Collecting and analyzing soccer-related graffiti with the spatial video technology and GIS: a case study in Krakow, Poland

Abstract
In this research, the spatial video technology is applied to the collection of soccer-related graffiti locations in the city of Krakow, Poland. Krakow is predestined for this research due to the long and often violent rivalry between fan groups of the two major soccer teams, MKS Cracovia and Wisla Krakow. This form of rivalry is often expressed by the application of graffiti by fans from both clubs, which can be observed in large parts of the city. Graffiti locations were digitized from spatial videos, stored in a Geographic Information System (GIS), and subsequently analyzed to explore (1) the overall spatial pattern, (2) the existence of spatial hotspots, and (3) changes to a previously conducted survey of graffiti locations in 2016. As expected, results indicate that graffiti locations are statistically significantly clustered, with pro-Wisla graffiti mainly concentrating in the north, pro-Cracovia graffiti dominating the south, and pro-Hutnik graffiti mostly found in the east of Krakow. The overall spatial pattern of graffiti locations remained relatively unchanged between the 2016 and 2018 surveys. Besides scientific inquiry, this research provides city officials with important information regarding graffiti locations in Krakow for a broader and more in-depth understanding of their spatial patterns.
Introduction
This proposed research builds upon two (unpublished) soccer-related graffiti maps compiled by Dr. Piotr Trzepacz in 2006 and 2016. He is currently a researcher at the Institute of Geography and Spatial Management (IGSM), Jagiellonian University in Krakow, Poland and an important facilitator of this project. The original collections of the soccer-related graffiti was conducted on a bicycle, pictures taken by a digital camera, and graffiti locations were manually recorded for subsequent visualization on maps. In contrast, this research applied the Spatial Video Acquisition System (SVAS), or spatial video technology, for short, for the data collection effort. An important advantage is that each frame of the spatial video is associated with a location and a time stamp, which makes its content accessible to and compatible with a GIS, where it can be subsequently analyzed, modeled, and results visualized. In this research, a total of three video cameras were mounted to the front, and left and right backseat windows of an automobile, which drove on predetermined survey paths and video recorded everything that came in the view of the video cameras.

The first main objective of this research was to find out whether the spatial video technology can be appropriately applied to the collection of soccer-related graffiti and to assess its advantages and disadvantages compared to the original survey technology that used a digital camera and a bicycle for travel. Upon the building of a soccer-related graffiti-GIS with information extracted from spatial videos, the second main objective was the analysis of graffiti locations with a series of spatial statistical methods in order to explore their overall spatial distribution, the possible existence of hotspots, and changes to the 2016 survey by Trzepacz.

This research proceeds with a historical discussion of graffiti and soccer-related graffiti. It then introduces the study area, the spatial video technology, and how graffiti locations and their attributes can be extracted from spatial videos. The next section spatially analyses soccer-related graffiti locations and compares the results between the 2016 and 2018 surveys. The final section is devoted to a discussion and possible future research.

History of graffiti
The application of graffiti can be traced back to the early beginnings of society, including cavemen during the late Pleistocene (Guthrie 2005), the ancient Greek, the ancient Egypt, or the Roman Empire (Baird & Taylor 2011). And, it is still widespread in today’s modern society. From an etymological point of view, the word graffiti comes from the Greek word ‘graphein’ and the Italian word ‘graffiare’, the latter word referring to carve, paint, or write (Grün 2016: 160). Scientific research concerning graffiti, their possible causes, and effects on the society, has been carried out by many disciplines, including sociology, anthropology, architecture, geography, psychology, criminology, arts, urban planning, and others. In general, opinions among researchers are divided, whether the application of graffiti should be viewed as an art or as a crime. For example, G. C. Stowes (1997) claims graffiti to be an art form. In contrast, M. Halsey & A. Young (2002: 165) associate graffiti with the aspect of vandalism and define graffiti as ‘both art and crime’, and G. Vanderveen & G. Van Eijk (2015) consider graffiti as ‘art crimes’. Similarly, K. - J. Lombard (2012: 261) separates graffiti into two forms, namely graffiti as urban/aerosol art ‘which is legal and commissioned by property owners’, and graffiti as vandalism ‘which is a crime committed mainly by young people’. G. Vanderveen & G. Van Eijk (2015: 108) agree, but also believe that ‘there is no clear-cut distinction between graffiti and street art’.

In the context of this article, the application of graffiti is viewed to be illegal. We follow the definition of the Oxford Dictionary, which states that graffiti are ‘writing or drawings scribbled, scratched, or sprayed illicitly on a wall or other surface in a public place’. This definition is echoed by A. Morgan & E. Louis (2009: 1), who consider graffiti ‘as the marking of other people’s property without their consent’. According to the Broken Windows Theory (Wilson & Kelling 1982), graffiti in association with broken windows and other signs of abandonment are important indicators of places of vandalism and elevated criminal activities. This theory assumes that ‘if a window in a building is broken and is left unrepaired, all the rest of the windows will soon be broken’ (Wilson & Kelling 1982: 2). This concept, according to D. L. Weisel (2002), can be transferred to graffiti, as well. For example, in terms of uncleaned walls or bus stop shelters, he observed that ‘graffiti has a serious cumulative effect; its initial appearance in a location is broken and is left unrepaired, all the rest of the windows and other signs of abandonment are important indicators of vandalism and define graffiti as art crimes’. Similarly, K. - J. Lombard (2012: 261) separates graffiti into two forms, namely graffiti as urban/aerosol art ‘which is legal and commissioned by property owners’, and graffiti as vandalism ‘which is a crime committed mainly by young people’. G. Vanderveen & G. Van Eijk (2015: 108) agree, but also believe that ‘there is no clear-cut distinction between graffiti and street art’.

In today’s modern society, graffiti appear in various forms and are an issue of great significance to its members, may it be local communities, local government, police, public transport agencies, or young people. Individuals within these groups can be affected in
various ways by graffiti, which range from acceptance and tolerance to social decline and criminality (Halsey & Young 2002). For example, B. Haworth, E. Bruce, & K. Iveson (2013: 53) state that 'graffiti is a prominent feature of urban landscapes, and graffiti culture plays an important role in defining the identity of urban environments'. For the average street user, the media, or authorities, which are unfamiliar with the underlying meaning and subcultural codes of graffiti, their application may be interpreted as criminal acts or at least as threats or forms of disrespect (Vanderveen & Van Eijk 2015).

Supporters of soccer teams express their affiliation to their team in various ways. In the stadium they sing, shout, chant, wave flags, hang banners, and create choreographies. Outside of the stadium these forms of expression can be extended in the form of graffiti sprayings (Grün 2016).

**Soccer-related graffiti**

Soccer-related graffiti can be attributed to the so-called 'gang graffiti', since graffiti artists express the affection to one soccer club and/or its allies. Graffiti sprayers are marking their territories, while trying to convey threats and insults to rivaling soccer clubs and their supporters, sometimes even resulting in hate graffiti. Graffiti, which are driven by such motives are also referred to as 'ideological graffiti'. They are characterized by its offensive content or symbols that are addressed to rivals and sometimes even ethnic or racial minorities, not uncommonly turning into racist slogans (Weisel 2002).

Most soccer graffiti include a token or the name of a soccer club and/or the associated fan-club. This is the reason why tags, which are particularly suited for marking the public space, are the most popular element of soccer-related graffiti. Their advantage is the comparatively easy and fast method of attaching the name of their city, club, or group, which informs members of the opposing team about their presence without great effort (Grün 2016). The artistic skill or design of the outcome plays a minor part for soccer-related graffitists, whereas awareness and the marking of territory are more important (Sommery 2010). Clearly, the quantity and the presence in the cityscape outrank the quality of soccer-related graffiti. Consequently, fan groups can show rivals, who the predominant club in the region is, especially in case of neighboring clubs. Graffiti can also be applied as a tool for criticism of commercialized soccer. Therefore, the old name of the stadium, which in most cases does not bear the name of any sponsor, is often visualized around the new home ground (Blickfang Ultra 2008; Grün 2016).

A very recent example for the analysis of soccer-related graffiti for a Polish city (Poznan) can be found in E. Bogacka & A. Siniecka (2017). The authors studied their spatial distribution and content in a particular neighborhood of Poznan, where supporters of the Lech Poznan soccer club have been very active.

**Study area**

The study area for this research is the city of Krakow, Poland, which is the capital of the Lesser Poland Voivodeship (Malopolska Voivodeship), one of 16 Voivodeships in Poland. It is located in southern Poland on the Vistula River and the second largest city in Poland behind Warsaw. In 2016, Krakow had a population of 765,320 and a surface area of 326.8 km², for a population density of 2,342 persons/km² (Znajewska et al. 2016). Krakow is subdivided into 18 districts. Two of these districts are occasionally mentioned in this article for orientation purposes. These are districts I and XVIII. District I, also called Stare Miasto (old town), is the central district and the touristic hotspot of the city. Its southern part is a former historical district called Kazimierz, which has been influenced by Jewish culture for centuries. Adjacent to District I in the west are Districts V (Krowodrza district) and VII (Zwierzyniec district), which include the stadiums of Wisla Krakow and Cracovia Krakow (MKS Cracovia), respectively. Both stadiums are a mere couple of hundred meters linear distance apart from each other. The easternmost district (XVIII) of Krakow is called Nova Huta (new steel mill). It includes the stadium of the Huta Nova Huta soccer club.

The city of Krakow is noticeably influenced by soccer, especially around derby times when the soccer clubs of MKS Cracovia and Wisla Krakow are playing against each other. This event, also termed 'Holy War', heats up the fan rivalry, often resulting in fights between them and the police or in vandalism (Wisla Krakow Vs... 2008; Mann 2009; Lukac 2014; Gyan 2017; McGirr 2017). This form of rivalry is also expressed by the application of graffiti by fan groups from both clubs, which can be observed in large parts of the city. S. Lukac (2014: 18) describes that locations of soccer-related graffiti and their spatial distribution in particular areas of Krakow 'provides a risk indicator of some sort' that 'informs the residents about how to navigate the city in a safe manner' and gives also information about the livability and attractiveness of areas. According to S.A. Cardais & J. Boissevain (2011), Krakow faces problems with graffiti and estimates that $45,000 annually are spent for graffiti removal actions. These local preconditions create a unique environment for the study of soccer-related graffiti and are the reasons for choosing Krakow as the study area. Table 1 shows some basic socio-spatial characteristics of the three soccer clubs analyzed in this research, such as year founded, stadium size, average attendance, etc.
The collection of graffiti and their locations proceeded with the Spatial Video Acquisition System (SVAS), or spatial video, for short. It allows to gain an on-site point of view, and can be applied to all kinds of research that demand impartial visual information (Curtis et al. 2007; Sagl 2008). The two main components of a SVAS are the digital video camcorder with an integrated Global Positioning System (GPS) receiver that allows the collection of spatially referenced digital video material. The Contour+2 Action Camera Model 1700 is employed in this research to collect the video material. It includes a 170 degree wide angle lens, which is favorable for recording graffiti in narrow streets. It can also be connected to other devices via a micro USB slot and stores the produced MP4 files on a mini SD card. Videos are recorded in high definition (1080p) and run at 120 frames per second.

The survey of graffiti locations proceeded with a car that had three cameras mounted to its inside windows. One camera was attached to the front window and the other two to the backseat side windows. This setup enabled the recording of graffiti from three different angular perspectives and allowed the collection of three GPS tracks of the driven route. In addition, a recharging unit which was compatible with the car’s cigarette lighter was used to keep all cameras running fully charged, even on longer survey trips.

Our survey was conducted during the first-half of 2018 and followed the same routes that Trzepacz established, when he collected soccer-related graffiti locations in two individual surveys during summers of 2006 and 2016. Instead of using a car and the spatial video technology, Trzepacz traveled on his bicycle, took pictures of graffiti with a digital camera, and noted their address location. In total, 31 routes, ranging from 10 km to 127 km in length with an average length of 60 km, were covered by our survey. However, the 31 routes traveled did not cover the entire street network of Krakow. The three cameras produced 2,082 GB of video files, equaling 347 hours of video material, in total.

### Extracting graffiti locations and attribute data from spatial videos

Following field surveys, recorded videos were imported into the Contour Storyteller 3.6.2.1043, which allowed to export the collected GPS locations in a format compatible for import into ArcGIS 10.2.2. In ArcGIS, GPS locations were converted into GPS tracks representing the driven routes and overlaid on OpenStreetMap for geographic reference purposes (Fig. 1.). GPS tracks do not necessarily match the street network due to inherent locational inaccuracies of the GPS technology. The actual extraction of graffiti locations, including their attributes, proceeded on two different computer screens. Spatial videos were viewed in Contour Storyteller or the VLC media player on one screen with graffiti identified in videos being digitized using ArcMap on the second screen.

Collected graffiti were put into eight different categories based in part on the fan groups’ ownership (Fig. 1.). Three of the eight categories included graffiti, where fan groups promoted or praised themselves or their own soccer club. They were categorized as (1) **Wisła Kraków**, (2) **Cracovia Kraków**, and (3) **Hutnik Nowa Huta**. The next three categories included graffiti that depreciated, threatened, or ridiculed a rivaling soccer club or their supporters. They were referred to as (4) **Anti_Cracovia**, (5) **Anti_Wisła Kraków**, and (6) **Anti_Hutnik**. A large number of graffiti was difficult to identify in terms of its ownership, because graffiti were overwritten and/or disfigured by other graffiti. They were categorized as (7) **unauthenticated**.
‘Conflict’ graffiti. When the graffiti content could not be determined, but was likely to be soccer-related graffiti, they were categorized as ‘Other Unknown’. Graffiti of soccer clubs or their fan base other than the three main clubs or fan groups discussed in this research were also categorized under the ‘Other Unknown’ type (Fig. 1).

An example of a ‘Conflict’ type graffiti is shown in Figure 2. This graffiti illustrates an agglomeration of graffiti with all three soccer clubs analyzed in this research being represented. In this example, graffiti were overwritten and disfigured, which created a problem concerning their allocation to a soccer club or ownership category. For instance, the swear word ‘Jebac’ was originally addressed to Wisla supporters and the police (‘JEBAC WISLE i POLICJE’), but later modified to ‘JEBAC CRAKE I POLICJE’. This modification changed the original graffito’s meaning and now humiliated Cracovia supporters. The question that arose was how to categorize this graffiti, since the original graffiti had to be allocated to Cracovia supporters, but the addition to Wisla supporters. In order to avoid such a conflict of defining the graffitist, the ‘Conflict’ category was invented and applied to a case like this.

The identification of soccer-related graffiti was based on the Polish-English Vocabulary of the Football Graffiti Content in Krakow compendium, which explained most of the soccer-related graffiti and translated their content from Polish into English, if necessary (Trzepacz 2018). This compendium included a total of 486 different graffiti, which were based on the author’s research and the two surveys in 2006 and 2016. Examples from the compendium ranged from simple written names related to the respective soccer club, abbreviations, special symbols, and signs, to rather incomprehensible designations, like references to historical events or names of soccer fan clubs. Without this collection of soccer-related graffiti (Trzepacz 2018), it would have been very difficult for the authors of this research to identify and understand the soccer-related graffiti landscape in the city of Krakow.

During our 2018 survey, we collected a total of 5,098 graffiti, while driving 1,873 kilometers along the street network of Krakow (Fig. 3). We estimate that we covered about 2/3 of the total street network of Krakow with our survey. The distribution of the total number of graffiti across the eight categories are included in Table 2, with almost 1/3 of all graffiti promoting the the Wisla Krakow soccer club and its fan groups and more than every fifth graffiti belonging to the ‘Conflict’ category. Compared to the 2016 survey by Trzepacz, our survey was 211 km longer and collected approx. 500 more individual graffiti locations. While both 2016
and 2018 surveys are based on the same routes, several reasons for the differences exist. For example, routes had to be adjusted for traveling by car (our 2018 survey), instead of by bicycle, as in the case of Trzepacz (2016 survey). Our survey resulted both in a loss of graffiti data by not driving some street segments, but also in a gain of graffiti locations along the newly covered street segments. Street segments that were missed with the car included most of the city center, where cars were not allowed to drive, gated apartment complexes, or ongoing construction that blocked off street segments. The quality of spatial videos was also influenced by weather and lightness conditions, speed of travel, and parked cars (see discussion below), which negatively impacted the success of collection efforts. Graffiti removal actions should also be mentioned, as well as the creation of new graffiti, which may have been responsible for the change in the total number of graffiti between the 2016 and 2018 surveys.

Spatial analysis of soccer-related graffiti locations

Graffiti locations collected with the spatial video technology during our 2018 survey were analyzed with a series of spatial statistical methods in order to explore (1) their overall spatial pattern, (2) the existence of spatial clusters (hotspots), and (3) changes to the 2016 survey by Trzepacz. All statistics were computed with CrimeStat 4.02 (Levine 2015) and, if necessary, visualized in ArcGIS 10.2.2. Only the most important results from our analysis are presented here. Detailed analysis results can be found in P. Krauthausen (2018).

Table 2:
All 2018 soccer-related graffiti locations by category
Source: own study

<table>
<thead>
<tr>
<th>Graffiti Category</th>
<th>Absolute</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisla_Krakow</td>
<td>1,521</td>
<td>29.84</td>
</tr>
<tr>
<td>Conflict</td>
<td>1,154</td>
<td>22.64</td>
</tr>
<tr>
<td>Cracovia Krakow</td>
<td>1,075</td>
<td>21.09</td>
</tr>
<tr>
<td>Anti Cracovia</td>
<td>608</td>
<td>11.93</td>
</tr>
<tr>
<td>Anti Wisla Krakow</td>
<td>402</td>
<td>7.89</td>
</tr>
<tr>
<td>Hutnik Nowa Huta</td>
<td>304</td>
<td>5.96</td>
</tr>
<tr>
<td>Other Unknown</td>
<td>29</td>
<td>0.57</td>
</tr>
<tr>
<td>Anti Hutnik</td>
<td>5</td>
<td>0.10</td>
</tr>
<tr>
<td>Total</td>
<td>5,098</td>
<td>100</td>
</tr>
</tbody>
</table>
General distributional pattern of graffiti locations

A standard statistic to measure whether a point pattern is randomly or regularly distributed, or spatially clustered, is the nearest neighbor analysis (NNA). Its index is calculated as the ratio between the observed mean nearest neighbor distance (the average distance between each graffiti location and its nearest neighbor graffiti location) and the expected mean random distance (the average distance between each graffiti location and its nearest neighbor graffiti location, if the observed point pattern were randomly distributed). The index’s range is from 0 and 2.149. A value of 0 means perfect spatial clustering (all points are on top of each other at the same location); a value of 1 means that the point pattern follows a perfectly random distribution; and a value of 2.149 means that points are perfectly regularly distributed. Results of the NNA are shown in Table 3 for seven of the nine graffiti categories, with ‘Anti_Hutnik’ and ‘Other_Unknown’ categories not included.

As expected, locations for all seven graffiti categories are statistically significantly different from a random distribution (p=0.00). Since their NNA indexes are all less than one, distributions of graffiti locations are statistically significantly clustered. However, the NNA is a global measure that does not identify the number or the location of individual graffiti hotspots. Graffiti locations associated with Hutnik Nowa Huta have the lowest NNA.

Table 3
Results of nearest neighbor analysis for six graffiti categories. All NNA indexes are significant at p=0.00.
Source: own study

<table>
<thead>
<tr>
<th>Graffiti Category</th>
<th>Mean nearest neighbor distance (m)</th>
<th>Mean random distance (m)</th>
<th>Nearest neighbor analysis (NNA) index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisla_Krakow</td>
<td>72.09</td>
<td>231.84</td>
<td>0.31</td>
</tr>
<tr>
<td>Cracovia_Krakow</td>
<td>94.52</td>
<td>275.77</td>
<td>0.34</td>
</tr>
<tr>
<td>Hutnik_Nowa_Huta</td>
<td>100.38</td>
<td>518.57</td>
<td>0.19</td>
</tr>
<tr>
<td>Anti_Wisla_Krakow</td>
<td>178.50</td>
<td>450.95</td>
<td>0.40</td>
</tr>
<tr>
<td>Anti_Cracovia</td>
<td>134.86</td>
<td>366.68</td>
<td>0.37</td>
</tr>
<tr>
<td>Conflict</td>
<td>83.58</td>
<td>266.16</td>
<td>0.31</td>
</tr>
<tr>
<td>Total</td>
<td>29.07</td>
<td>126.63</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Figure 3
5,000+ soccer-related graffiti locations collected during our 2018 survey along the Krakow street network
Source: own study, base map source: ArcGIS Online (esrictws)
index (0.19), meaning that their spatial pattern shows the strongest spatial clustering of all seven graffiti categories. This index is calculated by dividing the value of the mean nearest neighbor distance (100.38 m) by the mean random distance (518.57 m). The value of 100.38 m means that two immediately neighboring graffiti locations are, on average, 100.38 m apart from each other. The value of 518.57 m means that if the Hutnik Nova Huta graffiti locations were randomly distributed, then two immediately neighboring graffiti locations are, on average, 518.57 m apart from each other. Results from the NNA for the remaining graffiti categories can be interpreted in the same way (Tab. 3.). We also calculated the average distance between all 5,098 graffiti locations and each of the three stadium and found out that the average distance was shortest to the Cracovia stadium (6,003 km), followed by the Wisła stadium (6,323 km), and by the Hutnik stadium (7,992).

In order to establish the existence of graffiti hotspots, two different types of common cluster analysis methods were applied, and presented in the following section.

**Spatial hotspots of graffiti locations**

The first hotspot method to be considered was Nearest Neighbor Hierarchical (NNH) clustering. It is a hierarchical technique that defines spatial clusters with a higher number of graffiti locations that are closer together, than would be expected by chance. Accordingly, the user has to select the following two criteria. First, the minimum number of graffiti locations per hotspot, and second, a distance threshold between graffiti locations provided in the form of a probability. If the distance between two graffiti locations falls below this threshold, then both locations are assigned to the same cluster. Individual graffiti locations meeting both criteria were aggregated to so-called first order clusters, who, in turn, were aggregated to second order clusters (if criteria were met), etc. Resulting hotspots were displayed with standard deviational ellipses. The NNH clustering method was applied to all graffiti locations at once and to their individual graffiti categories. For the clustering of all graffiti locations in Krakow, a probability of 0.05 and a minimum cluster size of 20 graffiti locations were used. This resulted in a total of 40 clusters, with 37 first-order and three second-order clusters. As can be seen, the majority of all graffiti was located in the northern part of Krakow. In this area, almost one-fourth (23.1%) of all graffiti locations seem to form a ‘graffiti belt’, located inside the red rectangle, and bounded by two 2nd-order clusters (Fig. 4. top). A clearer picture of this ‘belt’ is visualized by a dashed green line in the zoomed-in version of Krakow in the bottom part of Figure 4.

NNH cluster results of the most important graffiti categories are shown in Figure 5. Ellipses in red define pro-Cracovia graffiti locations, which dominate in the central and southern areas of Krakow. Pro-Wisła graffiti are mainly found in northern Krakow and pro-Hutnik graffiti predominantly in the east. At the same time, Figure 5 also provides an overview of so-called ‘conflict zones’ within Krakow that is defined by overlapping graffiti clusters from different graffiti categories. For example, two conflict zones are located in the northeast, where clusters of Anti_Wisla and Anti_Cracovia overlap with Hutnik hotspots. The north of Krakow, which is primarily dominated by pro-Wisła graffiti, demonstrates another conflict zones, where pro-Wisła and Anti_Cracovia graffiti clusters overlap.

The second method to be considered was the kernel density estimation (KDE). It is both a hotspot and an interpolation method for spatially discrete graffiti locations that calculates density values for each cell of a regular grid superimposed over the study area. The more graffiti locations that can be found inside and in the (immediate) surrounding of a particular cell, the higher the density value of this cell is. The visualization of density values proceeds similar to choropleth mapping, with higher density values depicted with darker and lower density values with lighter color hues. In general, KDE results depend mostly on the selection of the type of the kernel function, its bandwidth length, and the cell size of the regular grid. For more information about KDE parameters and their settings can be found in N. Levine (2015). In this research, the KDE method was applied to all graffiti locations at once (Fig. 6.) and calculated with a quartic kernel function, an adaptive bandwidth with a minimum sample size of 100 graffiti locations, and a regular grid composed of 60,400 grid cells.

KDE hotspots of graffiti locations reveal similar patterns as NNH hot spots discussed previously. High KDEs with approximately 125 graffiti locations per km² are found in northern Krakow, forming a similarly shaped belt as NNH hot spots. To better support this visual interpretation, the 1st- and 2nd-order clusters of all graffiti locations from the NNH clustering algorithm are overlaid on top of KDE results (Fig. 6.). In addition to the ‘cluster belt’, both methods agree in identifying hotspots adjacent to the ‘cluster belt’ in the west and additional smaller high density pockets in the south, northeast, and west of Krakow. KDE results of individual graffiti categories are not shown here, but are discussed in detail in P. Krauthausen (2018).

**Comparing spatial patterns and hotspots between the 2016 and 2018 surveys**

The number of graffiti locations between our 2018 survey and the 2016 survey conducted by Trzepacz are shown in
Figure 4

Nearest Neighbor Hierarchical Analysis clusters of all graffiti locations in Krakow (top) and in the graffiti belt of Krakow (bottom) in 2018.

Note for top figure: Number in parenthesis indicates the number of clusters; 'p-value' defines the likelihood of clusters being created by chance; the minimum number of graffiti locations that each cluster includes is defined by 'min. cluster size'.

Source: own study, base map source: ArcGIS Online (esritws)
Table 4. As discussed before, the total graffiti count in 2018 was almost 500 higher than in 2016. This difference was primarily due to the different survey technologies applied to the collection of the graffiti data. Both surveys agree insofar, as pro-Wisla graffiti yielded the highest count, followed by pro-Cracovia graffiti, and pro-Hutnik graffiti. Similarly, counts of anti-Cracovia graffiti are higher in both surveys compared to anti-Wisla graffiti. The main difference was the number of ‘Conflict’ graffiti, which were more than twice as high in 2018 than in 2016 and the higher numbers of both pro-Wisla and pro-Cracovia counts in 2016 (Tab. 4). The main reason was the original categorization in the 2016 survey that did not include anti-Wisla and anti-Cracovia categories, which were later adjusted to our 2018 survey as best as possible.

The comparison of spatial hotspots between both surveys revealed minor differences concerning their overall distributional patterns, counts, and locations. Hence, in 2016, the north of Krakow was already dominated by pro-Wisla graffiti, the south by pro-Cracovia graffiti, and the east by pro-Hutnik graffiti, similar to locations of the 2018 graffiti hotspots.

Table 4
Graffiti counts comparing the 2016 with the 2018 surveys
Source: Trzepacz (2018); own study

<table>
<thead>
<tr>
<th>Survey Date</th>
<th>Graffiti Category</th>
<th>2016</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wisla_Krakow</td>
<td>1,855</td>
<td>1,521</td>
</tr>
<tr>
<td></td>
<td>Cracovia_Krakow</td>
<td>1,345</td>
<td>1,075</td>
</tr>
<tr>
<td></td>
<td>Hutnik_Nova_Huta</td>
<td>314</td>
<td>304</td>
</tr>
<tr>
<td></td>
<td>Anti_Wisla_Krakow</td>
<td>174</td>
<td>402</td>
</tr>
<tr>
<td></td>
<td>Anti_Cracovia</td>
<td>313</td>
<td>608</td>
</tr>
<tr>
<td></td>
<td>Anti_Hutnik</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Conflict</td>
<td>522</td>
<td>1,154</td>
</tr>
<tr>
<td></td>
<td>Other_Unknown</td>
<td>86</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4,609</td>
<td>5,098</td>
</tr>
</tbody>
</table>

Discussion and future research
In this research, the quality of spatial videos for information extraction depended on many different issues, including weather and lightness conditions, speed of travel, and parked cars. Heavy precipitation in the form of rain or snow, but also fog, limited the visibility and the clear identification of graffiti information. Especially spatial videos taken from the side windows of the car’s back seat that do not have windscreen wipers, were negatively affected by heavy rain and snow. Another
issue were lightness conditions. For example, a low sun angle above the horizon made it impossible to identify graffiti information with the front camera. However, that same graffiti may have been picked up with one of the side cameras. A second example was that not enough sunlight during dawn and dusk could reduce the identification of graffiti. If that was combined with a fast driving speed, then the chance of missing graffiti information was high. Finally, parked cars partially blocked unobstructed views of houses, garages, walls, etc., which were places, where graffiti were often attached to.

Additional issues that we experienced during graffiti collection and which reduced the quality of the spatial video material were being too close to buildings’ façades and unable to capture the entire graffiti scene. This was especially the case when driving through very narrow streets. Finally, we avoided morning and evening rush hours during work week and usually collected graffiti data between 9:30 am and 4:00 pm.

The main advantages of the spatial video technology with a car (2018 survey) over a digital camera and traveling on a bicycle (both 2006 and 2016 surveys) are less safety concerns, less dependency on weather conditions, and less time commitment. Additionally, the spatial video material can serve as an important historical document in the future. On the other hand, drawbacks of the spatial video technology are the higher costs for using a car, instead of a bicycle, and three video cameras, instead of one digital camera. In addition, cars are less accessible to specific urban areas (e.g., gated communities, historical districts with pedestrian zones, etc.), resulting in less complete surveys. Finally, the spatial video technology requires two people for its operation, including one person to drive the car and a second person, serving both as the navigator and operator of the equipment.

Future research can take different directions. One possibility is the addition and comparison of the 2006 survey of graffiti locations by Trzepacz with the two surveys discussed in this research. Another option is to analyze graffiti locations with additional hotspot methods to explore commonalities in the results between them. Infrastructure and socio-economic data, including crime, can be collected and their spatial relationship with graffiti locations explored using spatial regression analysis. The overall goal would be to provide city officials and other stakeholders with important information regarding covariates of graffiti in

![Map showing graffiti locations in Krakow in 2018](https://example.com/graffiti_locations.png)
Krakow for a broader and more in-depth understanding of their spatial patterns.

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References

Internet sources: