we take a closer look at contemporary geographic research and analyse interviews with adolescents on their use of social media platforms.

We start with an introduction of our theoretical framework of digital space and outline studies that were concerned with the production of space in social media. We then present our case study: a brief explorative analysis of interviews with adolescents who actively use Instagram in their everyday life. Finally, we discuss our findings regarding the production of space and the process of reception under digital conditions.

2 Digital space, and places on social media

Technological innovations have led to the spread of telecommunications, the internet, and profound digitization of everyday life. This transition results in a digital turn within geography, as Ash et al. (2018: 29) have stated, where 'the digital is mediating and augmenting the production of space and transforming socio-spatial relations'. Space is increasingly augmented by virtual interactions, so that life is determined by an interplay of online and offline contexts. Content is created in an interaction between people and non-human actors in which 'code' plays a major role (Kitchin & Dodge, 2011). Code consists of instructions and rules, producing programs that operate hardware and take multiple forms. Kitchin and Dodge (2011) distinguish between 'coded objects', which are non-networked objects that use code to function or store digital data that is only accessible via software, and 'coded infrastructures', which consist of networks that link coded objects that are monitored and regulated partially or fully by code. Moreover, they define 'coded processes' as the transaction and flow of digital data across coded infrastructure. Finally, 'coded assemblages' occur where several coded infrastructures coincide and work together. Code is embedded in everyday life, producing these coded objects, infrastructures, processes and assemblages. Software enables everyday actions as well as the creation of new spatial formations, which Kitchin and Dodge (2011: 261) refer to as 'code/space': 'A space that is dependent on software for it to be transduced as intended. Here the relationship between software and space is dyadic; they are mutually constituted, that is produced through one another.' Smartphones, mobile internet and social media allow users to share their location, to rate locations on Google, to take photos and send them directly via a messenger, or to upload them onto social media platforms whenever they wish. Therefore, the 'digital' is reshaping the production and perception of space, place, landscape and environment (Ash et al., 2018).

Social media platforms are coded infrastructures that play a vital role in our everyday life and serve a variety of purposes, e.g. sharing images (Instagram) or microblogging (Twitter). Information distribution via these platforms is becoming increasingly interactive. They mediate reality as the product of an interplay of technologies, society and spatial relations, helping us to make sense of the world. With the rise of coded infrastructures, location has become an organizing principle for online content and information services. Instagram's interface structures the content via spatial activities and therefore affects the user's experience (Leszczynski, 2015). Visuality also plays a major role in social media as the main medium for creating and presenting an online identity. Visual content is used to present news or comments; it is placed next to political, legal, economic, technological and sociocultural debates (Highfield & Leaver, 2016).

Ingrained in everyday life and a venue where cultural and social changes take place, the internet has become an object of research. A new medium requires new methods to fully understand it in its context (Rogers, 2013). Therefore, a variety of new research methods based on a variety of theoretical concepts and tools have emerged over the last decade. So far, some non-geographic research on Twitter (e.g. Bruns & Burgess, 2011; Bruns & Stieglitz, 2014), Instagram and Facebook (e.g. Burgess et al., 2017; Highfield & Leaver, 2016) has been carried out, but there has been less research in the field of geography that focuses on the production of space in social media.

Shelton et al. (2015) conducted a study analysing Twitter data to examine how big data sources can be mobilized for understanding urban socio-spatial processes. Segregation and inequalities were initially confirmed by pure mapping, but Shelton et al.'s data, through additional analysis using methods drawn from critical GIS, revealed them to be less clear and more complex, and to present. Butler et al. (2018) have a similar research interest as Shelton et al (2015). Their study aimed to investigate the stigmatization of places on Twitter. The data revealed that male users tend to refer to other places and paint a stigmatizing image from a distance, while female users often write about their home areas. This study raises the question of who determines the social media discourse on certain spatial images.

Kelley (2013) studied Foursquare in relation to the meaning of geosocial data in the context of socio-spatial 'imaginations' and the production of space on social media. His data revealed that observing the city through Foursquare constructs a patchwork landscape with invisible and visible spots.

Another study on Foursquare, carried out by Fekete (2015), asked how social media render certain ethnic groups invisible. She postulated that the geoweb is racially divided and does not eradicate social inequalities. Her data revealed that Foursquare appeals mostly to a white population, leading to an over-representation of white businesses and venues, while simultaneously under-representing venues in African-American neighbourhoods. She concluded that this lack of representation has a real-world implication, namely that people using the 'explore' feature will see predominantly venues in white areas, leaving others invisible and therefore inscribing digital inequalities.

Lundgren and Johansson (2017) took another approach to the production of space in social media, analysing how rural space is presented on Facebook. Their analysis revealed that rural space is portrayed as dying while at the same time also being very much alive, and that online activities like debates often coincided with offline activities like protests. They proposed that social media enable people to voice their opinions, and in doing so they contribute to the production of space and certain places. Boy and Uitermark (2017) traced the relationship between social media and peoples' presentation of their city on Instagram. Their data revealed that the users' feeds presented a limited number of places in a curated way and that the visual representation aestheticized their everyday life, which therefore never appears ordinary. This results in places being rendered either more visible or invisible, inequalities are re-inscribed, and the image of the city becomes fragmented.

Although these studies deal with different platforms and answer different questions, there seem to be common notions of digital space that the platforms' users produce: space is curated. Individuals preserve well-chosen moments and train themselves to spot moments that are worthy of preservation (Boy & Uitermark, 2017; Lundgren & Johansson, 2017). Social media enable a transformation of aesthetics: places are shown from certain angles or through filters provided by the platforms or other applications (Boy & Uitermark, 2017; Kelley, 2013). Why do users choose certain places, present them in a certain way, and how do these representations impact the places as well as the users? Social media not only permit the widespread dissemination of different perceptions of places, but also facilitate the production and dissemination of new meanings (Butler et al., 2018; Kelley, 2013; Lundgren & Johansson, 2017). Furthermore, social media platforms confirm status and (in-)visibility of places (Boy & Uitermark, 2017; Butler et al., 2018; Fekete, 2015; Shelton et al. 2015). Spatial practices lead to hotspots of activity and alleged inactivity. But who is talking about the location or evaluating it, who is visiting these places due to their online representation, and what kind of socio-spatial inequalities may occur as a result.

The production of space in social media take various forms, under various conditions. Since social media appeal foremost to young people, the question of how they experience places has become a crucial one, which we address in our case study.

3 Case study: Adolescents and Instagram

To understand how place is produced in social media by adolescents, in 2020 we conducted in-depth narrative interviews with 10 young people (5 females and 5 males), aged 14 to 18. All live in Frankfurt, own a smartphone, and use various social media platforms on a daily basis. We approached them in a youth centre and at a sports club. The interviews were held in German (quotations have been translated into English). We have changed their names and anonymized any sensitive data to protect their identities. Against the background of the changed spatial allocation of meaning through digitization processes, we use our textual corpus to gain a first impression of the spatial perception and practices emerging among young people.

We use a grounded theory approach for our analysis because of its open, explorative character. Grounded theory enables the development of new theoretical approaches based on peoples' everyday experiences. The aim of our analysis is to formulate new theoretical approaches regarding the production of space in social media. Grounded theory consists of the following steps: open coding, axial coding and selective coding. First, ideas are identified via text samples (theoretical sampling) and codes are formed. In the second step, the codes are transferred into categories. In the third step, core categories are formed (Breuer 2010).

Our interviews were divided into different sections: biographical background, use of social media platforms, digital practices, construction and perception of space, and visibility of algorithms. We asked a range of questions covering the participants' backgrounds, favourite social media platforms and content, and posting habits on different social media platforms. For this short explorative study, we decided to focus on Instagram because it was the most widely used platform and all participants had access to it. As already mentioned, Instagram is a visual platform that structures its content via spatial activities and allows users to search for places using geotags or hashtags. This led us to the assumption that users experience and post location-based content. First, we traced the young people's consumption and active production of posts on Instagram. Through open coding, we identified possible categories regarding their spatial practices: choosing locations, geotagging locations, editing locations, navigating through locations, and perception of locations. In the sections which follow, we present and discuss these categories regarding spatial practices, and our preliminary results.

4 Results

All the adolescents except one use Instagram on a daily basis. Their day usually starts with passive consumption as they browse different social media platforms and view new messages on WhatsApp or Instagram feeds. Although they exhibit multiple overlapping habits and practices, there are also differences regarding their use and uploading behaviour that lead to the production and perception of places on Instagram.

4.1 Choosing locations

Young people often think about the suitability of a location before taking a picture, although they also take quick snapshots of situations and places. They consider their home to be too ordinary a place for Instagram. Hence they hardly ever post their domestic activities. Isabella has strong opinions regarding how 'instagramable' places and situations are; she would never take a picture with a background that she perceives as unattractive, like an untidy room. She is very aware that her pictures only show a small segment or snippet, but she posts them regardless. In her opinion, the only purpose of taking a picture is to upload it to Instagram and share it with her followers: 'otherwise the picture doesn't do anything for me'.

4.2 Geotagging locations

When uploading pictures of their homes, the youngsters do not geotag them not just because they are concerned about their privacy. Sarah says: 'When I'm in Frankfurt, I won't tag it in the picture. I have one picture where I am at home, but I didn't tag it.' Isabella elaborates similarly: 'I want to tag places that seem cool, but not my home.' Sarah tends to tag places she finds exotic and wants to share with her followers. Geotags also help to conserve memories, serve as evidence of adventures and, as Jan puts it, tell a story. Our participants like to post emojis alongside textual descriptions of their pictures.

4.3 Editing locations

The aesthetics of their uploaded images seem to play a big role: Melanie, Isabella, Sarah and Jan all edit their photos using different filters, or by heightening contrast or adjusting saturation. Only Finn does not use any filters because he thinks it establishes a world of illusion that only exists on social media and covers up reality. Melanie strives for her Instagram feed to appear harmonious and uniform. Sarah goes as far as wanting to remove all her pictures, re-sort them, and edit them with a uniform filter before re-uploading.

4.4 Navigating through locations

Besides using Instagram as a photo-sharing and uploading platform, youngsters use it for navigation purposes. They use Instagram's 'explore' feature to browse places they have never been to but plan on visiting. Melanie and Jan like this feature because they can get first impressions of a place, as well as receive suggestions of locations to visit like restaurants or sightseeing spots. The feature also enables them to compare official representations of restaurants, cafés or holiday destinations to their own presentations of them on Instagram.

4.5 Perception of locations

The representation of places on Instagram does not entice Sarah to visit these places – only friends or family do that. Nor does she look for places she is already familiar with: 'I would not look for a place like Hafenpark on a whim, because I know that place pretty well and I would not take the representation seriously. I can determine my own personal perception [of a place].' Isabella consumes shared images of places, which she then proceeds to visit if she has the chance of doing so. Finn prefers to walk through a city or landscape and discover and explore places on the way, because he does not want social media to tell him 'what looks good and interesting, and what does not'. Melanie feels that 'meme-pages' that present places in a certain way often contribute to a negative image of those places and sometimes lead to avoiding the locations. The youngsters often referred to the 'Bahnhofsviertel', near Frankfurt Central Station, which is famous for its drug scene and brothels, as a place to avoid, especially at night. Nevertheless, these young people are aware that the representations on Instagram differ from reality. 'Everyone presents themselves in the best way possible,' Sarah reflects. Finn states: 'no one would post that they are feeling down today, but to show how great their lives are… and this is just so superficial.' Moreover, he feels that Instagram is a social media platform characterized by detachment: 'You never know how someone meant something.'

5 Discussion: Adolescents and the 'instagramability' of places

The practices for producing space on social media are highly intertwined with each other. Home is a place that can be understood as a symbol for ordinary everyday life and does not seem exciting enough to share with a larger crowd. At first glance, the young people in our study do not take part in the digital construction of everyday life that users of social media platforms are deemed responsible for (Boy and Uitermark (2017)). Whilst not tagging their home, they actively decide to tag other places they perceive as exciting, exotic, cool and the opposite of unremarkable. In doing so, they ascribe special meaning to the places they select for geotagging and attach greater importance to them than to their places of everyday life. As Isabella states, she tags remarkable places to maintain a certain self-image. This practice leads also to segmentation of space/place, because non-remarkable places are perceived as unimportant and remain largely invisible, as Boy and Uitermark (2017), Butler et al. (2018), Fekete (2015), Kelley (2013), Lundgren and Johansson (2017) and Shelton et al. (2015) all state. Moreover, as we have seen, some think about the suitability of a location before taking a picture and have decided views of what is 'Instagram worthy' while being aware that their pictures are staged and only show a small segment of reality. Isabella perceives her Instagram feed as a business card or portfolio, where the first impression must be flawless and shine a good light on her – hence her intensive endeavours to curate her profile and photos. She perceives spaces through their 'instagramability', meaning that for her personal experience and production of space are only possible through Instagram. Therefore, social media not only lead to the segmentation and altered meaning of space but also enable the curation of space (Boy and Uitermark (2017)).

The practice of geotagging exceptional places becomes a practice for constructing places as status symbols, meaning places are not only 'upgraded' but define a persons' affiliation to a certain group. Upgraded places can received a lot of attention, as we will argue later. a Within this process in which social media platforms – as coded infrastructure – act as mediators. In addition to constructing places as status symbols, geotags serve as means to archive digital memories and to validate the user's adventures. Thinking of places as status symbols enables us to understand the implications for their offline equivalents. There are countless examples of places that are overrun by young people due to their 'Insta-fame' (Spiegel, 2018). Some places accept or even foster the possibility that they might go viral by identifying 'good' Instagram-worthy locations. Kampen, a municipality on the German isle Sylt, for example, introduced selfie points (see Figure 2) throughout the town (Kampen, n.d.). Fostering such selfie points not only alters the meanings of these places and, therefore, influences perception of them, but also inevitably leads to further segmentation of space by encouraging the selection of certain specific locations.

Figure 2: Official selfie point in Kampen, Sylt
(Source: https://www.meyrose.de/wp-content/uploads/Kampen-Selfie-Point-Ines-Meyrose-Sylt-201602-Collage.jpg)

The young people in our study transform the places they share by editing them or applying filters. They place value on the artistic or aesthetic appearance of their Instagram feed, where places are intended to look more ‘beautiful’ and more ‘positive’ than they perhaps are in reality; the young people take an active part in their aesthetic transformation (Boy & Uitermark, 2017). This could lead to the assumption that places that are not presented on social media platforms might be ‘ugly’, ‘negative’ or not worth visiting (Butler et al. (2018). Moreover, this leads to questioning whether Instagram results in an ethnic division, as Fekete (2015) concluded in her study of Foursquare, or contributes to the unification of places. With its ‘explore’ feature, Instagram serves not only as a platform for uploading and sharing pictures but also as a navigation tool. By geotagging their pictures, users facilitate navigation for other users as well as the replication of places. Boy and Uitermark (2017) observe the same phenomenon in their study. As Melanie stated, she uses the ‘explore’ feature to find new locations (e.g. when going on vacation). Even though she knows that places are being presented with a certain aesthetic and look better on Instagram, she still perceives their representation as ‘more honest’. Consequently, Instagram produces a certain truth that is mediated through coded infrastructures and the perception and experience of other users.

As our results show, young people often select a location to photograph and upload to Instagram, and use a particular filter in order to create a certain aesthetic. They are driven by a desire to share and show off places that are exceptional; they use Instagram as a means of self-staging, giving us an explanation as to why they present and perceive places in a certain way. Our analysis confirms that the digital condition facilitates social media like Instagram, where digital spaces are being produced (Stalder 2018). These spatial practices produce a code/space (Kitchin & Dodge, 2011), which leads to the emergence of new perspectives for understanding and analysing space within social media. The perspectives are somewhat fuzzy and difficult to distinguish due to their high degree of intertwinement; social media platforms like Instagram mediate this new form of spatial perception (Leszczynski, 2015). The spatial practices discussed here challenge us to think about new perspectives on digital spaces as well as appropriate methods within geography education. Kanwischer and Schlottmann (2017) emphasize the inseparability of reflective abilities in the context of education for digital maturity. Therefore, geography education needs to adopt a reflective approach that enables young people to reflect on their spatial practices and perception as well as on their relation to the world (Kanwischer & Schlottmann, 2017).

6 Conclusions and future work

To understand how space is produced through social media and which processes of production and reception emerge among young people against the background of the changed spatial allocation of meaning through digitization, we analysed interviews with adolescents on their use and spatial experience on Instagram. We presented a first glimpse into our data, which gives us an impression of how adolescents produce and perceive places on social media. Software not only enables the production of a code/space but also leads to new spatial practices. We identified several practices using open coding that emerge in the production of code/space: choosing, geotagging and editing locations, and navigating through them. At the same time, social media shape adolescents' spatial perception. Our analysis not only demonstrates a change in the conditions under which space is produced, but also leads to questions regarding different aspects of the production of space: How and why do spatial practices differ? What role does the platform design play, and how does it enable these practices? What direct effects do social media have on the perception of spaces? What effects do spatial constructions on social media have on young people's own actions? How do algorithms co-produce space and shape spatial perception? How does the role of the subject in georeferenced social media change?

In the next step, we will transfer into categories our codes regarding young people's spatial practices, perception of space, and awareness of how media shape their identity, spatial perception and actions. We will then form core categories that enable us to articulate a theory concerning the production of space in social media. Since social media play such a major role and shape an individual's self-image and relation to the world, how to empower the critical questioning of self-image and spatial representations in social media also arises. Geography education must take into account these changed conditions and spatial practices, responding with appropriate concepts that integrate social media and consider these questions.

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Spatial Operators for Complex Event Processing

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Abstract

The types of data available have changed in the last decade. While, historically, data were gathered in batches and distributed as such, e.g. as a database or shapefile, today we are dealing increasingly with real-time data. This data is produced and consumed continuously in real time. The phenomenon is most commonly known as streaming data. Traditionally, software for spatial analysis, such as a Geographical Information System (GIS) or spatial database, was created and optimized for the batch processing of data. However, the inherent characteristics of streaming data provide new challenges for data-stream processing systems, which have not yet been solved. In this paper, we propose enhancing systems for the handling and analysis of streaming data through the use of spatial operators. We identify Complex Event Processing (CEP) as a promising underlying concept for such a system and use the (open source) self-service IoT toolbox 'StreamPipes' as a representative for this. On the basis of a review of the literature, we selected 6 core types of spatial operator and implemented 33 basic spatial operators in 11 groups. These can be combined with the existing non-spatial operators for in-depth analysis of streaming data that involves spatial dimensions.

Keywords:

streaming data, spatial analysis, big data, complex event processing

1 Introduction

Data are at the core upon which each information system is built. In the last decade, the use of data streams has increased massively. In turn, this has led to new approaches to deal with this type of data and to new opportunities to gain insight into the physical world. This is especially true in the field of geography. While research in the field of streaming data has focused mainly on financial transactions or industrial production (Industry 4.0 or Smart Factory), spatially referenced data from remote sensing, in-situ sensing, social sensing and health sensing are becoming a new focus of academia and industry (see e.g. Graser and Widhalm (2018) or Yu et al. (2020)). This has led to the definition of the term GeoStreaming as: 'the ongoing effort in academia and industry to process, mine and analyze stream data with geographic and spatial information' (Zhang et al. (2017, p. 1)). Another definition is proposed by Brandt and Grawunder (2018, p. 3): 'GeoStream is a data stream from spatio-temporal data. It is defined by three parts: (1) it is a data stream, (2) it has spatial information, and (3) it has temporal information.' They define three types of data which need to be handled by GeoStreams: point data at locations, data streams and evolving regions (e.g., weather phenomena).

These new opportunities come with additional challenges. Spatio-temporal data require special approaches to processing and analysis (see e.g. Yang et al. (2020)). Spatial databases as well as GIS were developed to deal with these challenges by using a batch processing approach. Streaming data, on the other hand are continuous but can be highly irregular, consisting of many different (small) events, which need to be gathered, processed, analysed and piped simultaneously as well as in real time. This is in contrast to the traditional IMAP (input, management, analysis and presentation) principle in the GIS world, where each of these steps is carried out sequentially. Their combination as a GeoStream requires solutions to be found for the existing challenges of spatio-temporal data within a continuous data stream, which can continue indefinitely.

In this paper, we address the research questions of how to handle GeoStreams efficiently and how to make them available to the wider GIS community. We identify and develop core operators for spatial analysis to be used in streaming systems. Complex event processing (CEP) is identified as the most promising concept from the field of streaming data processing. We base this decision on the research gaps identified by Brandt and Grawunder (2018, pp. 29–31): (1) Moving from static trajectories to continuous streams; (2) Connection of different types of GeoStreams; (3) Making sense of data, and (4) Extendable general-purpose systems.

2 State of the Art and Foundations

To achieve our goal in this paper, we need to investigate three different fields of research: Streaming data and CEP, GeoStreams and Spatial Operators. While some work exists which tries to combine these, this has been done mainly in relation to broader concepts as part of vision papers. Two examples for these broader concepts are PlanetSense, proposed by Thakur et al. (2015), which is a real-time streaming and spatio-temporal analytics platform for gathering geo-spatial intelligence from open source data, and BigGIS, presented by Wiener et al. (2016), which describes an overarching architecture in spatio-temporal big data. BigGIS envisions a system which integrates semantic information, streaming and batching in a continuous refinement process. Here, we focus on how to efficiently integrate and enhance state-of-the-art stream processing with spatial analysis.

2.1 Stream Processing and CEP

Stream processing describes the gathering, handling and use of continuous data flows (called data streams). Early works such as Terry et al. (1992) and Babu and Widom (2001) define data streams in contrast to traditional data, which they call persistent datasets. They demonstrate the key challenges with regard to queries on stream data: (1) The size of the data and therefore its storage need are unbounded; (2) While performing queries, the query itself requires unbounded storage; (3) It is unclear how to deal with updates to the data regarding queries; (4) An exact answer to a query is impossible for reasons 1–3. Babu and Widom (2001) then refer to the concept of triggers, called 'event-condition-action rules', which enable a system to act upon defined or learned rules in data streams.

Since then, the field of stream processing has progressed, and it is now a thriving area of research. Many frameworks for handling and analysis of data streams such as Apache Storm[1], Apache Kafka[2] and Apache Flink[3] have been developed. However, to deal with the research gaps identified by Brandt and Grawunder (2018), we need an approach that not only handles the data but also analyses complex interactions and events in a continuous data stream. CEP provides the means to do this. Bruns and Dunkel (2015) describe CEP as a software technology for the dynamic analysis of big data in real time. It allows the analysis of interconnected events, e.g. in causal, temporal, spatial or various other relations, via the three core components of the architecture of a CEP, as described by Etzion and Niblett (2011): (1) an event producer, (2) an event consumer, and (3) an event processing agent (EPA). These are analogous to a data source such as an air-quality sensor, a data sink such as a database, and a processing component such as an analysis algorithm. An event can be an unmodified, raw event, or a derived event, e.g. created by processing through an EPA. A derived event can include modified parameters or new attributes. By combining several EPAs, an event processing Network (EPN) is created (see Bruns and Dunkel (2015)). This allows the handling of complex events and processing chains.

2.2 GeoStreams

In comparison to the general fields of stream processing and CEP, their combination as GeoStreams is a new research topic. It is, however, an important one (see Zhang et al. (2017)).

Early work in this area was presented by Huang and Zhang (2008). They based their approach on existing spatio-temporal databases and proposed extending these with a new data type. Huang and Zhang identified the same core challenges as those identified in early work on streaming data, e.g. by Babu and Widom (2001): '(1) it is difficult to decide how frequently the program should issue the queries to the spatial databases; (2) it is computationally expensive to find the latest data from all the historical data each time when the query is issued; (3) an integrated query optimization cannot be performed by the database system and kept transparent [for] the user' (Huang and Zhang (2008, p. 107)). They also identified a lack of support for spatial data in existing methods and approaches from the stream processing community, as 'previous work […] can only handle streaming point locations naively' (Huang and Zhang, 2008, p. 109). However, they define the necessary data types only broadly and do not elaborate on the spatial operators used or how they are chosen.

Galić (2016) and Galić et al. (2017) propose a framework for highly scalable spatio-temporal stream computing called MobyDick. This framework is based on existing approaches from the

[1] https://storm.apache.org/
[2] https://kafka.apache.org/
[3] https://flink.apache.org/

field of spatial databases; it uses relational snapshot queries, which are also called 'continuous queries' in the context of streaming data. Their own work is inspired by work in the field of mobility data and by the insight that state-of-the-art Data Stream Management Systems (DSMS) have inadequate spatial capabilities: 'However, spatio-temporal properties of both data streams and continuous queries have been disregarded, and most of the current DSMSs offer very rudimentary support for mobility data' (Galić et al., 2017, p. 3). Like Huang and Zhang (2008), they do not explain how they chose their spatial operators; they also focus on new data types for databases.

A recent definition of GeoStreams can be found in Brandt and Grawunder (2018, p. 5). In their extensive survey paper, they define a GeoStream as 'the intersection of two fields in computer and geography science: Data Stream Management and Geographic Information Science (GIS)'. Their work looks at 137 different publications, over 100 of which are from the field of computer science – either from the ACM or the IEEE. However, key studies in the literature, such as the dissertation by Whittier (2018), are in the field of spatial information science and geography. As well as the key challenges and research gaps in the field, Brandt and Grawunder also identify the evaluation of (spatial) predicates on GeoStreams as a key topic.

GeoStreams and their inherent potentials and challenges are also an ongoing topic in industry. Schmutz (2019), for example, combines geofences from databases with KSQL (Kafka SQL) for location analysis. He identifies problems with the asynchronous processing of long-running operations or the combination of different analyses. Other key players in industry also start with proprietary tools and products such as Esri Stream Event, IBM Streams or IBM Pairs.

2.3 Spatial Operators

To identify the spatial operators required, we first need to identify the available operators for spatial analysis. As one question is how to provide accessibility to GeoStreams to a broad userbase of the GIS community, we follow the approach of Brauner (2015) and investigate the spatial operators of widely used GIS. A quick search in the spatial analyst toolbox of Esri (2018 version), one of the best-known commercial vendors of GIS, results in more than 180 tools in 20 categories. Additional operators are available in their add-ons. While it would be possible to re-implement all these operators, we argue that not all are needed, or provide a benefit for stream processing, or are essential for most tasks. Instead we investigate the GIS literature of the last 25 years to provide the scientific basis for identifying the core spatial operators which are needed for stream processing and CEP.

Bailey and Gatrell (1995) provide a working and broadly accepted definition of 'spatial analysis' as the quantitative investigation of phenomena which are located in a geographical space. Two key functionalities which operators for spatial analysis have to perform are (1) The selection of existing data, and (2) the transformation of data. However, these two functionalities are still too broad.

Albrecht (1998) provides a 'universal framework' using a well-known classification of GIS operators (see Figure 1). While, as the author emphasizes, this is an approximation, it provides a strong basis for our selection. The six key classes and therefore the six functions required are: Search, Locational Analysis, Terrain Analysis, Distribution Neighbourhood, Spatial Analysis and Measurements. The first five can be subdivided into more specific subclasses. The concepts are broad, and similar classifications were made by Jones (1997), Longley et al. (2011) and Burrough et al. (2015). It can be argued that this 'universal framework' is too focused on the operators of commercial tools. But for our research question, these links to existing GIS make them more suitable, as they are familiar to users. Other approaches were also investigated, namely: the 10 core concepts of spatial information of Kuhn (2012); the algebraic approaches to specify operators provided by Scheider et al. (2016); the question-based approach of Scheider et al. (2019) in which they implement 8 tools which are well known to GIS users in a SPARQL extension called SPARQL_Constraint; the problem-oriented approach by Chrismann (2002). For further discussion about spatial operators, we refer the reader to chapter 4 of Brauner (2015).

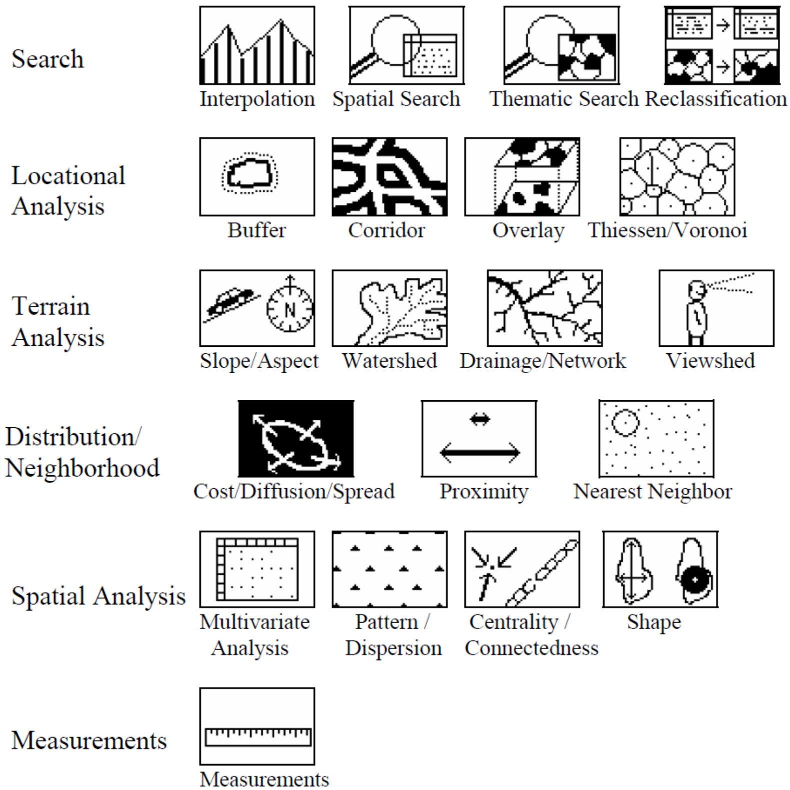

Figure 1: Classification of GIS-Operators by Albrecht (1998)

3 Spatial Operators for Streaming Data

In this section we will first describe the open source CEP tool StreamPipes (Riemer et al., 2015; Riemer, 2016; StreamPipes, 2020) which we used, second the operators selected and implemented, and finally two examples of analysis pipelines using the particular operators.

3.1 StreamPipes

StreamPipes, at its core, is a framework for the processing of streaming data in a big data environment – a CEP system in short (StreamPipes, 2020). This includes the import and handling of non-streaming data sources such as traditional databases, HDFS files, etc. It is designed to be a self-service analysis tool which allows complex analyses in a big data infrastructure without the need for technical expertise. StreamPipes can compute at least 54,000 events per second on a raspberry Pi (Zehnder et al., 2020), which was deemed acceptable for most use cases.

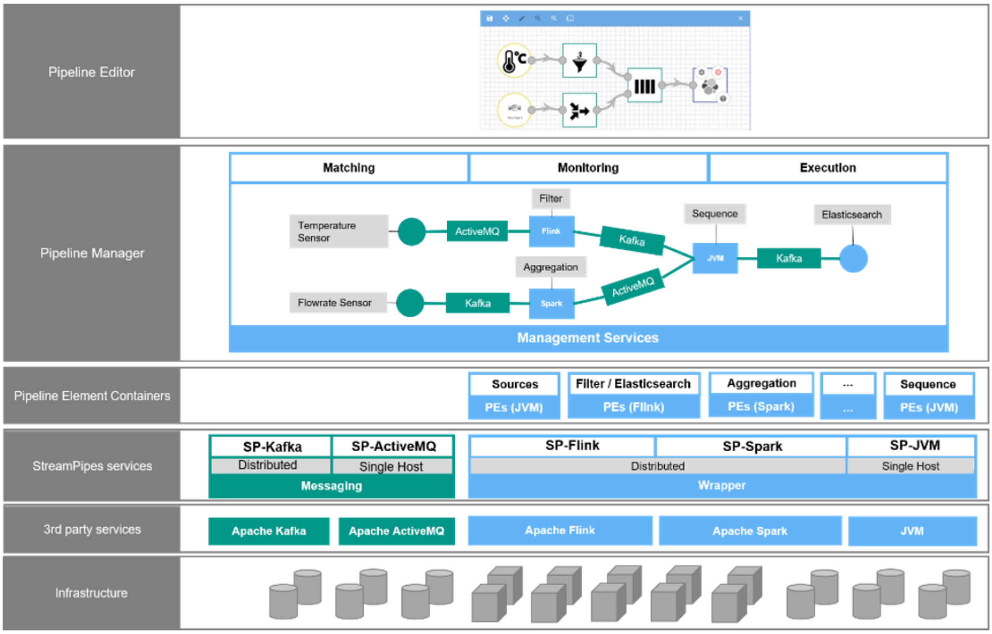

Figure 2: Overview of the StreamPipes architecture (StreamPipes, 2020)

StreamPipes uses a multi-layered technical architecture, shown in Figure 2. The user interacts only with the top layer, the pipeline editor. Here the different operators (called elements) are combined into an analysis pipeline. The user does not need to know how each component is connected to the underlying layers. However, semantic descriptors in the input and output of each element ensure that only valid data-processing pipelines can be created.

The pipeline manager manages the definition of the pipelines and their execution. It compares the semantic description of each element and ensures the validity of the pipeline. To execute a pipeline, the pipeline manager starts the Pipeline Element Containers, each of which contains a single element which has all relevant information. These elements in turn execute the code in an execution engine. Figure 3 shows an example of a meta-description element for a spatial event. It contains the core (spatial) attributes of the (spatial) position. The 'Schema' describes the different attributes of an event. The field 'Quality' defines different attributes, which are used to describe the quality inherent in the data. These attributes are dependent on the use event or analysis chain, so must be defined before the pipeline is executed. The 'Grounding' parameter describes how each event communicates with other events.

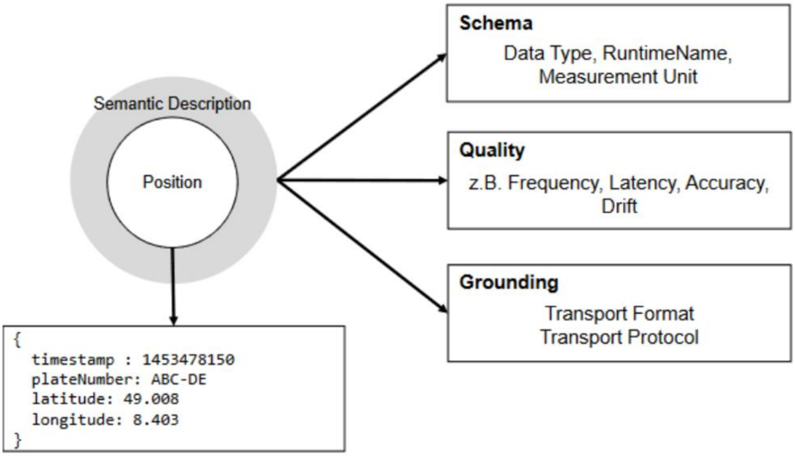

Figure 3: Description layer and data layer in StreamPipes for a geographical position (Riemer, 2016)

Finally, the last three layers in Figure 2 provide technical components such as virtual machines, third-party services, and the exact services which execute the element container. For a more in-depth view, we refer the reader to Riemer et al. (2015), Riemer (2016) and StreamPipes (2020).

We also need to discuss how implementation and integration of the spatial operators can be developed for StreamPipes. We use the StreamPipes SDK. This SDK allows the creation of new EPAs (see Section 2), which can be done using the Java programming language (Version 1.8.0_201 at the time of writing). We refer the interested reader to StreamPipes (2020) for more information and tutorials. A StreamPipes SDK consists of three different classes (see Figure 4). (1) The controller class defines the semantic model in the declairModel method, and the onInvocation method extracts the defined parameter for the algorithm class. (2) The parameter class therefore consists of the parameters from the controller class. (3) The algorithm class contains the algorithms for the data processing. Here, every parameter is initialized, e.g. through a database connection. The onEvent method then initializes every dynamic parameter to catch events and process these. Finally, in the onDetach method, every open connection is closed.

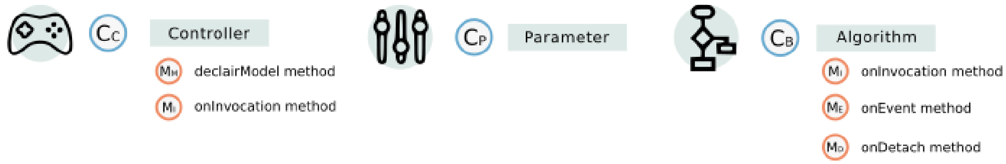

Figure 4: SDK class for a data processor

By using the StreamPipes SDK and its classes, we can freely define and implement any spatial operator needed for spatial analysis in a CEP system.

To summarize, we chose StreamPipes as it provides many advantages for our goal. While other tools would be feasible, the following key features needed for a spatial CEP system led us to our decision: (1) StreamPipes provides a native inclusion of different stream processing frameworks such as Apache Kafka, Apache Flink and Apache Spark; (2) It is built from the ground up with CEP in mind; (3) It is easy to modify as well as to create new pipeline elements with the StreamPipes SDK; (4) Each pipeline element can be created independently, but also combined with any other element, which allows for many different combinations in a pipeline; (5) It provides a simple drag-and-drop pipeline editor which reduces users' requisite technical know-how; (6) It is an open source tool under the Apache licence, which allows a wide range of fields and people to use it without restrictions, from academics and industry to the general public.

Additionally, a number of StreamPipes features are beneficial for a spatial CEP, and for future development of the system and the operators: (1) Since its inception, the system has been based on semantic technologies and concepts. This allows the easy combination of different operators. Each pipeline element describes its required input and the output it provides in a standardized semantic annotation. In addition, each dataset is transformed and annotated with the semantic information by the different EPAs. (2) The system uses JSON natively for the exchange of data. This allows an easy implementation of new data types, such as GeoJSON, and facilitates the integration in existing platforms. This means that: (3) It is interoperable at its core and can combine different data sources and types. (4) It already includes some simple, WGS84-based, spatial coordinates if they are point data. (5) It has advanced capabilities for time-series analyses as well as machine learning algorithms for stream processing. (6) It was granted Apache incubator status in 2019. This facilitates its high visibility and an active core team for the development of future features, as well as the integration of the operators developed.

3.2 Operators Implemented

For the selection of the spatial operators, we can now build on the foundations of StreamPipes, the challenges defined in the GeoStreams literature, and the classification of (spatial) operators for spatial analysis as set out in the existing GIS literature.

First, as discussed in the literature, we need to define and select a suitable spatial data model to use with the spatial operators in the CEP. As is well known, e.g. from Longley et al. (2011), there are two key models for spatial data: the entity model and the field model. Additionally, the data structure itself has to be modelled, either as vector or as raster data. For stream processing, we identified the entity and vector model as the most efficient, because the computation time is shorter, and storage needs of vector data are smaller compared to raster for stream processing. While raster is highly efficient in distributed computing and benefits from its similarity to image analysis, these benefits are mostly irrelevant here. To process and communicate data between the different CEP components, interoperability must be ensured (i.e. the autonomous interaction of software components by using standardized data formats; Andrae (2013)). Here, two further considerations come into play. First, for overall interoperability, we go to the OGC and use the standard ISO 9007 as well as the reduced simple feature model (OGC, 2019). Second, we need to define a semantic standard description of the data, an ontology. StreamPipes uses the basic geo vocabulary[4], but is missing an ontology domain for the geometry. Here, we propose a simple, provisional ontology which uses WKT. This allows us to minimize the computational workload. An example of code to define an event is shown in Figure 5. Alternatively, more extensive ontologies can be found in, for example, Bucher et al. (2017) or Scheider and Tomko (2016).

```
.requiredStream(StreamRequirementsBuilder
      .create()
      .requiredPropertyWithUnaryMapping(
          EpRequirements.domainPropertyReq("http://www.opengis.net/ont/geosparql#Geometry"),
          Labels.withId(GEOMETRY_KEY), PropertyScope.MEASUREMENT_PROPERTY
      )
      .requiredPropertyWithUnaryMapping(
          EpRequirements.domainPropertyReq("http://data.ign.fr/def/ignf#CartesianCS"),
          Labels.withId(EPSG_KEY), PropertyScope.MEASUREMENT_PROPERTY
      )
      .build()
)
```

Figure 5: Example of code for the provisional ontology

Not all spatial operators identified in the previous section are essential for our spatial CEP. From our point of view, the key operators are those that enable the analyses carried out most commonly by a GIS user. We therefore exclude statistical analysis functions and network analysis. Some of these common operations are already performed by existing EPAs, while others have specific requirements, such as the need for specific parametrizations for geostatistical models. Compared to other operators, the ones for such analyses are therefore of relatively little benefit for the initial system. Instead, additional operators such as the projection of coordinate systems, the integration of data sources and data sinks, as well as their use as static information like a geofence, provide a higher benefit and need to be implemented first. While these operators are not seen as special in traditional GIS, they need special care in a streaming environment. Additionally, adjustments to geometries, such as the refinement of lines into their subgroups, are needed. While we use vector data as the main data model, some

[4] https://www.w3.org/2003/01/geo/

special data usage scenarios and operations do exist which necessitate the implementation of raster operations. Galić (2016) and Galić et al. (2017) focus on this topic in their work.

The considerations just outlined lead us to 33 basic spatial operators, shown in Figure 5. Each operator is implemented as an EPA in StreamPipes. Therefore, complex operators can be realized either as a single EPA or as a combination of several EPAs. Following Brauner (2015, p. 38) that operators should be 'generally available, yet their discovery and usability is hampered', we divided the operators into eleven groups, for ease use: (1) Base Operators, (2) Change on Geometry Operators, (3) Geofence Operators, (4) Measure Operators, (5) Operators on Window Functions, (6) Thematic Operators, (7) Topology Operators, (8) Calculate from Raster Operators, (9) Routing Operators, (10) Data Operators and (11) Derived Geometry Operators. Some of the specific operations, particularly the raster operations and the routing operators, are implemented as a proof of concept and were required for the implementation of concrete realistic examples.

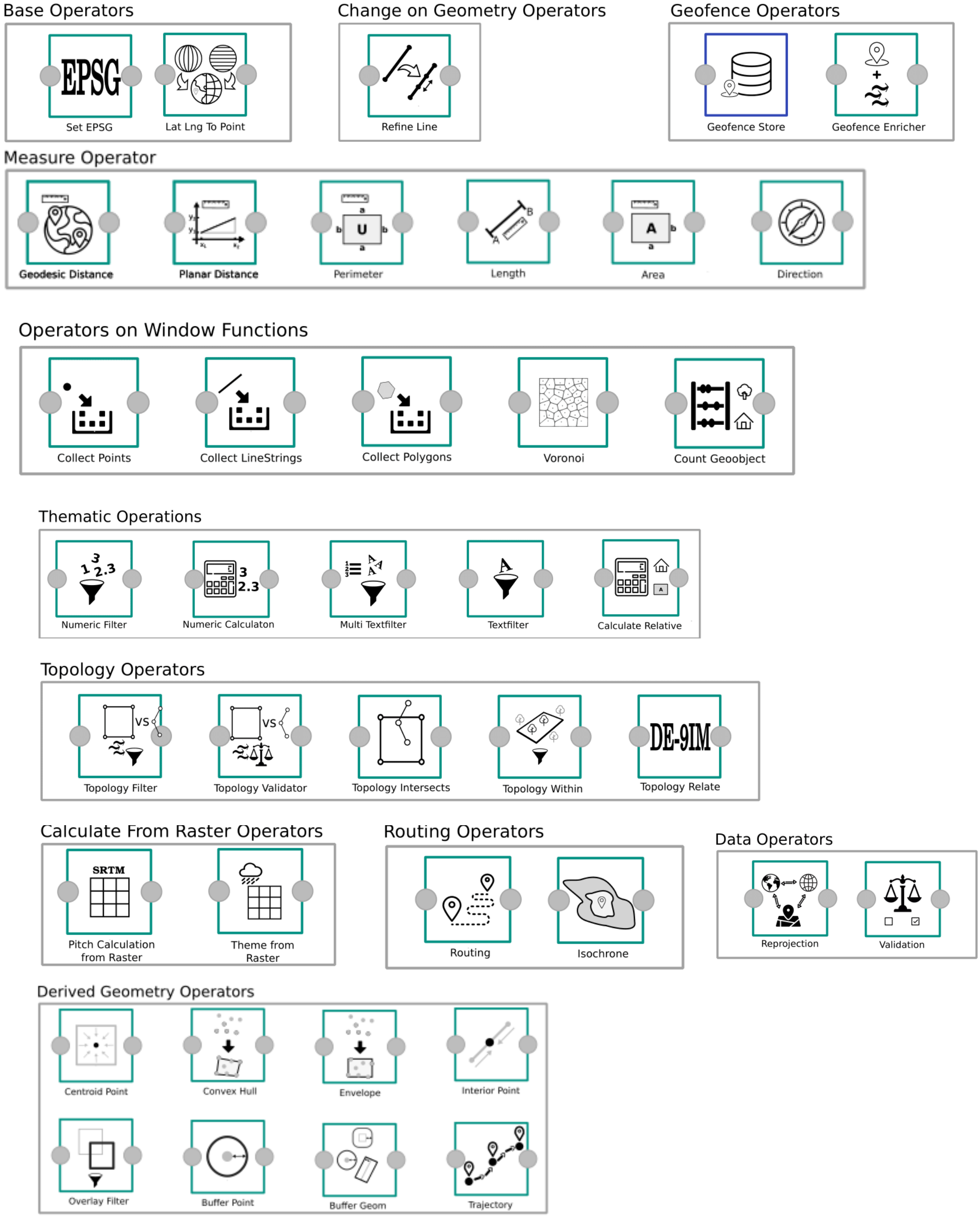

Figure 6: The basic spatial operators implemented

Which operator groups to include was by and large obvious, notably groups 1, 2, 4, 6, 7 and 10. We selected geofences as a key operator, as this operation is essential to detect the entering/leaving of moving objects in an area, which is often seen as a central functionality in GeoStreams. Window functions were included as the most efficient option to compute the number of objects in a time window, and for the temporary storage of events. This provides the basis for future extensions for statistical learning methods or machine learning algorithms. Raster operations are included for future extensions and to allow the addition of further data sources, such as remote sensing data or weather forecasts, as these are most often available directly only as raster data. Routing operators are included to enable flexible route planning or isochrones dependent on the changing circumstances. As any new event can, for example, change the road situation, it is important to be able to analyse the impact on other objects, such as an ambulance, and to react to the new situation. Finally, the derived geometry operators allow the most common operations between different data points as well as the plotting of the trajectory. The trajectory was chosen because the live movement of a point is a key benefit of a streaming approach compared to traditional GIS. We also used the existing operators of StreamPipes in addition to our selection.

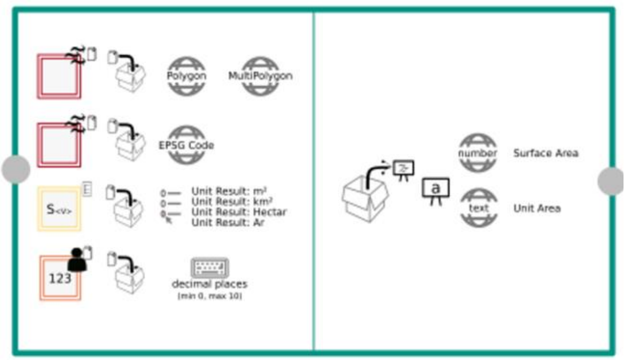

Figure 7: Example for (polygon) area calculator

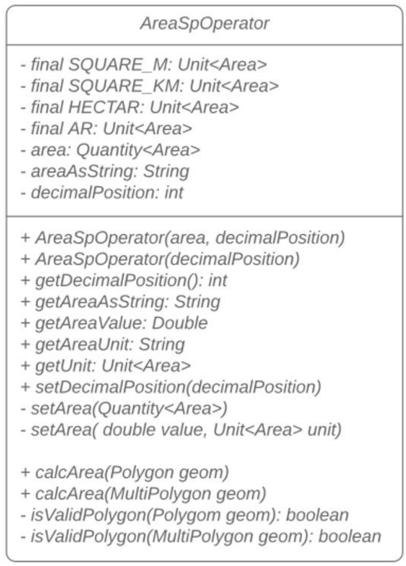

Figure 8: UML class diagramm

To show how each operator is implemented and what the required in- and outputs are, we use the (polygon) area calculator as an example. This operator allows the computation of the area of an object. Each operator can be shown as its SDK class with each operator or as the EPA in StreamPipes from a conceptual point of view. Figure 7 shows the different methods in the operator; Figure 8 shows the interaction of the classes within the StreamPipes SDK, as described in Section 3. The JTS geometry classes were used for the getLength and getPerimeter methods. As inputs, a polygon or multipolygon as well as an EPSG code are required. Additional required inputs are the accuracy, defined as the number of digits following the decimal point, and the unit result. The operator then returns the size of the area as a number, and the chosen unit result as a text. If a MultiPolygon is used for the input, the sum of all geometries is returned.

For the implementation of the operators and the data models, existing software libraries can be used to reduce complexity and the time spent on details. We use JTS (Davis, 2018) and Apache SIS as our libraries.

3.3 Example Pipelines

We present two simple pipelines to show the possibilities of our approach and to provide a simple, qualitative evaluation. These examples allow a starting point for future analyses. Open data is used in both pipelines.

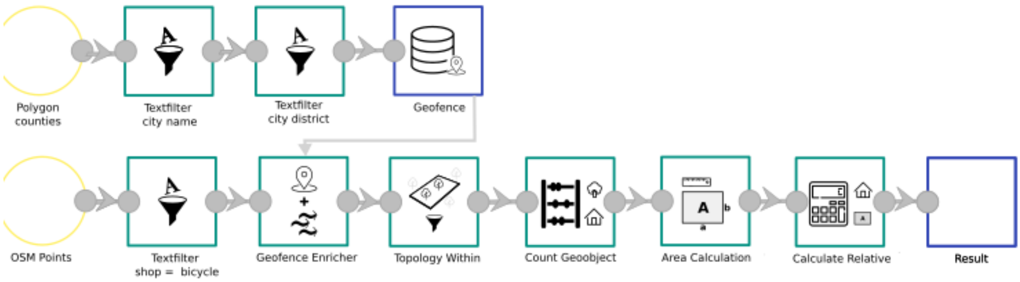

Figure 9: Computing the number of specific objects per area size in a polygon defined by a geofence

The first pipeline shown in Figure 9 is a simple computation of the number of bicycle shops per km^2 in a polygon defined by a geofence. This is a typical, simple computation, which can be done in a standard GIS. It illustrates how existing functions can be used, as well as future possibilities. To perform the analysis, two data streams are defined. The geofence is chosen by filtering existing polygons based on their name. In this example, the district of Karlsruhe is selected from a list of polygons of all districts in Germany. This geofence is stored in a database and combined with the second stream in the pipeline. For the second stream, first all OSM points are included and filtered to include only bicycle shops. These are combined and then filtered by the geofence using the 'topology within' operator. Finally, all geo objects are counted, the area of the geofence is calculated, and the number per km^2 is calculated. The result can then be further used, visualized and/or stored. To extend this example to a GeoStream, we simply need to change the input of the first and/or second stream to a real data stream, e.g. moving bicycles or cars. This then returns the density of vehicles in an area in real time, in order, for example, to monitor the risks of traffic jams. The usability of our chosen tools allows this operation without changing any operator in the pipeline itself.

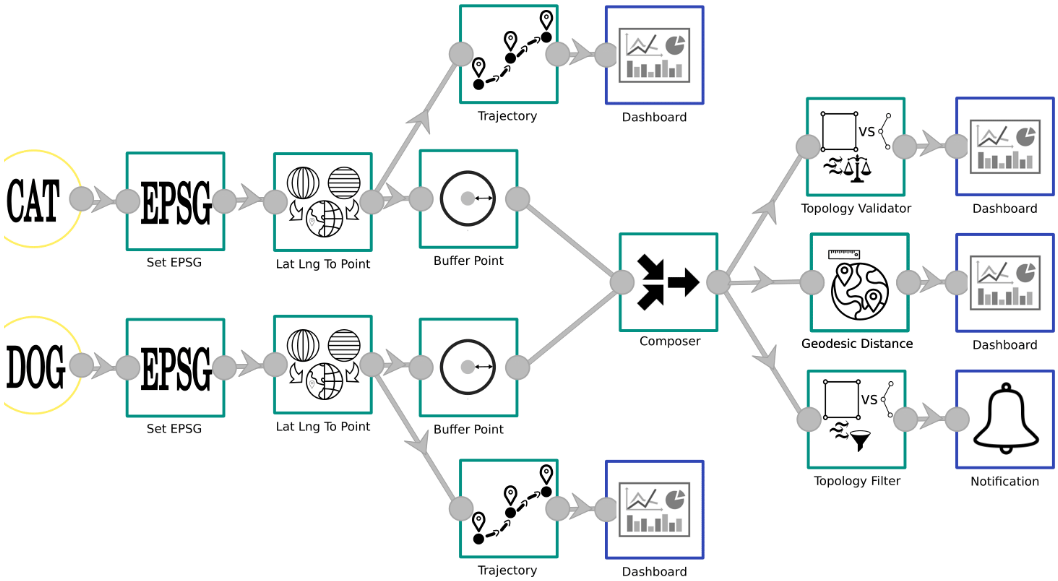

Figure 10: Computing distance and convergence of two moving points

A more interesting pipeline, which goes beyond the typical capabilities of a GIS, is shown in Figure 10. Here, we are interested in the live distance between two moving objects, the trajectory of each, and a warning if the objects risk converging. Two moving objects, a cat and a dog equipped with GPS sensors, were used as input streams. For each stream, the coordinate system was defined and transformed to a point geometry. The trajectories of the streams were first visualized in a dashboard as live data. Next, for each object, a buffer area was defined; both buffer areas were then merged into one stream for synchronization. Finally, their proximity was shown as 'TRUE' (close) or 'FALSE' (not close), the live (geodesic) distance between both points was visualized, and a notification was defined if the status was 'TRUE'. All of these operations are performed simultaneously. A simple, qualitative performance evaluation was done with 3,000 objects as input using an artificial data stream. No output lag could be detected when all streams were running.

The two examples show that combining the different spatial operators with existing StreamPipes operators allows for a broad range of analyses. Further examples of pipelines, together with the datasets and operators, can be found at https://StreamPipes.apache.org/ (StreamPipes, 2020).

4 Conclusion and Future Work

In this paper, we developed and presented spatial operators for a state-of-the-art, open source CEP tool, StreamPipes. These operators allow the execution of complex spatio-temporal analyses on streaming data for complex events. This addresses the research gaps identified by Brandt and Grawunder (2018), providing an easy-to-use tool which is modular and readily extendable. By using the semantic properties of StreamPipes in the operators we implement, we can easily connect different types of GeoStreams. The existing machine learning tools for CEP can leverage spatio-temporal analyses in combination with the spatial operators which we developed. Our operators for spatial analysis are based on the existing literature in the fields of stream processing, GeoStreams and classical GIS literature. We illustrated the ease of use as well as feasibility of our approach in two examples of pipelines for spatial analysis. By using open data and open source software, the examples can be easily reproduced and extended.

Regarding our research question of how to handle GeoStreams to allow the wider GIS community to be able to work with them, we have shown that by using CEP together with simple, commonly used spatial operators, we can handle GeoStreams efficiently and make them simple and intuitive to use.

The purpose of this paper was to promote a new category of software system / software functionality, namely spatial CEP systems for processing GeoStreams as a novel and upcoming paradigm. We have shown an example implementation with a focus on efficiency, extensibility and user-friendliness. Our examples should illustrate possible applications and the usefulness of the approach; they were not used for a crisp and formal evaluation of the system. Extensive evaluation of the strengths and weaknesses of the approach should be the subject of future work. In general terms, the evaluation dimensions should include: (i) expressiveness of the approach in order to solve theoretically and practically relevant problems; (ii) efficiency and scalability of the runtime; (iii) formal tests of usability for end-users with little prior geo(-ICT) knowledge; (iv) efficiency of the modelling environment for end-users (with aspects such as modular reuse of operators, pipelines and sub-pipelines, or ease of implementing new operators with the StreamPipes SDK). Initial studies and experiments regarding (i) and (iii) have been undertaken within the WEKOVI research project, but much more systematic analysis is certainly required.

Another key limitation of the work presented here is its scope. We provide a foundation for more extensive GeoStream analysis, but many other interesting operations have yet to be implemented. For future work we therefore identify two focus topics: spatial data mining, and asynchronous analysis. Spatial data mining encompasses methods from statistical analysis (e.g. kriging and clustering), and network analysis. By carrying out these approaches in GeoStreams, additional challenges emerge, solving which could lead to new analyses and insights. The problem of analysing asynchronous data streams was discussed by Schmutz (2019), and a potential solution was proposed independently by Whittier (2018). This problem is inherent in all stream processing and is a feature that is missing in StreamPipes. Using the well-known technique of a petri net (Petri, 1966) could be an alternative solution to Whittier (2018). In addition, a more thorough and extensive evaluation setup is planned.

This work further contributes by providing non-technical researchers with a more approachable way to perform spatial analyses on streaming data. Using the drag-and-drop possibility of StreamPipes, complex analysis pipelines can be created easily. By extending it with spatial operators, this open source tool will provide additional benefits for various fields, but it will be a boon in particular for geographical researchers. We hope that this will provide a starting point for future researchers and practitioners using GeoStreaming and analyses on GeoStreams, opening up new (research) questions.

Acknowledgements

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Measuring Ultrafine Particle Concentrations at Salzburg Airport: Using the Airport Closure due to Runway Reconstruction as a Natural Experiment

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Abstract

During April and May 2019 Salzburg Airport was closed for five weeks for runway renovation. As a result, landings and take-offs (LTOs) were impossible during this period. This offered a rare opportunity to carry out a field study to investigate the concentration of ultrafine particles prior to, during and after completion of the renovation work. During the construction phase, the sharp particle concentration peaks resulting from LTOs during normal operation were no longer encountered at the measurement site, 140 m from the runway. Towards the end of the airport closure, construction activity was all but completed and LTO activity was strictly limited to test purposes, which resulted in average ultrafine-particle concentrations of approximately 3,000 to 4,000 cm^{-3} (06–23 h average value). The reconstruction work itself and the high numbers of construction vehicles caused an increase in ultrafine-particle concentrations of an additional 1,000 to 2,000 cm^{-3} (06–23 h average value). In comparison, in the three weeks before and the three weeks after the closure, when airport operations were running as normal, concentrations increased by 3,000 to 4,000 cm^{-3} (06–23 h average value).

Keywords:

ultrafine particles, particle number concentration, airport, natural experiment, construction site

1 Introduction

The reconstruction and closure of the runway at Salzburg Airport (SZG) during five weeks in April and May 2019 provided a unique opportunity to assess environmental effects of activities at the airport. Particles smaller than 100 nm, so called ultrafine particles (UFP) or nanoparticles, were monitored before, during and after the closure. Every five seconds, the Condensation Particle Counter (CPC) counted the number of UFPs per cm^3 at a carefully selected fixed location about 140 m from the runway. UFPs entering the measurement container cannot, unfortunately, be directly attributed to their source. In an attempt to counter this problem, this study estimates the effects of landing and take-off (LTO) as well as construction activity on levels and profiles of particle number concentrations in the weeks before, during and after the closure and reconstruction of the runway.

UFP emissions from aircraft

All turbofan and turboprop aircraft burn kerosene-type fuel and therefore emit UFPs. Particle concentrations immediately after exiting the aircraft's engine peak at around 15 nm in size in lower engine power conditions (≤50 %) and at around 40 nm for higher power conditions (≥70 %) (Kinsey, 2009). Particles are spatially mobile and change over time. After having travelled 100 to 300 m downwind, aircraft exhaust plumes contain a nucleation peak of particles that are mostly smaller than 10 nm with concentrations of about 10^6 cm^{-3}, and a condensation peak with particles around 80 nm with concentrations of about 10^5 cm^{-3} (Herndon et al, 2008; Zhu et al, 2011; Lobo et al, 2012; Mazaheri et al, 2013; Timko et al, 2013; Lobo et al, 2015). Peak concentrations surpass $2 \cdot 10^6$ cm^{-3} at about 150 m, and $3 \cdot 10^5$ cm^{-3} at up to 750 m from the runway at medium-sized commercial airports, compared to an urban background of $5 \cdot 10^3$ cm^{-3} to $5 \cdot 10^4$ cm^{-3} (Morawska et al, 2008; Press-Kristensen et al, 2012; Møller et al, 2014; Peters et al, 2016; Ren et al, 2016; Stafoggia et al, 2016; Vorage et al, 2019). Based on short-term variations in particle number concentrations, engine power settings of individual planes can be deduced during LTO activity (Vorage et al, 2019). When conventional kerosene is replaced by biofuel for aircraft propulsion, particle number concentrations can be reduced, but significant challenges remain and the use of biofuel remains limited in practice (Moore, et al, 2017; Wang et al, 2019). As aircraft are a source of noise and particle matter not only during LTO activities proper, the city of Salzburg along with the airport authority operates a permanent, spatially embedded, NoiseDesk® monitoring system (EMS Bruel & Kjaer, Melbourne, Australia) that continuously allocates acoustic data to positions along the main flight routes from and towards the airport.

UFP emissions from construction activities during runway closure

Construction processes involving concrete generate UFPs. Impact demolition and recycling of dry materials cause a local increase in UFP concentrations by about $2 \cdot 10^5$ cm^{-3} (Kumar et al, 2012). In close proximity to the activity, cutting concrete results in concentrations that average more than $7 \cdot 10^5$ cm^{-3} and peak above $2 \cdot 10^6$ cm^{-3} (Azarmi et al, 2014). During certain phases of the abrasion and pouring of concrete, average and maximum concentrations surpass $1 \cdot 10^5$ cm^{-3} and $1 \cdot 10^6$ cm^{-3} respectively (Bujak-Pietrek and Mikołajczyk, 2019). These particles can indeed be caused by the construction activity itself, as UFPs with diameters of less than 30 nm can be created by mechanically fracturing concrete (Jabbour et al, 2017). Moreover, construction sites tend to involve the use of heavy vehicles. Clearly, diesel trucks emit UFPs as well (e.g. Zhu et al, 2002; Herner et al, 2007). As a result, some level of UFP emissions could be expected from multiple sources that were spatially linked to the runway reconstruction work.

A poorly regulated health hazard

UFPs are abundant in number but have small total mass. Because emissions regulation is historically built around limits on mass, UFP concentrations have remained largely unregulated. Unfortunately, this does not mean that they are harmless (see e.g. Gatti and Montanari, 2015). Airborne UFPs are capable of entering the body and circulating around the body. As a result of their small size, UFPs can enter the alveoli and pass through cell membranes while circumventing defence mechanisms like phagocytosis (Obersdörster et al, 2005; Bakand et al, 2012; Loane et al, 2013; Lu et al, 2015). Therefore, they can spread through lung tissues and organs such as the heart, liver, kidney and brain (Oberdörster et al, 2004; Kreyling et al, 2010; Yacobi et al, 2011) and even the central nervous system (Kleinman et al, 2008; Kreyling et al, 2013). While moving throughout the human body, UFPs can severely damage the immune and nervous systems, can cause inflammation, can negatively affect organ and cellular functions (e.g. mitochondrial activity), can damage DNA, and can pass to the foetal side of the placenta to pose a threat to the foetus during pregnancy (e.g. Bakand et al, 2012; Bové et al, 2019; Lu et al, 2015; Miller et al, 2017; Ulvestad, 2007). As UFPs are more abundant and collectively exhibit larger surface area than larger siblings, they interact with organic chemical structures relatively easily, especially inside the human body (Seinfeld and Pandis, 2016). It will come as no surprise, then, that increased exposure to UFPs is widely believed to reduce life expectancy (Hoek et al, 2010).

2 Methodology

Sampling equipment

Particle concentrations were measured using a condensation particle counter (CPC). CPCs employ a condensation principle whereby heated n-butyl-alcohol vapours are mixed with the nanometre-sized aerosol cloud. A condenser ensures that the supersaturated mixture provides rapid condensation onto the particle fraction. This has the effect of enlarging the aerosol sufficiently for a laser in the visible range to be used to screen the particles, to provide a clear signal.

A CPC of model 5421 (Grimm, Ainring, Germany) was used. This high-accuracy nanoparticle counter has a short response time allowing for reliable counting of concentrations up to 10^7 particles cm^{-3}. Particle concentrations were registered at five-second intervals, stored using specialized software, and exported into an Excel® spreadsheet. It should be noted that all CPCs have a range (smaller particle concentrations) in which each particle is counted individually, and another range (higher particle concentrations) in which this is no longer possible and concentrations are estimated photometrically using the Beer Lambert law. The switching point from individual to photometric measurements is at $1.5 \cdot 10^5$ particles cm^{-3}. It is important to realize that although ultrafine particles can be counted using a CPC, they cannot directly be attributed to their source. Due to the design of the measurement container, the sampling hose inlet of the CPC 5421 is about 2 m long and has a diameter of 40 mm. It therefore required an auxiliary pumping system (60 L min^{-1}) to route the sampling air through the chimney towards the extracting slot for the sampling instrument, at a flow rate of 1.2 L min^{-1}. The temperature in the measurement containers housing these instruments was maintained at 20° C to 24° C. Detailed information on the sampling equipment, including schematic representations, can be found in the Appendix, 'Operating principles of aerosol particle counting', at the end of this paper.

Sampling site
Salzburg airport (SZG) is located about 3 km to the southwest of the city centre, adjacent to highway A1. The Innsbrucker Bundesstrasse (local road B1) passes under the runway via a tunnel (see Figure 1). SZG has a single runway in direction 15 / 33 NS (or 150° / 330°) with a length of 2750 m, a stop-way of 100 m and a width of 45 m. The direction of the runway enables aircraft to take off and land against the prevailing winds (see Figure 2). SZG is comparatively small, with 18,457 landings and take-offs by commercial airlines in 2018 (Salzburg Airport, 2020). In addition, a large number of private flights are undertaken at SZG, with private landings and take-offs totalling 36,759 in 2016 (Vorage et al., 2019). The fixed sampling site was located approximately 140 m to the southeast of the runway. The site was carefully chosen as the better of two possible locations, one on each side of the runway, based on a previous investigation (Vorage et al, 2019). The site had to satisfy two important requirements: i) the air-conditioned measurement container is fitted with various high-tech instruments requiring a reliable high-capacity power supply; ii) for safety reasons and to minimize potential acts of vandalism, it is operated from inside a fenced area. Other locations considered were not close enough to the runway, and because the runway operates in both directions (150° to 330° or 330° to 150°) they would not have allowed appropriate monitoring of spatially distributed exhaust aerosols.

Airport development and runway reconstruction
The airport was opened at its current location in 1926, since when it has been expanded and modernized multiple times. A significant extension of the runway was undertaken in the 1960s. A second terminal building was added in 2003 to be able to better handle peak traffic during the winter holiday season. The runway at SZG was reconstructed in April and May 2019, leading to the airport's closure for five weeks from 24.04.2019 to 28.05.2019 (Salzburg Airport, 2019).

Noise Desk data and LTO activity
The flight routes for each individual flight at SZG can be combined into a single map using the permanent spatial NoiseDesk® monitoring system (EMS Bruel & Kjaer, Melbourne, Australia). Such a map was plotted for three individual 24-hour periods of flight movements (from 0 h in the morning to 24 h (midnight)). The three days shown here represent typical days before, during and after the airport closure for reconstruction: 24.04.2019 (Figure 3a; before closure), 15.05.2019 (Figure 3b; during closure) and 30.05.2019 (Figure 3c; after reopening). The closure of the airport inhibited any form of LTO activity, reducing associated UFP emissions to almost zero, while the nearby heliport was still in operation (see Figure 3b), generating some aircraft-related exhaust aerosols.

Construction activity and UFPs
The absence of airplane-related LTO activity does not imply a complete absence of ultrafine particles coming from the airport site. For example, approximately 115 kt of asphalt in four layers were needed for the top cover of the 45 m wide, 2850 m long runway, which was supplied by a constant flow of trucks (on average one every three mins). This four-layered stratum is porous enough to facilitate rapid rainwater draining, which makes runway grooving and the associated generation of dust obsolete (Agrawal & Daiutolo, 1985). The increase in particle concentration of 1,000 to 2,000 cm^{-3} (06–23 h mean value) as observed at the measurement site was attributed to high material turnover and the use of heavy machinery,

which was limited to 06:00–22:00. Only low-level noise-generating tasks (electrical wiring, installation of above-ground lighting sources, etc.) took place during the night hours, these same activities also being less generative of UFPs.

Limitations and study design

UFPs are very small, with a diameter up to 100 nm. They can be counted using elaborate and expensive technical equipment, but cannot be traced back to their source. Using a single carefully positioned, stationary measurement container (Vorage et al, 2019), particle concentrations were measured every five seconds in the weeks before, during and after the airport closure. The measurement container was located immediately outside the airport's safety perimeter. In this way, UFPs were counted as close as possible to normal LTO and construction activity. Nevertheless, because of the particles' small size, wind may carry UFPs towards or away from the measurement container. Therefore, the direction and speed of prevailing winds were taken into account when interpreting particle concentrations. This setup was chosen in order to obtain a more reliable estimate of the effects of LTO activity, as well as of the effects of different phases of the reconstruction process on particle concentrations at SZG.

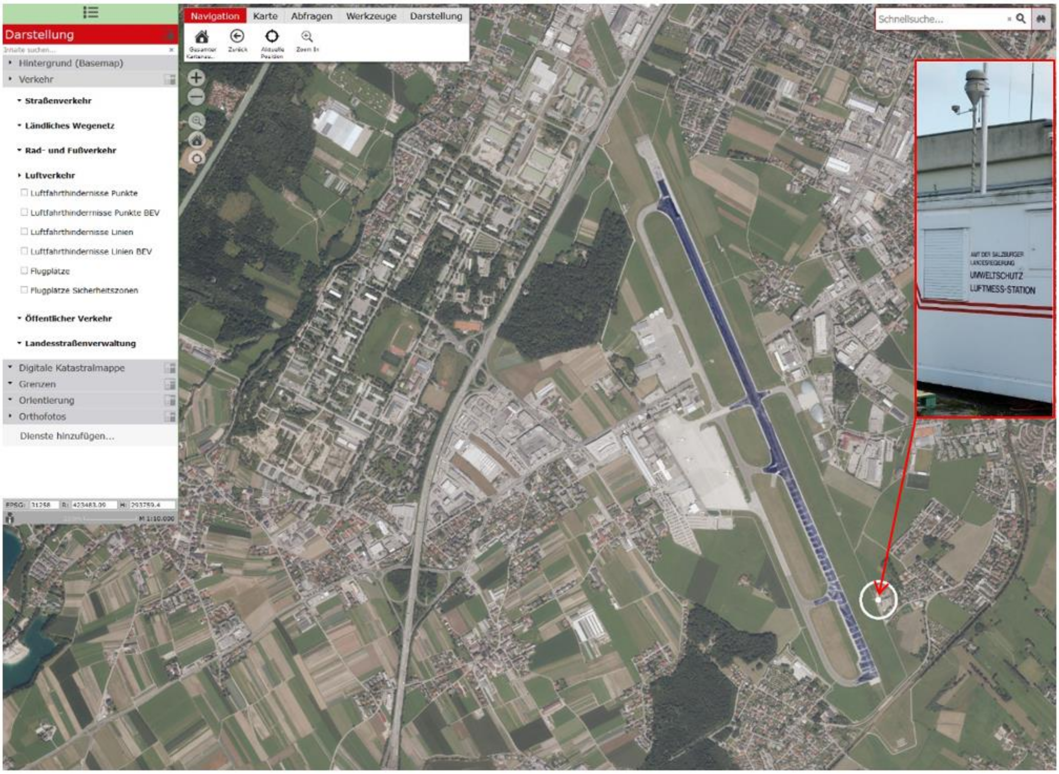

Figure 1: Satellite picture of Salzburg Airport during the reconstruction of the runway with sampling site (O) to the southeast of the runway (SAGIS Maps, accessed on 11 October 2019). When the wind was blowing from 170° to 335°, particles resulting from activities on the runway could be registered at the sampling site.

Figure 2: Simulated 3D-perspective in the direction 150°, showing the runway at SZG (accessed on 16 April 2020). Prevailing winds blow in both directions through the Salzach Valley, as shown by the superimposed arrow (modified Google Earth image).

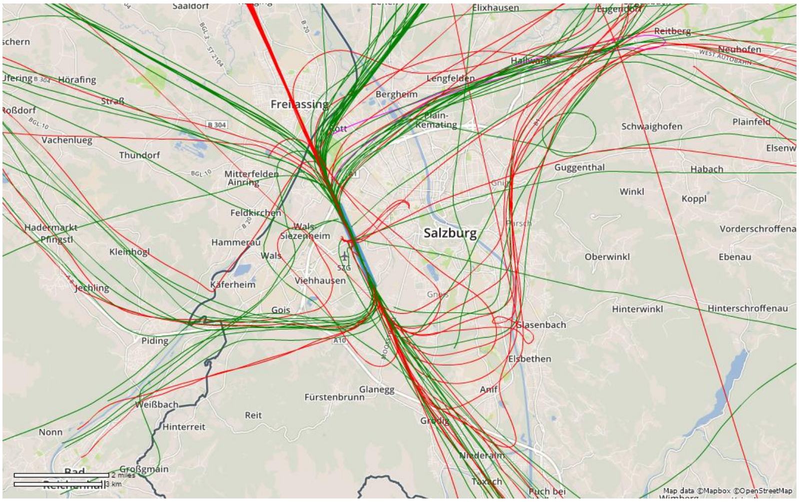

Figure 3a: LTO activity at SZG on 24.04.2019 (OpenStreetMap), monitored via the NoiseDesk® data-gathering system coupled to permanently installed sensor stations. Inbound flights in red, outbound flights in green highlight the wider airport neighbourhood subject to airplane-based aerosol exposure.

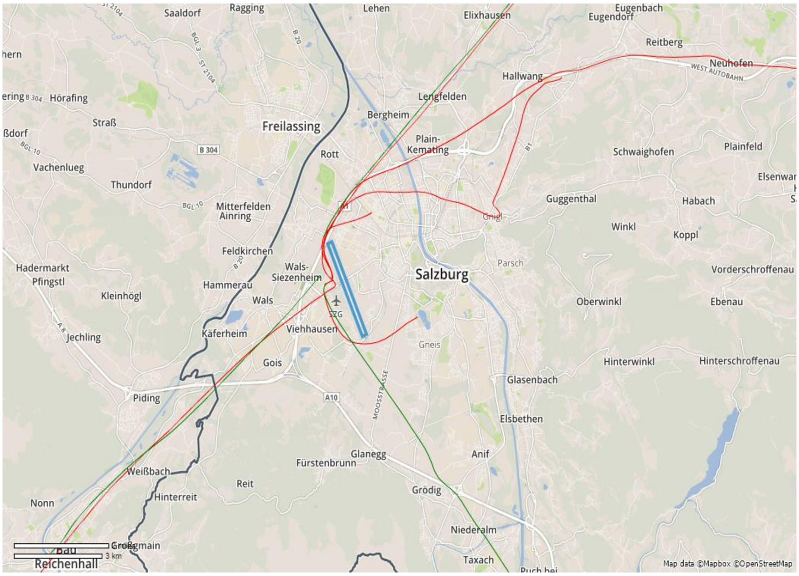

Figure 3b: LTO activity at SZG on 15.05.2019 (OpenStreetMap), monitored via the NoiseDesk® data-gathering system coupled to permanently installed sensor stations. Inbound flights in red, outbound flights in green. The presence of flight data during runway closure relates to helicopter activity at the nearby heliport, which explains the irregular shapes of the flight routes.

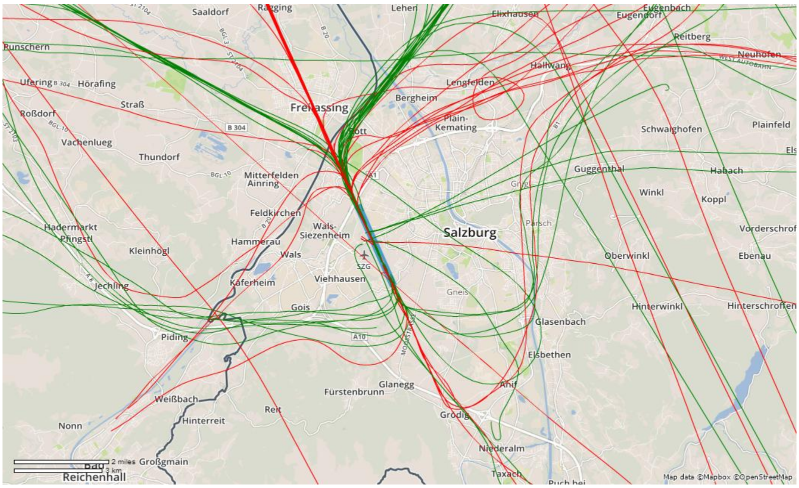

Figure 3c: LTO activity at SZG on 30.05.2019 (OpenStreetMap), monitored via the NoiseDesk® data-gathering system coupled to permanently installed sensor stations. Inbound flights in red, outbound flights in green highlight the wider airport neighbourhood subject to airplane-based aerosol exposure.

Satellite images of airport reconstruction

The reconstruction of the runway at SZG was captured by satellite images, some of which are presented here. Due to the length of the runway and the tight schedule for completing the work, different kinds of activity took place simultaneously at different locations.

Figure 4a (left): Satellite picture of Salzburg Airport during the reconstruction of the runway (Google Maps, accessed on 11th of October 2019).

Figure 4b: Satellite picture of work on the runway's bitumen layer (Google Maps, accessed on the 11th of October 2019).

Figure 4c: Satellite picture of work on the runway's drainage system (Google Maps, accessed on the 11th of October 2019).

Figure 4d: Satellite picture of work on the south-eastern end of the runway (Google Maps, accessed on 11th October 2019).

3 Results

SZG operates daily from 6 h to 23 h. The construction site was operational from 6 h to 22 h. To allow comparison between periods of normal airport operation and runway reconstruction, data from 6 h until 23 h is represented in the summary statistics consistently. The entire period of analysis runs from 03.04.2019 until 18.06.2019. It includes three weeks both before and after the five-week runway reconstruction period.

The CPC was permanently located at the sampling site and continuously measured particle concentrations at five-second intervals. Short interruptions occurred during pre-construction (04.04.2019: 10:06:25 to 10:38:25; 23.04.2019: 13:34:35 to 13:40:55), during construction (25.04.2019: 8:22:35 to 8:23:00; 27.04.2019: 07:02:55 to 07:03:00; 07.05.2019: 13:21:15 to 13:21:20; 10.05.2019: 07:10:35 to 07:10:40 & 07:29:05 to 07:29:10; 14.05.2019: 08:07:05 to 9:19:55), as well as during post-construction (03.06.2019: 06:02:50 to 06:03:00; 17.06.2019: at 22:04:25 only).

Table A: Summary of statistics of particle numbers at five-second intervals between 06:00:00 and 23:00:00 for the three-week period before, the five-week period during, and the three-week period after construction.

Aerosol counts	Sample size (n)	Average (cm^{-3})	Median (cm^{-3})	Minimum (cm^{-3})	Maximum (cm^{-3})	Standard Deviation (cm^{-3})	Wind to CPC (% time)
Three-week period before construction 03.04.2019 – 23.04.2019	256,863	6,665	4,274	393	285,700	9,982	32.24
Five-week period during construction 24.04.2019 – 28.05.2019	427,804	4,548	3,440	461	2,173,000	8,386	50.12
Three-week period after construction 29.05.2019 – 18.06.2019	257,756	7,251	5,180	950	258,900	10,803	41.36

Table B: Overview of wind speeds towards the sampling site measured at half-hourly intervals between 06:00:00 and 23:00:00 for the three-week period before, the five-week period during, and the three-week period after construction. Wind speeds are given in metres per second (m s^{-1}).

Wind direction and speed	Wind towards CPC (170° - 335°)						Other dir-ections (%)
	0-1 m s^{-1} (%)	1-2 m s^{-1} (%)	2-4 m s^{-1} (%)	4-6 m s^{-1} (%)	6-8 m s^{-1} (%)	8-12 m s^{-1} (%)	
Three-week period before construction 03.04.2019 – 23.04.2019	6.94	12.11	11.84	0.95	0.00	0.41	67.76
Five-week period during construction 24.04.2019 – 28.05.2019	4.16	13.96	21.71	8.41	0.82	1.06	49.88
Three-week period after construction 29.05.2019 – 18.06.2019	2.45	13.20	17.41	5.71	1.63	0.95	58.64

Average and median particle concentrations were much lower during construction compared to those during airport operation before or after construction. Winds that increase the spatial mobility of UFPs towards the sampling site were more prevalent during construction, with winds speeds mostly ranging from 1 to 6 metres per second (m s^{-1}), implying that the difference may be even larger than shown here. In addition to wind direction and wind speed, further meteorological conditions should be considered. Prior to the runway closure, the month of April was relatively mild and largely dry. The month of May, when the bulk of the reconstruction activity took place, was the coolest May for the last 200 years and experienced above-average rainfall. The period was characterized by unstable weather and good air mixing, which resulted in below-average pollutant concentrations at a reference site within the city of Salzburg that captures emissions from road traffic. In particular, the level of particles with a diameter of 10 µm or less (PM_{10}) and 2.5 µm or less ($PM_{2.5}$) were low compared to the May measurements of previous years (Kranabetter, 2019). After SZG was re-opened to air traffic, June was one of the warmest Junes on record for the last 200 years, with above-average sunshine and below-average precipitation.

In line with the presence of short-lived peaks associated with LTO activity during airport operation, the standard deviation and the difference between average and median particle concentrations were lower during the construction period. Interestingly, the highest particle concentrations were registered during two events of the runway restoration: one was attributable to the asphalting work (which is always associated with high hydrocarbon emissions); unfortunately, we are unable to retrospectively deduce what source caused the other maximum.

Table C: Summary of statistics for particle numbers at five-second intervals between 06:00:00 and 23:00:00 for the different construction phases (Salzburg Airport, 2019). Note that some of the phases overlap due to the length of the runway and the tight schedule for the runway reconstruction.

Aerosol counts during Construction (sub)phases	Sample size (n)	Average (cm^{-3})	Median (cm^{-3})	Minimum (cm^{-3})	Maximum (cm^{-3})	Standard deviation (cm^{-3})
Installing four-layer asphalt stratum 24.04.2019 – 18.05.2019	305,404	4,837	3,461	483	2,173,000	9,765
Drilling and cabling for LED-lighting, removing upper bitumen layer 12.05.2019 – 15.05.2019	48,378	4,953	3,494	483	744,100	11,082
Installing markings and borders, landscaping 13.05.2019 – 22.05.2019	121,818	4,809	3,556	461	2,173,000	13,661
Testing and finalizing site before usage 22.05.2018 – 28.05.2019	85,680	3,819	3,283	1,234	196,500	2,571
Official approval, test flights, re-establishing security perimeter 27.05.2019 – 28.05.2019	24,480	3,540	3,159	1,234	196,500	3,235

Table D: Overview of wind speeds towards the sampling site measured at half-hourly intervals between 06:00:00 and 23:00:00 for the four-week reconstruction period and the single week of testing and finalizing the runway. The official project description allocates 22.05.2019 to both project phases (Salzburg Airport, 2019). Wind speeds are given in metres per second (m s^{-1}).

Wind direction during construction	Wind towards CPC (170° - 335°)						Other dir-ections (%)
	0–1 m s^{-1} (%)	1–2 m s^{-1} (%)	2–4 m s^{-1} (%)	4–6 m s^{-1} (%)	6–8 m s^{-1} (%)	8–12 m s^{-1} (%)	
Runway re-construction 24.04.2019 – 22.05.2019	3.84	12.71	20.30	9.46	0.99	1.28	51.43
Testing and finalizing 22.05.2019 – 28.05.2019	5.31	21.63	31.43	2.86	0.00	0.00	38.78

Particle concentrations were higher during runway reconstruction from 24.04.2019 to 22.05.2019 than during testing and finalization (22.05.2020 to 28.05.2020). A higher prevalence of winds blowing towards the test site in the latter phase implies an underestimation of this difference (see Table D). Construction work involves the removal of existing runway infrastructure, drilling, landscaping, etc., with the accompanying movement of construction vehicles and up to 300 lorry-loads of construction materials having to be transported per day. These activities generate significant particle matter. Finalizing the runway, testing it and obtaining official approval do not require movements of significant numbers of vehicles. On the other hand, test flights result in sporadic short-lived peaks with high particle concentrations. If we compare the last week of airport closure to the four weeks of reconstruction preceding it, we see that construction activity increases UFP concentrations by an estimated 1,000 to 2,000 cm^{-3} on average. In a similar fashion, comparing UFP concentrations during the last week of the airport closure with the concentrations during normal airport operations offers the best opportunity to estimate the particle contributions of LTO activity at 3,000 to 4,000 cm^{-3} on average. Both estimates are likely to be on the conservative side, because most often the wind was blowing towards the sampling site during the period of testing and finalizing the site, which was used as a base-line because particle concentrations were at the lowest level (construction is completed and LTO activity remains limited to very few test flights at most).

To obtain further insights into the effects of the airport closure and runway reconstruction on particle concentrations, observe the particle concentration profiles during the week that included the closure of the airport (Figure 5), and the week during which the airport re-opened (Figure 6).

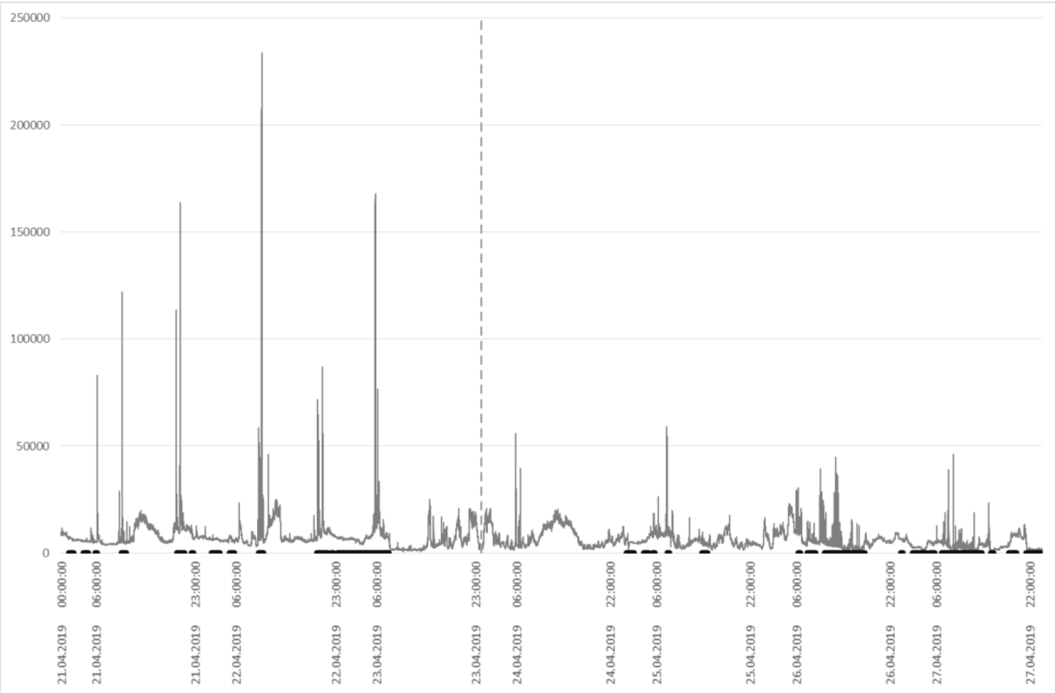

Figure 5: Particle numbers registered at the sampling site from 00:00:00 on 21.04.2019 to 24:00:00 on 27.04.2019. The runway was closed for reconstruction at 00:00:00 on 24.04.2019 (dashed line). Before the closure, the airport operated daily from 06:00:00 until 23:00:00. After the closure, the construction site was active daily from 06:00:00 until 22:00:00. During the periods marked by the black line at the bottom of the graph, the wind was blowing in the direction of the sampling site (170° – 335°).

Short-lived peaks in particle numbers typically associated with aircraft activities are clearly visible during airport operating times before the closure. These only occur when the wind is blowing from the runway towards the sampling site. After the closure of the runway, no such peaks are seen, even during winds towards the sampling site. Construction activity leads to particle concentrations of above 50,000 cm^{-3}. These are higher concentrations than can be attributed to flows of commuter traffic on roads A1 and B1 (see Figure 5). This is corroborated by particle concentrations just before the reopening of the airport. Even with winds towards the sampling site, particle concentrations tend to stay below 10,000 cm^{-3}. During the two days before the reopening, four or five sharp spikes can be distinguished. Given their shape, it is very likely that these were caused by test flights. After the reopening of the airport, the number of LTO-related spikes increases dramatically during winds towards the sampling site. A few such spikes even occur without the proven presence of such winds, which were measured only at half-hourly intervals (see Figure 6). Throughout the night, particle concentrations are low, no matter the wind or the operationality of the airport.

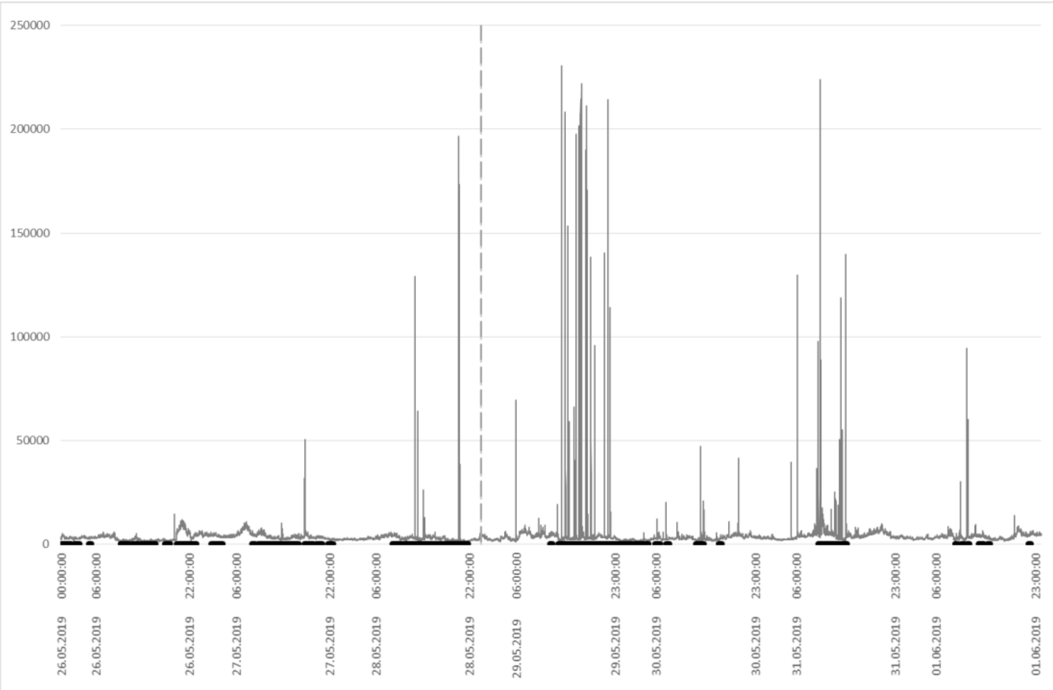

Figure 6: Particle numbers registered at the sampling site from 00:00:00 on 26.05.2019 to 24:00:00 on 01.06.2019. The runway was reopened at 00:00:00 on 28.05.2019 (dashed line). Before reopening, the construction site was active daily from 06:00:00 to 22:00:00. After reopening, the airport operated daily from 06:00:00 to 23:00:00. During the periods marked by the black line at the bottom of the graph, the wind was blowing in the direction of the sampling site (170° – 335°).

4 Conclusion

The closure of the runway at Salzburg Airport (SZG) for reconstruction during spring 2019 created a unique opportunity to evaluate the differences in numbers of airborne particles between no-flight conditions and normal LTO activities. Despite the comparatively small number of landings and take-offs at SZG, the measurements in this study suggest an air-traffic related impact that amounts to an average of 3,000 to 4,000 particles cm^{-3} during airport operations at our sampling site, about 140 m from the runway. The typical short-lived peaks associated with LTO activity disappeared during the construction work, other than for a few test flights shortly before the airport was reopened. Aircraft emissions are not geographically limited to LTO activity at the airport itself; they persist over the approach and take-off flight routes at SZG. The measurements were conducted at a single location at ground level and are not readily transferrable to large geographical areas due to the three-dimensional movement of the particle sources (i.e. aircraft) and complicated particle dynamics over space and time. Construction activity increased concentrations by about 1,000 to 2,000 cm^{-3}, as measured at the same location. Both estimates are expected to be on the conservative side due to the prevailing winds during our measurements, which greatly affect the spatial distribution of the exhaust plume. Moreover, LTO activity at SZG tends to be significantly lower in spring than in winter, the latter being related to the peak skiing season.

In the context of the current debate around emissions and climate change in relation to aircraft and construction sites, these findings add new information to help improve decision-making processes. The findings are particularly important in light of the lack of regulation surrounding UFPs. The current gravimetric limits are not effective in regulating them, because UFPs are large in number and small in mass. Such regulations are designed for use at European level, but foremost for road traffic-related exhaust (e.g. EuroLex, 2019). Aviation emissions are currently being assessed as part of the EU's H2020 research programme (Aviator, 2020). If regulatory limits prove to be difficult to impose, a legal framework for active measurement could at least be put in place. To improve local knowledge and decision making, we recommend extending fixed air-monitoring stations to include UFP counters, such as the one at SZG, at all airports.

During airport operation, landing fees could reflect the (expected) effects of specific LTO activity on air quality, as different types of aircraft and fuel as well as engine settings generate different emissions (Kinsey, 2009; Moore et al, 2017). Because wind speed and direction affect the distribution of the emission plume (Vorage et al, 2019) and weather conditions affect particle dynamics (especially during winter by facilitating the formation of inversion layers and increased particle number concentrations at ground level; Janhäll et al. (2006)), LTO-related emissions for a given aircraft can be deduced by statistical inference. In the longer term, the number of scheduled flights of a specific aircraft type (and engine) would yield a dataset that could provide an airplane-specific emission factor and its landing-fee category.

During airport (re)construction, further measures could be taken to limit the impact of UFPs. Trucking routes could be adapted to reduce local residents' or workers' exposure to UFPs. Air inlets of airport ventilation systems should include modern, well-serviced filter systems (Stephens and Siegel, 2013) because outside air is used for ventilation (Morawska et al., 2009; Quang et al., 2013). Although further measurements would be needed to determine the optimal setup, ventilation inlets could potentially be positioned at locations that exhibit relatively low particle numbers. Moreover, ventilation systems could include air-monitoring to actively adjust the mixing of inside and outside air, as well as to take air from a variety of inlets. This could be particularly effective in an airport setting, given that UFP concentrations at airports fluctuate heavily in relation to LTO activity.

Appendix

The next few pages will briefly highlight the basic components for accurate and reproducible aerosol-counting under fluctuating meteorological outdoor conditions. The entire sampling line, consisting of sampling pipe and Condensation Particle Counter (CPC) along with other environmental monitoring systems, is housed in an air-conditioned container (see Figure 7), which is kept at a constant temperature of 20° C throughout the measurement campaign.

Figure 7:
Setup of the aerosol measurement unit within the air-conditioned container, showing the CPC-5421 unit with the attached sampling pipe and data processing unit.

Dehumidification (Permature stage)

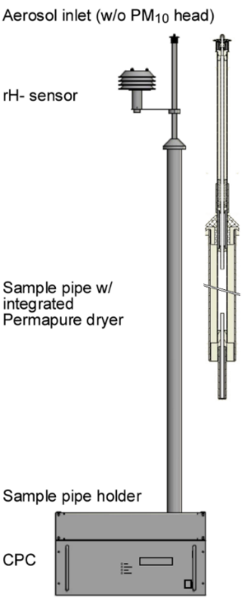

Figure 8:
Schematic representation of the core unit consisting of CPC-5421 with attached dryer stage. As other environmental measurement devices in the container are also fed with outside air, a collection chimney (throughput 60 L min-1, supplying all instruments) was installed on the container. An enlarged section of the inlet with permapure dryer is depicted to the right of the entire unit.

The relative humidity (rH) and outdoor temperature (T) are recorded by appropriate rH- and T-sensors. Sample air entering the measuring unit via the sample inlet (see Figure 8) is routed past a permapure dryer (consisting of a Nafion-membrane) straight towards the CPC. Once a threshold rH-value of 55 % is exceeded, the drying stage is activated autonomously. Once it drops below 55 %, the dryer is deactivated. Aerosol drying is essential particularly during the warmer months of the year as the fairly cool conditions within the measurement unit would inevitably result in condensation, flooding the sampling line with significant amounts of water that could damage sensitive parts of the sampling equipment.

The main advantage of dehumidifying air with Nafion is that sample air is not heated. Thus, drying takes place at almost the same temperature as counting the aerosol particles, thus avoiding degassing of volatile organic carbons even before the measurement cell is reached. As outlined in the upper part of Figure 9, dried air flows in the opposite direction, on the outside of the Nafion-membrane, which separates it from the aerosol sample flow. Aerosol drying using a Nafion membrane is achieved by generating a pressure gradient across the membrane. This gradient is obtained by mixing 1.2 L min^{-1} of exhaust air from the system (sample out) with 1.8 L min-1 of room air (inside air); in a second step, it is filtered and sucked through a critical orifice (needle valve) via a vacuum pump. The counter-flow of this sleeve of clean, dry air assures that the removal of residual humidity from the sample air occurs steadily and at the same time avoids the accumulation of humidity along the Nafion-membrane. Nafion consists of a fluorocarbon backbone dotted with sulfonic-acid side chains that exhibit three distinct properties:

i) acts as acid catalyst due to the strongly acid properties of the sulfonic acid group;
ii) functions as an ion exchange resin when exposed to solutions;
iii) readily absorbs water, from the vapour phase; i.e. each sulfonic acid group will absorb up to 13 molecules of water. The sulfonic acid groups form ionic channels through the bulk hydrophobic polymer enabling water to be readily transported through these channels.

Once the water has passed the membrane, a vacuum pump routes the moisture to a condensation drain, where it is released to the exhaust outlet.

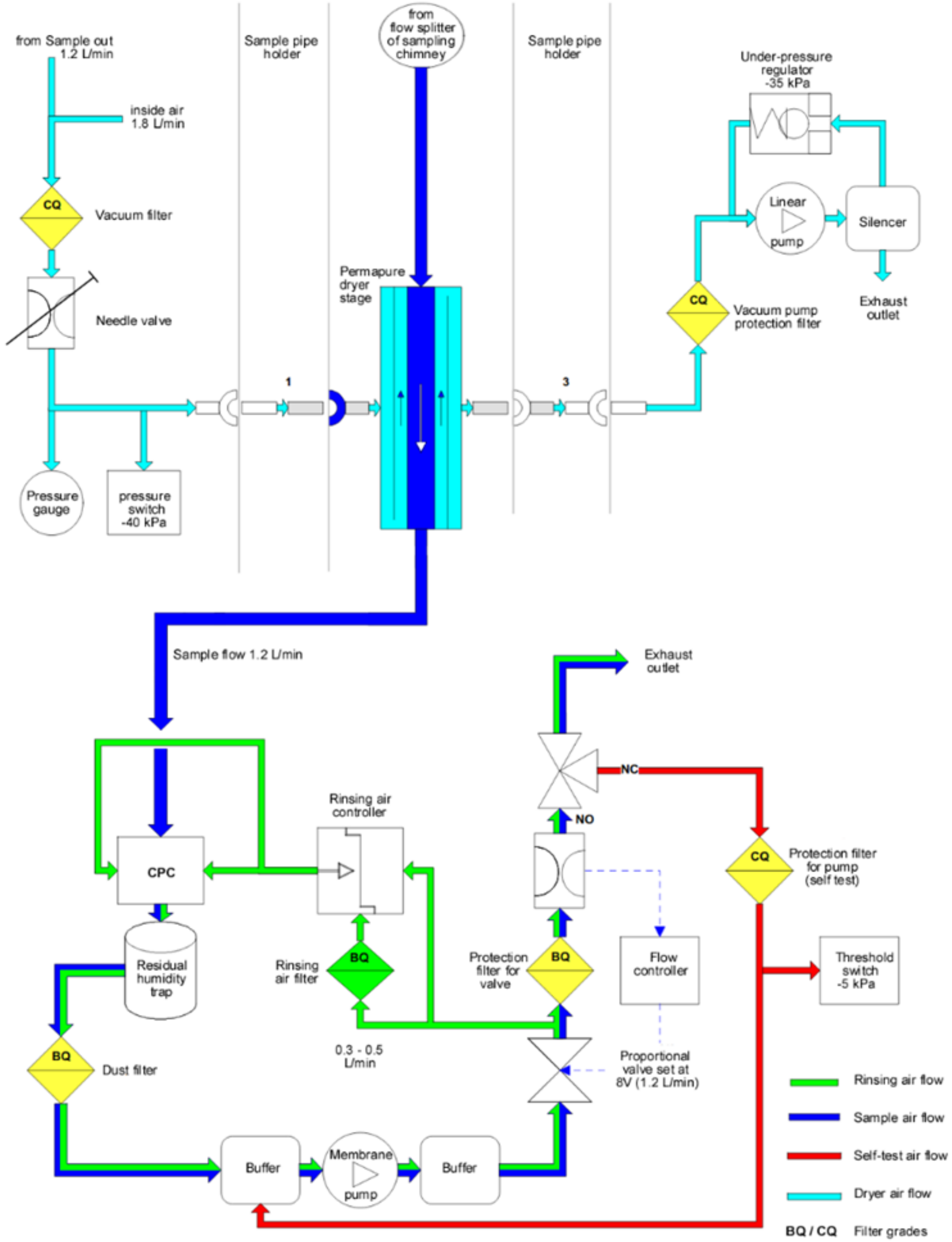

Figure 9: Block diagram of the principal components of the sampling unit consisting of Nafion-dryer stage and CPC detection unit.

The dried sampling air is then routed towards the actual measurement unit (lower part of Figure 9), where various auxillary sampling lines are embedded. These are necessary to flush the system with clean air, enable repetitive self-test modes along with zero-check count modes at regular intervals, and continously monitor the flow through the pipeline. These additional modes are necessary in order to maintain a calibrated count mode throughout the entire operation of the system. Once these control parameters are within a given tolerance window, the dried aerosol is routed into the CPC, where the actual counting takes place.

Condensation Particle Counter (CPC)

The working principle of a CPC (Grimm, 2020a; Grimm, 2020b; Grimm, 2020c) is basically identical to an optical particle counter (OPC). However, owing to the fact that the optical detection uses a laser operated in the visible size range, this would imply that only particles >250 nm would be detectable. Sensing particles as small as 5 nm requires an additional pre-treatment of the coarse aerosol prior to counting. As shown in Figure 10, this can be achieved via a condensation technique using an alcohol that works with both hydrophilic and hydrophobic aerosols.

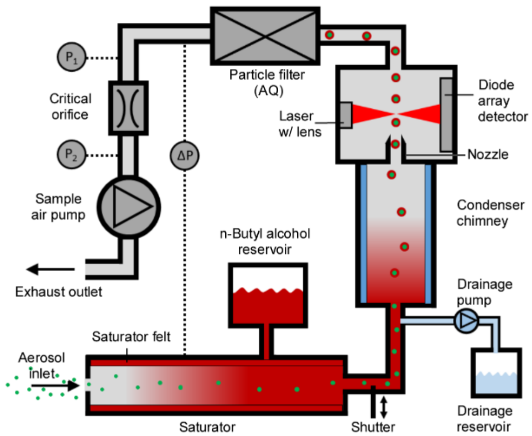

Figure 10: Basic functional units of the CPC-5421 unit.

The sample air flow is first routed through a saturation chamber. It consists of a n-butyl-alcohol-saturated felt that is heated to a constant 36° C. This temperature assures saturated conditions within the saturator stage of the CPC, where both aerosol and alcohol vapour can mix properly. To induce particle growth via heterogeneous condensation, the aerosol-alcohol vapour is chilled down to 10° C in the condenser stage of the CPC. Rapid cooling (maintained via the constant aerosol flow of 1.2 L min^{-1}) assures that alcohol condenses onto the nm-sized aerosol fraction within the condenser's chimney, generating µm-sized particles that can be easily detected within the optical particle counter unit. To do this, the enlarged aerosol is routed through a nozzle that generates a train of aerosol particles, which feeds directly into the down-stream OPC-unit (see below).

Principle of Optical Particle Counting (OPC) within the CPC

A tiny aerosol stream leaves the condensor stage via a stainless-steel tube (d_i=3 mm) and interacts with an orthogonally positioned laser beam (see Figure 11). Since the laser is orthogonally aligned, the detector array will not be blinded by the light coming from the laser beam. Only aerosol-induced scattered light will reach the detector. In order to enhance the detection threshold, a mirror is used to increase yield. The count rate is derived from the number of particles and the volume flow rate.

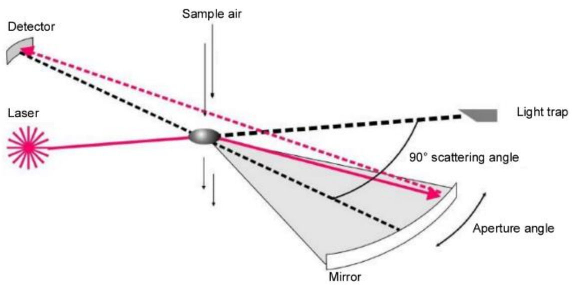

Figure 11: Particle counting via scattered laser light

Depending on aerosol concentration, two counting modes are used in the CPCs: the single particle count mode, which detects single scattered light pulses, is predominant for low particle concentrations ($<1.5\cdot10^5$ cm^{-3}). The photometric mode, on the other hand, detects an aerosol cloud and becomes the dominant counting mode at high aerosol concentrations ($> 1.5\cdot10^5$ cm^{-3}). The single counting mode represents an absolute count mode, whereas the photometric mode is a nephelometer-like absorption mode that requires empirical calibration. There is a transitional regime close to the switching point in which both modes are active and the particle concentration is calculated based on both modes depending on their proximity to the switching point.

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Using Spatial Concepts to Integrate Data and Information from Various Sources for a Knowledge-based Assessment of Impervious Surfaces

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Abstract

In this study, we present a concept for the assessment of impervious surfaces integrating VHR satellite data and *a-priori* information from additional datasets. Spatial concepts like neighbourhood and region, distance, spatial dependence or spatial variability are adapted in a knowledge-based approach using an object-based image analysis model to accumulate evidence from different sources. We look at constraints for timely and comprehensive VHR optical data acquisition that covers larger areas with adequate image characteristics (sensor family, seasonality, sensor viewing angles and sun inclination). For a study area covering the municipality of Hallein (Austria), we discuss preliminary results with a focus on real-world object characterization (including surface material, spectral reflectivity, object size and shape) and on building a knowledge-base for the classification of real-world objects. We also assess image characteristics and effects on image analysis. The knowledge about real-world object characteristics and image object statistics will be used to develop an integrated approach that aims for transferability to larger areas.

Keywords:

imperviousness, VHR Pléiades imagery, OBIA, rule-based approach, data integration

1 Introduction

Knowing the spatial distribution and the annual increase of impervious surfaces (i.e. soil-sealing) is of high community interest and is used as an important indicator for spatial management and planning actions. In particular, soil-sealing causes the loss of the biological functions of soils and soil fertility, the loss of ecological functions and biodiversity, the increase of natural disasters (e.g. flooding), the reduction of quality of life, and the missing of climate-change goals (e.g. due to heat effects). The Environment Agency Austria assesses annually the total area of artificial impervious surfaces, using the available digital cadastral information, the result being a soil-sealing rate of approximately 12.0 ha/day for the period 2017–2019 (Umweltbundesamt, 2020). However, due to delays that are the result of the process of cadastral data assessment (several years; sporadic update of data), the results do not necessarily reflect the current situation of soil-sealing in Austria. In this context, we use the term 'imperviousness' or 'impervious surface area' synonymously for human-driven (artificially) soil-sealed areas; natural bedrock and bedrock material (e.g. rock debris) are not considered 'impervious surfaces'.

Optical satellite data with very high spatial resolution (VHR) and state-of-the-art data analysing methodologies provide standardized, reproducible, transparent and timely analysis products with a mapping scale < 1:5000. Thus, VHR analytic products fulfil the technical requirements needed for fine-scale spatial management and planning actions. Impervious surface areas can be derived from VHR imagery by the specific spectral reflectance of the surface materials used (Weng, 2012), which are usually mineral, metallic or of hydrocarbon origin (Heiden et al., 2007; Kotthaus et al., 2014). However, analysing imperviousness in urban and urban-rural environments based on VHR satellite imagery is challenging, as the variety of real-world objects results in complex image content with high spectral heterogeneity (Weng, 2012; Myint et al., 2011; Hamedianfar et al., 2014). In urban areas, impervious surfaces comprise mainly man-made constructions like buildings (with different sorts of roofing materials), roads, parking areas, pavements, squares, sports fields, permanent swimming pools and others, which are fully or partially impervious (Hamedianfar et al., 2014; Heiden et al., 2007). Real-world objects can be characterized by a sensor/image model and a scene model, a simplification of the real world, which describe objects 'as the analyst would like to extract them from images in terms relevant to image processing' (Blaschke et al., 2014; Strahler et al., 1986). Thus, objects can be interpreted from images, e.g. by their size, shape, texture and context. Using other data sources (e.g. LiDAR or multitemporal images), the set of describing attributes is expanded with information on object height, topographic information and surface roughness, as well as with temporal characteristics (seasonal variation, change, or stable conditions). By summarizing these attributes of real-world objects in a knowledge-base and formulating specific rules, the information can be converted into a consistent hierarchical (semantic) model of remote sensing-based land-cover and land-use types (Andrés et al., 2017; Arvor et al., 2019). However, depending on the spatial and spectral resolution of the satellite sensors used, the granularity of the derived information varies.

In what follows, a conceptual object- and knowledge-based classification framework using earth observation (EO) data is presented. The classification aims in general terms to be of use for annual monitoring of artificial impervious surfaces, from regional to national scale (map scale of analysis products < 1:5000). Preliminary analysis results for the study area of Hallein (Austria) are also discussed. The methodological framework includes: 1) considerations with respect to data availability (revisit period, required sensor parameters for full area coverage) and resulting data quality; 2) transparency, reproducibility and transferability of the methodology; 3) improvement of results by a comprehensive integration of a priori knowledge in the form of ancillary data and the use of spatial concepts in the information-extraction process.

2 Objectives and Methodological Framework

Spatial management and planning institutions need comprehensible up-to-date spatial information of very high resolution and quality (map scale < 1:5000) for monitoring and decision support. In Austria, currently, aerial orthographic imagery with a ground sample distance of < 25 cm is used as base data to derive adequate information by expert-based visual interpretation and manual delineation. In general, this approach is both labour and time intensive, and thus expensive. Although orthophotos are available in Austria every three years (consisting of spectral bands red, green and blue (RGB); near infrared band (NIR) is optional), because of the missing spectral calibration of data and the absence of yearly repetition these data are inappropriate for cost-effective large-scale data analysing methodologies that use a high degree of automation. On the other hand, large-scale analysis products of impervious surface areas, like the European-wide high-resolution layer of imperviousness[1] (HRL Imperviousness, 20 m pixel resolution), offer insufficient spatial detail and are not sufficiently up-to-date (3-year repetition interval, delayed distribution) to meet the spatial management requirements of local planning authorities.

Recent VHR satellite imagery fulfils the requirements of spatial and spectral resolution (at least < 1 m panchromatic, RGB and NIR bands, top-of-atmosphere (TOA) calibrated), as well as ready data acquisition over large areas in a specific timeframe and at yearly intervals (Banko et al., 2014). However, to achieve complete VHR-imagery coverage using the same sensor family for a larger area in a certain timeframe, constraints in image quality (primarily sensor-viewing, shadow and temporal effects) must be considered. Knowledge-based or rule-based approaches can foster the transparency of data-analysing methodologies, and in the best case their reproducibility and transferability using other data of similar characteristics. Object-based approaches minimize the salt-and-pepper effect that could emerge from using pixel-based approaches (Blaschke and Strobl, 2001) and allow a complete attribution of real-world object-features and their relations (Lang, 2008; Tiede et al., 2010). Data integration of available a-priori information increases cost-efficiency and enhances image classification stability and validity through evidence accumulation (Matsuyama and Hwang, 1990).

In general, impervious surface materials differ spectrally in VHR imagery from vegetation (high reflectance in the NIR band), water or shadow (low reflectance in the NIR band), and snow (high reflectance in RGB and NIR bands). Additional 2.5D information (in our case, based on LiDAR data) on object height and object-height variation (i.e. homogeneity or 'roughness') is valuable to distinguish real-world objects of similar spectral reflectivity, but differing in height (e.g. roads vs. buildings, or grassland – shrubs – trees). Even if the LiDAR data is not up to date, it may help in defining the initial status quo as an additional source of evidence – i.e. the state of affairs pertaining when further monitoring is initialized using VHR optical data only. Ancillary data may be useful for identifying imperviousness that has already been assessed, as well as for distinguishing the likelihood of impervious surface areas based on spatial concepts (e.g. buildings occur primarily next to roads). Still, additional data must be evaluated regarding its availability, precision, areal coverage, date and completeness.

[1]Copernicus land monitoring service – Pan-European High Resolution Layers (2006–2015): https://land.copernicus.eu/pan-european/high-resolution-layers

Developing an appropriate data-analysis approach requires various factors to be taken into consideration. Hence, we propose the following methodological framework for a knowledge- and object-based image analysis (OBIA) approach to identify artificial impervious surfaces from VHR optical data, and to monitor their development over time in the context of soil-sealing:

- General considerations

  1. The methodological design is modular, extendable and adaptable (i.e. has the potential to be developed further, e.g. integration of optional thematic information or of future remote-sensing data, as well as of multi-temporal analysis of big-data analysis solutions)
  2. Reducing free parameters in the image classification as much as possible and enriching rule-based classification using valid spatial concepts / spatial relations to increase transparency, reproducibility and transferability of the methodology. Doing this also takes into account the main issues (principally viewing geometry and image registration) for further annual change detection monitoring by integrating concepts of object-based change detection (Chen et al., 2012)
  3. Extracting impervious surface areas primarily from VHR optical data (the data actuality is of utmost importance), but enriching the classification results with additional information in a rule-based classification (e.g. correction of object shadow effects, or building displacement resulting from sensor-viewing effects).

- Considerations for defining the main pillars of the technical implementation

  4. Top-of-atmosphere calibrated **VHR satellite imagery**, ideally from just one sensor family, is able to cover the area of interest yearly within a specific timeframe (e.g. Pléiades, WorldView-2/3, SuperView-1 etc.). This is the most important data source; hence, other data sources (often not the most recent ones) provide further evidence but are weighted less compared to the up-to-date VHR data.
  5. Building a **knowledge base** (Andrés et al., 2017) that contains a qualitative description of real-world objects with certain attributes and values, a sensor-specific statistical characterization of image objects, and a formulation of rules to represent real-world objects in images. For the statistical characterization, ancillary information on buildings, roads, vegetation, water etc. help to reduce the subjectivity in the sampling procedure. Information on image objects is contained in an **object feature library** (Strasser et al., 2014), which consists of spectral statistics, and structural, textural and shape-related information on different spatial and spectral scales.
  6. **Using image segmentation** algorithms based on knowing the pros and cons (Hossain and Chen, 2019); increasing the transferability of the methodology by using strategies of over-segmentation (over-segmented image objects can still be merged based on additional knowledge; Drăguţ et al., 2014), which makes the subsequent enhancement of object delineation easier by integrating expert-knowledge and ancillary information.
  7. Developing expert rules and stable classes for **data classification** and to mitigate data limitations (primarily spatial displacement of objects due to sensor viewing angles, shadow and temporal effects), using the information from the knowledge base.

8. Indication of **classification probability**: integrating expert knowledge on contextual coherence increases the plausibility, stability and transferability of the assessment (e.g. buildings are more likely next to a road; natural rock is more likely than other forms of impervious surface close to streams or rivers).

3 Study area and Data

The municipality of Hallein (47.683 N, 13.090 E) is located in the federal state of Salzburg (Austria). Hallein covers 26.98 km² and is characterized by urban structures (roads and buildings, industrial areas), as well as urban-rural structures (mix of small and large buildings, roads, grassland, agricultural land, forest). In this area, around 9,600 buildings were identified from ancillary building data; 75% of buildings are less than 10 m high and 95% are less than 16.5 m. Altitude ranges from 420 to 1,368 m, resulting in an altitudinal vegetation zonation from sub-montane to high-montane. Figure 1 shows seasonal characteristics in Hallein indicated by the phenological season (vegetation period, snow-free period and period of low precipitation). Additionally, sun inclination and cloud-free periods are used to detect optimal and sub-optimal satellite-image acquisition periods for multi-purpose usage (optimal: beginning of June to mid-August; sub-optimal: mid-April to end of May / mid-August to end of September).

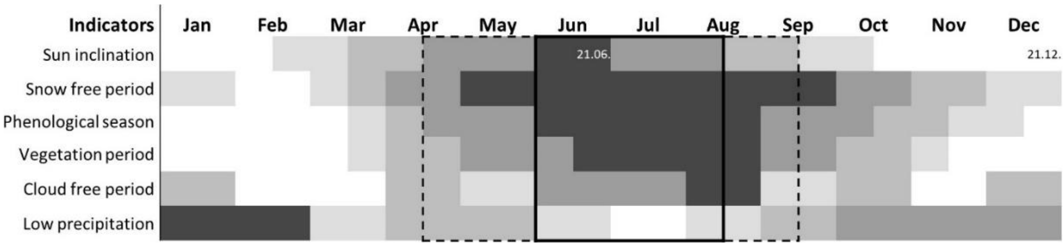

Figure 1: Optimal (black frame) and sub-optimal (dashed frame) image-acquisition periods for multi-purpose usage in the area of Hallein, derived from six different indicators. Indicators categorized from dark (favourable) to light (less favourable): sun inclination (at 47° latitude, highest inclination on 21.06 and lowest on 21.12); snow-free period (expert interpretation by webcam analysis); phenological season (in-situ observations[2] of vegetation); vegetation period (daily temperature ≥ 10° for Salzburg ZAMG[3]); cloud-free period (using EO-Compass[4] meta-data analysis of Sentinel-2 time series); low precipitation (daily precipitation measurement at Salzburg airport).

VHR Pléiades satellite imagery (RGB and NIR 2 m pixel resolution[5], and 0.5 m panchromatic, 11-bit) was tasked within the optimal image acquisition period (see Figure 1). The imagery was

[2] ZAMG – Yearly phenological observations: https://www.zamg.ac.at/cms/de/klima/klima-aktuell/phaenospiegel/jahr

[3] ZAMG – Daily temperature and precipitation observations: https://www.zamg.ac.at/cms/de/klima/klimauebersichten/jahrbuch

[4] EO-Compass – Your map of the Sentinel-2 archive: http://eo-compass.zgis.at/

[5] Spatial resolution provided by Airbus Defence and Space resampled from original spatial resolution 2.8 m (multi-spectral) and 0.7 m (panchromatic) respectively.

acquired on 26.07.2019 (sun elevation 59.4°, sun azimuth 150.9°) with a mean sensor inclination of 12.7° and a mean viewing angle of *ca.* 20°. The image covers an area of ~ 756 km^2. Due to the viewing angle of the sensor, real-world objects are spatially displaced in the image to the southwest by a distance relating to their height. Thus, real-world objects less than 10 m high show an approximated maximum spatial displacement of 2.25 m in flat areas (other examples: 16.5 m high → 3.71 m; 20 m → 4.51 m; 30 m → 6.76 m). High objects shadow to the north-north-west. Accordingly, the shadow of a 10 m high object in flat terrain is around 6 m; objects of 15 m have shadows of 9 m; 20 m high objects have shadows of ca. 12 m. The Pléiades data was converted into TOA reflectance values and orthorectified using the rational polynomial coefficient (RPC) model as well as a LiDAR-Raster digital terrain model with 5 m spatial resolution (covering the federal state of Salzburg). Coregistration of images was conducted to the latest orthophotos (2017) using 44 ground control points (GCP); image pixel registration was in the coordinate system UTM33N. The coregistered multispectral and panchromatic images were combined to create a pansharpened image using the Gram-Schmidt methodology with specific weightings for the multispectral bands used (R / G / B / NIR = 0.9 / 0.75 / 0.5 / 0.5 respectively).

Several datasets were tested for optional data integration, such as the latest (2016) LiDAR point cloud (point density 4–8 pts / m^2, including a point cloud classification) and the derived digital elevation models (spatial resolution of 0.5 and 1 m pixel size), as were various thematic datasets (including data for buildings, roads, forests and water bodies; EU-defined IACS data for agriculture; biotope-type mapping).

4 Initial steps and preliminary results

4.1 Building a knowledge base using samples and expert-based information

Generally speaking, artificial impervious surfaces are constructions of different materials such as minerals (concrete, fibre cement, slate, roofing tiles, rock in the form of cobblestones, paving stones and loose chippings), metals (aluminium, zinc, copper, lead), or organic compounds (asphalt, asphalt concrete, tar paper, polyvinyl chloride, polyethylene, polyisocyanate etc.) (Heiden et al., 2007). In the near infrared spectral range, these materials differ mainly from water (absorbance) and vegetation (high reflectance); the reflectance in the near infrared spectral range is similar to the reflectance in the red spectral range, with some exceptions (e.g. plastic material). Other spectral characteristics can be attributed by colour in the visible spectral region. Additional object characteristics (size, shape etc.) are listed with descriptions and examples in Table 1.

Table 1: Real-world object attributes, additional descriptions and examples

Object attributes	**Additional description**	**Examples, including land-cover or land-use classes**
Size	valuable to characterize artificial objects of certain size and common dimensions	cars / trucks (width < 2.6 m; length < 6 m (cars) / < 18.75 m (trucks)); small round swimming pools (< 36 m^2, diameter < 7 m)
Shape	specific shape or ratio	rivers or roads (high ratio of length to width)
Texture	high or low variance in values	grassland with low variance in values vs. forest (high variance)
Neighbourhood / distance	logical context	cars on roads or parking lots; small round swimming pool is close to a house, distance to roads (accessibility)
Height	difference in object height	roads vs. buildings; grassland (< 2 m) vs. shrubs (2 -5 m) vs. trees (> 5 m)
Topographic roughness (DTM)	high or low variance in values of digital terrain models	standing water bodies (flat), rock debris (rough) vs. bedrock (less rough)
Surface roughness (DSM / nDSM)	high or low variance in values of (normalized) digital surface models	grassland with low variance in values vs. forest (high variance);
Temporal characteristics	seasonal change or stable characteristics (change due to snow excluded)	roads (less change in spectral reflectivity) vs. meadows (vegetation growth stages – cropping event etc.)

Spectral characteristics of real-world objects were derived, pixel-based, from RGB and NIR Pléiades image bands using ancillary datasets and eCognition 9.5 (Trimble Geospatial) (see Figure 2). Using existing spatially-explicit data reduces the subjectivity of expert-driven sampling strategies and increases transparency and cost-effectiveness. The spectral information we extracted includes the band intensities and remote sensing-based indicators NDVI, NDWI, NDSI[6]. Statistics for minimum and maximum values, as well as data distribution between different quantiles, were calculated per class or specific category and visualized. The following ancillary data were used:

- Roads and parking areas: specific categories for road types (e.g. motorways, major roads to forest roads) were selected and extracted from the Austria-wide polyline GIP data ('Graphenintegrations-Plattform', a standardized dataset used by public administration; polyline = road centre); extraction was done by pixelating the polylines. Roads with more than one lane show less tree-canopy coverage than e.g. forest roads, which needs to be taken into account for optical image classification.

[6] NDVI (Normalized Difference Vegetation Index) = (NIR-R)/(NIR+R); NDWI (Normalized Difference Water Index) = (G-NIR)/(G+NIR); NDSI (Normalized Difference Soil Index) = (R-B)/(R+B).

- Rooftops: a building dataset (polygon) was provided by the federal state administration of Salzburg. Simulating the spatial displacement of buildings in the image, a rule-based algorithm for growing and shrinking built objects was implemented using the building dataset and a LiDAR-Raster nDSM (1 m spatial resolution). For areas where buildings post-date the LiDAR acquisition and/or the building dataset, the VHR information is essential.
- Forest: 60 randomly distributed circular sample areas with a diameter of 20 m (> 75.000 pixel) were selected within a forest dataset (map scale 1:10.000, provided by the federal state administration of Salzburg) and visually inspected for coverage by deciduous or coniferous trees.
- Meadows and agricultural land: EU IACS polygon data from 2019 (Integrated Administraion and Control System, European-wide) was used to extract spectral information from the middle of agricultural fields within a circular sample area of 20 m diameter. Samples exceeding the extent of the agricultural field were not considered. 211 grassland and 27 agricultural sample areas were analysed.

The sampling strategy using validated data of GIP, buildings and EU IACS is reproducible and transferable to approaches using similar characteristics (in terms of available data, spatial and temporal resolution, aim of analysis, geographic area etc.).

Figure 2: Sampling image pixel information using ancillary data. Upper left: motorway (black lines), roads of smaller order (white lines) including forest roads and tracks (partly covered by trees). Upper right: building data (white outlines) and modelled correction of the spatial displacement caused by the sensor view (black outlines); light-coloured buildings without correction vs. grey-coloured buildings. Lower left: randomly distributed sample circles (diameter 20 m; white circles) within forest areas (black lines; map scale 1:10.000). Lower right: sample circles for grass and agricultural land (diameter 20 m; white circles) in the centre of EU IACS fields (Integrated Administration and Control System; year 2019; black lines).

4.2 Image segmentation

The well-known multi-resolution segmentation algorithm (Baatz and Schäpe, 2000) was used for building initial image segments based on Pléiades RGB and NIR bands. For the adjustment of the three variables – scale parameter (which controls the heterogeneity of pixel values forming an object), shape and compactness – the algorithm was adapted to a fully-automated iterative approach (expert-based definition of start- and end-point and increments, automated calculation of image objects, iteratively increasing parameters, and export to shape datasets). Selection of the best-fitting image objects for imperviousness assessment was based on an expert evaluation. Results derived using a scale parameter of around 120 and high values of shape and compactness were found to fit best for our approach (over-segmentation, including small real-world objects like swimming pools, delineation of real-world objects). Since the whole approach is designed for use with Pléiades data (to ease up-scaling), the selected parameters should be transferable to other areas of similar characteristics. Preliminary results of image segmentation are shown in Figure 3. Distinguishing small round swimming pools from surrounding elements is challenging, since swimming pools show similar reflectance values in the NIR spectral range to mineral or metallic material. This is because of the low absorbance of NIR light by shallow water. Optionally, a hierarchical segmentation might be implemented to overcome challenges in deriving real-world objects of different sizes (Drăguţ et al., 2014) – for example by covering small real-world objects with segments on a lower scale, and larger objects on a higher scale. However, image segmentation and in particular the evaluation of image segmentation results are still biased to some degree, depending on the analyst.

Figure 3: *Expert-evaluated results of automated iterative multi-resolution segmentation. Image segments (white lines; scale parameter = 120, shape = 0.6, compactness = 0.9; bands: RGB and NIR) revealing over-segmentation of large real-world objects (e.g. agricultural fields, buildings) as well as delineating small objects (e.g. swimming pools, single trees). VHR image in false-colour infrared (NIR / G / B), showing vegetation in red, buildings and roads in light to dark grey, and swimming pools in light blue.*

5 Future steps for image classification

The knowledge base is the source for extracting impervious surface areas from optical images. Thresholds of NDVI, NDWI etc. are determined for general classes of mineral and metallic materials (fully and partially impervious materials, natural rock material, cars and trucks), artificial hydrocarbons, bare soil, vegetation (trees, shrubs, grassland, meadows, crops), and water or shadow by interpreting the statistics of real-world objects using the spectral reflectivity in Pléiades imagery. If necessary, the knowledge base can be revised and thresholds adapted by transferring the methodology to other Pléiades imagery of similar characteristics. The TOA calibration of the data aims to allow transferability of the thresholds, but this will be evaluated in a follow-up study. In the first step, thresholds are fixed and then optionally fuzzified if this results in a better transferable classification. Optional improvements in image classification and classification stability can be achieved by integrating additional data and drawing conclusions based on spatial concepts:

- Distance to roads (categories of GIP data): determining the distance from classified mineral surface materials to roads in order to calculate the probability of impervious surfaces (distinguishing impervious surfaces from natural mineral material such as bedrock or rock debris)
- Distance to running water (rivers, streams): the probability of rock material close to running water is valuable to distinguish real-world objects of natural mineral material from impervious surfaces
- Building dataset and LiDAR-Raster nDSM (1 m spatial resolution): to overcome the spatial displacement of buildings in optical imagery due to the effects of satellite image acquisitions
- DSM and DTM LiDAR-Raster: calculating object and topographic shadows at the time of optical image acquisition and including rule-based algorithms for refinement of image-object classification.

To overcome the mono-temporal view of the VHR data, freely available Sentinel-2 optical imagery (European Copernicus programme) will be integrated in the future as additional evidence: temporal characteristics of real-world objects are addressable with big-data time-series analyses. Sentinels 2A and 2B acquire images with 10 m GSD for RGB and NIR, as well as with 20 m in red edge and the SWIR spectral region with a revisit time of 5 days under the same viewing conditions; for some areas in Austria, the frequency is increased to intervals of 2/3 days due to overlapping swathes of adjacent orbits. Thus, seasonal variations (phenological, snow coverage, change in water level, topographic and object shadows), temporal changes (mowing or harvesting events), permanent changes with long temporal effects (soil-sealing, clear cuts), as well as temporally stable conditions (e.g. no change of impervious surface areas), can be detected and integrated into VHR remote-sensing analysis. Temporal information derived from inter-seasonal time-series analysis will be used as thematic information and compared with the image objects and classification derived from VHR satellite imagery using sophisticated plausibility checks and validation. A connection to the Sentinel 2 Semantic Data Cube Austria (www.sen2cube.at; Tiede et al., 2019) is envisaged, where human-like queries on all Sentinel 2 data for Austria can be executed on semantically enriched Sentinel-2 data (Augustin et al., 2019); the results can be integrated as an additional evidence layer.

6 Conclusion

The conceptual object- and knowledge-based classification framework presented here for assessing impervious surface areas is the result of a preliminary study to increase the reproducibility, transferability and transparency of VHR remote-sensing based approaches. VHR satellite data is the only data source meeting the requirements for spatial analysis and planning, while data actuality and spatial coverage, as well as spatial and spectral resolution (sensor-calibrated data), are the highest priority for up-to-date and cost-effective information for large areas. Using knowledge- and rule-based classification systems (including known and adaptable thresholds and *a-priori* knowledge) aims to increase both the transparency and the transferability of the methodologies. However, parameterized image segmentation is still a challenging task and requires expert and/or user evaluations. Automation by iterative segmentation processes and expert evaluation is just one approach to address segmentation quality issues: in general, the over-segmentation of real-world objects in imagery and further object-refinement using additional knowledge are recommended. Focus on one sensor family (same resolution and bit depth) and sound calibration help to increase the degree of transferability. The integration of ancillary data with the help of spatial concepts in an object-based data model is valuable, e.g. to correct spatial displacements of high real-world objects due to sensor-viewing effects, distinguishing water from topographic or object shadows, or increasing classification stability and validity by integrating *a-priori* knowledge with classification plausibility. Additionally, multi-temporal (big) data analyses are envisaged to incorporate knowledge on seasonal variability of geo-objects, or to identify finite changes in land cover or land use (e.g. soil-sealing). Detecting annual changes using VHR imagery in combination with indications from satellite data that are spatially coarser but of temporal high resolution requires sophisticated strategies over time, concentrating on relevant objects only. Thus, as an overall conclusion, remote-sensing monitoring approaches for land-cover or land-use classes (such as imperviousness) demand a modular, extendable and adaptable methodological design which can be improved with future developments and data.

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A Histogram Curve-matching Approach for Object-based Image Change Analysis of Urban Land Use

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Abstract

Geographic object-based image analysis (GEOBIA) is commonly applied for land-cover and land-use mapping, updating and change-identification analyses. Following image segmentation, conventional GEOBIA routines classify image objects based on parametric statistical measures, assuming that within-object pixels have normally distributed image brightness signatures. The context for this study is updating extant land-use GIS layers that are out of date as a result of urban expansion. The objective is to develop, test and compare GEOBIA techniques based on a histogram classifier and on a nearest-neighbour classifier, for updating land-use layers. Frequency distribution signatures of land-use change and no-change objects are evaluated for different feature inputs and classifiers within an urbanizing area in San Diego County, California, USA. The results demonstrate that a histogram classifier consistently outperforms a conventional nearest-neighbour classifier. A Histogram Matching Root Sum Squared Differential Area classifier combined with temporal-spectral difference inputs and arithmetic mean for combining multi-feature classifier metrics yielded the greatest accuracy: 79.82% overall accuracy, with 78.72% and 81.07% for change and no-change objects respectively.

Keywords:

land-use change identification, urban growth, GEOBIA, histogram matching

1 Introduction

With the greater availability of high spatial resolution (H-res) remote sensing imagery, geographic object-based image analysis (GEOBIA) has been widely adopted for land-cover and land-use mapping and change analyses (Blaschke et al. 2014). GEOBIA is commonly more accurate than traditional per-pixel-based classification and change-identification approaches because it combines individual pixels into image objects (aka segments), which are subsequently classified based on spectral or contextual criteria with statistical (e.g. mean and standard deviation) or rule-based measurements (Cleve et al. 2008; Gao and Mas 2008; Whiteside, Boggs and Maier 2011). Conventional parametric statistical measurements assume that the within-object pixels are normally distributed and may ignore the richness of frequency distribution signatures of within-object pixels, particularly for objects derived from H-res imagery of urban scenes having spatially heterogeneous material compositions. A few studies have taken advantage of the shape characteristics of within-object histograms for land-cover/land-use (LCLU) classification based on a single-date H-res image (Stow et al. 2012; Toure et al. 2013). However, the curve-matching approach for classification of temporal-spectral objects has not been tested prior to this study.

The growing development of GEOBIA techniques facilitates research on delineating and identifying land-change objects using geographic object-based image change analysis (GEOBICA) (Stow 2010). Many studies demonstrate that GEOBICA outperforms traditional per-pixel-based change identification when applied to multi-temporal H-res imagery for land-use/land-cover change analysis (Chen et al. 2012; Hussain et al. 2013; Johansen et al. 2010). Desclée, Bogaert and Defourny (2006) segmented and classified a multi-temporal SPOT-HRV image layerstack consisting of three layers of reflectance difference bands. The resultant forest land-cover change map yielded high detection accuracy (> 90%) and overall kappa (> 0.80).

GEOBIA approaches to land-cover and land-use change (LCLUC) analysis can be categorized as (1) post-classification comparison or (2) multi-temporal image layerstack (Stow 2010). For post-classification comparison, individual GEOBIA classifications are performed, and then 'from–to' LCLUC (e.g. bare soil to residential built) are mapped by map overlay. Zhou et al. (2008) and King (2011) applied post-classification comparison to GEOBICA for urban land-use/land-cover changes with H-res aerial imagery and achieved substantially greater change-identification accuracy in the resultant LCLUC maps compared to those created by a pixel-based approach. Multi-temporal image layerstack classification takes advantage of multi-temporal transitions to identify LCLUC from co-registered image objects in single segmentation and classification processes. Im et al. (2008) utilized object/neighbourhood correlation images and segmentations of the bi-temporal correlation image layerstack to delineate and identify land-use/land-cover changes.

The objectives of this study are to test and compare land-use change (LUC) identification methods based on a histogram curve-matching classification. The histogram curve-matching classification results are compared to products generated by the standard nearest-neighbour classifier. This change-identification procedure is tested for a study area in southern San Diego County, California, based on multispectral aerial orthoimages having 1 m spatial resolution. The application context for this research is the semi-automatic updating of existing land-use GIS layers that become out of date following urban growth.

The following research questions are examined as part of the research:

1. Do LUC and no-change objects have non-normally distributed histogram curves when extracted from a multi-temporal H-res image layerstack captured for an urbanizing area?
2. Does the classification of temporal-spectral LUC objects based on histogram curve-matching demonstrate potential to improve classification accuracy relative to traditional nearest-neighbour classifiers?
3. Which feature inputs to a histogram-matching classifier yield the highest overall agreement when identifying LUC /no-change objects?

2 Study Area and Data

Figure 1 shows a bi-temporal aerial orthoimage layerstack covering a 266 km2 study area that encompasses portions of the cities of National City, Chula Vista and San Diego, in San Diego County, California, USA. The geographic coordinates of the study area are 32°41'07" to 32°33'20"N and 117°05'19" to 116°53'41"W. In the last two decades, this area has experienced substantial LU change, especially from vacant and undeveloped land to new single-family and multi-family residential land use.

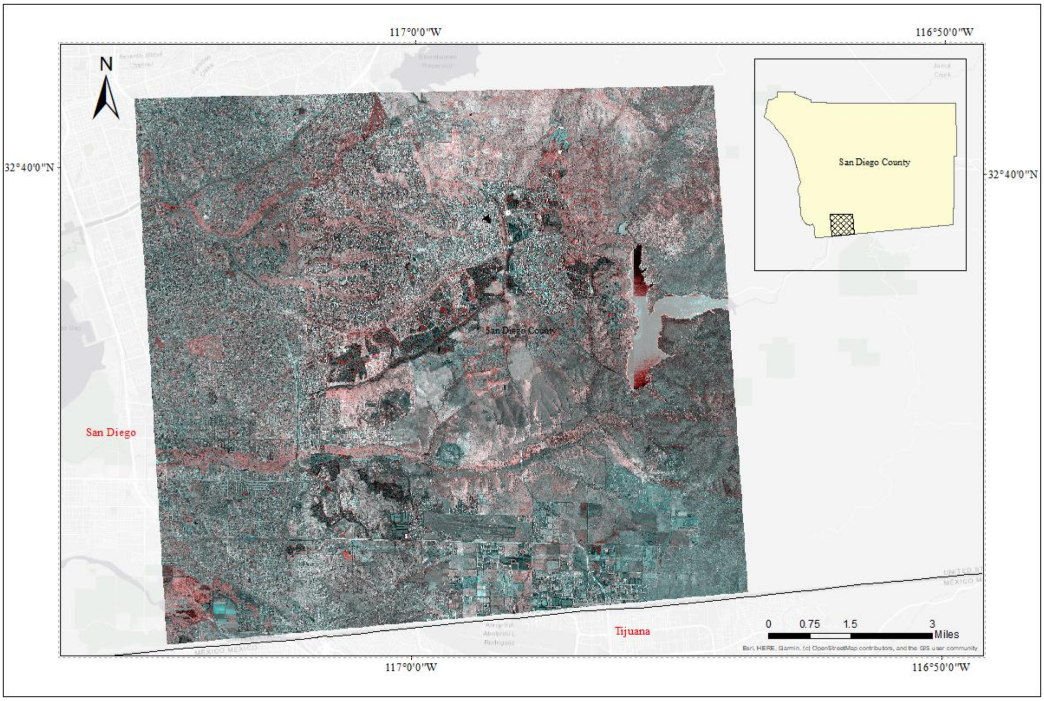


Figure 1: Study area within southern San Diego County, California, USA. Bi-temporal aerial orthoimage layerstack with Red image difference band displayed in the red colour plane and near-infrared (NIR) difference in the blue and green colour planes. Areas represented by red and cyan portray land-cover and land-use changes.

The specifications of bi-temporal aerial orthoimages obtained from the San Diego Association of Governments (SANDAG) and the National Agriculture Imagery Program (NAIP) are given in Table 1. The SANDAG imagery was captured between June and September 2000 with a positional accuracy similar to the USGS DOQQs (+/- 33 feet; ~ 10 m). The NAIP imagery was captured between April and August 2016 and met the accuracy requirement of < 4 m upon generation of mosaicked digital orthophoto quarter quadrangles. Spectral-radiometric data from the two ortho-image sets are uncalibrated 8-bit integer digital number (DN) values. Only the two-date Red and NIR bands were used to build multi-temporal image layerstacks for this study. Toure et al. (2013) demonstrated that using these two wavebands achieves high accuracy in single-date LU mapping based on GEOBIA with histogram-matching classifiers, without the high computational cost of using other, highly correlated, visible wavebands.

Table 1: Image characteristics

Image Source	Original GSD	Reprojected GSD	Spectral Bands	Radiometric Quantization (bit)	Year of Acquisition
SANDAG	0.6 m	1 m	Red, NIR	8	2000
NAIP	0.6 m	1 m	Red, NIR	8	2016

Two-dates (2000 and 2016) of parcel-level land-use layers acquired from SANDAG (Table 2) provided the basis of the classification system (Table 3) and were used to generate LUC polygons for training and testing purposes. The classes of interest are general analytical LUC classes. These are divided into subclasses representing variations in land-cover composition within land-use polygons because of differences in age of development, building materials, etc. Subclass polygons served as thematic layers to assist the selection of parameter settings (i.e. Scale parameter for segmentation using eCognition GEOBIA software), and as a reference layer to refine the shape of resultant image objects manually.

Table 2: Land-use classification scheme

Specific Analytical LU Classes	SANDAG LU Code and Description
Single-Family Residential (SFR)	1100 Single-Family Residential
Multi-Family Residential (MFR)	1200 Multi-Family Residential
Light Industry (LIND)	2103 Light Industry – General
Commercial Development (COM)	5002 Regional Shopping Centre
	5003 Community Shopping Centre
	5004 Neighbourhood Shopping Centre
Undeveloped (UNDEV)	9101 Vacant and Undeveloped Land

Table 3: Land-use change and no-change classification scheme

Type of Object	General Analytical LU Transition Classes	Subclasses
Change	UNSFR, Undeveloped Land to Single-Family Residential	• saUNSFR, Undeveloped (cleared for construction) to Single-Family Residential • sbUNSFR, Undeveloped (dry and grassy land) to Single-Family Residential

		• scUNSFR, Undeveloped (cleared for construction) to Single-Family Residential • sdUNSFR, Undeveloped (soil, subshrub, small trees and trails) to Single-Family Residential
	UNMFR, Undeveloped to Multi-Family Residential	• saUNMFR, Undeveloped (cleared for construction) to Multi-Family Residential • sbUNMFR, Undeveloped (cleared for under construction) to Multi-Family Residential
	UNLIND, Undeveloped to Light Industry	• saUNLIND, Undeveloped (dry and grassy land) to Light Industry • sbUNLINDL, Undeveloped (cleared for under construction) to Light Industry
	UNCOM, Undeveloped Land to Commercial Development	• saUNCOM, Undeveloped (cleared for construction) to Commercial Development
No Change	No Change	• NCSFR, No-change Single-Family Residential • NCMFR, No-change Multi-Family Residential • NCLIND, No-change Light Industry • NCCOM, No-change Commercial Development

3 Methodology

A sequence of image-processing and analysis procedures were applied to delineate and identify transition classes for LUC objects using R, ArcGIS Pro, eCognition and Excel software packages, as shown in Figure 2. The general procedures consist of five steps: (1) image pre-processing, (2) segmentation, (3) generating training and testing histograms and regions of interest, (4) classification, and (5) classification accuracy statistics.

3.1 Image pre-processing

ArcGIS Pro software was used to perform image pre-processing to standardize characteristics of aerial orthoimages. Both images were subset to the extent of the study area, co-registered, and reprojected to 1 m GSD with UTM coordinates. Two layerstack images were created: (1) composites of bi-temporal Red and NIR bands; (2) temporal-spectral differences (time2 – time1) of Red and NIR wavebands.

3.2 Segmentation and selection of regions of interest

Potential temporal-spectral image objects (i.e. regions of interest, or ROIs) for training and testing were delineated by segmentation of two multi-temporal orthoimagery layerstacks using the multi-resolution segmentation algorithm in eCognition software. After trial and error, the segmentation Scale parameters ranged between 200 and 300 per class. We segmented fine-scale objects and then merged the resulting segments into larger image objects. The final segmentation layer was overlaid with polygons representing LUC classes derived from the reference GIS layer, to enable delineation of ROIs used to extract training data (e.g. pixels representing known LUC objects and used for training classifiers). Image objects were manually edited (i.e. polygons were split and merged) during the refinement process. ROIs of LUC subclasses were delineated based on the refined image objects and the reference LUC class layer. The number of training and testing ROIs per subclass was determined from the resulting ROIs by visual image interpretation (Table 4). These ROIs were utilized to extract histogram signatures (i.e. frequency distribution of within-object digital numbers) using the Zonal Histogram tool in ArcGIS Pro, and applied to nearest-neighbour classification using eCognition.

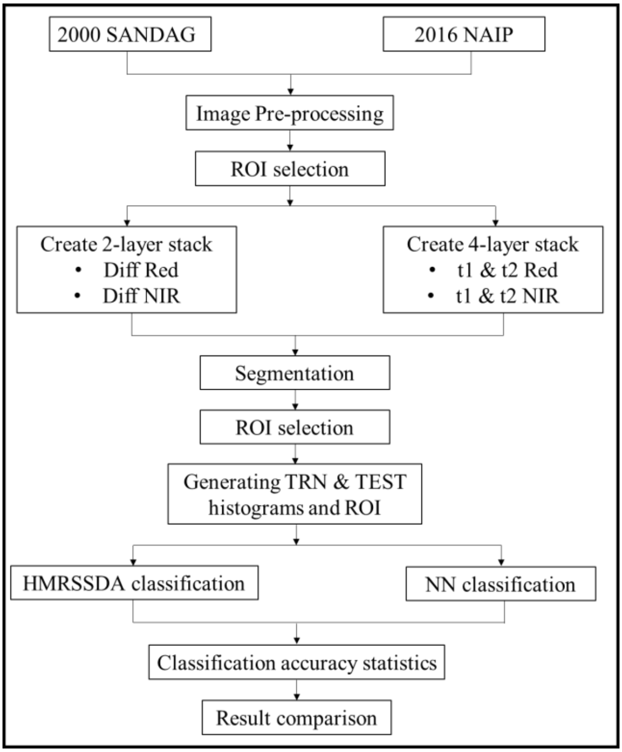


Figure 2: Processing flow. Diff Red and Diff NIR stand for temporal-spectral Red and NIR wavebands respectively. SANDAG = San Diego Association of Governments; NAIP = National Agriculture Imagery Program; ROI = regions of interest; TRN = testing; TEST= testing; NN = nearest neighbour; HMRSSDA = histogram matching root sum squared differential area.

3.3 Generating training and testing histograms and regions of interest

Training and testing histograms for each subclass were evaluated by plotting histogram signature curves. The histogram curves that consistently represented the curve patterns for within-class LUC objects were used to compute mean training histograms for each subclass based on three different mathematical measures of means (arithmetic, geometric and Pythagorean). Three different mean values were computed for layerstacks with bi-temporal and bi-spectral feature inputs as follows:

$$\text{Arithmetic Mean} = (\text{t1NIR} + \text{t1RED} + \text{t2NIR} + \text{t2RED})/4 \quad (1)$$
$$\text{Geometric Mean} = \sqrt[4]{\text{t1NIR} \times \text{t1RED} \times \text{t2NIR} \times \text{t2RED}} \quad (2)$$
$$\text{Pythagorean Mean} = \sqrt[4]{\text{t1NIR}^4 + \text{t2RED}^4 + \text{t2NIR}^4 + \text{t2RED}^4} \quad (3)$$

For layerstacks with temporal-spectral difference bands, mean values were calculated as follows:

$$Arithmetic\ \text{Mean} = (\text{Diff NIR} + \text{DIFF RED})/2 \quad (4)$$
$$\text{Geometric Mean} = \sqrt{\text{Diff NIR} \times \text{Diff RED}} \quad (5)$$
$$\text{Pythagorean Mean} = \sqrt{\text{Diff NIR}^2 + \text{Diff RED}^2} \quad (6)$$

where t1 = time 1, t2 = time 2, Diff = temporal-spectral difference band, NIR = near-infrared red.

Histogram curves were averaged by the arithmetic method to generate a mean testing histogram for each within-class LUC object. Their corresponding image objects also served as training and testing ROIs for nearest-neighbour classification; resultant mean training and testing histograms were applied in histogram curve classification.

Table 4: Number and area coverage of training and testing ROIs per subclass

LU Transition Subclasses	No. TRN ROI	Area Covered by TRN ROI (km^2)	No. TEST ROI	Area Covered by TEST ROI (km^2)	No. TOTAL ROI
saUNSFR	8	0.04	48	0.23	56
sbUNSFR	7	0.03	41	0.15	48
scUNSFR	10	0.04	52	0.19	62
sdUNSFR	9	0.04	31	0.12	40
saUNMFR	3	0.01	14	0.05	17
sbUNMFR	4	0.01	20	0.05	24
saUNLIND	3	0.03	10	0.10	13
sbUNLIND	3	0.01	10	0.03	13
saUNCOM	4	0.05	9	0.11	13
NCSFR	34	0.27	115	0.96	149
NCMFR	8	0.05	49	0.51	57
NCLIND	6	0.06	16	0.28	22
NCCOM	9	0.05	26	0.40	35

3.4 Histogram curve classification

Histogram Matching Root Sum Squared Differential Area (HMRSSDA) was adopted to measure histogram similarity of LUC and no-change objects. The HMRSSDA calculation is derived as (Stow et al. 2012):

$$\mathrm{HMRSSDA} = 1 - \sqrt{\left(\sum_{i=DN_{min}}^{n=DN_{max}} (FS_i - FR_i)^2\right)} \quad (7)$$

where *FSi* = frequency of the mean testing histogram at bin *i* = *DN*, *FRi* = frequency of the mean training histogram at bin *i* = *DN*, and *DN* = digital number.

The total number of pixels in each LUC/no-change object was divided by frequency count at each histogram bin for the normalization of bin values, to minimize the possible influence on varying object sizes (i.e. numbers of within-object pixels).

The accuracy of the HMRSSDA classifier was tested based on the layerstack change analysis approach within a GEOBIA framework using a set of R scripts and Excel. The hybrid of feature inputs (i.e. Diff_NIR and Diff_RED combined, or the t1NIR, t1RED, t2NIR and t2RED combined) provides information that can yield high classification accuracy (Toure et al. 2013).

3.5 Nearest-neighbour classification

The classification of layerstack images with the nearest-neighbour classifier was conducted using eCognition. Nearest-neighbour classification in eCognition computes the feature space distance from the testing object to each of the training objects as follow (eCognition Developer (2014):

$$\text{Feature Space Distance (d)} = \sqrt{\sum_f \left(\frac{v_f(s) - v_f(o)}{\sigma_f}\right)} \quad (8)$$

where *d* = distance between the testing object (*s*) to the training object (*o*); *vf(s)* = feature value of training object for feature *(f)*; *vf(o)* = feature value of testing object for feature *(f)*; *σf* = standard deviation of the feature values for feature *(f)*. The testing objects are assigned to the class of the training object having the shortest distance.

3.6 Classification accuracy assessment

Classification accuracy metrics based on subclasses were created using R programming scripts. The metrics were aggregated to a more general LUC class level which includes the targeted change and no-change classes for this study (Table 5). Overall classification accuracy for all objects, change and no-change objects, as well as producer's and user's accuracy are documented for each of the metrics. Since the goal of this study was to classify general analytical LUC classes, the resultant accuracy metrics were restructured by aggregation of subclasses to general LUC and no-change classes.

Table 5: Number and area coverage of training and testing regions of interest per general class

LU Transition Subclasses	No. TRN ROI	Area Covered by TRN ROI (km2)	No. TEST ROI	Area Covered by TEST ROI (km2)	No. TOTAL ROI
UNSFR	34	0.15	172	0.70	206
UNMFR	7	0.02	34	0.10	41
UNLIND	6	0.05	20	0.13	26
UNCOM	4	0.05	9	0.11	13
No Change	57	0.43	206	2.14	263

Total extent of the study area, 266.18 km^2; ROI = regions of interest; TRN = training; TEST = testing

4 Results

4.1 Classifier influence

The HMRSSDA (histogram) classifier consistently yielded higher classification accuracy compared to the nearest-neighbour classifier for identification of change and no-change objects, no matter which feature inputs or approaches to combining multiple-feature classification measures were applied, as shown in Tables 6–8. The combination of HMRSSDA with arithmetic mean and temporal-spectral difference bands yielded the highest accuracies: 78.72% overall accuracy for change objects and 100% for no-change objects.

Table 6: Overall accuracy results for arithmetic mean

Classifier	HMRSSDA		Nearest Neighbour	
Layerstack Input	Diff NIR Diff RED	t1NIR t1RED t2NIR t2RED	Diff NIR Diff RED	t1NIR t1RED t2NIR t2RED
Overall_Accuracy (ALL)	79.82	76.19	60.09	74.15
Overall_Accuracy (TRANS)	78.72	60.85	48.09	69.36
Overall_Accuracy (NC)	81.07	93.69	73.79	79.61

ALL = all testing objects; TRANS = change objects; NC = no-change objects

4.2 Influence of type of mean calculation

Using arithmetic and Pythagorean mean for combining classification measures of multiple histogram-matching features (e.g. spectral bands), 77% of change objects were successfully identified, which is 8 to 9% higher than when using the geometric mean. For no-change objects, arithmetic and geometric means achieved the highest (93% and 100%) classification accuracy, which is about 6% higher than with the Pythagorean mean (87.38%). Additionally, classifications based on the arithmetic mean show the smallest difference between the highest and the lowest accuracies for change and no-change objects individually. The accuracy of only one classification product (48.09%) is below 60% and most are well over 70%, suggesting that the arithmetic mean is preferable to the other two mean inputs.

4.3 Feature input influence

For most of the feature combinations, the layerstack feature inputs containing temporal-spectral difference bands generally outperformed the layerstack approach with bi-temporal spectral bands in classifying change objects. However, the opposite resulted when classifying no-change objects. The temporal-spectral difference bands resulted in the highest classification accuracy for change (78.72%) and no-change (87.38%) objects, compared to 69.36% and 100% accuracy yielded with bi-temporal spectral bands. This suggests that histograms of temporal-spectral difference bands contained more distinctive change signals than the histograms associated with bi-temporal spectral bands. The layerstack that has bi-temporal spectral bands uses full histogram information from each band input, which intensifies no-change histogram signatures; therefore, no-change objects were generally well-differentiated.

Table 7: Overall accuracy results for geometric mean

Classifier	HMRSSDA		Nearest Neighbour	
Layerstack Input	Diff NIR Diff RED	t1NIR t1RED t2NIR t2RED	Diff NIR Diff RED	t1NIR t1RED t2NIR t2RED
Overall_Accuracy (ALL)	70.29	71.20	53.06	45.35
Overall_Accuracy (TRANS)	69.79	45.96	43.40	36.17
Overall_Accuracy (NC)	70.87	100.00	64.08	55.83

ALL = all testing objects; TRANS = change objects; NC = no-change objects

Table 8: Overall accuracy results for Pythagorean mean

Classifier	HMRSSDA		Nearest Neighbour	
Layerstack Input	Diff NIR Diff RED	t1NIR t1RED t2NIR t2RED	Diff NIR Diff RED	t1NIR t1RED t2NIR t2RED
Overall_Accuracy (ALL)	69.84	43.99	53.74	46.49
Overall_Accuracy (TRANS)	54.47	12.34	43.83	39.15
Overall_Accuracy (NC)	87.38	80.10	65.05	54.85

ALL = all testing objects; TRANS = change objects; NC = no-change objects

4.4 Most accurate combination of inputs and classifier

Overall, the change-identification approach yielding the highest accuracy for histogram classification is the combination of HMRSSDA, arithmetic mean and the layerstack that has temporal-spectral difference bands. For nearest-neighbour classification, the most accurate approach is the combination with arithmetic mean and the layerstack that has bi-temporal spectral bands. Classification performance for each general LUC class is shown in Tables 9 and 10. Among the change classes, the HMRSSDA approach classified UNSFR most accurately (82.56%), and UNLIND least accurately (65%). The nearest-neighbour method classified UNSFR most accurately (75.58%), and UNCOM least accurately (44.44%). For the no-change class, both approaches produced similar accuracy, of around 80%, but the HMRSSDA is 1.61% higher than for the nearest-neighbour classifier.

The HMRSSDA classification yielded 79.82% overall accuracy, with 39 change objects misclassified to no-change, and only seven no-change objects misclassified to change classes (i.e. UNSFR, UNMFR, UNLIND and UNCOM). The nearest-neighbour classification resulted in 74.15% overall accuracy, with 42 change objects incorrectly classified to no-change, and 52 no-change objects allocated to the LUC classes. This suggests that the nearest-neighbour classification over-classified change and no-change objects, while the HMRSSDA classification limited such over-classification of change objects (52 to 7) substantially, and slightly for no-change objects (42 to 39).

Table 9: Histogram classification accuracy matrix for the combination of HMRSSDA, arithmetic mean, and layerstack having temporal-spectral difference bands.

		Reference Data						
		UNSFR	**UNMFR**	**UNLIND**	**UNCOM**	**No Change**	**Total**	**User's**
Histogram Classification	**UNSFR**	142	9	7	0	27	185	76.76
	UNMFR	20	24	0	1	0	45	53.33
	UNLIND	5	0	13	1	10	29	44.83
	UNCOM	0	0	0	6	2	8	75.00
	No Change	5	1	0	1	167	174	95.98
	Total	172	34	20	9	206	441	
	Producer's	82.56	70.59	65.00	66.67	81.07		

Overall accuracy, 352/441=79.82%; User's = user's accuracy; Producer's = producer's accuracy

Table 10: Nearest-neighbour classification accuracy matrix for the combination of NN, arithmetic mean, and layerstack having bi-temporal spectral bands.

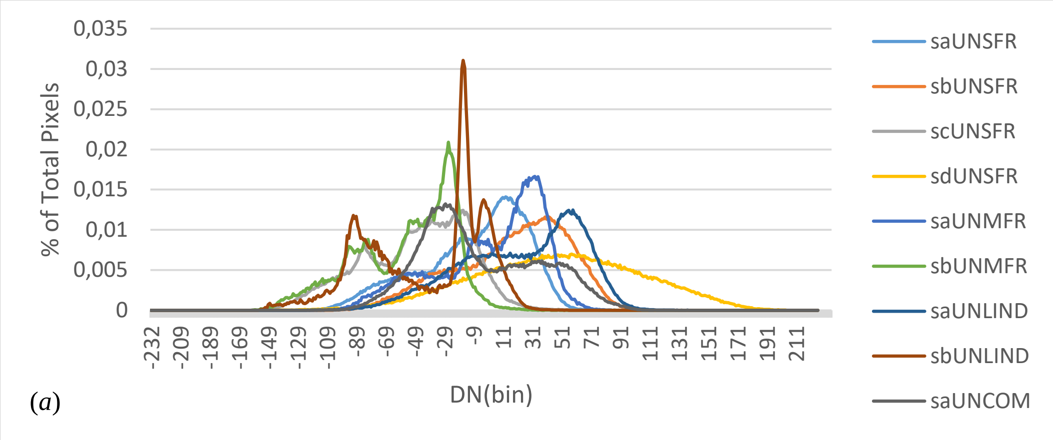
		Reference Data						
		UNSFR	**UNMFR**	**UNLIND**	**UNCOM**	**No Change**	**Total**	**User's**
Nearest Neighbour Classification	**UNSFR**	130	6	2	0	29	167	77.84
	UNMFR	5	19	1	1	6	32	59.38
	UNLIND	3	1	10	1	2	17	58.82
	UNCOM	0	0	0	4	5	9	44.44
	No Change	34	8	7	3	164	216	75.93
	Total	172	34	20	9	206	441	
	Producer's	75.58	55.88	50.00	44.44	79.61		

Overall accuracy, 327/441=74.15%; User’s = user’s accuracy; Producer’s = producer’s accuracy

5 Discussion and Conclusion

The objective of this study was to develop, test and compare multi-temporal image change identification approaches through GEOBICA techniques that use histogram and nearest-neighbour classification with various feature inputs, in the context of updating extant land-use GIS layers that become out of date as a result of urban growth. In such a context, an outdated land-use GIS layer could be updated based on multi-temporal images. The full information content of frequency distributions of pixels within LUC/no-change objects was evaluated by the feature inputs (i.e. layerstack, classifier and mean calculation). The resultant classification products depict five general classes (i.e. four LUC classes and one no-change class), which were created by aggregation of temporal-spectral subclasses.

The core (second) research question addressed in this study pertains to the comparative performance of a histogram and a nearest-neighbour classifier. Classifier influence was evaluated, and we found that the histogram classifier consistently outperformed the nearest-neighbour classifier, with just two exceptions. The histogram classifier exploits the complex frequency distributions of the LUC objects better than the nearest-neighbour classifier, which answers the first research question. Figures 3 presents training (mean) histogram curves for (a) change and (b) no-change subclasses derived from the Red temporal-spectral difference band. The majority of LUC curves tend to be non-normally distributed, while the no-change objects have normally distributed curves. Overall, the shapes of the histogram curves for each subclass appear to be consistent for both Red and NIR temporal-spectral difference bands.



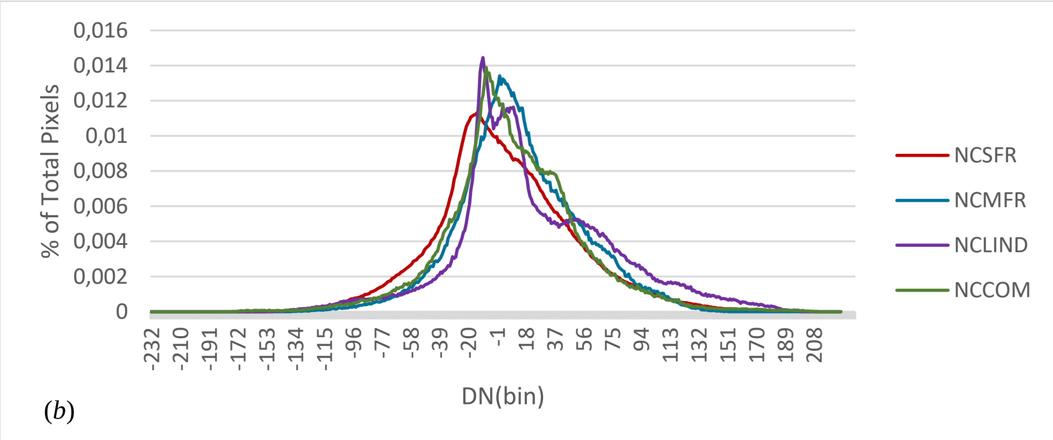


Figure 3: Training (arithmetic mean) histogram curves for (a) change and (b) no-change subclasses based on each RED temporal-spectral difference feature input.

Another research question pertains to which combination of feature inputs results in the most accurate identification of change and no-change objects, as well as what the classification accuracy of different types of LUC/no-change objects is. We demonstrate that the combination temporal-spectral difference bands, HMRSSDA and arithmetic mean is the most accurate change-identification approach. This combination identified UNSFR most accurately (82.56%). UNLIND was classified least accurately (65%). Compared to the most accurate nearest-neighbour classification combination (arithmetic mean and bi-temporal spectral bands), the HMRSSDA combination limited over-classification of change objects substantially, and slightly for no-change objects. The overall accuracy for all objects is 5.67% higher than the nearest-neighbour method.

A further research question was which type of mean calculation for combining histogram classification metrics and feature inputs yielded the highest change-identification accuracy. We found that the arithmetic mean (78.72%) slightly outperformed the Pythagorean mean

(77.87%), followed by geometric mean (69.79%). For no-change objects, the geometric mean resulted in the highest identification accuracy (100%), followed by arithmetic mean (93.69%) and Pythagorean mean (87.38%).

For the question concerning feature input influences, the layerstack with temporal-spectral difference bands generally yielded more accurate identification of change objects. The highest identification accuracy was 78.72%, which is 9.36% higher than the greatest accuracy using bi-temporal spectral bands. Using a temporal-spectral layerstack yielded 100% identification accuracy for no-change objects, which is 12.62% higher than the highest accuracy obtained using temporal-spectral difference bands.

While the histogram classifier was shown to more accurately identify change and no-change objects for our study area and context, some challenges and limitations need to be addressed. Histogram curve-matching classification may be challenging if the classification level is too detailed (e.g. land-use data at parcel level) or if the size of image objects is very small (e.g. land parcels). Greater effort would be required to train on LUC types that exhibit high within-class temporal-spectral variability, which would necessitate adding more subclasses for classification, and then aggregating subclasses post-classification. Another challenge is to find appropriate segmentation parameters (e.g. Scale and the composition of the homogeneity criterion) depending on class of interest, feature inputs, image resolution characteristics, and/or study regions.

Follow-on research should include testing the histogram classifier in other study sites/contexts with different LUC classes and using different image types. Developing significance tests for the histogram classifier is another topic for further investigation. Influences of spatial resolution, band inputs and quantization level (i.e. number of bins) should also be assessed. Finally, we recommend that the histogram classifier be tested for a post-classification comparison approach to GEOBIA-based LUC analysis.

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