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MASTER

The Influence of the Built Environment on Crime

Using Geographically Weighted Regression Analysis to Understand the Influence of the Built Environment on the Occurrence of Crime in Neighborhoods of Amsterdam

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Graduation Thesis MSc Construction Management and Engineering:

The Influence of the Built Environment on Crime

Using Geographically Weighted Regression Analysis to Understand the Influence of the Built Environment on the Occurrence of Crime in Neighborhoods of Amsterdam

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This thesis can be considered as public information.

This Master's thesis has been carried out in accordance with the rules of the TU/e Code of Scientific Integrity.

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Preface

This graduation thesis is the final part of my master program Construction Management and Engineering at the Technical University of Eindhoven. During my master (and premaster) program I developed more interest in urban planning and how the built environment affects human behavior and daily activities. Therefore, this research, concerning the relation between crime and the built environment, fits well.

I would like to use this opportunity to thank everyone who helped me to carry out my research and write this thesis. First, Gamze Dane, who acted as my first supervisor and guided me through this process. I would also like to thank Aloys Borgers and Dena Kasraian-Moghaddam, as chairman and second supervisor, for their feedback and contributions to my thesis. Although all meetings we had were online through video calls, I still feel like the whole process went smoothly and that this did not hold me back. Finally, I would like to thank everyone else who supported me throughout my studies.

The final result of my research is beyond the expectations I had when I started. I am therefore satisfied with the final product. I hope you will enjoy reading my thesis as much as I did writing it.

Stephan Albert Leeuw
Heerenveen, August 2021

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Samenvatting

Tot nu toe is er relatief weinig onderzoek gedaan naar de relatie tussen gebouwde omgeving en criminaliteit. Echter, de onderzoeken die gedaan zijn tonen aan dat het vormgeven van de gebouwde omgeving op een specifieke manier criminaliteit kan doen verminderen. Dit onderzoek is gericht op het vergroten van de kennis over de relatie tussen de gebouwde omgeving en verschillende soorten criminaliteit. Door de gebouwde omgeving zo in te richten dat er minder criminaliteit plaats vindt, zal het veiligheidsgevoel op straat verbeterd worden en dus ook de kwaliteit van leven. In dit onderzoek wordt gebruik gemaakt van een geografisch gewogen regressie analyse.

In dit onderzoek worden vijf verschillende soorten misdrijven genalyseerd; woninginbraak, vandalisme, geweldadige misdrijven, drugs & overlast en diefstal. Ook wordt het totaal aantal misdrijven geanalyseerd. Het onderzoeksgebied betreft de gemeente Amsterdam. De eenheid van analyse zijn de buurten van Amsterdam.

Jane Jacobs (1961) was een van de eersten die een verband legde tussen de fysieke omgeving en criminaliteit. Jacobs beredeneerde dat gebouwde omgeving sociale/informele controle kon realiseren. De belangrijkste ideeën van Jacobs om deze controle te realiseren waren het maximaliseren van het aantal verschillende functies in een gebied, veel kruispunten en een mix van oude en nieuwe gebouwen. Oscar Newman (1972) ging verder met deze ideeën en kwam met de ''defensible space theory''. Deze theorie is gericht op het stimuleren van territoriaal gedrag van bewoners en legitieme gebruikers van de omgeving. Tegenwoordig is CPTED (crime prevention through environmental design [criminaliteits preventie door omgevings ontwerp]) de standaard. CPTED heeft vier principes, teritorialiteit, natuurlijke surveillance, gecontroleerde toegang en onderhoud & imago. CPTED is voortgekomen uit de eerder genoemde bijdragen. Variabelen uit de literatuur naar voren kwamen zijn: gemengd landgebruik, residentieel en commercieel landgebruik, groenvoorzieningen, straatverlichting, kruispunten, doodlopende straten, parkeerplaatsen, leegstand, percentage huurwoningen, bevolkingsdichtheid, adresdichtheid, kunstwerken, cameratoezicht en toeristische attracties. Als controle variabelen zijn variabelen uit de ''social disorganization theory'' gebruikt; socio-economische status en ethnische heterogeniteit. Het percentage huurwoningen kan gelinkt worden aan de bevolkingsstabiliteit.

Voor afhankelijke variabelen zijn per buurt bepaald hoeveel misdrijven er per vierkante kilometer per jaar plaatsvonden in 2019. Dit resulteert in een misdrijfdichtheid. Een wortel-transformatie is gebruikt om grote verschillen in waarden te nuanceren en om de staart in de distributie te verkleinen.

Een verkennende regressie analyse is uitgevoerd per misdrijf type om het meest optimale model te vinden voor reguliere lineare regressie analyse. Deze analyse vindt de meest geschikte combinatie van de eerder genoemde variabelen aan de hand van de R^2-waarde en Akaike's Information Critereon. Vervolgens wordt er een reguliere lineare regressie uitgevoerd om de coëfficienten van de onafhankelijke variabelen te verkrijgen. De residuen worden vervolgens getest op ruimtelijke autocorrelatie, omdat dit van invloed kan zijn op een geografisch gewogen regressie analyse. Bij voorkeur zijn de residuen willekeurig verspreid over het onderzoeksgebied, anders zou dit implicaties kunnen hebben voor de geografisch gewogen regressie. Vervolgens is de geografisch gewogen regressie uitgevoerd met een bandbreedte van drie kilometer.

De resultaten tonen aan dat de gebouwde omgeving inderdaad van invloed kan zijn op criminaliteit. Verschillende variabelen hebben invloed op verschillende misdrijftypen. De invloed van deze variabelen verschilt ook per gebied in Amsterdam.

Interesante resultaten met betrekking tot woninginbraken zijn dat het aantal kruispunten positief is gecorreleerd, net als gemengd landgebruik. Verder is door de geografisch gewogen regressie deduidelijk geworden dat de socio-economische status van een buurt een bijzondere relatie heeft; de resultaten tonen dat zowel buurten met een lage als een hoge socio-economische status meer last hebben van woninginbraken. Wat betreft vandalisme zijn de meest interessante resultaten dat toersistische attracties en kunstwerken positief gecorreleerd zijn.

Het model met betrekking tot geweldadige misdrijven volgt over het algemeen de literatuur. Opmerkelijk is dat straatverlichting positief gecorreleerd is. Verder komt dit model overeen met de ‘’social disorganization theory’’. Drugscriminaliteit en overlast vindt het meest plaats in het stadscentrum van Amsterdam. Ook hier is het aantal toeristische attracties positief gecorreleerd. Verder is het aantal kruispunten van invloed op drugs gerelateerde misdrijven wat ook in de literatuur naar voren komt. Diefstal komt ook verreweg het meest voor in het stadscentrum. De resultaten tonen dat toeristische attracties positief zijn gecorreleerd met diefstal, wat in lijn is met de bekende problematiek van zakkenrollerij bij toeristen.

Tot slot is de totale hoeveelheid misdrijven geanalyseerd. Dit model toont veel overeenkomsten met het diefstal model. Dit was te verwachten omdat diefstal de meest voorkomende soort misdrijf is. Een ander interessant punt is dat het aantal bomen negatief gecorreleerd is met criminaliteit. Dit is interessant omdat de literatuur dit ook aangeeft; het is echter niet naar voren gekomen in de misdrijfspecifieke modellen. Tot slot is het noemenswaardig dat gemengd landgebruik negatief gecorreleerd is.

Wat betreft de CPTED principes, kan er geconstateerd worden dat deze in de basis effectief zijn. Gemengd landgebruik, dat negatief is gecorreleerd met criminaliteit, kan gelinkt worden aan natuurlijke surveillance, omdat hierdoor “voetgangers activiteit”gestimuleerd wordt. Dit gaat ook op voor leegstand en het onderhoud en imago principe, kruisingen en parkeerplaatsen met betrekking tot het gecontroleerde toegang principe en tot slot territorialiteit en het percentage gehuurde woningen.

Geconcludeerd kan worden dat de gebouwde omgeving daadwerkelijk invloed heeft op criminaliteit. Het moet wel vermeld worden dat toeristische attracties een grote rol hierin spelen. Desalniettemin biedt dit onderzoek aanknopingspunten om effectiever beleid te gaan voeren om criminaliteit tegen te gaan. Hierbij kan het raadzaam zijn om verschillende functies in buurten te implementeren

Summary

Abstract

Crime in neighborhoods have a significant impact on the quality of life and safety of the residents. This study aims to gain a better understanding of the influence of the built environment characteristics on the occurrence of crime in the neighborhoods in Amsterdam. Multiple theories and contributions on the subject, such as CPTED, defensible space theory, the broken window theory and the social disorganization theory are discussed. Relevant variables were obtained from these theories and contributions and were empirically tested. Relevant variables were operationalized using geographical information systems. An exploratory regression analysis was performed for different crime types to obtain the most optimal ordinary least squares regression models. The variables of this regression analysis were subsequently used in a geographically weighted regression analysis to identify local variations in the relationships between the built environment and crime. The results show that different types of crime are influenced by different characteristics of the built environment. Moreover, variations over space were observed for these relationships. One of the key findings of this research is that tourist attractions heavily correlate with various crime types. Another interesting finding is that mixed land-use is negatively correlated with crime in general, which is supported the literature. Where some of the results confirm the current knowledge on this subject, some contraries could also be observed. it can be concluded that the built environment does influence the crime rates in Amsterdam, but it should be noted that the excessive number of tourists in Amsterdam also interferes with these relationships.

Keywords: *geographically weighted regression, geographical information systems, environmental criminology, crime prevention through environmental design (CPTED), urban planning*

Introduction

The relation between crime and the built environment has been researched relatively little. However, research that has been done, reports that designing the built environment in a particular way could reduce the number of criminal activities, the fear of crime and victimization of residents and legitimate users of the area. In 1961, Jacobs presented in her book, *The Death and Life of Great American cities*, that the urban environment could affect the behavior of users in the area, especially that land-use diversity and a high pedestrian activity influence the perception of safety. Subsequently, Newman (1972) developed the defensible space theory in the early 70s of the previous century. The defensible space theory is characterized by low urban density with high proportions of residential areas with limited access to strangers. Jeffery introduced the term Crime Prevention Through Environmental Design (CPTED) in 1971. All these contributions were aimed to reduce crime by shaping the built environment.

This study aims to understand the influence which characteristics of the built environment, socio-demographics and socio-economics have on crime numbers of different types of crimes for the neighborhoods of Amsterdam. In this research, the following types of crime are considered: burglary, vandalism, violent crimes, drugs and nuisance related crimes and theft. Moreover, all crimes combined are analyzed. The unit of analysis are the neighborhoods of Amsterdam.

Literature

Jane Jacobs was one of the first who established a relation between the physical environment and crime. Jacobs (1961) argued that crime occurs when residents feel isolated and anonymous, and when they believe that they have no stake in their neighborhood (Wortley & Mazerolle, 2008). Jacobs proposed four conditions of urban design: (I) mixed land-uses to stimulate pedestrian activity on the streets and parks; (II) districts should be divided into small blocks with frequent corners and interconnecting streets; (III) diversity of old and new buildings to ensure diversity of enterprises; (IV) a sufficient population density to stimulate activity among residents (Wortley & Mazerolle, 2008). The four conditions all contribute to ‘’eyes on the street’’ which is the term Jacobs introduced for informal surveillance.

Oscar Newman, an architect and urban designer, developed the defensible space theory in the early 70s of the previous century. According to Donnelly (2010), the defensible space theory has four key concepts: territoriality, surveillance, image and milieu. ‘’*The four elements of defensible space can translate the latent territoriality and sense of community of residents into a responsibility to secure and maintain a safe, productive and well-maintained neighbourhood’’* (Cozens, 2008). Newman (1972) also argued that high-rise buildings and high urban density results in anonymity which in turn has an influence on the occurrence of crime.

The contributions of Jacobs (1961) and Newman (1972) formed the basis of what is now known as crime prevention through environmental design. CPTED is considered to be mostly a ‘natural’ strategy in preventing crime which implies that it is not labor intensive. Fennelly & Crowe (2013) state that there are four principles of CPTED: (I) territoriality, (II) surveillance, (III) access control and (IV) image and maintenance. Territoriality is aimed at the demarcation of public and private space. Natural surveillance is involved in creating more ‘’eyes on the street’’. The third principle, access control, relates to control the people in areas where they should not be. Finally, the principle of maintenance and image, which is concerned with appearance of the area, which can be related to the broken window theory by Kelling & Wilson (1982). In the upcoming section relevant characteristics of the built environment that have been researched in relation to crime prevention are discussed.

Land-use

Jacobs (1961) mentioned the importance of different land-uses in an area to improve pedestrian activity and thus increase the natural surveillance (eyes on the street) in the neighborhood. The study by Wuschke & Kinney (2018) concluded that rates of property crimes and violent crimes are most present on residential land-uses. However, these types of crime occur disproportionally higher in areas classified as commercial or recreational.

Greenspace

According to de Vries, Verheij, Groenewegen, & Spreeuwenberg (2003), greenspace leads to more physical activity such as walking and cycling and therefore the presence of greenspace may have a positive effect on natural surveillance. Shepley, Sachs, Sadatsafavi, Fournier, & Peditto (2019) found in their extensive literature review of 45 quantitative researches that greenspace helps reducing crime. Bogar & Beyer (2016) concluded that the current research body is too small and that there is too much variation among the researches to draw conclusions.

Streetlighting

Streetlighting is commonly mentioned in studies regarding CPTED (Gulak, Kun, Koday, & Koday, 2007; Hedayati Marzbali, Abdullah, Ignatius, & Maghsoodi Tilaki, 2016; Hedayati Marzbali, Abdullah, Razak, & Maghsoodi Tilaki, 2012; Lee, Park, & Jung, 2016) as it increases visibility and therefore also increases the natural surveillance. Moreover, Lee et al., (2016) found that streetlighting reduces the fear of crime and that it increases pedestrian activity.

Street layout

The design of infrastructure is associated with the access control principle of CPTED. Sohn (2016) found the street density and intersection density to be significantly correlated with residential crime density. Block & Block (1995) found that many, liquor related, crimes occur near intersections, especially in grid and diagonal street patterns.

Newman (1972) argued that cull de sacs (dead end streets) are the streets where crime occurs the least, as small group of neighbors can survey the area that is accessible from their dwelling (Hillier, 2004). This is contrary to the argument of Jacobs' (1961), which stated that areas should be well connected in order to create a more vibrant area where informal surveillance acts as a mechanism against crime. These finding are contrary to those of the research of Yang (2006), which shows that residential burglary occurs most on streets with ''through traffic'' and the least on dead-end streets.

Parking

Limited (public) parking places is believed to have a positive effect on access control, and furthermore, the fewer cars that are parked, the fewer the opportunities for car related crimes. Moreover, Bennet & Wright (1984), found that burglars look for parked vehicles in the immediate area next to their target as a sign of occupancy. By limiting the number of parking places, it is more likely that they are occupied, and therefore, a higher percentage of the parking places is occupied.

Housing

''*Scholars have long known that homeowners and long-term residents have a greater incentive to protect their local area and might be willing to take more risk in doing so*'' (Felson, 2018). Hence it could be argued that the number of rented (or owned) homes is of importance in this research.

Vacancy is often mentioned as a determinant of the image and maintenance principle of CPTED. The study conducted by Fuentes & Hernandez (2014) regarding property crime and vacancy, found that for every point increase in vacancy, the number of property crime rose by .84%. Moreover, Cui & Walsh (2015) found that violent crime increased by 19% in the immediate area once a foreclosed home became vacant.

Another determinant of crime, in relation to housing, is population density. A high population density is facilitated by high-density housing. Sampson & Groves (1989) found in their study in which they tested the social disorganization theory that the level of urbanization is significantly positive correlated with multiple types of crime. They argued that a high level of urbanization weakens local social structures (decreased social control, weakened local kinship and friend networks). These findings are supported by the finding of Sohn (2016).

Artworks

''*Art and sculpture are powerful tools in promoting territorial behavior and proprietary concern for space. They attract attention to spaces and help people find their way. One of the greatest values of street art is how it contributes to triangulation, which helps people psychologically connect places, thus increasing perceptions of territoriality and control*.''(Fennelly & Crowe, 2013). No empirically research was found in which artworks and cultural heritage symbols are tested against crime.

CCTV

The presence of closed circuit television (CCTV) is a mechanical crime prevention method which is aimed at increasing surveillance. Lee, Park, & Jung (2016) argued that the presence of CCTV also provides symbolic barriers that deter criminals and thus CCTV could besides surveillance, also be effective as a measure of access control. Hedayati Marzbali, Abdullah, Ignatius, & Maghsoodi Tilaki (2016) used a similar reasoning.

Tourist attractions

It is generally known that the city of Amsterdam is a tourist intensive city; in 2018 the city was ranked 23rd in the top 100 city destinations by Euromonitor (Geerts, 2018). Bhati & Pearce (2016) stated that many tourist sites experience vandalism. Moreover, Merrill (2011) stated that cultural heritage monuments/areas often are vandalized with graffiti, which is a textbook example of vandalism. Crime types that occur most due to tourist attractions are vandalism and theft related crimes (Bhati & Pearce, 2016; Jud, 1975). Jud (1975) found that tourism is mainly concerned with property related crimes.

Social disorganization

Whereas this research is mostly concerned with the physical part of environmental criminology, it seems wise to include socio-economic and socio-demographic variables as control variables, since crime prevention is a multi-disciplinary and integrated endeavor (United Nations Office on Drugs and Crime, n.d.). The social disorganization theory will be used for the socio-economic and demographic variables. The social disorganization theory is considered to be one of the most influential contribution to environmental criminology on the meso-level of analysis, besides the contribution of Jane Jacobs (Wortley & Mazerolle, 2008). The social disorganization theory, in short, states that three variables cause social disorganization. These variables are (I) the physical state of the neighborhood, (II) the economic status and (III) ethnic heterogeneity. Shaw & McKay (1942) argued that these three all contributed to creating social disorganization, which in turn results in higher crime and delinquency rates in the neighborhood.

The physical state was defined as a combination of population change, vacant and condemned housing and the proximity to industry. Shaw & McKay (1942) argued that a high turnover in the local population makes it difficult to create a social structure in the neighborhood. Rogerson & Pease (2019) also mentioned that residential mobility is a challenge for CPTED. Rogerson & Pease (2019) also found that crime is an incentive to move.

Shaw & McKay (1942) argued that ethnic heterogeneity in the population also affects the social structure in the neighborhood. Ethnic heterogeneity is often solely used as a measure of social disorganization. Often the heterogeneity index, developed by Blau (1977) is used, which is a measure which indicates the level of ethnic heterogeneity on a scale from zero to one (Bruinsma, Pauwels, Weerman, & Bernasco, 2013; Davies & Bowers, 2018; Kimpton, Corcoran, & Wickes, 2017; Sampson & Groves, 1989).

Data

Data regarding crimes was obtained from the Dutch police department. It provides crime rates per crime type and per neighborhood. Per neighborhood the crime density was determined by dividing the number of crimes by the area of the neighborhood. A square root transformation was performed on the crime density to create a more normal-like distribution. Logarithmic transformations were not considered due to crime densities of less than one or even zero. The operationalization of the independent variables is displayed in table A.

Table A: operationalization independent variables

Variable	Operationalization	Data source
Cul-de-sac density	# of dead-end streets per square kilometer	Rijkswaterstaat (2021)
Intersection density	# of intersections per square kilometer	Rijkswaterstaat (2021)
Mixed land-use	Heterogeneity index: $Mixed\ land\ use = \frac{1-\sum_{i=1}^{k} {L_i}^2}{(k-1)/k}$ L_i = ratio land-use type i K = number of categories	(PDOK, 2015)
Percentage of residential land-use	Ratio of land covered by residential land-use	(PDOK, 2015)
Percentage of retail and catering land-use	Ratio of land covered by retail and catering land-use	(PDOK, 2015)
Ratio CCTV	Ratio of land covered by CCTV coverage	(Gemeente Amsterdam, 2021)
Streetlighting	# of streetlights per square kilometer	(Data.overheid.nl, 2021)
Artworks	# of public artworks per square kilometer	(Gemeente Amsterdam, 2021)
Ratio greenspace	Ratio of land covered by greenspace. A 50 meter buffer was used for greenspace outside the research area	(PDOK, 2015)
Tree density	# of trees per square kilometer	(Gemeente Amsterdam, 2021)
Parking density	# of parking spots per square kilometer	(Gemeente Amsterdam, 2021)
Population density	# of inhabitants per square kilometer	(Statistics Netherlands, 2019)
Address density	# of addresses that are present within one kilometer	(Statistics Netherlands, 2019)

Vacancy rate	percent of vacant dwellings in the neighborhood	(Statistics Netherlands, 2019)
Tourist attraction density	# of tourist attractions per square kilometer	(Data.overheid.nl, 2019)
Ethnic heterogeneity	Heterogeneity index by Blau (1977) $Blau\ index = 1 - \sum_{i=1}^{k} {p_i}^2$ P_i = portion of specific ethnic groups k = number of different ethnic groups	(Statistics Netherlands, 2019)
Socio-economic status	Sum of z-scores of (I) average real-estate value, (II) share of high educated residents and (III) labor participation.	(Statistics Netherlands, 2019)
Percentage rented homes	Percentage of rented homes in the neighborhood.	(Statistics Netherlands, 2019)

Method

The first step of the analysis is an exploratory regression, which will find the most optimal combination of variables to minimize the corrected Akaike's Information Criterion for the OLS regression model. An exploratory regression performs an ordinary least squares regression for each possible combination of independent variables. It is expected that per crime type different variables will be included in the models. The model with the lowest score for Akaike's Information Criterion will be selected for further analysis.

Next, an ordinary least squares regression analysis will be performed with the variables which were obtained from the exploratory regression. This OLS regression will provide coefficients and significance levels of the relevant variables. The residuals of the OLS regression will be tested for spatial autocorrelation by using Moran's I. This is done for verification purposes, as clustered residuals will interfere with the effectiveness of the geographically weighted regression. Moreover, it could also indicate that variables are missing which are apparent in areas with overpredictions and underpredictions.

The last analysis is a geographically weighted regression to identify spatial variability in the coefficients. The bandwidth for the fixed kernel will be set at three kilometers. Kubrin & Weitzer (2003) mentioned that researchers that research ''social disorganization'' slowly start addressing the problem with aggregation of social data into officially defined areas. They argued that this is problematic as these officially defined areas are seldom spatially independent and that crime levels in one neighborhood influence crime levels in adjacent neighborhoods. Cahill & Mulligan (2007) argue that one of the problems with global regression models is that possible variations over space are suppressed. Hence, the use of a geographically weighted regression analysis seems more appropiate.

Results

The results of the exploratory regression analyses and ordinary least squares regression analyses are summarized in table B. The variables that came forward from the exploratory regression are included with a parameter. Variables without coefficient are variables that did not come forward in the exploratory regression and thus do not improve the model.

Table B: results exploratory regression and ordinary least squares regression for several crime types

Variables	Burglary	Vandalism	Violent crimes	Drugs and nuisance	Theft	Total crimes
Constant	-.940	-.560	-.369	-.356	2.527**	2.869
Cul-de-sac density	-	-	-	-	-	-
Intersection density	.007***	-	-	.004	-	-
Mixed land-use	1.496**	-	-2.690***	-	-3.250***	-7.424***
Percentage of residential land-use	2.182***	1.131*	-	-	-	-
Percentage of retail and catering land-use	-	7.417***	18.418***	18.443***	26.662***	56.455***
Ratio CCTV	-1.111**	2.004***	2.792***	3.875***	3.230***	5.413***
Streetlighting	-	.00032*	.00042**	.00043*	.002***	.003***
Artworks	.022*	.027**	-	-	-	-
Ratio greenspace	1.911*	-	-	-	-	-
Tree density	-	-	-	-	-	-.001**
Parking density	-	-	.00027**	-.00043***	-	-
Population density	.000204***	.00007***	.00011***	.00005*	.00012***	-
Address density	.000134**	.00024***	.00038***	-	.00048***	.002***
Vacancy rate	.049**	-	.068**	.047*	.104***	-
Tourist attraction density	-	.019*	-	.099***	.146***	.212***
Ethnic heterogeneity	-	4.201***	7.585***	-	-	11.354***
Socio-economic status	-.099*	-	-.256***	-	.397***	.686***
Percentage rented homes	-	-	-	.016*	.032***	.064***

R^2-adjusted	.530	.654	.709	0.724	.807	.877
AICc	1796.67	1865.54	2044.70	2120.61	2302.83	2650.37
Max VIF-value	2.670	2.829	3.088	2.088	3.002	2.285

****** variable significant at the p < 0.01 level***
***** variable significant at the p < 0.05 level***
**** variable significant at the p < 0.10 level***
- not included in the model

From a look at the results of the OLS regression analyses, it can be observed that all variables, except the cul-de-sac density, are included at least once. Moreover, high significance levels can be observed. This is no surprise due to the prior executed exploratory regression, which will ensure that only relevant variables are included. The results of the OLS regression show global relationships and more generalizable results. In general, the results are in line with the literature, with a few exceptions; such as the greenspace in the burglary model and streetlighting for all models in which it is included. Moreover, CCTV has opposite signs, as was expected.

The most remarkable result of the burglary model is the inclusion of greenspace; other variables make sense. In regard to vandalism, streetlighting and artworks having a positive sign is contrary to the literature. On the other hand, it could be argued that streetlighting and artworks are targets of vandalism, and thus attract vandalism. The other models do not seem to have any remarkable or strange variables besides the earlier mentioned CCTV and streetlighting.

The residuals of all models were tested for spatial autocorrelation using Moran's I; the results are displayed in table C. The residuals of all models were found to be not spatially autocorrelated as the p-value for all crime types was higher than 0.10. Hence, the residuals were distributed randomly throughout the research area.

Table C: Moran's I for OLS regression residuals

	Burglary	**Vandalism**	**Violent crimes**	**Drugs and nuisance**	**Theft**	**Total crimes**
Moran's I	0.005360	0.002210	0.000396	0.001985	0.000238	-0.000081
Z-score	1.411898	0.855496	0.520057	0.811449	0.491463	0.433635
P-value	0.157980	0.392277	0.603024	0.417108	0.623099	0.664553

Bandwidth 3000 meter, Euclidean distance method

Next, per crime type a geographically weighted regression is performed. These analyses will be elaborated per crime type in the upcoming section. The most interesting/influential variables will be elaborated more in depth.

Burglary

The results of the GWR for the burglary model are displayed in table D. The differences in the coefficients and local R-squared values indeed show that there are local changing relationships. The improvement of the adjusted R-squared value and the AICc shows that taking spatial relationships into account is beneficiary, although a better improvement was expected.

Table D: GWR results burglary

	Lowest	Mean	Highest
(Constant)	-3.273	-1.115	1.946
Intersection density	0.001	0.007	0.020
Art density	-0.026	0.025	0.105
Ratio CCTV	-5.054	-1.434	0.097
Percentage residential land-use	-3.504	2.327	4.999
Mixed land-use	-5.559	1.147	2.505
Socio-economic status	-0.471	-0.046	0.280
Ratio greenspace	-1.132	1.341	8.127
Population density	0.00005	0.00020	0.00046
Address density	-0.00023	0.00017	0.00037
Vacancy rate	-0.040	0.058	0.158
Local R-squared	0.480	0.548	0.883

R^2adjusted: 0.563; AICc: 1766.98

Looking at the burglary model from the GWR, the most interesting findings are the intersection density and the socio-economic status. The intersection density perfectly follows the empirical results of Sohn (2016) & Yang (2006). On the other hand, it is contrary to Jacobs' (1961) argument of increased permeability which should decrease crime. Socio-economic status having positive and negative coefficients is also found to be interesting, as it suggests that burglaries should occur the least in areas with a socio-economic status that is close to the mean.

In figure A the local R-squared values are displayed. It can easily be observed that the model performs better in peripheral areas of the city, whereas the model performs worse in the city center. The model performs better in areas with a lower number of burglaries. This implies that the variables explain less variance in the city center and more in the peripheral areas. The city center has a relatively large negative coefficient for the intercept (figure B). This could possibly be due to one or more missing variables. This could also explain the lower R-squared values in the city center, as less variance is explained by the model in this specific region.

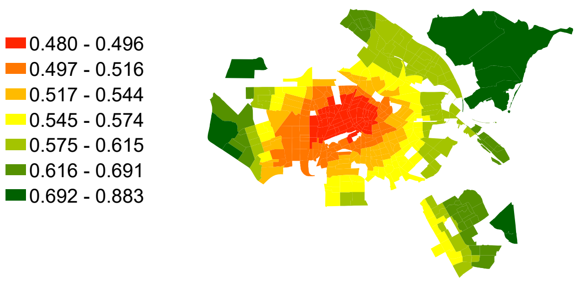

Figure A: local R-squared burglary model

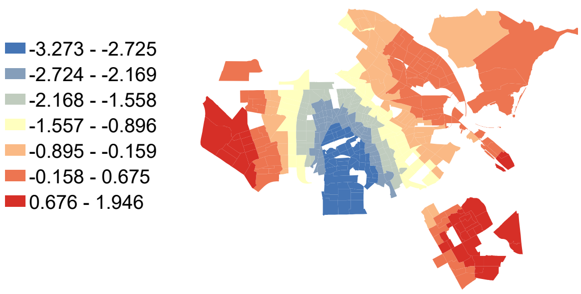

Figure B: coefficient for the intercept burglary model

Population density, which has the highest standardized coefficient in the OLS regression, seems to have a somewhat random pattern considering the areas with a high number of burglaries in combination with highly populated areas (figure C).

As the values for the socio-economic status range between approximately -6 to 6, this in combination with coefficients ranging from approximately -0,5 to 0,3 makes the GWR results relatively difficult to interpret. Neighborhoods with a poor socio-economic status and also a negative coefficient for this variable would experience more burglaries, as multiplying negative values will become positive. On the other hand, neighborhoods with a high socio-economic status and also a positive coefficient will also experience more burglaries.

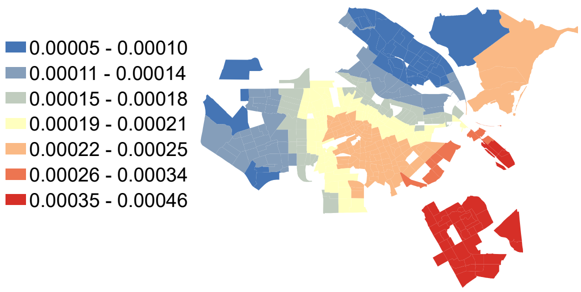

Figure C: coefficient for population density burglary model

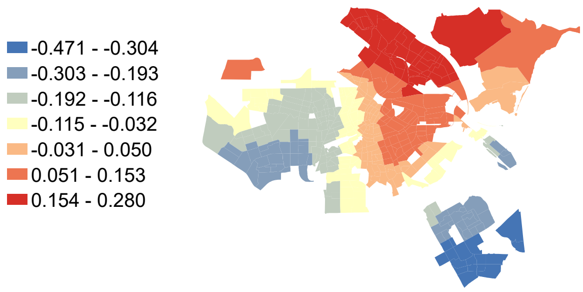

Figure d: coefficient for socio-economic status burglary model

Vandalism

The results of the vandalism model are displayed in table E. Again, it can be observed that there are varying relationships. The adjusted R-squared and AICc indicate a significantly better model fit than the OLS regression model.

Table E: GWR results vandalism

	Lowest	Mean	Highest
(Constant)	-2.752	0.415	2.519
Art density	-0.067	0.026	0.085
Ratio CCTV	-0.057	2.691	4.086
Ethnic heterogeneity	-0.895	2.705	12.364
Percentage residential land-use	-1.811	1.100	3.442
Percentage retail and catering land-use	-6.147	6.770	15.601
Tourist attraction density	-0.239	0.041	0.443
Streetlighting density	-0.00027	0.00019	0.00074
Population density	-0.000013	0.000083	0.000359
Address density	-0.00104	0.00025	0.00047
Local R-squared	0.415	0.549	0.880

R^2adjusted: 0.666; AICc: 757.00

The most interesting finding of the vandalism model is the high positive correlation with tourist attractions, which was initially unexpected. However, the literature suggested that this correlation does make sense (Bhati & Pearce, 2016; Merrill, 2011).

It can be observed that the model performs worst in the area west of the city center, whereas it performs best east and north of city center. The local R-squared values for areas with many vandalism related crimes, seem to differ (figure E).

The intercept seems to be the highest in the city center, while the peripheral areas have lower coefficients (figure F). Arguably, the intercept might compensate for variables which are not included but which stimulate vandalism, since the local R-squared values are also the lowest near the city center where vandalism occurs the most.

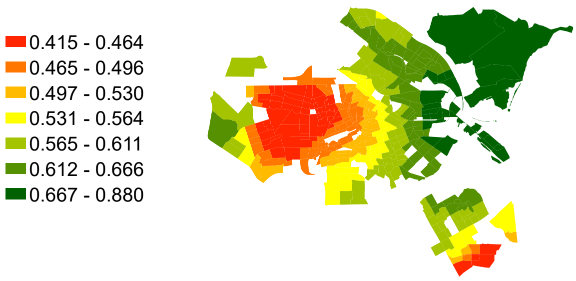

Figure E: local R-squared vandalism model

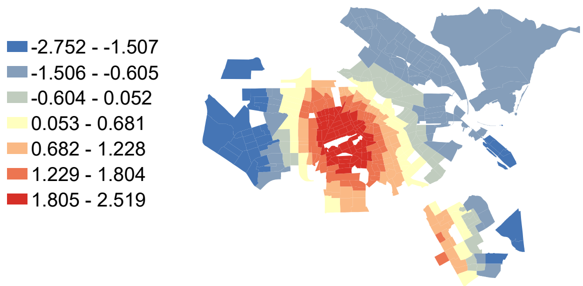

Figure F: coefficient for the intercept vandalism model

Looking at the coefficients for the address density (figure G), it stands out that the south-east region has a negative coefficient. This pattern could be explained as the literature shows that more urbanized areas experience more crime.

Unexpectedly, tourist attractions density has the lowest coefficients in the area where most tourist attractions are located (figure H). A possible explanation is that the tourist attraction density is much higher in that area and that the model uses a lower coefficient to somehow compensate this by giving tourist intensive areas lower coefficients.

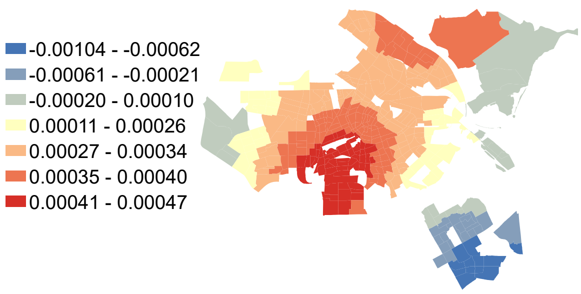

Figure G: coefficient address density vandalism model

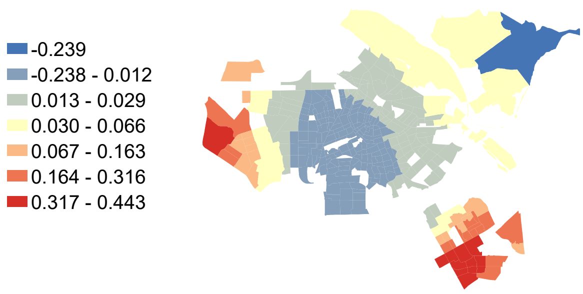

Figure H: coefficient tourist attraction density vandalism model

Violent Crimes

Table F shows the results for the violent crimes model. Like the vandalism model, a significant model fit improvement can be observed.

Table F: Results GWR violent crimes

	Lowest	Mean	Highest
(Constant)	-3.692	0.412	5.238
Parking density	-0.000801	-0.000268	0.00156
Ratio CCTV	-0.426	3.838	6.649
Ethnic heterogeneity	1.182	7.139	11.527
Percentage retail and catering land-use	-0.395	17.054	23.084
Mixed land-use	-6.928	-3.196	2.428
Socio-economic status	-0.565	-0.233	0.188
Streetlighting density	-0.00126	0.00018	0.00159
Population density	-0.00019	0.00011	0.00049
Address density	-0.00060	0.00041	0.00083
Vacancy rate	-0.014	0.081	0.160
Local R-squared	0.617	0.728	0.909

R^2adjusted: 0.803; AICc: 412.99

The most interesting results of the violent crimes model are that a large number of variables included are perfectly in line with the literature; variables originating from the social disorganization theory, vacancy, mixed land-use and retail and catering land-use.

Looking at the local R-squared values, there are areas in Amsterdam in which 90 percent of the variance can be explained by the GWR model (figure I). A clear division between east and west can be observed; in the east high values are present, whereas the lowest values appear in the west. The city center where most violent crimes occur, has a R-squared value that is slightly higher than the mean.

The intercept appears to have the highest coefficient in the southern part of the city, except the south-east region (figure J). The city center still has a relatively high coefficient whereas the rest of the city has a coefficient of zero or a negative value.

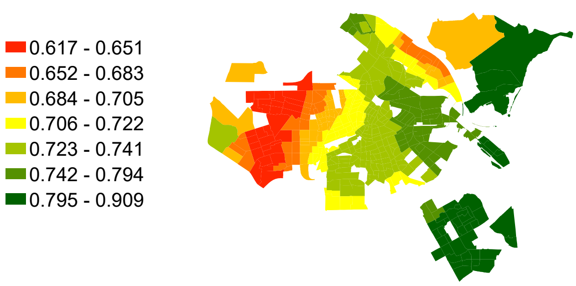

Figure I: local R-squared values violent crimes model

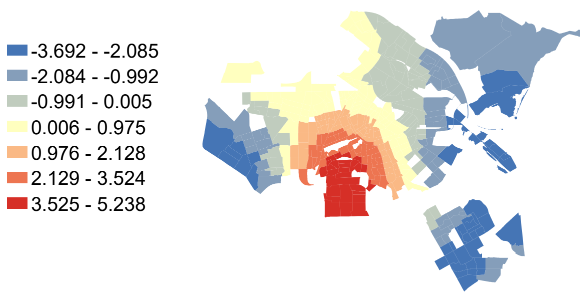

Figure J: coefficient for the intercept violent crimes model

The percentage of retail and catering land-use is the highest in the south-east region and the city center (figure K). The city center having a relatively high coefficient seems logical, as the city center experiences most violent crimes and the other variables seem to have less influence in the city center.

Ethnic heterogeneity seems to be influencing violent crimes most in the west, where a high level of ethnic heterogeneity can be observed (figure L). It is interesting that the south-east region, which also has a high level of ethnic heterogeneity, has a relatively low coefficient. Remarkably to see is that ethnic heterogeneity follows a pattern that is similar to that of the local R-squared values. The coefficient for ethnic heterogeneity is the highest in areas where the R-squared is low.

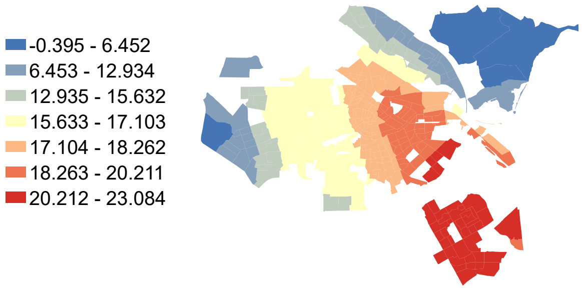

Figure K: coefficient for retail and catering land-use violent crimes model

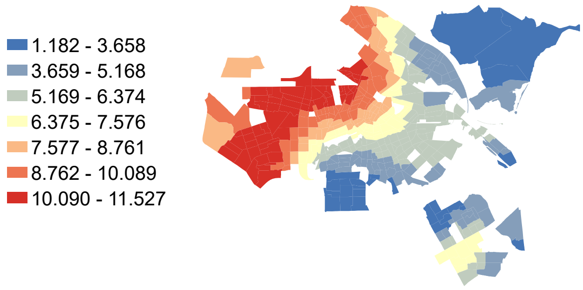

Figure L: coefficient for ethnic heterogeneity violent crimes model

Address density has the highest coefficients in a few neighborhoods in the far west, whereas the city center also has a relatively high coefficient (figure M). This makes sense as the literature shows that more urbanized areas experience more crime.

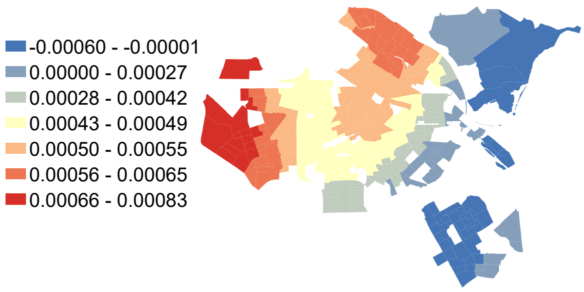

Figure M: coefficient address density violent crimes model

Drugs and nuisance

The GWR results for Drugs and nuisance related crimes are summarized in table G. It is remarkable that there are no signs of improvement by taking spatial relationships into account. Hence, it could be argued that drugs and nuisance related crimes have stationary relationships with the variables included. However, a look at the variables individually shows that varying relationships can be observed.

Table G: Results GWR drugs and nuisance related crimes

	Lowest	**Mean**	**Highest**
(Constant)	-1.653	0.029	2.393
Intersection density	-0.009	0.004	0.012
Parking density	-0.00077	-0.00047	0.00031
Ratio CCTV	0.944	5.138	18.458
Percentage retail and catering land-use	0.705	18.331	31.537

Tourist attraction density	-0.063	0.095	0.267
Streetlighting density	-0.00036	0.0002	0.00122
Population density	-0.000019	0.000065	0.00029
Percentage rented homes	-0.015	0.015	0.049
Vacancy rate	-0.023	0.068	0.118
Local R-squared	0.453	0.721	0.840

R^2adjusted: 0.732; AICc: 2137.37

The local R-squared values show that the model explains variance in the south-east region and the city center the best (figure N). This is preferable as most crimes occur in these areas. The intercept has the highest coefficient in the south-eastern part of the city (figure O). The coefficient of the intercept for the city center, where most drugs and nuisance related crimes occur, is close to zero. Hence, it could be argued that the variables in the model predict these types of crime well.

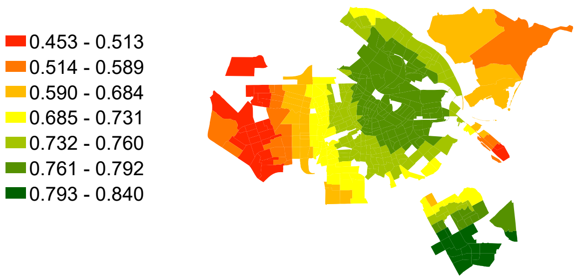

Figure N: local R-squared values drugs and nuisance model

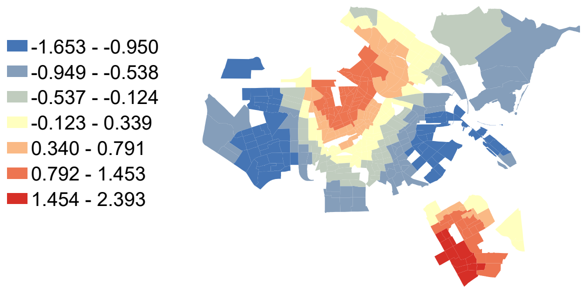

Figure O: coefficient for the intercept drugs and nuisance model

The tourist attraction density has a relatively low coefficient in the areas where there are more tourist attractions (figure P). Like in the vandalism model, it is expected that this is due to the high number of tourist attractions in the city center compared to the other areas of the city. A high coefficient would probably result in extreme overpredictions.

It is interesting to note that the coefficient for the parking density is negative in the areas where drugs and nuisance related crimes occur most (figure Q). A similar pattern as with the violent crimes model can be observed. Another remarkable aspect is that in the western part of the city, the coefficient becomes positive.

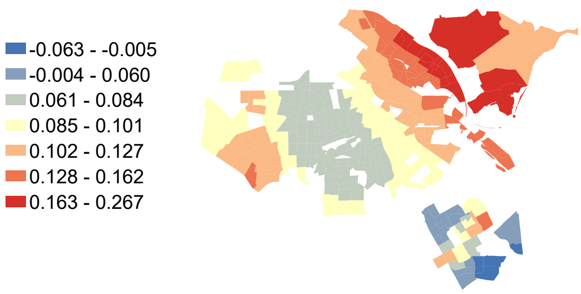

Figure P: coefficient for tourist attraction density drugs and nuisance model

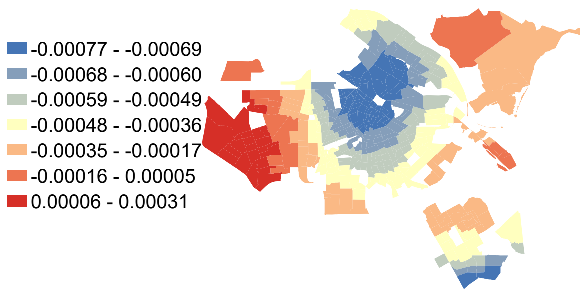

Figure Q: coefficient for parking density drugs and nuisance model

Theft

In table H the coefficients obtained from the GWR for the theft model are displayed. Only a limited improvement can be observed when taking spatial relationships into account.

Table H: Results GWR theft model

	Lowest	Mean	Highest
(Constant)	-4.269	3.677	7.783
Ratio CCTV	-1.852	4.662	17.415
Percentage retail and catering land-use	3.221	23.616	30.033
Mixed land-use	-7.051	-3.018	3.251
Tourist attraction density	-0.302	0.126	0.278
Socio-economic status	-0.194	0.327	0.762
Streetlighting density	0.000	0.001	0.003
Population density	-0.00017	-0.000096	0.00019
Address density	0.00022	0.00048	0.00120
Percentage rented homes	-0.023	0.018	0.073
Vacancy rate	-0.044	0.147	0.319
Local R-squared	0.622	0.795	0.865
R^2adjusted: 0.824; AICc: 2298.92			

From looking at the local R-squared values it becomes clear that the variance is best explained in neighborhoods near the city center (figure R). This makes sense as most theft related crimes occur near the city center, especially pickpocketing, which is generally speaking near tourist attractions.

The intercept has the highest coefficient in the city center, whereas the peripheral areas of the city have to lowest coefficients (figure S). Taking into consideration that the improvement of the GWR model in comparison to the OLS model is quite poor, it could be argued that theft is stationary, and that the intercept of the GWR acts as a measure of distance to the city center.

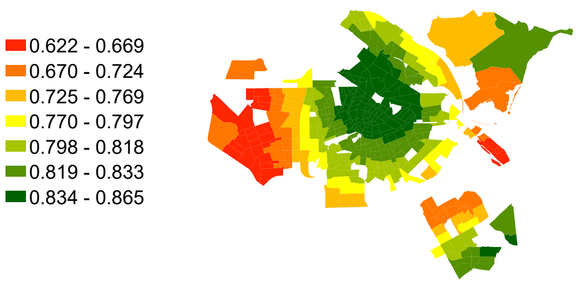

Figure R: local R-squared theft model

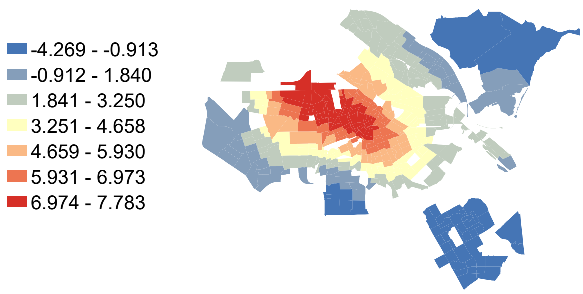

Figure S: coefficient for the intercept theft model

Tourist attraction density has surprisingly a relatively low coefficient in the city center where most tourist attractions are present (figure T). Arguably, this is due to the big differences in the values of the tourist attraction density of city center compared to the rest of the city. The highest coefficients for retail and catering land-use can be found in the city center (figure U). In this area, most land is covered by retail and catering facilities. This implies that the effect of retail and catering facilities is amplified when using a GWR

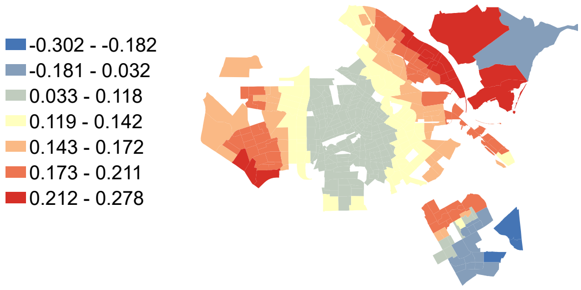

Figure T: coefficient tourist attraction density theft model

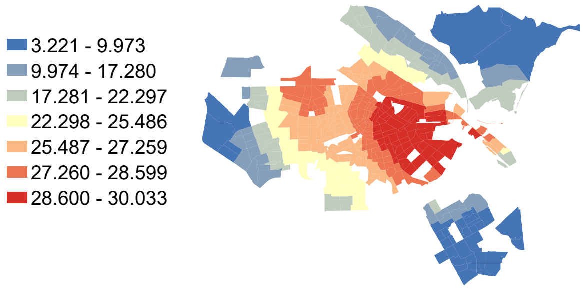

Figure U: coefficient retail and catering land-use theft model

Total

Finally, all crimes combined were analyzed. The results are displayed in table I. Taking spatial relationships into account will result in a better model fit. Whereas an improvement of approximately .03 in the adjusted R-squared value might seem marginal, it should be noted that the adjusted R-squared of the OLS regression was .877, hence there is less room for improvement. Moreover, the AICc is more than 2000 lower than the OLS regression model.

Table I: Results GWR total crimes model

	Lowest	Mean	Highest
(Constant)	-2.621	6.734408	17.414023
Tree density	-0.003	-0.001	0.003
Ratio CCTV	0.658	7.357	21.990
Ethnic heterogeneity	0.016	8.443	17.185
Percentage retail and catering land-use	22.614	55.477	64.419
Mixed land-use	-12.564	-7.541	1.610
Tourist attraction density	-0.478	0.194	0.891
Socio-economic status	-0.245	0.553	1.083
Streetlighting density	0.0013	0.0026	0.0046
Address density	0.0011	0.0016	0.0036
Percentage rented homes	0.006	0.042	0.126
Local R-squared	0.799	0.864	0.942

R^2adjusted: 0.916; AICc: 555.92

As can be seen, the areas with highest crime rates also have a higher local R-squared value (figure V). It is preferable that the R-squared is highest in areas with the highest crime rates, as the upmost part of the total crimes are explained by the model.

The intercept appears to have the highest coefficient in the city center, where relatively many crimes occur (figure W). Arguably, the intercept is compensates for variables which are not included in the models. A coefficient for the intercept of approximately 15, in combination with the square root transformation suggests that the intercept is compensates for more than 200 crimes per square kilometer per year in those areas.

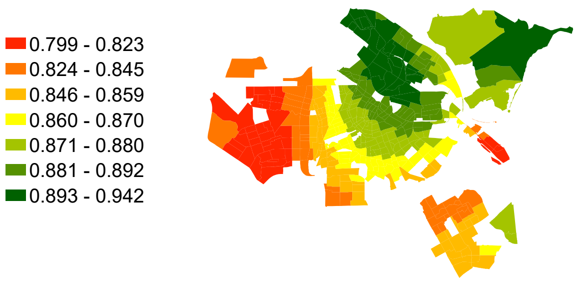

Figure V: local R-squared values total crimes model

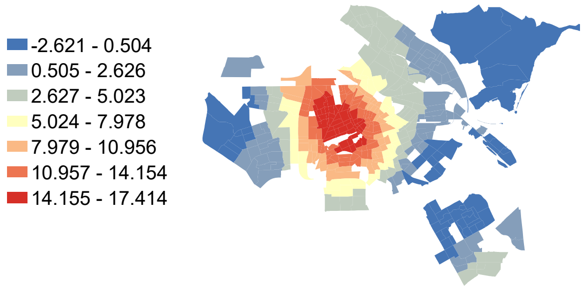

Figure W: coefficient for the intercept total crimes model

Mixed land-use has the highest coefficients in the east; towards the west the coefficients decrease (figure X). When looking at the coefficient for the tree density, it can be observed that the city center has negative coefficients, whereas the peripheral areas have coefficients near zero or positive ones, which implies that in those areas the tree density does not seem to reduce crime as much as in the city center (figure Y).

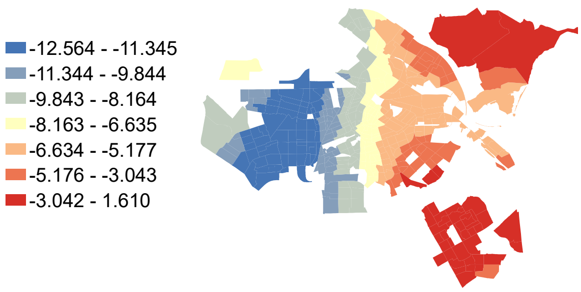

Figure X: coefficient for mixed land-use total crime model

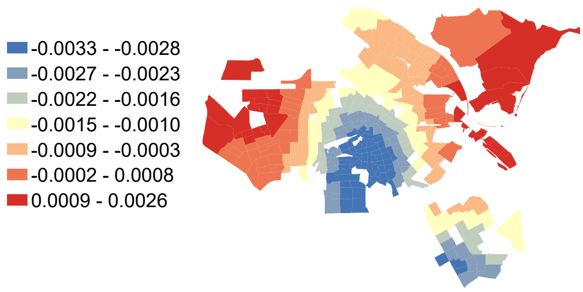

Figure Y: coefficient tree density for total crimes model

Tourist attractions density again follows a pattern in which the city center, with most tourist attractions, has a relatively low coefficient (figure Z).

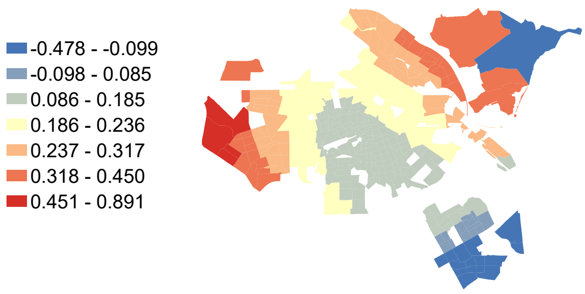

Figure Z: coefficient tourist attraction density total crimes model

Conclusion and discussion

As regards the CPTED principles, some confirming findings can be observed. The number of intersections increasing crime is in line with the CPTED principle of access control, as the number of intersections increases the permeability of the neighborhood and thus weakens the access control. Mixed land-use should act as a measure to improve natural surveillance, which it does as all the signs are negative. The vacancy rate is also in line with CPTED, namely the image and milieu principle. As vacancy is argued to have a negative effect on the image of the neighborhood, resulting in more crime. The vacancy rate is positively correlated with drugs and nuisance related crimes, violent crimes and theft. The number of rented homes, arguably, can be seen as a negative measure of territoriality, as people are more inclined to defend their own property. The percentage of rented homes is positively correlated with drugs and nuisance related crimes, theft and crime in general. Hence, variables representing all CPTED principles are in line with the CPTED strategy. However, there are also some variables out of line. CCTV for example, which should act as a measure of surveillance and access control, however, shows a positive correlation. The same goes for the streetlighting as a measure of natural surveillance, artworks as a measure of territoriality and parking places as a measure of access control.

When taking spatial relationships into account, it can easily be observed that for burglary, vandalism, violent crimes and crime in general the models improve significantly. Drugs and nuisance related crimes as well as theft seem to have a limited, if any, improvement. Hence, it could be argued that drugs and nuisance related crimes and theft are stationary. Moreover, taking into account spatial variation of the coefficients provides the opportunity to observe where certain variables are more influential and where they are not.

As regards to policy making to decrease criminal activities in the city center of Amsterdam, it is recommended to limit the amount of retail and catering facilities in the city center, as they seem to stimulate criminal behavior for different types of crime. Research should be done to establish to what extend the retail and catering facilities can be reduced while it is still able to provide the population of Amsterdam. Limiting the retail and catering facilities, would also provide an opportunity to implement different types of land-use to increase the number of different functions. Mixed land-use will in its turn also lower the population density, which stimulates crime, as multiple functions besides residential are present in the area. Concerning tourism, it is recommended to evaluate whether the benefits of the high number of tourists outweigh the disadvantages such as crime, but also the deterioration of the city center, sustainability issues and the nuisance in general that the residents of Amsterdam experience. Limiting the number of tourists could be done by implementing a higher tourist tax or by regulating the number of hotel rooms.

In general, it can be concluded that the built environment does have an influence on the occurrence of crime and that this influence differs among crime types. Moreover, different characteristics of the built environment influence different types of crime. It should be stated that there is consistency in variables between crime types, i.e. the percentage of rented homes and the vacancy rate are consistently positively correlated in all models in which they were included. Further research is recommended to increase the knowledge on the influence of the built environment on crime and to do this for multiple contexts and levels of analysis to get a more thorough understanding of this matter.

List of Abbreviations

AIC	Akaike information criterion
AICc	Corrected Akaike information criterion
CCTV	Closed Circuit Television
CPTED	Crime prevention through environmental design
GIS	Geographical information system
GWR	Geographical weighted regression
OLS	Ordinary Least Squares (regression)

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1. Introduction

The relation between crime and the built environment has been researched relatively little. However, research that has been done, reports that designing the built environment in a particular way could reduce the numbers of criminal activities, the fear of crime and victimization of residents and legitimate users of the area. The built environment could reduce crime, but it should be noted that ‘’*crime prevention is a multi-sectoral, multi-disciplinary, and integrated endeavor*’’ (United Nations Office on Drugs and Crime, n.d.) and therefore crime could not be prevented only by designing the built environment in a particular way.

Some researchers and professionals have linked the built environment with crime. In 1961, Jacobs presented in her book, *The Death and Life of Great American Cities*, that the urban environment could affect the behavior of users in the area, especially, that land-use diversity and a high pedestrian activity influence the perception of safety. Subsequently, Oscar Newman, an architect and urban designer, developed the defensible space theory in the early 70s of the previous century. With this theory he explains the basis of territorial control which basically means that anonymous strangers are more easily identified. The defensible space theory is characterized by low urban density with high proportions of residential areas with limited access to strangers. Jeffery introduced the term Crime Prevention Through Environmental Design (CPTED) in his eponymous book in 1971. Since then, CPTED (pronounced sep-ted) has become more popular among urban planners among the United States and its principles were even included in the building codes of several states in the USA. Nowadays the relation between the built environment and crime is inevitably linked with CPTED and will therefore play an important role in this research.

Fennelly & Crowe (2013) mention three different approaches to crime control: organized, mechanical and natural. Organized crime prevention is based on labor by humans to provide security. The mechanical approach is aimed at controlling crime by using machines such as closed circuit television (CCTV). Finally, the natural approach is based on behavior management. The CPTED measures are mainly focused on the natural approach supplemented with mechanical approaches.

1.1 Problem Definition & Objectives

1.1.1 Problem definition

NOS (2020) states that in Amsterdam, the crime numbers are not decreasing anymore as they used to be (2019 compared to previous years), which results in an overwhelmed police department in Amsterdam, which is alarming. Moreover, crime infested neighborhoods often experience lower levels of quality of life. Finally, crime has a negative influence on real-estate values.

1.1.2 Objectives

The Dutch national planning vision states that it has four key strategies, making the Netherlands competitive, accessible, livable and safe (Ministry of Infrastructure and the Environment, 2011). Reducing crime levels in neighborhoods is believed to increase the quality of life of the residents as it makes the neighborhood more livable and safer and decreases the chance of victimization. Moreover, by using a natural approach to crime prevention/reduction, crime management requires less labor from the police departments.

This study aims to understand the influence which characteristics of the built environment, socio-demographics and socio-economics have on crime numbers of different types of crimes for the neighborhoods of Amsterdam. Hence, effective policies could be implemented to prevent crime.

1.2 Research Questions

The following research questions are being asked:

Main question:

To what extent do characteristics of the built environment and especially CPTED measures influence the amount of crimes in the neighborhoods of Amsterdam and how does this relation vary among different neighborhoods?

Sub questions:

1. How do characteristics of the built environment relate to the principles of CPTED?
2. What are the current crime levels in neighborhoods of Amsterdam and how do they vary among the neighborhoods of Amsterdam?
3. How do socio-demographic and socio-economic characteristics vary among the neighborhoods of Amsterdam and how do they influence crime numbers in the neighborhoods of Amsterdam?
4. How do these relationships vary with different crime types?

1.3 Research Design

In Figure 1 the research design is displayed. The research starts off with a literature review to identify the relevant variables. The identified variables will be operationalized afterwards, this will be done in ArcMap, Excel and SPSS. Next, each crime type will be analyzed, first the most optimal model will be determined by using an exploratory regression analysis, next an ordinary least squared regression analysis will be performed and finally a geographically weighted regression will be performed.

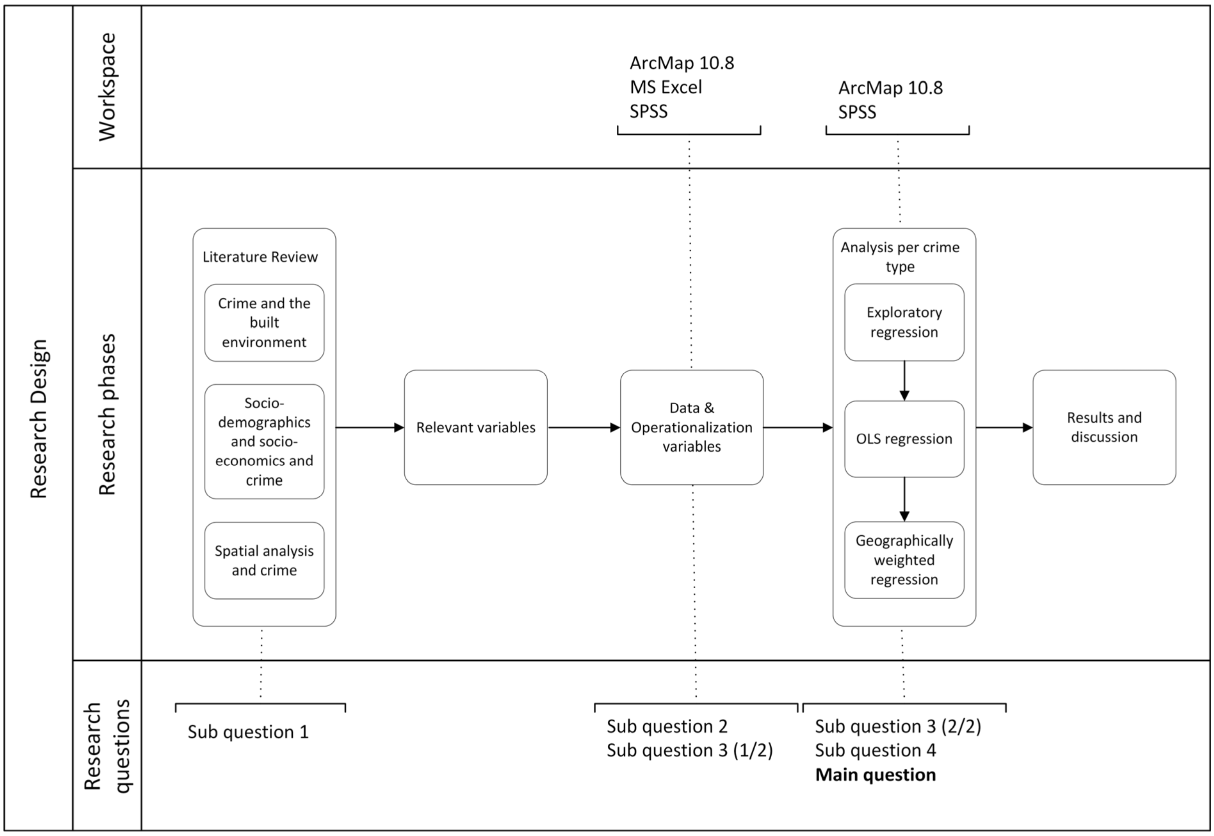


Figure 1: Research design

1.4 Importance of the Thesis

This research is concerned with the role of the built environment in relation to crime. A better understanding of this relation could result in better policies in regard to urban planning/design to create safer neighborhoods with a higher quality of life. It is needless to say that society would benefit if less crime occurs.

Looking at the scientific importance, there are some studies regarding effectiveness of CPTED or the influence of specific characteristics of the built environment on crime. Looking from a methodological point of view, a geographically weighted regression is not often used in crime related researches, although in the researches where it is used, the results are generally positive. Finally, in general, researches in this field are concerned with crime in general or only investigate one specific type of crime. The added value of this research for the scientific discussion is that it will combine spatial statistics with (multiple) characteristics of the built environment for different crime types.

1.5 Scope

This research is concerned with the research area of Amsterdam. Furthermore, the level of analysis is on the neighborhood/meso level due to the availability of crime statistics. Therefore, CPTED principles from the urban planning/design will be considered. CPTED also provides micro-level strategies for crime prevention, however, these are not suitable for operationalization due to the aggregation of crime to a neighborhood level. Moreover, these micro-level tools are not the result of planning/design policy but rather personal/private initiatives as they will lead to operationalization problems.

Crimes that are being considered in this research are burglary, vandalism, violent crimes, drugs and nuisance related crimes and theft. Whereas the Dutch police keeps track of crime types on a detailed scale, some crime types are being combined. In Table 1 is displayed how the crime types that are being considered are constructed.

Table 1: Crime types considered in this research

Combined crime types	***Subparts***	***Police code***
Burglary	Burglary dwelling	1.1.1
Vandalism	Vandalism and destruction of public property	2.2.1
Violent crimes	Murder/manslaughter	1.4.2
	Public assault	1.4.3
	Threatening	1.4.4
	Physical abuse	1.4.5
Drugs and nuisance	Drugs and liquor nuisance	2.1.1
	Livability related crimes	2.7.3
	Drug trade	3.1.1
	Violation of public order	3.6.4
Theft	Pickpocketing	1.2.4
	Street theft	1.4.6
	Theft from motorized vehicles	1.2.5/1.2.1

The types of crime, mentioned in Table 1, are generally speaking also the crimes considered in the current literature. Since crime is reported differently in countries or even police departments, an exact match is not possible, however, major differences are not expected.

1.6 Reading Guide

This research consists of six chapters, of which this introduction is the first one. The literature review is presented in the next chapter. Herein the physical environment and crime, the social disorganization theory and the importance of spatial analysis will be elaborated. The third chapter is concerned with data management, the operationalization of the data and the descriptive statistics of the operationalized variables. In chapter 4 the methodological approach is being discussed. The results of the analysis will be discussed per crime type in chapter 5. This chapter ends with a general discussion of the results. This research finishes with the conclusion and recommendations for further research.

2 Literature Review

Wortley & Mazerolle (2008) mention that there are two perspectives on crime in criminology. First, the traditional point of view is focused on criminality, in which the focus is on the criminal offender. Another perspective is the environmental perspective, where crime is the point of focus. In this perspective, the offender is one element, and the socio demographic background of the offender is of little or no relevance. The focus is thus on the current dynamics of crime. The goal of the environmental perspective is to prevent crime and not to ''cure'' offenders.

Wortley & Mazerolle (2008) also state that the environmental perspective on crime analysis is based on three premises: (I) ''*criminal behavior is significantly influenced by the nature of the immediate environment in which it occurs*'', (II) ''*The distribution of crime in time and space is non-random*'', (III) ''*Understanding the role of criminogenic environment and being aware of the way crime is patterned are powerful weapons in the investigation, control and prevention of crime*''. They also state that the environmental perspective is multi-disciplinary and draws on the expertise of sociologists, psychologists, geographers, architects, town planners, industrial designers, computer scientists, demographers, political scientists and economist.

Brantingham & Brantingham (1991) mention three levels of (environmental) crime analysis: the macro, the meso and the micro level. The macro level is involved in the distribution of crime between countries or cities. The micro level is concerned with specific crime sites. The meso level of crime analysis focuses on cities and the variation between neighborhoods. This study is thus done on a meso level. According to Wortley & Mazerolle (2008) there are two seminal contributions to the environmental perspective namely the ''*social disorganization theory'' by* Shaw and McKay and that one of Jane Jacobs in her book ''*the Death and Life of Great American Cities''*. Both contributions argue that neighborhood characteristics influence the crime numbers in the neighborhood. The perspective from Shaw and McKay is considered to be more influenced by socio demographic and socio economic characteristics, whereas Jacobs' view is considered to be from an urban planning/design perspective.

This literature review is divided into three parts, the first part deals with the relation between the physical environment and crime. It first discusses the relevant theories and contributions. Characteristics which were found in literature to be associated with crime are being discussed. The second part is concerned with the social disorganization theory. The importance of space in the analysis of crime is being discussed afterwards. Finally, the section ends with a conclusion of the literature review.

2.1 Physical Environment and Crime

Jacobs (1961) was one of the first who established a relation between the physical environment and crime. Her book *The Death and life of Great American Cities* is seen as a major influence on environmental criminology and her work acted as an inspiration for Newman's *Defensible Space Theory* and modern day *Crime Prevention Through Environmental Design* concept. In the upcoming section, the contributions of Jane Jacobs and Oscar Newman are being discussed. Furthermore, the current standard, crime prevention through environmental design will be elaborated. Finally, specific characteristics of the built environment that influence crime numbers are being discussed.

2.1.1 The Death and Life of Great American Cities

As mentioned before, the first major contribution which linked the built environment to crime came from Jane Jacobs. In 1961, she presented in her book, *The Death and Life of Great American Cities*, that the urban environment could affect the behavior of users in the area, especially, that land-use diversity and a high pedestrian activity influence the perception of safety.

Jacobs used the district of North End in the Boston metropolitan area. This area fulfilled all characteristics of ''disadvantaged'' neighborhoods or slums, while in fact Jacobs found that the area was actually vibrant and relatively crime free. She proposed four conditions of urban design:

I. Mixed land-uses to stimulate pedestrian activity on the streets and parks;
II. Districts should be divided into small blocks with frequent corners and interconnecting streets;
III. Diversity of old and new buildings to ensure diversity of enterprises;
IV. A sufficient population density to stimulate activity among residents (Wortley & Mazerolle, 2008).

Jacobs argued that sidewalks play an important role in the (perceived) safety of the area. She argued that everyone that uses the sidewalk, participates in the creation of a safer area by ''fighting disorder''. Sidewalks that are constantly in use, do not rely on the police to keep it safe, but on the pedestrians. Jacobs argued that empty sidewalks are believed to be unsafe. Empty streets that are perceived unsafe will be avoided by people, creating a negative feedback loop. To increase pedestrian activity, Jacobs proposed a mix of different functions to improve pedestrian activity. She refers to this mechanism as *''eyes on the street''.*

Jacobs (1961) argued that a safe street consists of ''three main qualities'', (I) a clear demarcation between public space and private space, (II) there must be eyes upon the street and buildings must be orientated on the street and (III) a consistent use of the street (Cozens & Love, 2015).

All in all, Jacobs argued that crime occurs when residents feel isolated and anonymous, and when they believe that they have no stake in their neighborhood (Wortley & Mazerolle, 2008). Her book can be seen as an advocate for planning policies that bring people together and can create a sense of community.

Cozens (2008) criticizes Jacobs ideas on two points. He argued that her ideas were mostly ''anecdotal'' and that the primary focus was only on one American city, Boston. Jacobs also advised that her ideas/findings were not suitable for smaller cities or suburbs alone (Cozens, 2008).

Later on, Oscar Newman extended Jacobs' vision in his book ''*Defensible Space: Crime Prevention Through Urban Design''* in which he basically operationalized some of Jacobs' ideas.

2.1.2 Defensible Space Theory

Oscar Newman, an architect and urban designer, developed the defensible space theory in the early 70s of the previous century. With this theory he explains the basis of territorial control which basically means that anonymous strangers are more easily identified. The defensible space theory is characterized by low urban density with high proportions of residential areas with limited access to strangers. This relates back to Jacobs' argument of safe streets, since one of the main qualities a street needs, is a clear demarcation between public and private space.

According to Donnelly (2010), the defensible space theory has four key concepts: territoriality, surveillance, image and milieu. ''*The four elements of defensible space can translate the latent territoriality and sense of community of residents into a responsibility to secure and maintain a safe, productive and well-maintained neighbourhood''* (Cozens, 2008). Newman (1972) also argued that high-rise buildings/high urban density results in anonymity which in turn has an influence on the occurrence of crime.

Since the defensible space theory is basically a predecessor of ''Crime prevention through environmental design'', which will be elaborated in the next section and is also the current ''standard'' in crime prevention in regard to the built environment, these concepts will not be elaborated here. All four key concepts of the defensible space theory are also present in CPTED.

Reynald & Elffers (2009) stated that one of the main critics on the defensible space theory is that it is vaguely defined and therefore difficult to test empirically. Hillier & Shu (2000) argued that the theory is more a ''fashionable consensus''. Remarks on the theory by Cozens, Hillier, & Prescott (2001) and Cozens, Pascoe, & Hillier (2004) are in line with this statement, they argue that there is a need for clarification of the theoretical structure (Reynald & Elffers, 2009). On the other hand, the theory has been applied to multiple projects and reduced crime significantly (Reynald & Elffers, 2009).

2.1.3 Current CPTED

Jeffery introduced the term Crime Prevention Through Environmental Design (CPTED) in his eponymous book in 1971. Since then, CPTED has become more popular among urban planners among the United States and its principles were even included in the building codes of several states in the USA. Nowadays the relation between the built environment and crime is inevitably linked with CPTED and will therefore play an important role in this research.

However, while Jeffery came up with the name crime prevention through environmental design, ''current'' CPTED is more in line with Newman's defensible space theory. The name ''Crime prevention through environmental design' suggests that the physical environment is the main focus of the principle. However, Jeffery's ideas on crime prevention, were more concerned with biological factors (Lab, 2010). ''Rather, *Jeffery argues that increasing citizen involvement in community activities and surveillance, and increased proactive programs by police and other of social control, hold great potential for the prevention of crime''* (Lab, 2010). Cozens (2008) states that Jeffery's ideas also involve behavioral, political and psychological systems in addition to biological factors.

These days, CPTED is best known for its definition/form made by Timothy Crowe (former director of the American National Crime Prevention Institute) in 1991, his work was an extension of Newman's theory using Jeffery's name of CPTED (Cozens, 2008).

Fennelly & Crowe (2013) mention three different approaches to crime control: organized, mechanical and natural. Organized crime prevention is based on labor by humans to provide security. The mechanical approach is aimed at controlling crime by using machines such as closed circuit television (CCTV). Finally, the natural approach is based on behavior management. The CPTED measures are mainly focused on the natural approach supplemented with mechanical approaches.

Fennelly (2020) argues that there are three necessities for a crime to occur, (I) the desire to commit the crime, (II) the skills to commit the crime and (III) the opportunity to commit the crime. CPTED rests on the assumption that criminals commit crime based on opportunity, which is commonly accepted, according to Fennelly & Crowe (2013). Felson & Clarke (1998) support this as they state that crime can be prevented by reducing opportunities, as all three beforementioned necessities need to be present. As the name suggests, the goal of CPTED is to prevent crimes. By implementing the principles of CPTED, opportunities are denied or reduced and thus crime is less likely to occur.

CPTED is considered to be mostly a 'natural' strategy in preventing crime. From its origin, it consists of three pillars/main principles: (I) territoriality, (II) surveillance and (III) access control. Territoriality is aimed at the demarcation of public and private space. By clearly marking public and private space, a psychological barrier is created. Natural surveillance is involved in creating 'more eyes' on the street. This could, for example, be accomplished by shaping the environment in such way that more pedestrians are present in the neighborhood, or by facilitating activities. The third principle, access control, relates to control the people in areas where they should not be. There are different interpretations on what the key principles of CPTED are, due to new insights. For this research, the principles mentioned by Fennelly & Crowe (2013) in their book *Crime Prevention Through Environmental Design,* will be used (Access control, surveillance, territoriality and maintenance/image). So, maintenance/image will be added to the three original pillars.

CPTED is not considered to be a theory but rather a framework or design strategy, which identifies key aspects to be taken into account for designers and planners. There is not a single solution when using CPTED, there are for example many methods to increase the number of eyes on the street. So basically, CPTED is a framework, in which built environment strategies could be placed. Furthermore, it should be stated that certain measures are effective for multiple principles of CPTED. For example, cul-de-sacs, are known to be effective in regard to access control but also for creating a sense of territoriality among the residents living there.

Nowadays, the CPTED principles are used all over the world. In cities in the USA, Canada, New-Zealand, Australia and European countries it has become common practice to use the principles of CPTED (Cozens & Love, 2015). However, in the Netherlands, relatively little attention is being paid to this matter, which is in contrast with the National planning vision in relation to the objectives of making the Netherlands more livable and safer (Ministry of Infrastructure and the Environment, 2011).

There is also a guideline from the European Committee for Standardization, *CEN 14383-2: prevention of crime – Urban planning and building design* (European Committee for

Standardization, 2007). This guideline is a voluntary guideline and thus not an obligation, but it indicates that there is an increasing attention for the matter.

According to Oxley et al. (2005), in the Netherlands, CPTED principles started to take off in 1985 with the new policy, named *''Crime and Society'',* in which the scope of crime management broadened. Instead of focusing primarily on catching and convicting offenders, crime prevention became more important. Adjusting public space, managing social structures and improving surveillance received more attention. These three aspects could be directly linked to the three original key pillars of CPTED, adjusting public space to access control, social structures to territoriality and surveillance speaks for itself. In extension to this policy, van Soomeren, de Savornin Lohman, Caron, de Savornin Lohman, & Van Dijk, (1987) wrote the report ''Criminaliteit en Gebouwde Omgeving'' [crime and the built environment] commissioned by the Dutch ministry of housing, spatial planning and environmental management. The goal of this report was to provide the ministry with knowledge on crime prevention in relation to the built environment. The report discussed the theories from the Chicago School, Jane Jacobs, Oscar Newman and more. Later on, more policies regarding crime prevention took place and research was done on CPTED. Nowadays, the most common CPTED measures in place are security labels provided for dwellings, business areas and shopping malls. However, from an urban planning perspective, very little is being done on this subject.

In the upcoming section, the principles of CPTED that will be used for this study are being discussed. The characteristics of the built environment in section 2.1.4 will be categorized based on these ''main'' principles.

2.1.3.1 Surveillance & Activity Support

''Surveillance is a design concept directed primarily at keeping intruders under observation'' (Fennelly & Crowe, 2013).

Surveillance and activity support can be seen as the heritage of Jane Jacobs in CPTED. Her concept of ''eyes on the street'' has many similarities with the surveillance principle of CPTED. Activity support can also be traced back to Jacobs' ideas, by implementing different types of land-use and/or function in the area, the area offers more activities, which in turn will attract more (legitimate) people to the area and thus more eyes on the street. Jacobs mentioned two methods of creating eyes on the street, increasing the number of legitimate users in the area and by the placing of windows in the buildings looking out on the street.

''*In summary, natural surveillance (e.g. residents' self-surveillance opportunities as facilitated by windows) formal surveillance (e.g. police patrols) and mechanical surveillance strategies (e.g. streetlighting and CCTV) have all proven effective in reducing both crime and the fear of crime*.''(Cozens, Saville, & Hillier, 2005)

2.1.3.2 Access Control

''*The primary thrust of an access control strategy is to deny access to a crime target and to create a perception of risk in offenders*'' (Fennelly & Crowe, 2013). By this statement it could be argued that access control is concerned with the management of illegitimate users of the area and to increase the risk of getting caught. This latter statement, arguably, could also be achieved by other CPTED principles such as surveillance and territoriality, as these also increase the risk of getting caught.

Denying access to crime targets and opportunities are difficult to implement on a neighborhood level as in the Netherlands, for example, a neighborhood is part of the public space, and thus it is difficult to deny access for non-residents. Therefore, access control on a meso-level is argued to be more concerned with the creation of perceived risk in the offenders.

In extension to the statement of Fennelly & Crowe (2013), Cozens (2008) stated that spatial definition acts as a mechanism to access control. This is contrary to Jacobs' argument of small blocks with interconnecting streets which increases the permeability of the area, which results in more strangers in the area.

2.1.3.3 Territoriality

The built environment can contribute to a sense of territoriality, which means that the built environment can create a sense of influence so that users develop a sense of proprietorship (Fennelly & Crowe, 2013). Newman (1972) argued that to create a sense of territoriality (and to deter criminals from entering the space / access control) psychological barriers should be put up to limit the number of strangers in the area. ''*Oscar Newman's (1972) theory of defensible space, a socio-physical phenomenon requiring both social and physical elements, asserts that crime is diminished in an area when residents take responsibility and ownership over common spaces in combination with environmental design*'' (Valasik & Tita, 2018).

Territoriality is often seen as the primary concept of CPTED, from which the other concepts/principles are derived (Cozens, 2008). The main thrust of territoriality is a clear demarcation between public and private space. Cozens (2008) argued that the other CPTED concepts of natural surveillance and access control, also act as a measure of territoriality, as they deter non-legitimate users of the area. Taylor's (1988) territorial model, moreover, mentioned a distinction between regular and anonymous users of the area. Taylor argued that an increased number of anonymous users shrink the area that is being taken under responsibility and maintenance by the residents of the area (Browning et al., 2010).

2.1.3.4 Maintenance, Image & Environment

The maintenance principle can be traced back to the *broken window theory*. The broken window theory, developed by Kelling & Wilson in 1982, describes how one broken window (which is not repaired immediately) could lead to a signal that no one cares about the area/neighborhood, and thus that breaking more windows will cost nothing. A deteriorated neighborhood in which nobody cares is believed to offer opportunities to commit crimes. According to Wagers, Sousa, & Kelling (2008), the broken window theory is an ''intellectual'' extension of an experiment done by Phillip Zimbardo in the 1960s. In this experiment Zimbardo placed a car in an apparent stable neighborhood, the car was untouched for weeks, but once one window was purposely broken, the car was almost destroyed within hours (Wagers et al., 2008). Based on this experiment by Zimbardo, Kelling & Wilson placed the key concept to a broader context, neighborhoods.

The theory is not only concerned with the physical deterioration, but also the social ties. While not repairing a broken window sends a message about the area, it also sends a message about the residents, as they did not repair the window.

''According to the theory, fear causes stable families to move out of the neighborhood and the remaining residents to isolate themselves and avoid others''(Bruinsma & Johnson, 2018).

The maintenance and image principle is often characterized by vacant and abandoned buildings, graffiti and litter.

2.1.3.5 Critics and Challenges of CPTED

As in the case of the defensible space theory, there is also criticism on CPTED. Cozens, Saville, & Hillier (2005) mention five major criticisms on CPTED:

I. Irrational offenders (e.g. intoxicated by alcohol or drugs) are less deterred by CPTED principles.
II. Socio-economic and demographic dynamics interfere with the effectiveness of CPTED.
III. CPTED measures could lead to displacement of crime, so to say that crime is not reduced but moved to a location which does not limit the objectives of the offenders.
IV. There is some sort of threshold in every neighborhood concerning the number of activities and functions; once these numbers fall below this threshold, the effectiveness of CPTED is considerably lower.
V. When CPTED is applied, without community participation, the neighborhood is dependent on the access control and target hardening (locks and fencing), resulting in a ‘’fortress mentality’’ which is against the principles of CPTED.

According to Cozens et al. (2005), the first three points are considered to be drawbacks on all crime prevention methods, and thus not merely accountable to CPTED. Bruinsma & Johnson, (2018) state that offenders engage in a brief decision making process when committing a crime. This decision making process is limited or absent when the offender is irrational or under the influence of substances that limit rational behavior. Cozens et al. (2005) also argued that the displacement of crime could be considered as a positive tool, when monitoring the wider area rather than just one neighborhood.

Most of these critics can also be traced back to the social disorganization theory, which will be elaborated more in section 2.2. It is argued that the drawbacks of CPTED (including the broken windows theory) and/or the defensible space theory are covered in the social disorganization theory.

Moreover, another critic on CPTED is that it is often thought of as ‘’one size fits all’’. Crowe (2000) stated that CPTED should be considered as a process and not a belief system. Cozens argued that the concepts are not enough on their own (Cozens & Love, 2015). Cozens & Love (2015), moreover, argued that CPTED be should considered as a process of thinking, analysis and evaluating. *‘’Avoiding oversimplification requires assessing crime risks among other considerations* (Clancey, 2010; Cozens, 2014; 2011)*.’’* (Cozens & Love, 2015)

2.1.4 Built Environment Characteristics in Combination with Crime Prevention

In the upcoming section relevant characteristics of the built environment that have been researched in relation to crime prevention are being discussed.

2.1.4.1 Land-Use

Jacobs (1961) mentioned the importance of different land-uses in an area to improve pedestrian activity and thus increase the natural surveillance (eyes on the street) in the neighborhood. The mix of different functions will increase pedestrian activity, which in turn create a more vibrant street. Browning et al. (2010) stated that high pedestrian activity is characterized by high commercial density. This increased pedestrian activity will increase the number of eyes on the street.

It should be noted that it seems more than logic that for residential crimes, the ratio of residential area is correlated. This is supported by the research of Sohn (2016), which found that the ratio of residential area is positively correlated with residential crime density.

Contrary to these findings are the findings of Anderson, MacDonald, Bluthenthal, & Ashwood (2013): they found that areas with only residential land-use experience less crime than areas with commercial or mixed land-uses. Anderson et al. (2013) also mentioned the suggestion that Jacobs (1961) might have had it backwards.

Angel (1968) introduced the concept of ‘’crime as a function of land-use intensity’’ (see Figure 2). In addition to Jacobs arguments, he argued that land-use intensities determine number of crimes (Cozens, 2008). He argued that a low land-use intensity experiences low levels of crime due to low number of opportunities (zone 1). Areas with high land-use intensities also experience low levels of crime, as he argued that there will be more eyes on the street (zone 3). Crime occurs most in the areas that attract sufficient people to create opportunities to commit a crime, but not enough people to keep the whole area under surveillance (zone 2).

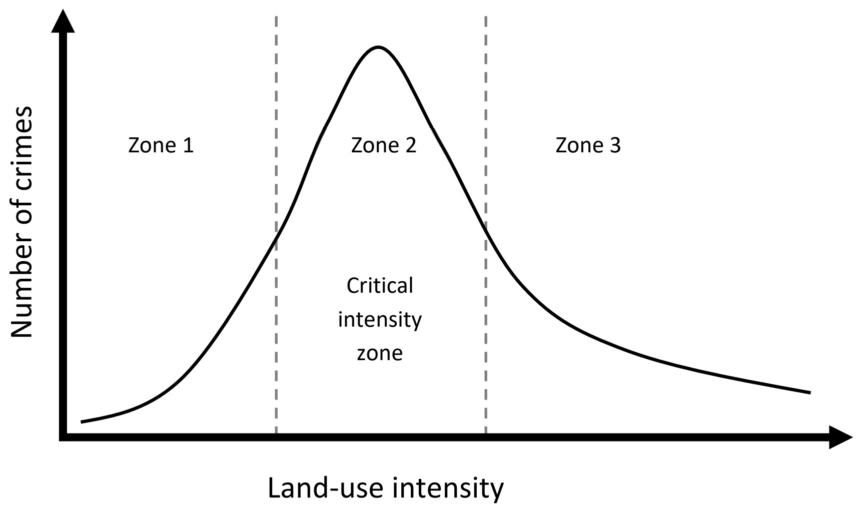


Figure 2: Crime as a function of Land-use intensity (Angel, 1968) adapted/reproduced from (Cozens, 2008)

Finally the study by Wuschke & Kinney (2018) concluded that rates of property crimes and violent crimes are most present in residential land-uses. However, these types of crime occur disproportionally higher in areas classified as commercial or recreational.

In regard to the CPTED principles, mixed land-use fits best as a measure to increase the natural surveillance and activity support, since more people will be active on the street and thus more surveillance.

2.1.4.2 Greenspace

According to de Vries, Verheij, Groenewegen, & Spreeuwenberg (2003), greenspace leads to more physical activity such as walking and cycling and therefore it is likely that the presence of greenspace has a positive effect on natural surveillance. They also stated that more greenspace results in a less polluted area, resulting in a better image. Another benefit is that greenspace offers space for outdoor activities, which in turn will increase the number of activities in the area. Contrary, Bogar & Beyer (2016) stated that residents fear that criminals hide in urban green space, and thus, that greenspace increases the fear of crime. Lee, Park, & Jung (2016) found that an increased fear of crime significantly decreases walking frequency, and thus less natural surveillance.

Shepley, Sachs, Sadatsafavi, Fournier, & Peditto (2019) found in their extensive literature review of 45 quantitative researches that greenspace helps in reducing crime. In their research, a distinction was made between different type of greenspace: (I) parks, (II) trees and ground cover, (III) Vegetated streets and walkways and (IV) less developed green areas. All types of greenspaces were found to be reducing different types of crime. Moreover, Shepley et al. (2019) argued that the presence of greenspace influences crime partly via the ''mediating variable'' *legibility and perceived order.*

Bogar & Beyer (2016) also reviewed literature and concluded that there were too few studies and too much variation among these studies. Nevertheless, the studies that were reviewed in this study, showed mainly that crime was reduced significantly when implementing greenspace in the area.

2.1.4.3 Streetlighting

Streetlighting is commonly mentioned in studies regarding CPTED as it increases visibility (Gulak et al., 2007; Hedayati Marzbali et al., 2016, 2012; Lee et al., 2016). Farrington & Welsh (2002) evaluated multiple studies in the USA and UK as regards of streetlighting and crime. In conclusion they found, in half of the USA studies, streetlighting was effective in reducing crime and five studies in UK found that streetlighting is an effective measure to reduce crime.

Streetlighting is often mentioned as a measure to increase the natural surveillance. It is generally aimed at improved visibility and to reduce the fear of crime (Ceccato, 2011). Lee et al. (2016) found that improved streetlighting reduced fear of crime, which leads to increased pedestrian activity, which in its turn leads to more eyes on the street.

2.1.4.4 Infrastructure & Street Layout

The design of infrastructure is associated with access control in several studies. Sohn (2016) found the street density and intersection density to be significant correlated with residential crime density. Street density is believed to be increasing the natural surveillance, but to lower the access control due to many possible routes to exit and enter the area.

''*Brantingham & Brantingham (1981,1998) argued that areas with gridded patterns have higher potential crime rates than organic street patterns''* (Schneider & Kitchen, 2007). Schneider & Kitchen (2007) argued this is due to the difficulty to escape the area. So, increased ''complexity'' of the street patterns is argued to improve the access control. On the contrary, White (1990) found that the number of access streets from ''traffic arteries'' into the neighborhood has an influence on the number of burglaries.

Block & Block (1995) found that many, liquor related, crimes occur near intersections, especially grid and diagonal street patterns. Whereas Cozens et al. (2005) stated that CPTED measures are not effective for irrational offenders (among which liquor related crime), their findings are in line with other studies regarding the street layout/pattern.

Newman (1972) argued that cull de sacs (dead end streets) are the streets where crime occurs the least, as small group of neighbors can survey the area that is accessible from their dwelling (Hillier, 2004). This is contrary to the argument of Jacobs' (1961) which stated that areas should be well connected in order to create a more vibrant area where informal surveillance acts as a mechanism against crime. These findings are contrary to those of the research of Yang (2006), which shows that residential burglary occurs most on streets with ''through traffic'' and the least on dead-end streets. Finally, the study of Sohn (2016) found that the intersection density of a neighborhood has a significantly positive correlation with crime whereas the street density was significantly negatively correlated with crime.

Hillier (2004) also argued that the street lay-out affects different types of crime in a different way. For example, he argued that drug related crime occurs most in areas with many street corners, pickpocketing occurs near crowds and that burglary occurs most in quiet areas. However, as beforementioned, burglary is often empirically connected to areas with a high connectivity.

As regards to CPTED, the street layout can be categorized as measures of surveillance, access control and territoriality. Another point of interest is that most of the mentioned researches were aimed at burglaries and property theft. In general, other forms of crime are not considered.

2.1.4.5 Parking

Research shows that parking could play a role in crime prevention, and especially, in relation to crimes related to motorized vehicles. Jongejan & Woldendorp (2013), argued that cars should be parked in a close boundary around the dwelling/office building. Fennelly & Crowe (2013), also argued that car parking should be in direct line of sight from residential buildings, as a measure of natural surveillance. This is aimed to protect the car from car theft or theft from the car. Another reasoning could be to limit the options for offenders to park their vehicle, as according to van Daele & Beken (2010) offenders generally travel more than three kilometers to the place of crime. This is confirmed by the study of Fiselier (1972), which showed that in neighborhoods in the Netherlands crime rates had a low correlation with offender rates. This implies that crime occurs somewhere else than where the offender lives. Van Soomeren, de Savornin Lohman, Caron, de Savornin Lohman, & Van Dijk (1987) stated that the average distance from the offender's place of residence to the site that is broken into is 3,4 kilometers.

Figure 3, the probability of a crime as a function of distance from the place of residence of the offender is displayed. The figure shows that the probability to commit a crime is the highest at a certain distance from the offender's residence.

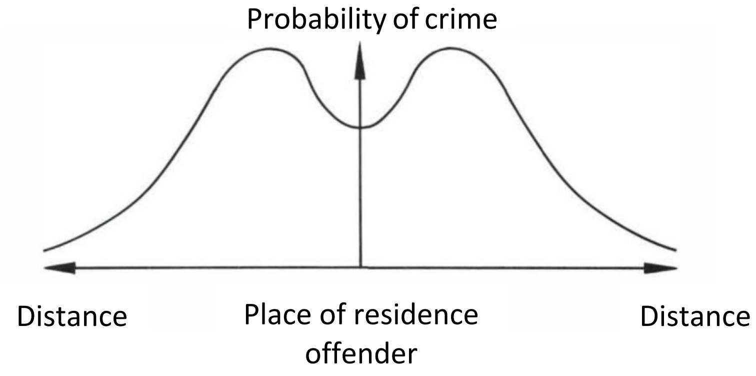


Figure 3: Probability of crime as a function of distance from place of residence of the offender adapted from van Soomeren et al., (1987)

So, limiting (public) parking places is believed to have a positive effect on access control, and furthermore, the fewer cars that are parked the fewer the opportunities for car related crimes. Moreover, Bennet & Wright (1984), found that burglars look for parked vehicles in the immediate area next to their target as a sign of occupancy. By limiting the number of parking places, it is more likely that they are occupied, and therefore, a higher percentage of the parking places are occupied.

Research as regards to parking facilities and crime is often concerned with characteristics of parking lots; street parking (parking alongside streets) is left out of consideration.

2.1.4.6 Housing Characteristics

''Scholars have long known that homeowners and long-term residents have a greater incentive to protect their local area and might be willing to take more risk in doing so'' (Felson, 2018). Moreover, generally speaking, owned homes represent a higher value than homes up for rent, which could possibly imply that the socio-economic status is higher. Another aspect of the ratio as regards to rented and owned homes, is that residential mobility is higher in areas with a high portion rented homes. People tend to reside longer in owned homes, therefore it could be argued that a higher portion of rented homes results in higher residential mobility. Aarland & Reid (2019) concluded that homeownership has a significant positive impact on residential stability. The effect of socio-economic status and residential mobility on crime is elaborated in section 2.2, in which the social disorganization theory is being discussed.

Another relevant housing characteristic is vacancy. Vacancy is often mentioned as a determinant of the image and maintenance principle of CPTED. The study conducted by Fuentes & Hernandez (2014) regarding property crime and vacancy, found that for every point increase in vacancy, the number of property crime rose by .84%. Moreover, Cui & Walsh (2015) found that violent crime increased by 19% in the immediate area once a foreclosed home became vacant.

Another determinant of crime, in relation to housing, is population density. A high population density is facilitated by high-density housing. Sampson & Groves (1989) found in their study in which they tested the social disorganization theory that the level of urbanization has a significantly positive correlated with multiple types of crime. They argued that a high level of urbanization weakens local social structures (decreased social control, weakened local kinship and friend networks). Sohn (2016) also found that a high population density increases the density of residential crimes. Finally, the Federal Bureau of Investigation (2011) also mentions population density and the level of urbanization as variables that influence crime.

An increased portion of owned homes in relation to rented homes, is believed to increase the territoriality of the area. As mentioned before, people are more likely to defend their own property. Vacancy, as mentioned before, is believed to have a negative relation with the maintenance and image principle of CPTED.

2.1.4.7 Artworks & Remembrance Monuments

''*Art and sculpture are powerful tools in promoting territorial behavior and proprietary concern for space. They attract attention to spaces and help people find their way. One of the greatest values of street art is how it contributes to triangulation, which helps people psychologically connect places, thus increasing perceptions of territoriality and control*.''(Fennelly & Crowe, 2013).

Pathak (2018) argued that the installation of public arts discourages criminals, as the area gives criminals a feeling that they might be challenged by other users of the area. Partners for Livable Communities (n.d.) also make the link with Kelling's & Wilson's (1982) broken window theory, as the presence of public artworks creates the perception that the area is being taken care of. Finally, the New Zealand Minstry of Justice (2005), in their report with guidelines for the implementation of CPTED, also state that public art should be installed to personalize the space and to promote local identity.

However, no empirically research was found in which artworks and cultural heritage symbols are being tested against crime. It could also be argued that artworks are considered as a possible target for being vandalized. So Fennelly's and Crowe's statement regarding arts could have different relations with different type of crimes.

As mentioned before, artworks are believed to create a sense of community and therefore increase territorial behavior of the residents in the area. It is also argued that artworks improve the general image of the area.

2.1.4.8 Closed Circuit Television

The presence of closed circuit television (CCTV) is a mechanical crime prevention method which is aimed at increasing surveillance. Lee, Park, & Jung (2016) argued that the presence of CCTV also provides symbolic barriers that deter criminals and thus CCTV could also be effective as a measure of access control, Hedayati Marzbali, Abdullah, Ignatius, & Maghsoodi Tilaki (2016) used a similar reasoning. McLamb (2015) also stated that the presence of CCTV is an effective CPTED measure. Finally, Lee et al. (2016) found that the presence of CCTV also increases pedestrian activity which will increase the natural surveillance. Cerezo (2013) found that the implementation of CCTV reduced crime. However, the research also states that the implementation of CCTV could lead to displacement of crime. This is in line with criticism on CPTED of Cozens et al. (2005), which is elaborated more in section 2.1.3.5.

The presence of CCTV, in relation to the CPTED principles, will act as a measure of surveillance, as real-time observations as well as in the past. Moreover, the presence of visible CCTV can also act as a measure of access control, as it increases the perception of risk in getting caught by the offenders.

2.1.4.9 Tourist attractions

It is generally known that the city of Amsterdam is a tourist intensive city, in 2018 the city was ranked 23rd in the top 100 city destinations by Euromonitor (Geerts, 2018). Multiple researches show that tourism is correlated with crime (Bhati & Pearce, 2016; Biagi & Detotto, 2014; Merrill, 2011).

Bhati & Pearce (2016) stated that many tourist sites experience vandalism. Moreover, Merrill (2011) stated that cultural heritage monuments/areas often are vandalized with graffiti, which is a textbook example of vandalism. Crime types that occur most due to tourist attractions are vandalism and theft related crimes (Bhati & Pearce, 2016; Jud, 1975). Jud (1975) found that tourism is mainly concerned with property related crimes.

Tourist attractions might not be subject to policy making in regard to urban planning/design as their locations are already determined. However, they are a part of the built environment and are found to be influencing crime rates. Hence, tourist attractions should be included in the analysis as a control variable.

2.2 Social Disorganization Theory

The social disorganization theory is considered to be one of the most influential contribution to environmental criminology, besides the contribution of Jane Jacobs (Wortley & Mazerolle, 2008). Where Jacobs argued that the physical environment/urban design was of importance, the social disorganization by Shaw & McKay (1942) argued that socio-economic and socio-demographic characteristics of the neighborhood are of importance. The theory of Shaw and McKay is listed in the top 25 theoretical contributions in the ''*Encyclopedia of criminological theory*'' by Cullen & Wilcox (2010)

Whereas this research is mostly concerned with the physical part of environmental criminology, it seems wise to include socio-economic and socio demographic variables as control variables, since crime prevention is a multi-disciplinary discipline (United Nations Office on Drugs and Crime, n.d.), as mention before. The social disorganization theory finds its origin in the concentric zone model.

Burgess introduced the concentric zone model in 1925 (Burgess, 1925). He argued that a city can be divided into five zones. Zone I or the ''the Loop'' contained the central business district, which was surrounded by zone II, which is an area in transition that is deteriorating. Zone III was inhabited by the workers of zone II who escaped the deteriorated zone II. Zone IV was inhabited by the upper classes. Finally, zone V is the zone where the commuters lived. Shaw & McKay (1942) used Burgess concentric model to research the relationship between neighborhoods and delinquency. They found delinquency was most present in zone II of the concentric model. Zone II contained the poorest and least support systems. These findings formed the basis for the ''*social disorganization theory*''.

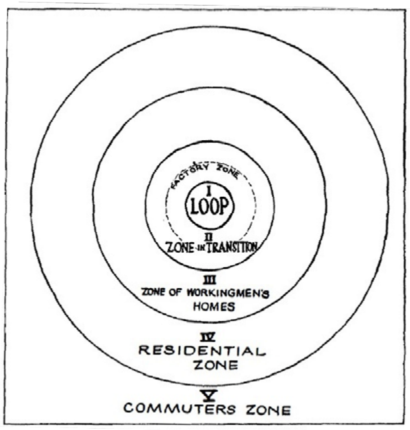


Figure 4: Burgess Concentric Model (1925)

The social disorganization theory, in short, states that three variables cause social disorganization. These variables are (I) the physical state of the neighborhood, (II) the economic status and (III) ethnic heterogeneity. Shaw and McKay argued that these three all contributed to creating social disorganization, which in turn results in higher crime and delinquency rates in the neighborhood.

The physical state was defined as a combination of population change, vacant and condemned housing and the proximity to industry. Shaw and McKay argued that a high turnover in the local population makes it difficult to create a social structure in the neighborhood. Rogerson & Pease (2019) also mentioned that residential mobility is a challenge for CPTED. Rogerson & Pease (2019) also found that crime is an incentive to move. It could be argued that this latter statement in combination with the social disorganization theory results in a diverging feedback loop (Figure 5), which results in more crime.

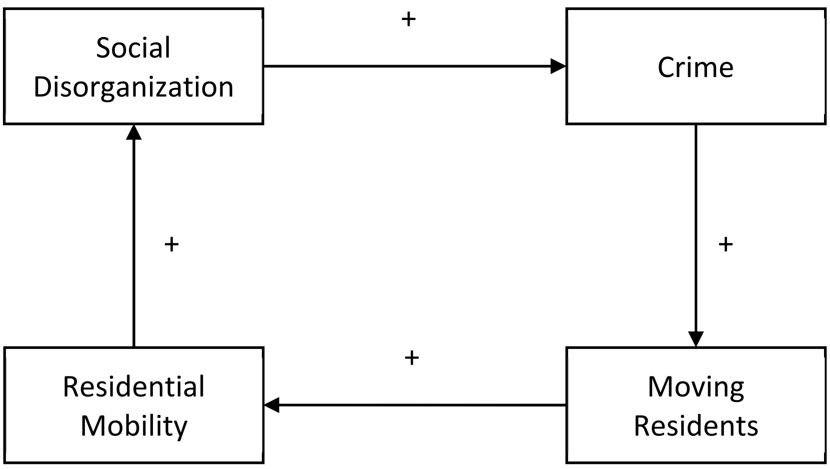


Figure 5: Feedback loop residential mobility and crime

In the original work, the economic status of neighborhood initially consisted of (I) the number of families receiving social assistance, (II) the median rent price of the area and finally (III) the proportion of rented homes in relation to the number of owned houses (Shaw & McKay, 1942). Sampson's & Groves' (1989) results showed that the socio-economic status of the neighborhood significantly ($p < 0,10$) correlated with burglary, car theft and vandalism. The socio economic status was constructed as the sum of z-values of (I) education (percent college educated), (II) occupation (percent of professionals in managerial positions) and (III) income.

Finally, ethnic heterogeneity. Shaw and McKay argued that ethnic heterogeneity in the population also affects the social structure in the neighborhood. Ethnic heterogeneity is often solely used as a measure of social disorganization. Often the heterogeneity index, developed by Blau (1977) is used, which is a measure which indicates the level of ethnic heterogeneity on a scale from zero to one (Bruinsma et al., 2013; Davies & Bowers, 2018; Kimpton et al., 2017; Sampson & Groves, 1989). Ethnic heterogeneity is the variable in relation to social disorganization that is found most of the time to be significant in empirical researches.

Sampson & Groves (1989) empirically tested the social disorganization theory. Their results were in favor of the theory. Bruinsma, Pauwels, Weerman, & Bernasco (2013) also tested the theory for the Dutch city of The Hague. They found less convincing results compared to Sampson & Groves (1989), as only ethnic heterogeneity was found to be significant. It should be noted that the sample in this research consisted only of a limited number neighborhoods, which influences the reliability of the results.

In their research regarding the street network and crime, Davies & Bowers (2018) also found variables originating from the social disorganization theory to be significant. They included these variables as control variables, just as intended in this research. Their ethnic heterogeneity measure was established in the same manner as the research by Sampson & Groves (1989). Furthermore, they included the unemployment rate as a measure of socio-economic status, the percentage of students and the percentage of 10 to 15 year-olds.

2.3 Importance of Spatial Analysis

The Centrum voor Criminaliteitspreventie en Veiligheid (2020) mentioned that criminality in the Netherlands is not evenly distributed. Moreover, it also stated that the five most criminal neighborhoods experience 2200 to 2300 crimes each year, combined to the fact that in 2018 more than 780 thousand registered crimes were committed spread over 12822 neighborhoods in the Netherlands, averaging to approximately 36 crimes per neighborhood. This indicates that crime indeed concentrates.

2.3.1 Crime and Space

When researching crime, in urban context, it is of importance to take into account the spatial component of crime. Ceccato (2011) stated that crime concentrates in cities, however, not in a homogenous way. Bruinsma & Johnson (2018) argued that, while there are differences in theories regarding environmental criminology, there are a couple of aspects that are common among these theories. The relevant similarities are quoted below.

I. ''*Crime is not randomly distributed in space*''.
II. ''*The mix of targets, offenders and potential guardians varies by the time of the day and by the social and physical characteristics of the location*''.
III. ''*Opportunities for offending are likely to differ in space and time for different crime types*''.
IV. ''*Offenders do not commit crime somewhere in general, but engage in some form of decision-making process (however brief) and take advantage of specific crime opportunities at particular locations and time*''.

V. ''*Changes to the environment – as a result of natural variation or intervention - can influence levels of crime*''.

2.3.2 Importance of Spatial Analysis

The beforementioned statements by Bruinsma & Johnson (2018) make it more evident, why space needs to be taken into account when researching crime from an environmental perspective.

Kubrin & Weitzer (2003) mentioned that researches that research ''social disorganization'' slowly start addressing the problem with aggregation of social data into officially defined areas. They argued that this is problematic as these officially defined areas are seldom spatially independent and that crime levels in one neighborhood influence crime levels in adjacent neighborhoods. It could be argued that this problem does not only occur when researching social disorganization, but also other crime related studies that have neighborhoods as the unit of analysis.

''*An oft-debated issue is whether census tracts—the unit of analysis used most frequently in social disorganization studies—are sufficient proxies for neighborhoods. Residents who live across the street from one another are likely to identify themselves as living in the same neighborhood, yet if they reside in different census tracts, they are not counted as "neighbors"*''(Kubrin & Weitzer, 2003). Morenoff, Sampson, & Raudenbush (2001) also mentioned this argument as an argument to highlight the problem of artificially borders/ census tracts. Both studies argued that the use of spatial models could produce better and more reliable results.

Moreover, Kubrin & Weitzer (2003) stated that researches that have taken into account the spatial autocorrelation, found that there is indeed a significant spatial interdependency among neighborhoods. Moreover, Messner et al. (1999) stated that ignoring this spatial dependence may lead to false indications of significance, biased parameters and misleading suggestions of fit, when the spatial relationships are not taken into account.

Andresen (2018) furthermore, wondered whether the change in unemployment rate from 2 to 3 percent in a rich neighborhood has the same effect as a change from 14 to 15 in a poor neighborhood. This question highlights the importance of location specific coefficients. Moreover, Fotheringham (1997) argued that there are at least three reasons that global regressions models, which assume spatial stationary, should not hold when analyzing local relations: (I) there will be variations by random sampling variations, (II) relationships are intrinsically different across space and (III) spatial non-stationary may be found because of statistical misspecification.

The research done by Cahill & Mulligan (2007) found that by using a geographically weighted regression analysis, in which they researched violent crime, that the average of the local R-squared was 0.861. Compared to the R-squared of 0.361 from the ordinary least squared regression this improvement was significant. Malczewski & Poetz (2005) also found a significant improvement by using a geographically weighted regression, 0.59 compared to 0.202 when using an ordinary least squares regression.

The research done by Wang, Lee, & Williams (2019) also found an improved R-squared value by using a geographically weighted regression in comparison to an ordinary least squares regression. In their study on property crimes, they found an increase of 0.09 points (from 0.71 to 0.80). Han & Gorman (2013) found a similar improvement in their study on the effect of liquor stores and violent crimes (0.628 to 0.704). Compared to previous mentioned examples, these improvements were significantly lower. However, the R-squared values of the ordinary least squares regression analysis were higher which in turn leads to less room for improvement.

All these arguments/statements and researches justify the use of a geographically weighted regression model.

2.4 Conclusion Literature Review

In this literature review, attention is paid to the historic perspective of crime prevention in relation to the built environment. It was found that the works of Jane Jacobs and Oscar Newman have an enormous influence on modern day strategies as regards to crime prevention in urban context. Their work has been translated into a set of design principles, which are now widely known as CPTED.

Characteristics of the built environment which have been associated with crime in literature were researched. It was found that mixed land-uses in an area influence crime. Moreover, it was also found that the intensity of the land-use matters. Literature also states that greenspace helps in reducing crime, but on the other hand, greenspace could also function as an attractor and/or generator of crime.

Streetlighting was found to be influencing crime due to a number of different mechanisms. It increases the risk of getting caught when committing a crime, but it also reduces the fear of crime resulting in more people on the street and thus more surveillance.

Research has shown that the design and layout of infrastructure influences crime. Gridded street patterns are found to be increasing crime. This is believed to be due to higher traffic flows. The effect of cul-de-sacs are uncertain, different theories/researches show different results. Parking places help burglars identifying unoccupied homes, and therefore, increasing the chance that a parking place is occupied helps creating a sense that the dwellings in neighborhood are currently occupied.

It was found that several housing characteristics are connected with crime. First, it was found that long-term residents are more likely to ‘’defend’’ their home against crime, following up on this, it is argued that the ratio owned homes versus rented homes influence crime numbers, as people tend to stay longer in owned homes. Several studies found that vacancy is related to crime. Finally, population density, which is a result of the housing density of the area, was found to be correlated with crime.

The literature found that the presence of CCTV could deter offenders, as it increases the perception of risk in getting caught. Moreover, it acts as a measure for increased surveillance. Another characteristic from the built environment that is being discussed is the presence of artworks. Artworks are argued to increase a sense of territoriality and strengthen community ties, which in turn are believed to be decreasing crime. Finally, it was found that tourism is positively associated with crime.

Crime prevention requires a multi-disciplinary approach. Shaping the built environment in a particular way does not prevent crime solely. Therefore, control variables are needed in the analysis. The control variables will be derived from the social disorganization theory. This theory consists of three main variables: the socio-economic status, the ethnic heterogeneity and finally, residential mobility. These variables may be increasing social disorganization which in turn will influence the number of crimes in an area.

In Table 2, the results from the literature are summarized, for each measure/variable it is indicated whether it is aimed at crime in general or a specific type of crime. Drugs and nuisance related crimes were not found in the literature which was studied. Arguably, these types of crime could be related to crime in general column.

Table 2: Variables in relation with types of crime

Variable	*Crime in general*	*Burglary*	*Vandalism*	*Theft*	*Violent crime*
Built environment					
Mixed land-use	X	X*		X*	X*
Residential land-use	X*	X*			
Retail and catering land-use	X*				
Greenspace	X		X	X*	X *
Streetlighting	X	X			
Infrastructure and layout		X*			
Parking		X		X	
Housing	X	X			X*
Vacancy	X				X*
Artworks	X		X		
CCTV	X				
Tourist attractions	X		X*	X*	
Social disorganization					
Socio-economic status	X*				
Residential Mobility	X*				
Ethnic heterogeneity	X*				

*Variables marked with an asterisk * are empirically tested.*

As crime occurs non-randomly in space and time, it is of importance to take this into account. A frequent criticism on research on this matter is that it is based on artificial neighborhoods/ census tracts, due to data provision. However, adjacent neighborhoods influence each other. Therefore, it is recommended to take the spatial interdependency of the neighborhoods into account when researching crime. Moreover, non-spatial forms of regression analysis suppress local variations, while the relation between the characteristics of the neighborhood and crime is expected to vary among neighborhoods.

3 Data

In this chapter, the data used in this research will be discussed. First the data collection will be elaborated. Afterwards the operationalization of the variables will be discussed. Next, the operationalized variables are summarized with descriptive statistics. The chapter finishes with a conclusion.

3.1 Data Collection

In this section, the data collection will be discussed. First, the crime data will be discussed, followed by the data regarding the built environment. Finally, data regarding the neighborhoods and its geospatial data format will be elaborated.

3.1.1 Dependent Variables

Multiple models will be constructed with crime numbers of different types of crime per neighborhood as dependent variable. Burglary, vandalism, violent crimes, drugs and nuisance related crimes, theft and crime in general are considered in this research. Crime numbers are available per month and per year. Crime numbers from the year 2019 will be used, since socio economic data from 2019 is available at the moment of writing. The data was obtained from Politie Nederland (2021).

3.1.2 Built Environment Variables

Different methods were used in obtaining data regarding the built environment. There were three main sources of data: (I) data from the Dutch National government, (II) the WFS (web feature service) from the municipality of Amsterdam and finally, (III) Statistics Netherlands.

Most variables regarding the built environment were obtained through the WFS service of the municipality of Amsterdam. The WFS service was made available through a public API provided on the open data website of the municipality of Amsterdam (Gemeente Amsterdam, 2021). This API was used in QGIS 3.10, which offers a straightforward method to connect to the server/service and to download and export the data. The data obtained from the WFS service were dated real-time, and were obtained on the 15th of February 2021, therefore the data is dated for this day. Data regarding (I) CCTV, (II) artworks, (III) trees and (IV) parking was obtained through this WFS service. However, as the built environment is considered to be static, no major differences between the end of 2019 and early 2021 are expected.

Data regarding the road network was obtained from Rijkswaterstaat (2021), this data was also available through the WFS service of the municipality of Amsterdam. However, this data contained only data for the municipality of Amsterdam. For the operationalization of the street layout a larger area needs to be taken into account. This will be further elaborated in section 3.2.2.1. Data regarding the streetlighting was obtained from the open data platform of the Dutch Government (Data.overheid.nl, 2021). The data was presented in comma separated values containing geographical coordinates.

Every couple of years Statistics Netherlands provides a map with land-uses (Statistics Netherlands, 2021). Currently, the latest map dates from 2015. The maps are made available through a WFS service from PDOK (PDOK, 2015). Finally, data regarding tourist attractions, was obtained from (Data.overheid.nl, 2019). The dataset contains all tourist attractions in the

Amsterdam region that are managed/hosted by *I amsterdam* and their geographical coordinates.

3.1.3 Neighborhood Variables

Statistics Netherlands provided shapefiles containing all neighborhoods (Statistics Netherlands, 2019). Besides the geographical configuration of neighborhoods, this shapefile, also provided socio economic data and socio demographic data from the neighborhoods. The dataset provided data regarding income, education, age, demographics, ethnicities, housing and more. The dataset was filtered for the municipality of Amsterdam. The latest dataset that is complete dates from 2019. This is the main reason that crime data is also taken from 2019. Data regarding education levels in 2019 was also provided by Statistics Netherlands (2020), however in a different dataset.

3.2 Operationalization

In the upcoming section the operationalization of the variables is being discussed, starting with the crime data followed by the variables regarding the built environment and finally, socio-demographic and socio-economic variables.

3.2.1 Operationalization Dependent Variables

Due to extensive reporting by the Dutch Police Department, many crimes are divided into subcategories. For the purpose of this research certain crimes will be combined. See Table 1 in chapter 1.5 for the description how crime types are constructed.

Crime data will be standardized by dividing the crimes per type by the area of the neighborhood. By doing this the crime density per crime type will be determined. Another measure for standardization that is often used is to divide the number of crimes by the population of the area. In this research, crime will be standardized using the area, as the spatial component is thought to be important in this research. Moreover, the population density will also be included in the model as a measure of housing and urbanization.

Next, a square root transformation is performed to increase the model fit. The aim is to relax big differences. For example, looking at burglaries, the mean of the crime density was approximately 47, the minimum was zero and the maximum was more than 300. By taking the square root, these extreme values will be nuanced as the difference between 200 and 300 will be relatively smaller. In Figure 6 the distributions of the burglary per square kilometer and the square root transformation are displayed. It can be observed that the square root transformation offers a more normal-like distribution rather than a poison distribution. Moreover, the ‘’tail’’ is smaller when using a square root transformation.

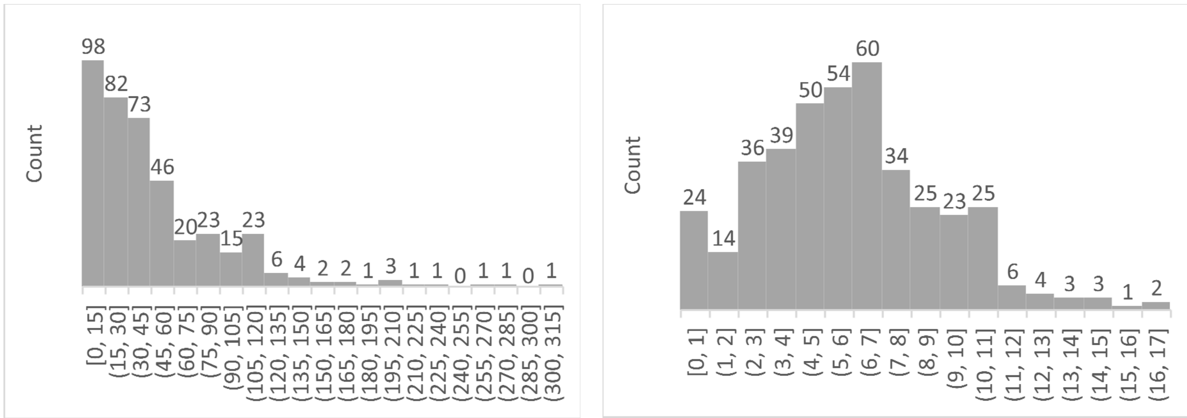


Figure 6: Left: distribution of burglaries per square kilometer, Right: distribution square root of burglaries per square kilometer

Logarithmic transformations were also considered; however, this would result in problems as there were neighborhoods with a crime density lower than one (resulting in extreme negative values) or even with a crime density of zero, resulting in a null value.

3.2.2 Operationalization Built Environment

In this section the operationalization of variables regarding the built environment are being discussed.

3.2.2.1 Street Configuration

As the street configuration is often found to be associated with crime, it is of big importance to operationalize the street configuration so that it explains the structure of the neighborhood. Whereas there are several methods to do so, it is believed that for the purpose of this research, the most important aspects of the street network are the number of dead-end streets, or cul-de-sacs, and the number of intersections in the neighborhoods.

The number of cul-de-sacs, is perhaps the variable that has the most discussion as there are multiple theories/claims about them, as mentioned in the literature review, section 2.1.4.4. Whereas Newman (1972) argued that cul-de-sacs increase a sense of territoriality and make it easier to identify strangers in the area, as dead end streets are not connected to the rest of the city, so that pedestrian activities are low.

The cul-de-sac density is determined by dividing the number of dead-end streets in the area by the area of the neighborhood. The number of dead-end streets were determined by using a tool from ArcMap 10.8, which enables to mask road lines that are not connected on one end. This results in a polygon at the end of the road-line. These polygons were in turn converted to point data. Next, by using a spatial join, the number of points in the neighborhood were counted. Finally, the number of dead-end streets were divided by the area to obtain the cul-de-sac density. A point of interest is that road data was used including a buffer outside the research area. This was done so that the point where a road crosses the border of the research area would not be masked as dead-end-street.

Intersections are believed to be increasing the permeability of the area and therefore increase the number of pedestrian and strangers in the area. It is believed that a higher number of intersections in the area decreases the sense of territoriality. Moreover, intersections are also a measure of how well connected the area is.

The intersection density is determined by intersecting the road-data. By selecting point as output feature, the place where two or more lines cross is marked with a point. However, some intersections are marked more often due to multiple roadways or roundabouts. To resolve this, a buffer was created of 7.5 meters around the points. Next, these buffers were merged to polygons, so that points that are less than 15 meters (two times 7.5 meters) become one feature. These polygons were, just as the dead-end masks converted to point data, counted and divided by the area of the neighborhoods to obtain the intersection density.

3.2.2.2 Mixed Land-Use

There are several methods to quantify the different type of land-uses in the area. For this research, a heterogeneity index will be used. The index is similar to the Blau index (1977) used for ethnic heterogeneity which is elaborated more in section 3.2.3.1. The index for mixed land-use is given by the following equation:

$$Mixed\ land\ use = \frac{1 - \sum_{i=1}^{k} {L_i}^2}{(k-1)/k} \tag{1}$$

Here, L_i is the ratio of land-use type i and k is the number of different types of land-uses. The equation is divided into two parts, the first one in the numerator is the actual heterogeneity index and the part in the denominator acts as a measure of standardization so that the value ranges from zero to one, since the maximum score of the upper part is given by ''(k-1)/k''. A value of zero indicates that the neighborhood only has one type of land-use and a value of 1 indicates that all land-use types are present and all cover equal parts of the land in the neighborhood.

For this research seven land-use types are being considered: (I) residential, (II) retail and catering, (III) recreational, (IV) public facilities, (V) other commercial, (VI) infrastructure and water and (VII) other. Some of the land-use types are a combination of a couple of different land-use types. The classification of land-use types is given in Table 3.

Table 3: Classification of land use types

Land-use	*classification*
Residential	Residential
Retail and Catering	Retail and Catering
Recreational	Forest Recreational terrain Parks Sports facilities Residence recreation Garden
Public Facilities	Public facilities
Other Commercial	Business park
Infrastructure and Water	Water Railway Inner waters Natural area (wet) Main Roads
Other	All other land-uses

The data regarding land-use is presented in polygon format. To obtain the area for specific land-uses, first all types of land-use were dissolved by land-use type. Next, the land-uses that need to be combined, were merged. This results in seven multi-polygons, one for each land-use type. By intersecting these multi-polygons with the neighborhoods, the present land-uses per neighborhood and their size are known. By dividing the area of the land-use type per neighborhood by the total area of the neighborhood the ratio of the land-use type is obtained. These ratios can be filled in the beforementioned equation to obtain the value for mixed land-use.

Besides mixed land-use, the percentage of residential area will be included in the model as well as the percentage of retail and catering area. These values are obtained during the process of determining the mixed land-use value.

3.2.2.3 Closed Circuit Television

Since data regarding the CCTV is presented as an area that is being covered, the choice is made to operationalize this by calculating the area that is covered and to divide this area by the total area of the neighborhood, resulting in a ratio or percentage of the land covered.

Similar to the land-uses, CCTV data was obtained as multi-polygon through the WFS service of the municipality of Amsterdam. Since only the geometry is needed, the data was dissolved. When dissolving, all different features are being merged into one feature. This is essential, since the polygons will be intersected with the neighborhood features afterwards. By intersecting, the polygons representing the area that is being covered by CCTV will obtain attributes from the neighborhood (and thus its name). In Figure 7 these different steps are visualized; note that in the last picture neighborhood borders (blue) are covered by the CCTV borders (red).

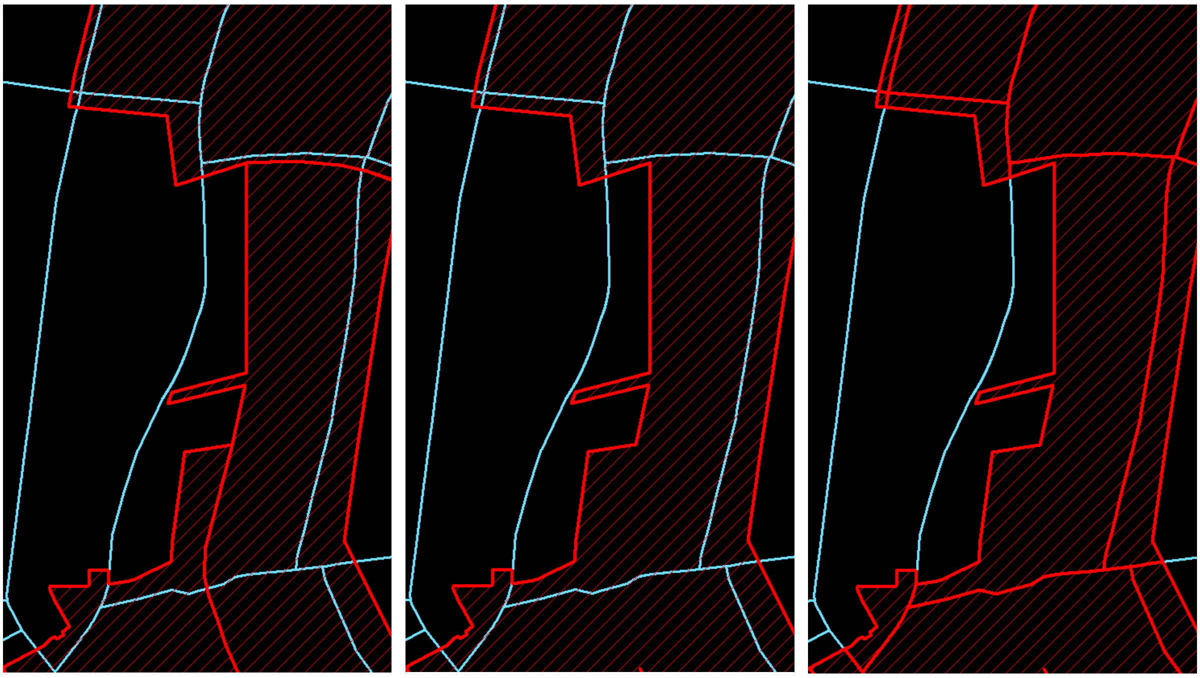


Figure 7: (l) original data CCTV, (m) dissolved data CCTV, (r) dissolved data CCTV intersected with neighborhoods

By dividing the area covered by the total area of the neighborhood, the ratio of CCTV coverage is obtained.

3.2.2.4 Streetlighting

Streetlighting data is provided by the open data portal of the Dutch government. The data provided in a comma separated values file, contained geographical coordinates. These coordinates were plotted/placed on the map. Subsequently they were counted per neighborhood using a spatial join function. Finally, the number of streetlighting installation were divided by the area of the neighborhoods to obtain the streetlighting density.

3.2.2.5 Artworks

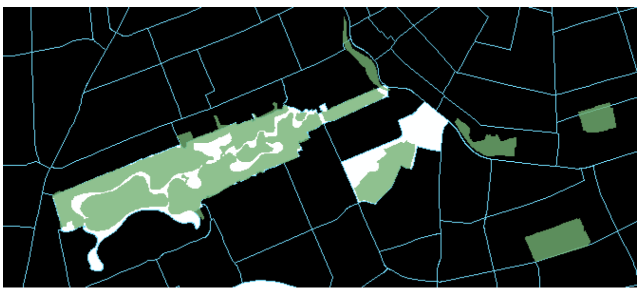
Data regarding artworks was also provided through the WFS server of the municipality of Amsterdam. Two types of art were present: ordinary artworks and remembrance artworks. The WFS service provided point data, these points were counted using a spatial join function. Subsequently, per neighborhood the two types of art were summed to obtain the total number of artworks. Finally, the number of artworks were divided by the area of the neighborhoods to obtain the artworks density.

3.2.2.6 Greenspace

Greenspace is operationalized as the ratio of area covered by greenspace in the neighborhood. The area of greenspace is based on the following land-uses: (I) parks, (II) forests and (III) gardens.

Special attention is paid to major parks such as the Vondelpark, which covers two entire neighborhoods. These two neighborhoods do not give any characteristics regarding the built environment or regarding residents as there are no residents. However, it is believed that such parks do have an influence in the surrounding neighborhoods. To operationalize this, a buffer of 50 meters is created around greenspace that lies outside the research area, so the parks in the research area do not have this buffer. This is visualized in Figure 8. Here is displayed how, for example, the Vondelpark is included, although it lies outside the research area. In the upper figure, the merged greenspace data is projected over the neighborhoods. In the middle figure, the 50 meter buffer is realized around the greenspace outside the research area. In the bottom one, the ratio of greenspace is visualized for the same area.

Merging the greenspace inside and outside the research area and subsequently intersecting the result with the neighborhoods the greenspace that is being considered in this research is obtained. Next a similar approach as the CCTV is used to obtain the ratio of greenspace.



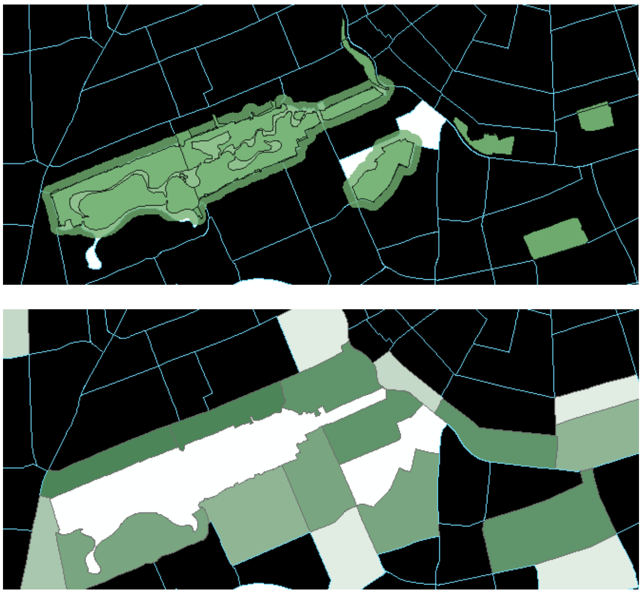


Figure 8: Up: greenspace, Middle: 50 meter buffer of greenspace outside research area, Bottom: ratio greenspace visualized

Besides the ratio of greenspace, the number of trees per square kilometer are included. Data regarding trees were available as point data through the WFS service of the municipality of Amsterdam. The tree density is obtained in a similar way to streetlighting and artworks.

3.2.2.7 Parking

Parking facilities are operationalized as the number of parking spaces per square kilometer. As data regarding parking facilities is offered in multi polygon shapefiles through the WFS service of the municipality of Amsterdam, a couple of geoprocesses need to be executed. The multi polygon contained in the attribute table how many parking spots that particular feature contains. Therefore, the data was not dissolved, but immediate intersected with the neighborhoods. The result of this process is that every feature contains the neighborhood name in its attribute table. ArcMap 10.8 offers a feature to summarize values of the attribute given a condition/circumstance. This tool provides a method to sum all values of the number of parking spaces per neighborhood. The result of this operation is a text-file in which the number of parking spaces are given per neighborhood. This text-file was converted to a comma separated values file which in turn was joined to the neighborhoods.

3.2.2.8 Housing

There are several housing characteristics that need to be operationalized. However, all relevant characteristics are available in the neighborhood datasets provided by Statistics Netherlands. Population density is used as a measure of urbanization/housing as well as a control variable. The Address density is a measure of urban density in relation to the area in which it is located. For each address in the neighborhood is determined how many (other) addresses there are within a radius of one kilometer. The address density on neighborhood level is the average of all addresses in the neighborhood.

The vacancy rate in dwellings is also available via Statistics Netherlands. It is measured as the percentage of the whole housing stock in the neighborhood that is vacant on the first day of the year. The vacancy rate only concerns dwellings, vacant retail facilities or other real estate are not considered in this measure. The literature also only mentioned residential real estate, hence other vacant real estate than residential is not considered. The percentage of rented homes is also concerned with housing characteristics. However, the number of rented homes is included as a measure of residential mobility and will thus be more elaborated in section 3.2.3.3, in which the operationalization of the social disorganization theory is being discussed.

3.2.2.9 Tourist Attractions

As it is generally known that Amsterdam suffers from extreme tourist crowds, which act as crime attractors for crimes like theft and drug dealing, it seems wise to take tourism into account as a control variable. A dataset that was obtained contained all tourist attractions managed by *I Amsterdam*, which is a tourist agency in Amsterdam, and their exact locations. This dataset was operationalized in the same manner as the streetlighting, by projecting the attractions on the map, counting them by a spatial join and finally dividing the number of attractions by the area of the neighborhood to obtain the ''tourist attraction density''.

3.2.3 Operationalization Socio Demographics and Socio Economics

In this section the operationalization of socio demographic and socio economic variables originating from the social disorganization theory are elaborated.

3.2.3.1 Ethnic Heterogeneity

The most common method found in literature to measure ethnic heterogeneity is by making use of the index introduced by Blau (1977). In this index the ethnic heterogeneity is measured by the following equation:

$$Blau\ index = 1 - \sum_{i=1}^{k} {p_i}^2 \qquad (2)$$

Here p_i is the portion of a specific ethnic group and k the number of different ethnic groups considered (Biemann & Kearney, 2010). The maximum value for this index is given by the following equation:

$$max\ Blau\ index = (k-1)/k \qquad (3)$$

Hence the maximum value of the index is based on the number categories (ethnic groups) (Biemann & Kearney, 2010). For this research, the following ethnic groups will be included: (I) native Dutch, (II) western immigrants, (III) Moroccans, (IV) Dutch Antilles, (V) Surinamese, (VI) Turks and (VII) other nonwestern immigrants. Therefore, the maximum score for ethnic heterogeneity in this research is (7-1)/7 = 0.857. The percentages of all ethnic groups are provided by the dataset regarding neighborhoods from Statistics Netherlands.

3.2.3.2 Socio-Economic Status

The socio-economic status of the neighborhood can be operationalized in several methods. Multiple variables are available which are related to the socio-economic status. However, it is expected that these variables are highly correlated. Therefore, a similar approach is used as Sampson & Groves (1989) did in their research in which they empirically tested the social disorganization theory; they summed z-scores of several variables to combine them to one single variable.

The advantage of summing z-scores is that multiple correlated variables can be included in the regression models. For this research, three variables were included, namely the average real-estate value, the percentage of high educated residents and finally, the labor participation or rather an inverse of the number of jobless residents. Per variable, there were a few null values, these null values were substituted for the mean value. In Table 4 descriptive statistics of the beforementioned variables are displayed.

Table 4: Descriptive statistics socio-economic variables

Variable	*Low*	*High*	*Mean*	*Standard dev.*
Real estate value (x 1000 euros)	56	1985	413.75	209.489
Share high educated	0.065	0.856	0.420	0.162
Labor participation	32	87	69.028	7.449

The descriptive statistics of the to z-score converted variables are displayed in Table 5.

Table 5: Descriptive statistics socio-economic variables after z-transformation

Variable	*Low*	*High*	*Mean*	*Standard dev.*
z-Real estate value	-1.708	7.500	0	1
z-Share high educated	-2.194	2.687	0	1
z-Labor participation	-4.971	2.413	0	1

The only operation left to do is summing the z-scores to obtain the intended measure of socio-economic status.

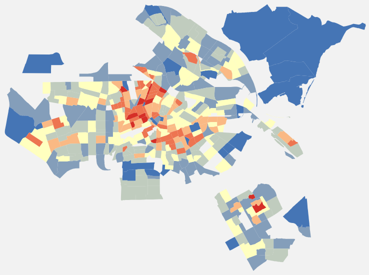
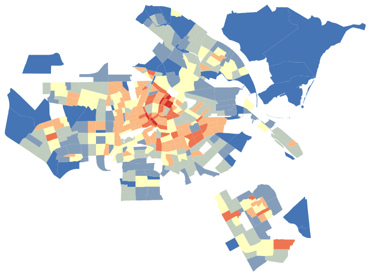
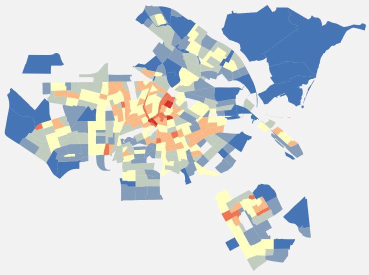
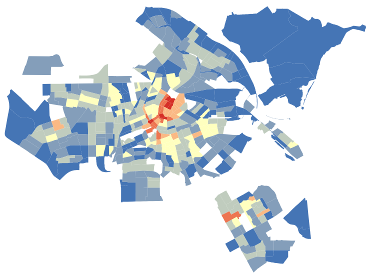
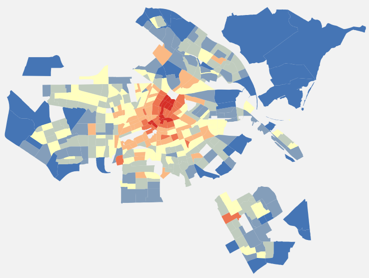
3.2.3.3 Residential Mobility

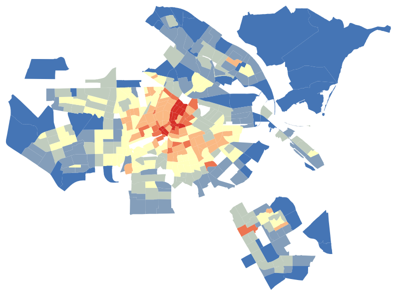
Residential mobility is concerned with the stability of the population in a certain area. There are a couple of methods of operationalizing this. For this study the is choice is made to use the percentage of rented homes. As mentioned in the literature review, people in owned homes tend to reside longer in their home. In addition, it could act as a measure of territoriality, as people that own a home are willing to take more risk in protecting their property, and thus this measure also acts as a measure of territoriality.

3.3 Descriptive Statistics Variables

In this section descriptive statistics of all variables are being discussed. In Table 6 descriptive statistics of the dependent variables and their distribution over the municipality of Amsterdam are displayed.

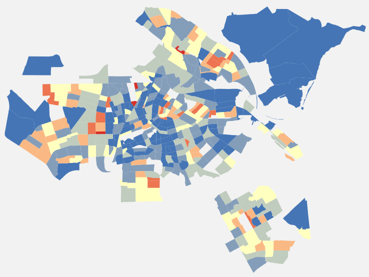
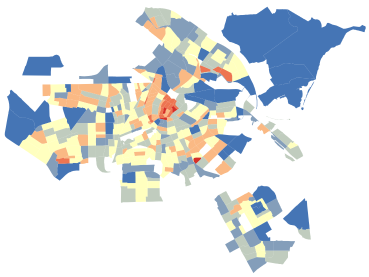
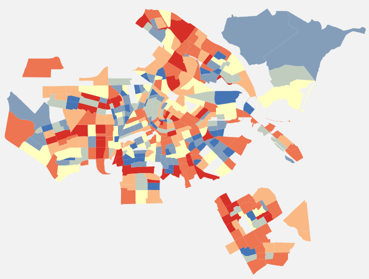
Table 6: Descriptive statistics dependent variables

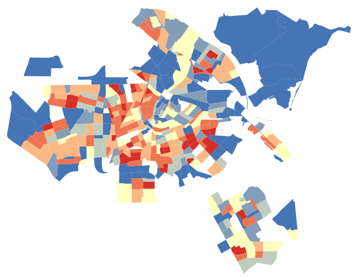
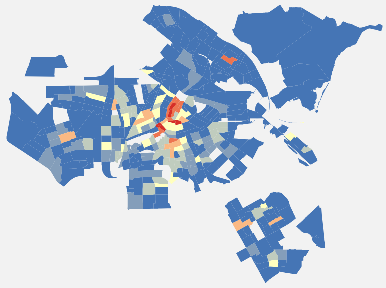
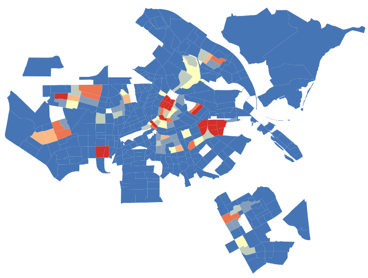
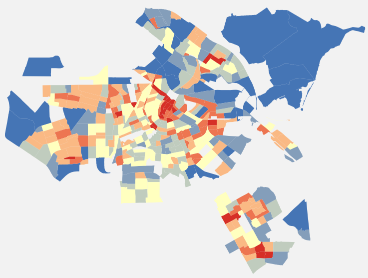
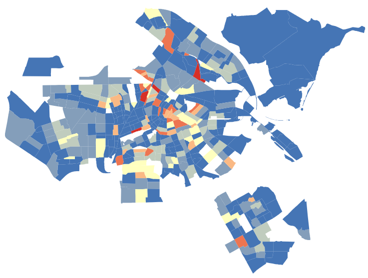
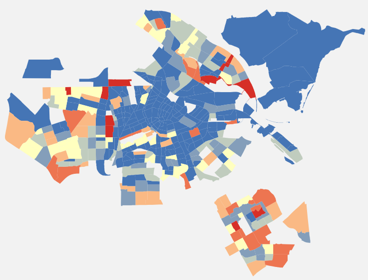
Variable	*Descriptive statistics*	*Map*
Sqrt(burglary/km2)	Mean 6.025 Low 0.000 High 17.473 Std. dev. 3.222 low mean high	
Sqrt(vandalism/km2)	Mean 6.857 Low 0.000 High 27.955 Std. dev. 3.646 low mean high	
Sqrt(violent crimes/km2)	Mean 9.000 Low 0.000 High 42.293 Std. dev. 5.565 low mean high	
Sqrt(drugs and nuisance/km2)	Mean 4.528 Low 0.000 High 53.050 Std. dev. 6.288 low mean high	
Sqrt(theft/km2)	Mean 11.848 Low 0.000 High 67.829 Std. dev. 9.427 low mean high	

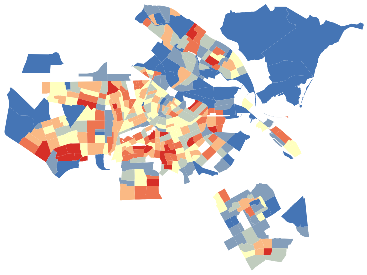
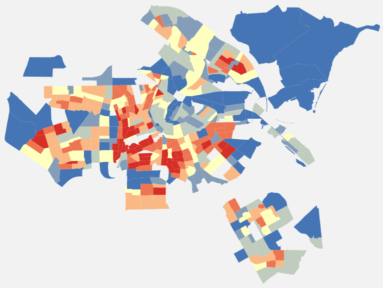
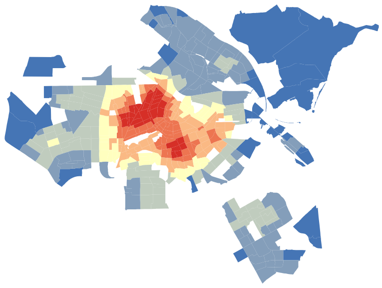
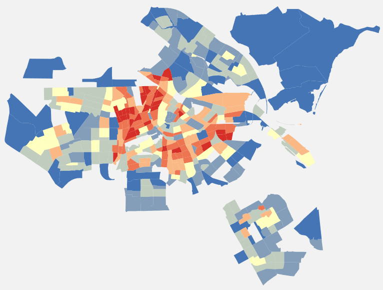
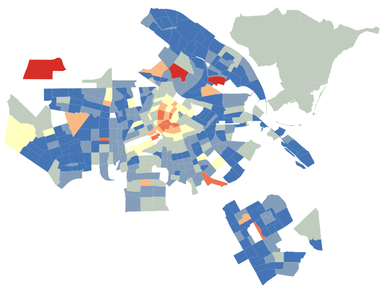
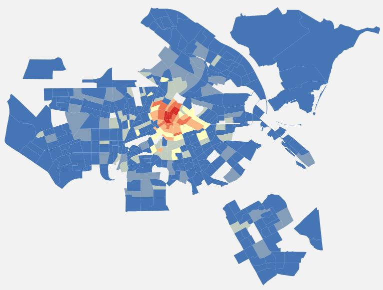
Sqrt(total/km2)	Mean 30.380 Low 0.869 High 124.664 Std. dev. 18.151 low mean high	

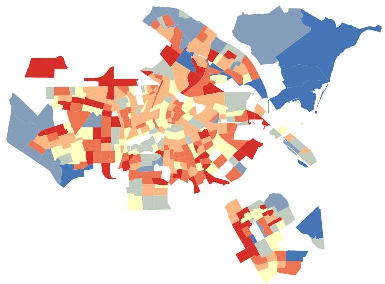
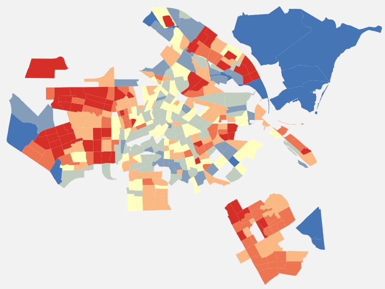
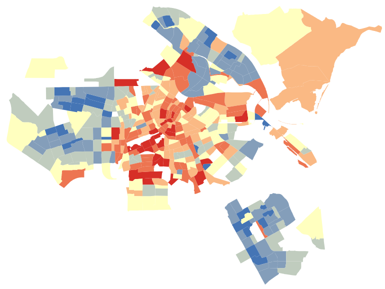
When looking at the maps, it can be observed that the majority of the crimes occur in the city center. Hence it is no surprise that the total crimes also concentrate in the city center. Only burglary seems to be occurring most in some sort of ring around the city center. In Table 7 the descriptive statistics of the independent variables are mentioned, as well as the distribution throughout the research area.

Table 7: Descriptive statistics independent variables

Variable	*Descriptive statistics*	*Map*
Cul-de-sac density	Mean 21.659 Low 0.000 High 167.040 Std. dev. 23.349 low mean high	
Intersection density	Mean 146.574 Low 1.363 High 605.945 Std. dev. 79.895 low mean high	
Mixed land-use	Mean 0.554 Low 0.000 High 0.915 Std. dev. 0.206 low mean high	

Percentage residential land-use	Mean 0.521 Low 0.000 High 1.000 Std. dev. 0.295 low mean high	
Percentage retail and catering land-use	Mean 0.0750 Low 0.000 High 0.890 Std. dev. 0.156 low mean high	
Ratio CCTV coverage	Mean 0.095 Low 0.000 High 1.000 Std. dev. 0.246 low mean high	
Streetlighting density	Mean 2418.775 Low 19.508 High 6002.020 Std. dev. 988.354 low mean High	
Art density	Mean 5.604 Low 0.000 High 87.823 Std. dev. 10.077 low mean high	
Greenspace	Mean 0.092 Low 0.000 High 0.786 Std. dev. 0.148 low Mean high	

Variable	Statistics	Map
Tree density	Mean 1205.577 Low 0.000 High 3216.420 Std. dev. 613.906 low mean high	
Parking density	Mean 2847.093 Low 0.000 High 6954.150 Std. dev. 1666.157 low mean high	
Address density	Mean 5746.099 Low 28.000 High 12417.000 Std. dev. 3240.471 low mean high	
Population density	Mean 13045.184 Low 32.000 High 35855.000 Std. dev. 8127.880 low Mean High	
Vacancy rate	Mean 7.955 Low 1.000 High 54.000 Std. dev. 7.119 low mean high	
Tourist attractions density	Mean 6.257 Low 0.000 High 129.599 Std. dev. 15.821 low mean high	

Percentage rented homes	Mean	67.124	
	Low	3.000	
	High	100.000	
	Std. dev.	20.821	
	low mean high		
Ethnic heterogeneity	Mean	0.642	
	Low	0.184	
	High	0.819	
	Std. dev.	0.115	
	low mean high		
Socio-economic status	Mean	0.000	
	Low	-6.535	
	High	6.182	
	Std. dev.	2.357	
	low mean high		

3.4 Conclusion Data

In this chapter data collection, the operationalization of the data and descriptive statistics of the variables were discussed. Most of the data that was obtained originated from government agencies. Statistics Netherlands provided the remaining data.

Crime data was operationalized as the square root of the number of crimes per square kilometer. This resulted in a more normal-like distribution in which big differences were nuanced. It was found that crime concentrates in the city center and gradually decreases when moving away from the center. Burglary is an exception; burglary occurs most in the area right outside the city center.

Variables regarding the built environment were, generally speaking, operationalized by standardizing them to the area of the neighborhood. The operationalized variables were, generally speaking, clustered in the city center or randomly distributed. Intersection density, retail and catering land-use, CCTV, streetlighting, address density, population density, vacancy and tourist attraction density were found to have the highest values in the city center.

Ethnic heterogeneity was operationalized by using the index of Blau (1977). It was found that ethnic heterogeneity is the highest in the western and south-eastern parts of Amsterdam. The socio-economic status was found to be the poorest in the south-east and the western parts of the city.

4 Method

In this section, the methodological approach is elaborated. The section starts off with an explanation of the exploratory regression analysis. In this section also the Akaike's information criterion is elaborated as it is a main parameter on which the most suitable regression models are chosen. Besides, the AICc will also be used to compare the OLS regression models with the models of the GWR. Next, the ordinary least squares will be elaborated. Here special attention paid to spatial autocorrelation of the residuals of the OLS regression analysis (Moran's index or Moran's I), as non-spatial autocorrelated residuals are a condition for performing a geographically weighted regression. Finally, the geographically weighted regression and its parameters will be elaborated more in depth.

4.1 Introduction

For this research, geographic weighted regression will be used instead of a ''normal'' ordinary least squares regression. The advantage of the geographic weighted regression over a normal regression is that it takes into account the geospatial distribution of the unit of analysis, in this case the neighborhoods of Amsterdam. Since the crime data is aggregated to a neighborhood level, the exact location of the crime event is not known. It could be that the crime event took place near the border of two neighborhoods. By using a regular ordinary least squares regression analysis, the model will only take into account the characteristics of the neighborhood in which the crime event took place. A geographical weighted regression does also take into account the surrounding neighborhoods of the neighborhood where the crime event took place. Therefore, a geographical weighted regression analysis is preferred and believed to produce more reliable results. Moreover, it is expected that crime does not correlate consistently throughout the research area with the independent variables. Taking this into account, a geographically weighted regression seems to be the most suitable tool for this analysis. Furthermore, ESRI for ArcGIS (2020) states that for a geographically weighted regression several hundreds of observations are needed, which makes it suitable for the Amsterdam region with its approximately 400 neighborhoods.

Before performing a geographically weighted regression, first a suitable ordinary least regression model has to be found. To do so, an exploratory regression analysis will be performed. Next, an ordinary least squares regression is performed to obtain the coefficients and model performance. Finally, the geographically weighted regression is performed with the same variables as the ordinary least squares regression, this will make it possible to compare the GWR with OLS regression models. These steps will be ellaborated more in the upcomming sections.

4.2 Exploratory Regression Analysis

As mentioned before, it not expected that all variables are correlated with all crime types. To find the most suitable variables for the ordinary least squares regression, an exploratory regression analysis was performed for each crime type considered in this research. An exploratory regression analysis is a tool in ArcMap 10.8 which considers all possible models given a set of variables. The models with the lowest score for the corrected Akaike Information Criterion (AICc) and highest R^2-adjusted are chosen for further analysis. A requirement of a maximum number included variables was set to 10 plus the constant/intercept. The main reasons for this requirement are (I) the number of neighborhoods/observations in combination with the number of variables would be too little and (II) more variables in the model will increase the probability of local multicollinearity in the GWR.

ESRI (2020) mentions that using an exploratory regression should be done carefully. They warn that exploratory regression analysis, just like STEPWISE regressions, are controversial. From a scientific point of view, regression models should be used for hypothesis testing rather than just finding the best model fit. For this research, however, the variables included are already hypothesized as they come from the literature review. The exploratory regression is used to find the best set of variables for specific crime types.

4.2.1 Corrected Akaike Information Criterion

Besides model selection, the AICc value will play further on an important role in the comparison between the ordinary least squares regression and the geographically weighted regression analysis. Hence it is briefly elaborated in this section. The following equation is the equation as Akaike (1974) formulated it in his original work:

$$AIC = (-2)\,log(max\ likelihood) + 2(parameters\ in\ the\ model) \quad (4)$$

So basically, the AIC is a tradeoff between increasing the maximum likelihood and the number of variables included in the model. The lower the AIC, the better the model. As increasing the number of variables will always improve the R-squared values and also the likelihood of a correct prediction, a penalty is included for the number of variables, since the goal of analysis to understand underlying mechanisms, only variables that increase the likelihood of a good prediction that are ‘’bigger’’ than the penalty for adding a variable are included in the model. In regards to the corrected Akaike information criterion (which is used in ArcMap 10.8), an extra component is added to the original formula. This extra component acts as a correction for small sample sizes. Burnham & Anderson (1998) formulated the corrected Akaike information criterion (AICc) as:

$$AICc = AIC + \frac{2K(K+1)}{n-K-1} \quad (5)$$

Here, K is the number of parameters in the model and n is the sample size. As the sample size increases, the added part will asymptotically reach zero.

4.3 Ordinary Least Squares Regression

For the ordinary least squares regression analysis, the variables from the exploratory regression will be included. The main objective of the OLS regression is to get an understanding of the global correlations between the variables and crime and to see which variables explain most variance. Moreover, it is used for comparison between the geographically weighted regression later on, to determine whether using a local form of regression analysis will improve overall model performance. For this comparison, the same dependent and independent variables will be included.

4.4 Moran's I of Residuals OLS regression

Another point of interest regarding the OLS regression is that in order to perform a geographically weighted regression, it should be made sure that the residuals of the OLS regression are not spatially clustered. In the case of clustering of residuals, it is probable that at least one key variable is missing, which is apparent in the areas where the under and over predictions are located. To determine whether the residuals are clustered, Moran's I (index) is used. This index determines whether geographical features are clustered, dispersed or randomly distributed throughout the research area. The index ranges between -1 and 1. A value of -1 indicates that the features are negatively spatial autocorrelated (dispersed) and a value of 1 indicates that the features are positively spatial autocorrelated (clustered). This is displayed in Figure 9. Converting the index to z-scores offers the possibility for statistical hypothesis testing, in which the null-hypothesis is that there is no spatial autocorrelation in the research area, hence the features are randomly distributed. If the significance of the test is $p < 0.10$, it suggests that the features are spatially autocorrelated, which implies that the features are either clustered or dispersed. For this research, Moran's I will be determined by the tool provided by ArcMap 10.8. The bandwidth for this test is set at 3 kilometers (for all crime types).

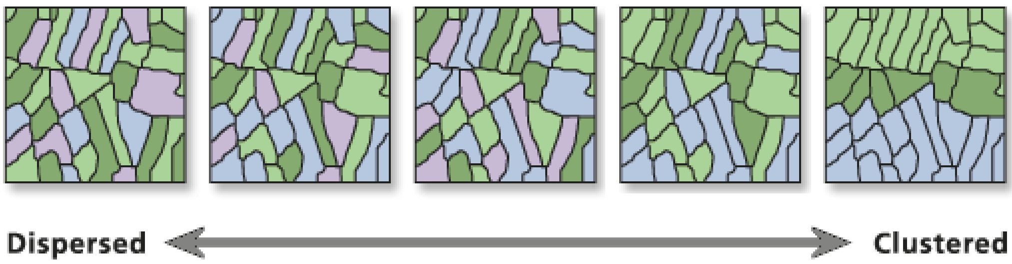


Figure 9: Visualization of Spatial Autocorrelation (ArcMap 10.8, 2020)

4.5 Geographically Weighted Regression

As stated before, one of the premises mentioned by Wortley & Mazerolle (2008) is that crime is not distributed randomly in space. Furthermore, as the literature review has shown, crime is considered to be non-stationary, which justifies the use of a geographically weighted regression analysis.

The last step of the analysis is a geographically weighted regression (GWR). A geographically weighted regression takes spatial variation between the dependent and independent variables into account. Cahill & Mulligan (2007) argued that one of the problems with global regression models is that possible variations over space are suppressed.

A geographically weighted regression, which is a local form of regression, is similar to a standard ordinary least squares regression model. However, instead of estimating one parameter per independent variable, a geographically weighted regression model estimates parameters for each location in the area, in this case, the neighborhoods of Amsterdam.

Brunsdon, Fotheringham, & Charlton (1996) formulated the following equation for the geographically weighted regression:

$$Y_i = a_{i0} + \sum_{k=1,m} a_{ik}\, x_{ik} + \varepsilon_i \qquad (6)$$

The difference in this equation, compared to an ordinary least squares regression are the parameters a_{i0} (intercept) and a_{ik} (coefficient for variable x_{ik}). These parameters are neighborhood specific, unlike an ordinary least squares regression in which these parameters are determined for the whole research area. So, by using a geographically weighted regression, each neighborhood has its own set of parameters. These parameters are estimated by only taking into account the surrounding neighborhoods within the bandwidth. The neighborhoods which are closest, will obtain a higher weight and thus have more influence in the estimation than neighborhoods which are further away.

Because of this ''weighting'', the locations close to the estimation point have more influence. The weighting is based on the kernel that is being used and the bandwidth of this kernel. The kernel and bandwidth selection are discussed in section 4.5.1. The weighting of the coefficients is based on a gaussian kernel/weighting scheme. The gaussian kernel ensures that nearby features will have a bigger impact than features further away. This is visualized in Figure 10.

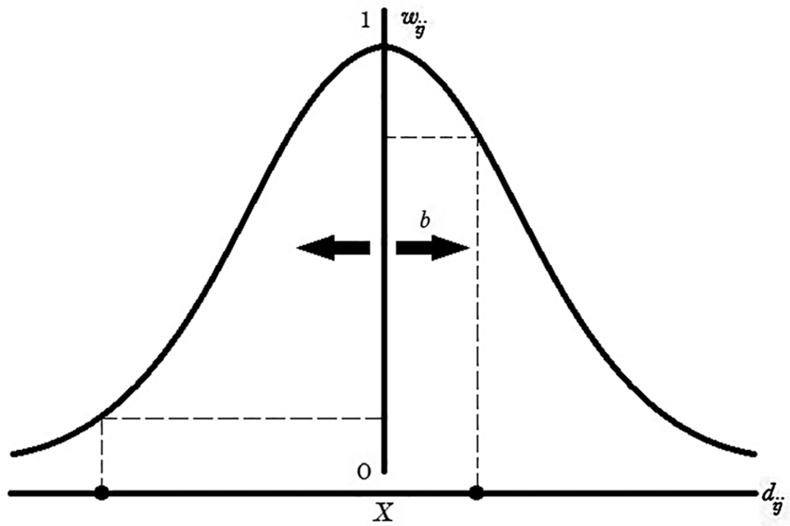


Figure 10: The concept of a spatial kernel used in a geographically weighted regression (Bidanset & Lombard, 2014).

''Where:

X is the regression point

● is a data point

w_{ij} is the weight applied to the j-th property at regression point i

b is the bandwidth

d_{ij} is the geographic distance between regression point and property j'' (Bidanset & Lombard, 2014).

In short, the unique neighborhood specific parameters will be estimated based on the neighboring neighborhoods within the bandwidth in which the closest will have a higher weight and thus are more influential.

4.5.1 Kernel & Bandwidth Selection

To determine the weights, a kernel type and a bandwidth must be selected. ArcMap 10.8 offers two kernel types: fixed and adaptive. The fixed kernel type is based on a distance parameter to determine the bandwidth for the estimation of the parameters, whereas the adaptive kernel type is based on the number of neighborhoods. The adaptive thus has a larger bandwidth in areas where the geographical features are larger and a smaller bandwidth where these features are smaller.

For this research, the fixed kernel type will be used, as it provides more generalizable results as the bandwidth for each feature will be the same. Moreover, it is believed that when using an adaptive kernel, the bandwidth for the larger neighborhoods will be too big. Finally, studies regarding crime using a geographically weighted regression all use a fixed bandwidth (Cahill & Mulligan, 2007; Malczewski & Poetz, 2005).

The bandwidth for this research is set at three kilometers. The research by Malczewski & Poetz (2005) and Cahill & Mulligan (2007) found respectively a bandwidth of 2392 meter and 2280 meter to be most suitable. In both studies the bandwidth was determined by an optimalization process to minimize the Akaike’s information criterion. Moreover, Malczewski & Poetz (2005) state that these bandwidths also fit the empirical results of ‘’spatial offender-target relationships, as Evans (1989) found that approximately 50 percent of the burglaries occur within 0.8 kilometer of the offender’s home.

In this research on the city of Amsterdam, the minimum bandwidth is approximately 2200 meter, implying that smaller bandwidths result in neighborhoods not having a neighbor to estimate parameters. Therefore, it seems appropriate to take a larger bandwidth, so that every neighborhood has at least a couple of neighbors. Moreover, by using a too small bandwidth, the regression model will estimate parameters so that they will ‘’fit the model’’ and thus producing more unreliable results. Hence, a bandwidth of 3 kilometers is choses for this research.

4.6 Conclusion Method

In this chapter, the methods of analyzing the relation between the built environment and different crime types are discussed. The first step of the analysis is an exploratory regression, which will find the most optimal combination of variables to minimize the corrected Akaike's Information Criterion. Next, an ordinary least squares regression analysis is performed with the variables which were obtained from the exploratory regression. This OLS regression will provide coefficients and significance levels of the relevant variables. The residuals of the OLS regression are tested for spatial autocorrelation by using Moran's I. Preferably the residuals are randomly distributed over the research area as it indicates that it is probable that no key variables are missing. Moreover, if residuals are clustered, this clustering will interfere with the GWR, which will be performed next. The geographically weighted regression is performed to identify spatial variability in the coefficients. The bandwidth for the fixed kernel is set at three kilometers.

5 Results

In this section the results of the analysis mentioned in section 4 will be discussed per crime type. Total crime numbers will also be analyzed.

5.1 Burglary

In Table 8 the best model of the exploratory regression analysis is summarized. In general, all signs are in line with the literature, except for artworks, which should be negative according the literature. Furthermore, greenspace is included with a positive sign, which is also remarkable, as burglary is not mentioned in the literature regarding greenspace and crime.

Table 8: Variables and their sign that are included in the best specified OLS regression model for the crime type burglary

	INTERSECTION DENSITY	*ADDRESS DENSITY*	*POPULATION DENSITY*	*VACANCY RATE*	*ART DENSITY*	*RATIO CCTV*	*SOCIO-ECONOCMIC STATUS*	*PERCENTAGE RETAIL AND CATERING LAND-USE*	*MIXED LAND-USE*	*RATIO GREENSPACE*	*R2-ADJUSTED*	*AICC*	*F-STATISTIC*	*STD. ERROR OF THE ESTIMATE*
BURGLARY	+	+	+	+	+	-	-	+	+	+	0.53	1796.67	46.400	2.211

Next, all variables mentioned in Table 8 are included in an ordinary least squares regression analysis to obtain coefficients, significance levels and VIF-values. In Table 9, the coefficients of the regression analysis are displayed. In general, the significance levels are quite high, this could be expected due to the prior executed exploratory regression analysis. All variables are significant at the $p < 0.10$ interval, except for the intercept. Multicollinearity issues do not arise, as the highest VIF-value (variance inflation factor) is 3.121.

Table 9: Regression coefficients burglary

	Coefficients	*Std. Error*	*Standardized coefficients*	*t*	*Sig.*	*VIF*
(Constant)	-.940	.639		-1.470	.142	
Intersection density	.007	.002	.167	4.097	.000*	1.415
Art density	.022	.011	.068	1.918	.056	1.070
Ratio CCTV	-1.111	.503	-.085	-2.206	.028*	1.269
Percentage residential land-use	2.182	.580	.200	3.762	.000*	2.415
Mixed land-use	1.496	.670	.095	2.234	.026*	1.561
Socio-economic status	-.099	.058	-.072	-1.698	.090	1.553
Ratio greenspace	1.911	.854	.088	2.238	.026*	1.324
Population density	.00020	0.000024	.515	8.532	.000*	3.121
Address density	.00013	0.000056	.135	2.421	.016*	2.670
Vacancy rate	.049	.019	.108	2.538	.012*	1.539

Dependent variable: sqrt_burg (square root of number of burglaries per square kilometer)
* variable significant at the $p < 0.05$ level

Perhaps the most interesting variable in this model is the intersection density, as there were some conflicting theories in regard to the connectivity and permeability of neighborhoods. According to Jacobs (1961), intersections increase pedestrian activity and thus crime reduction due to increased natural surveillance. On the other hand, the empirical results of Sohn (2016) and Yang (2006) are in line with the results of this research. As burglary, generally speaking, occurs in the nighttime, pedestrian activity is believed to be lower in the nighttime. So, the permeability of the neighborhood could act as an advantage for the burglars as it provides opportunities for multiple escape routes.

Another contrary finding to the literature is that mixed land-use seems to be increasing the number of burglaries, whereas Jacobs (1961) argued that crime should occur less in areas with an increased number of different functions to increase pedestrian activity. It could be argued that both the intersection density and mixed land-use generate opportunities to go down the street more anonymously, which may facilitate burglars. Moreover, an increased number of anonymous pedestrians in the area is thought to weaken the territoriality of the neighborhood, and thus its residents will not be watching out for each other as much as in neighborhoods with only a few anonymous pedestrians.

Another remarkable included variable is greenspace. Arguably, this is due to the low number of people in parks in the nighttime (as it is assumed that burglaries occur most at night) and thus the chance of getting caught is less.

Artworks are positively and significantly ($p < 0.10$) correlated with the number of burglaries in a neighborhood. This is contrary to the findings of the literature. However, no empirical research has been found in regard to crime prevention and art. It is expected that the artworks are correlated due to chance. Besides, the coefficient remains low (0.022), meaning that the influence is close to zero.

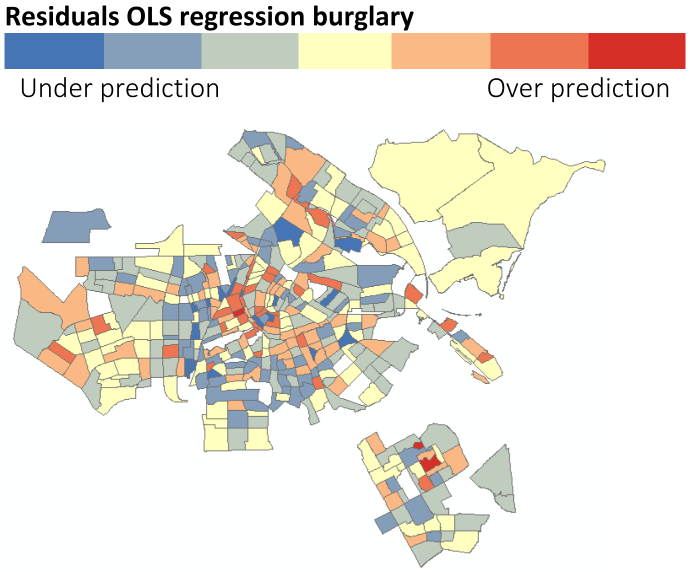
The address density, population density and percentage of residential land-use can be explained from the perspective that an increase in these variables also increases the number of homes in the neighborhood and thus the number of opportunities for a burglary. Especially the population density is highly correlated with burglaries as the standardized coefficient is 0.515.

Initially, the ratio CCTV having a negative sign is looking positive, as it is confirming the findings from the literature review. As the ratio of CCTV coverage decreases the number of burglaries. However, taking into account the results of the other crime types, it might be the case that the ratio CCTV coverage is more concerned with the geographical placement rather than the actual CCTV coverage itself. This concern regarding CCTV will be more elaborated in the sections in which results of other crime types are being discussed.

Looking at the vacancy rate, a positive and significant correlation can be observed. This finding is in line with the broken window theory, as vacant properties have a bad influence on the image of the neighborhood. In these neighborhoods, people tend to care less about the neighborhood and are more likely to ignore suspicious people according to the literature. Another point of view on the correlation between vacancy and burglaries is that vacant properties are an easy target for burglars. As no data is available whether burglaries occur in vacant homes, it is difficult to test whether this is the case. Although being the least significant variable (besides the intercept), with $p < 0.10$, the socio-economic status having a negative sign is in line with the social disorganization theory.

In regard to model performance, it is important that the residuals of the OLS regression model are randomly distributed across the research area, as mentioned in section 0. Hence a test for spatial autocorrelation was conducted (Moran's I). The parameters for this test are mentioned before in section 0. In Table 10 the results of this test are displayed.

Table 10: Spatial autocorrelation (Moran's I) of the residuals of the OLS regression (burglary)



Fixed distance	3000
Distance method	Euclidean
Moran's Index	0.00536
Z-score	1.412
P-value	0.158

A value close to zero for Moran's Index, given the input parameters, indicates that the residuals are randomly spread across the research area. The p-value indicates that the residuals do not cluster or disperse significantly, which means that the residuals from the OLS regression analysis are spread randomly across the research area. The full spatial autocorrelation report can be found in appendix 1.

Since the residuals are spread randomly, a geographically weighted regression, using the same variables as the OLS regression and a fixed kernel with a bandwidth of 3 kilometer, is performed. A summary of the coefficients as well as a comparison to the coefficient of the OLS regression is given in Table 11.

Table 12 shows the model performance of the GWR in comparison to the OLS regression.

Table 11: Coefficients GWR for the burglary model

	Coefficients			
	OLS	***GWR***		
		Lowest	***Mean***	***Highest***
(Constant)	-.940	-3.273	-1.115	1.946
Intersection density	.007	0.001	0.007	0.020
Art density	.022	-0.026	0.025	0.105
Ratio CCTV	-1.111	-5.054	-1.434	0.097
Percentage residential land-use	2.182	-3.504	2.327	4.999
Mixed land-use	1.496	-5.559	1.147	2.505
Socio-economic status	-.099	-0.471	-0.046	0.280
Ratio greenspace	1.911	-1.132	1.341	8.127

Population density	.00020	0.00005	0.00020	0.00046
Address density	.00013	-0.00023	0.00017	0.00037
Vacancy rate	.049	-0.040	0.058	0.158

Table 12: Model performance of GWR for the crime type burglary

	GWR		*Model improvement*
R^2-adj	0.563		0.033
AICc	1766.98		30.31
	Low	***Mean***	***High***
local R2	0.480	0.548	0.883

The first thing which stands out is the limited model improvement compared to other studies using a geographically weighted regression analysis. However, there is an improvement as the adjusted R-squared value increases with 0.033 and the AICc value decreases with approximately 30. Moreover, the added value in a GWR is that local variations can be identified.

In Figure 11 the local R-squared values are displayed. It can easily be observed that the model performs better in peripheral areas of the city whereas the model performs worse in the city center. Comparing the local R-squared values with the observed values in Figure 12, it becomes clear that the model performs much better in areas with a lower number of burglaries. This implies that the variables explain less variance in the city center and more in the peripheral areas.

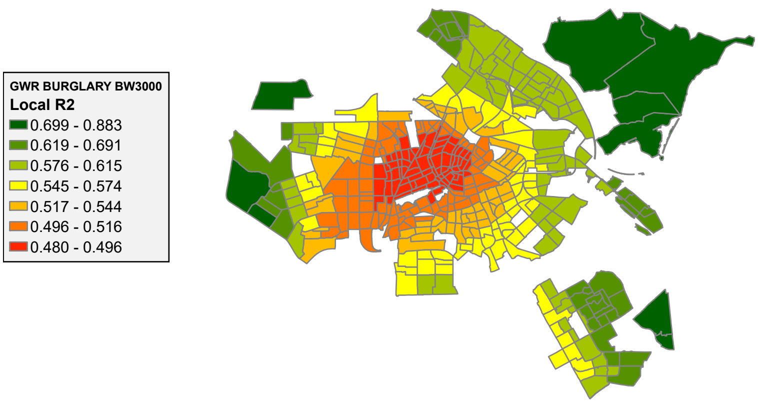


Figure 11: Local R-squared values GWR burglary

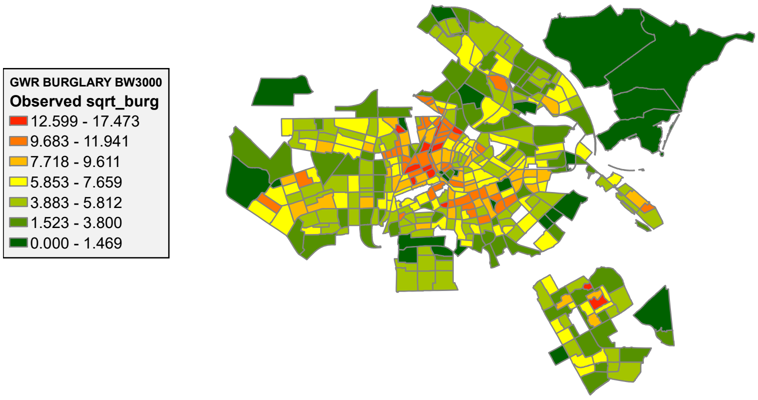
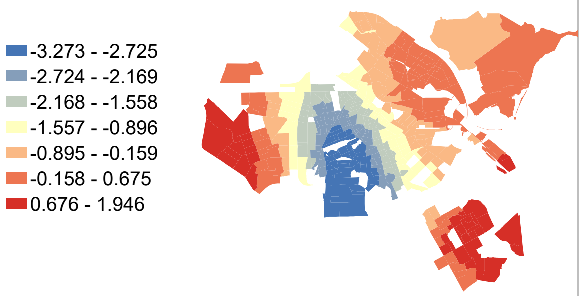


Figure 12: Observed values burglaries (square root of burglaries per square kilometer)

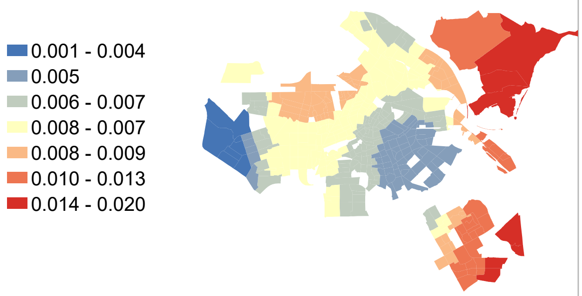
Table 13 shows maps representing the local coefficients for all included variables.

Table 13: Visualization of coefficients GWR burglary model

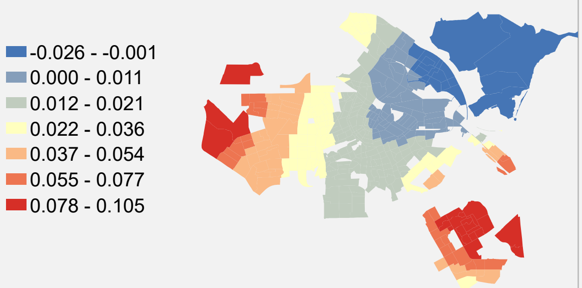
Intercept



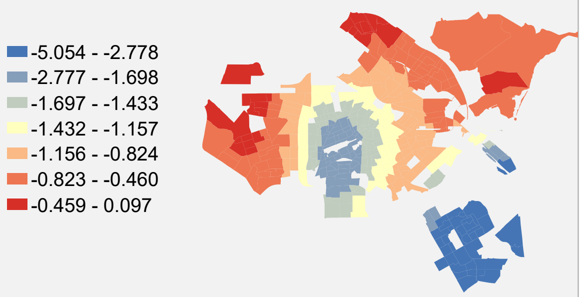
Intersection density



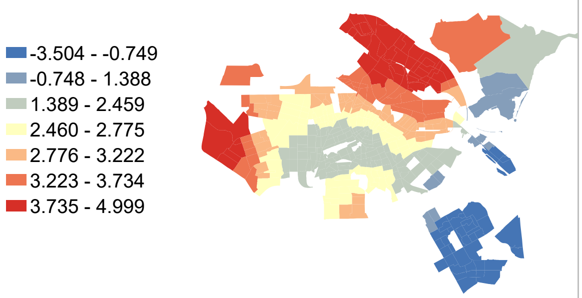
Art density



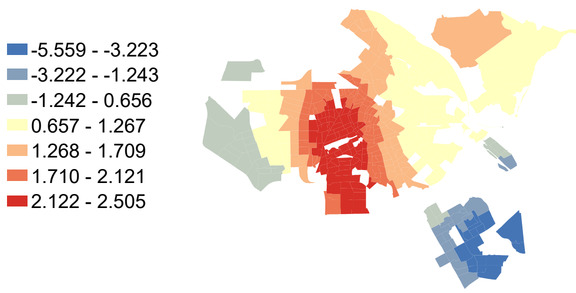
Ratio CCTV

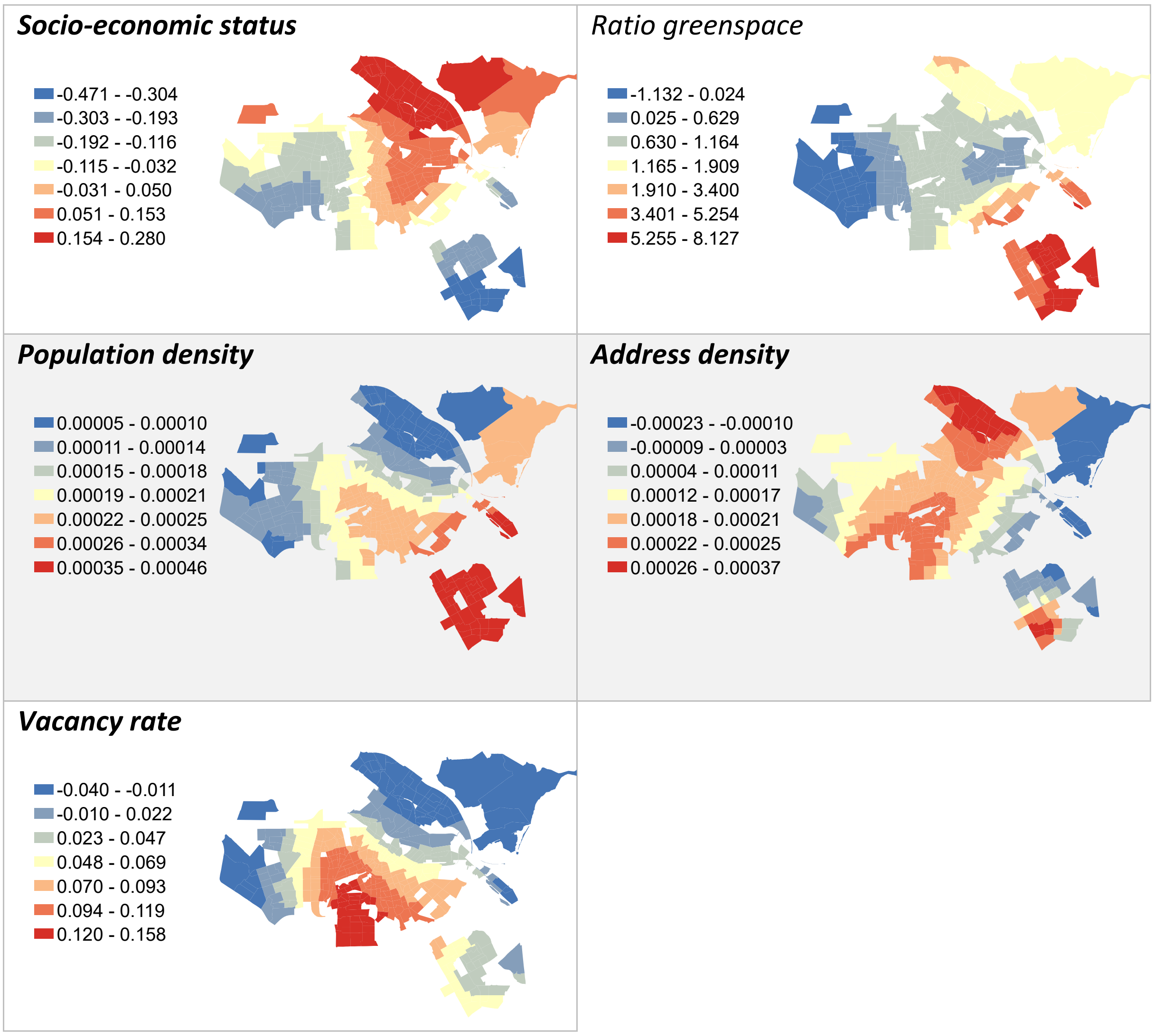


Percentage residential land-use



Mixed Land-use





The intercept seems to have the lowest coefficient in the south and in the city center, whereas it is the highest in the peripheral areas of the city. This could be due to missing variables. This could also explain the lower R-squared values in the city center, as less variance is explained by the model in this specific region.

Artworks appear to have the least influence around the city center and the most in the west and south-east. The ratio of CCTV coverage seems to be having the largest negative coefficient in the areas where it is most present, suggesting that CCTV is effective in reducing the number of burglaries. The areas where the coefficient for CCTV is the highest (close to zero) have, generally speaking, only have a little or even no CCTV coverage, hence the effect/contribution is also close to zero.

The percentage of residential land-use appears to have a somewhat random pattern, that to say, coefficients do not seem to be tied to certain areas. Mixed land-use, on the other hand, has a clearly higher coefficient in areas that also have a higher observed value for the number of burglaries. Where the OLS regression showed that mixed land-use correlates positively with burglary, the results of the GWR seem to even scoop these results up, although, negative coefficients can be observed for the south-east region of the city.

As the values for the socio-economic status range between approximately -6 to 6, and coefficients ranging from approximately -0,5 to 0,3 the GWR results are relatively difficult to interpret. Neighborhoods with a poor socio-economic status and also a negative coefficient for this variable would experience more burglaries as multiplying negative values will become positive. On the other hand, neighborhoods with a high socio-economic status and also a positive coefficient will also experience more burglaries. When comparing the map in which the socio-economic status is plotted (see section descriptive statistics) with the map of the coefficients, a similar pattern can be observed. This means that neighborhoods with a higher socio-economic status as well as neighborhood with a lower one experience more burglaries. The social disorganization theory can explain the neighborhoods with a lower socio-economic status, but it does not explain the ones with a higher one. A possible explanation is that the reward for a burglary is more likely to be higher in neighborhoods with a high socio-economic status.

A similar thing as the CCTV is happening with the greenspace. The city center where relatively little greenspace is present, has a low coefficient, whereas the south-east area of Amsterdam with more greenspace has a high coefficient.

Population density and the address density are considered to be two variables that are related to each other; however, the VIF values in the OLS regression remained low. The maps of the coefficients show that there are regions in which both have the highest coefficients, namely in the city center and the most southern part. The vacancy rate seems to have the highest coefficients in the area that has the most vacancy besides the city center.

5.2 Vandalism

In Table 14, the results of the exploratory regression for the crime type vandalism are displayed. Interesting is that all signs herein are positive.

Table 14: Variables and their sign that are included in the best specified OLS regression model for the crime type vandalism

	ADDRESS DENSITY	POPULATION DENSITY	STREETLIGHT DENSITY	ART DENISTY	RATIO CCTV	ETHNIC HETEROGENEITY	PERCENTAGE RESIDENTIAL LAND-USE	PERCENTAGE RETAIL AND CATERING LAND-USE	TPURIST ATTRACTION DENSITY	R2-ADJUSTED	AICC	F-STATISTIC	STD. ERROR OF THE ESTIMATE
VANDALISM	+	+	+	+	+	+	+	+	+	0.56	1865.54	58.704	2.411

In Table 15 the results of the OLS regression analysis are displayed. Here many variables appear to be significantly correlated. Moreover, there are no signs of multicollinearity as all VIF values remain below 3 whereas a common threshold is 7.5.

Table 15: Regression coefficients vandalism

	Coefficients	*Std. Error*	*Standardized coefficients*	*t*	*Sig.*	*VIF*
(Constant)	-.560	.747		-.749	.454	
Art density	.027	.012	.073	2.148	.032*	1.075
Ratio CCTV	2.004	.627	.135	3.195	.002*	1.656
Ethnic heterogeneity	4.201	1.184	.133	3.548	.000*	1.286
Percentage residential land-use	1.131	.609	.091	1.856	.064	2.238
Percentage retail and catering land-use	7.417	1.260	.317	5.887	.000*	2.665
Tourist attraction density	.019	.010	.083	1.898	.058	1.780
Streetlighting density	.00032	.00017	.086	1.848	.065	2.018
Population density	.00007	.00003	.163	2.946	.003*	2.829
Address density	.00024	.00006	.215	4.111	.000*	2.514

a. Dependent variable: sqrt_vand (square root of number of vandalism related crimes per square kilometer)

* variable significant at the $p < 0.05$ level

According to the literature, artworks should increase territorial behavior in the area and in turn reduce the number of crimes. However, the results from the OLS regression indicate the opposite: the number of artworks increases vandalism related crimes. A possible explanation could be that the artworks are seen as ''targets'' for vandalism. Besides, there is always a chance of correlation without any form of causation.

The ratio of area that is being covered by CCTV also conflicts with the literature. A possible explanation could be that CCTV is implemented in areas where more vandalism occurs. If this is the case, it will be difficult to determine the effectiveness of CCTV on reducing crime using regression analysis, as crime statistics dating from before the implementation of CCTV should be taken into account.

Ethnic heterogeneity having a positive sign confirms the literature and the social disorganization theory. It indicates that in neighborhoods consisting of different ethnicities experience less social cohesion and thus less informal control is present and that the residents neglect to act when they observe vandalism or they do not care.

The positive sign for tourist attraction density corresponds with literature. Bhati & Pearce (2016) stated that many tourist sites experience vandalism. Moreover, Merrill (2011) stated that cultural heritage monuments/areas are often vandalized with graffiti, which is a textbook example of vandalism.

It is no surprise that variables present most in the city center, like retail and catering land-use, are correlated with vandalism, as vandalism occurs most in the city center. It could also explain the positive sign for artworks, as they could be considered tourist attractions.

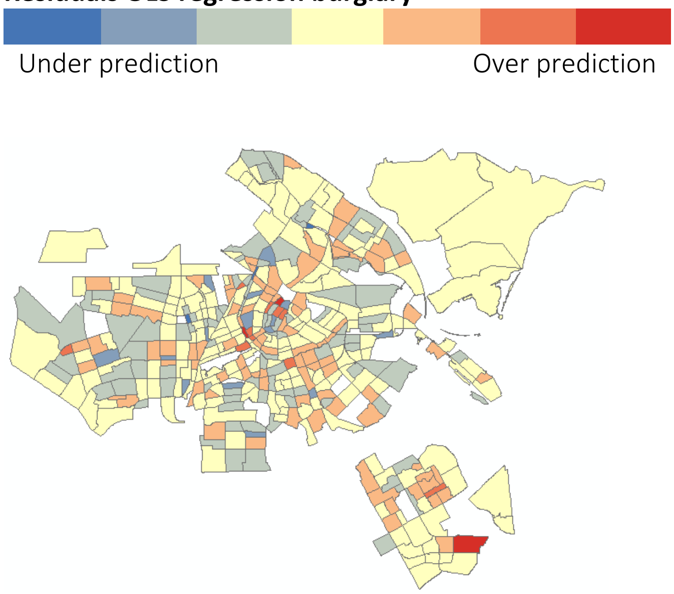
The positive coefficient for streetlighting is contrary to the literature. However, the areas where the streetlighting is most present are those areas that experience most vandalism. It is expected that the most streetlighting is located in the city center as the city center has the most pedestrians at night. Moreover, streetlighting installations could be seen as potential targets for vandalism, like artworks.

The positive sign for both address density and population density suggest that the level of urbanization has a positive effect on vandalism. This is in line with the literature. The area of residential land-use as well as that of retail and catering are both positively correlated with vandalism.

Again, the residuals were tested for spatial autocorrelation. In

Table 16 the results of the spatial autocorrelation test are summarized. In appendix 2 the full spatial autocorrelation report can be found. The p-value of approximately .39 indicates that the residuals are randomly distributed across the research area.

Table 16: Spatial autocorrelation (Moran's I) of the residuals of the OLS regression (vandalism)

Residuals OLS regression burglary	Fixed distance	3000
	Distance method	Euclidean
	Moran's Index	0.00221
	Z-score	0.855
	P-value	0.392

As the residuals appear to be distributed randomly across space, the GWR can be performed. In

Table 17 the results of the GWR are displayed, the dependent and independent variables used are the same as those in the OLS regression. Like the burglary model, a fixed bandwidth of 3 kilometer was used as explained in section 4.5.1.

Table 17: Coefficients GWR for the vandalism model

Coefficients

	OLS	***GWR***		
		Lowest	***Mean***	***Highest***
(Constant)	-.560	-2.752	0.415	2.519
Art density	.027	-0.067	0.026	0.085
Ratio CCTV	2.004	-0.057	2.691	4.086
Ethnic heterogeneity	4.201	-0.895	2.705	12.364

Percentage residential land-use	1.131	-1.811	1.100	3.442
Percentage retail and catering land-use	7.417	-6.147	6.770	15.601
Tourist attraction density	.019	-0.239	0.041	0.443
Streetlighting density	.00032	-0.00027	0.00019	0.00074
Population density	.00007	-0.000013	0.000083	0.000359
Address density	.00024	-0.00104	0.00025	0.00047

In Table 18, the GWR model performance is compared to the OLS regression model.

Table 18: Model performance of GWR for the crime type vandalism

	GWR		*Model improvement*
R^2-adj	0.666		0.106
AICc	757.00		1108.54
	Low	*Mean*	*High*
local R2	0.415	0.549	0.880

Looking at the improvement of the GWR, there is a significant improvement. The adjusted R-squared value increased with more than 0.10 points and the AICc dropped with more than 1100 points.

Besides the model improvement, one of the advantages of a GWR is that local R-squared values can be computed. This is valuable, as the model performance can be displayed on a map, and differences in performance can be observed. In Figure 13 the local R-squared values for the GWR model for vandalism are displayed and the observed values are displayed in Figure 14. It can be observed that the model performs worst in the area west of the city center, whereas it performs best east and north of city center. The local R-squared values for areas with many vandalism related crimes, seem to differ.

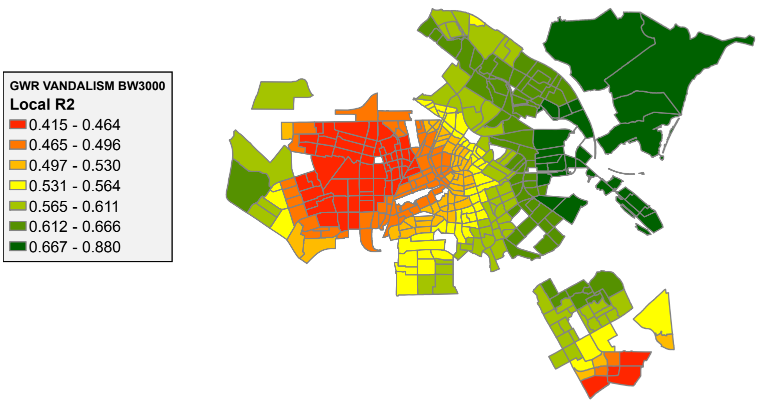


Figure 13: Local R-squared values GWR vandalism

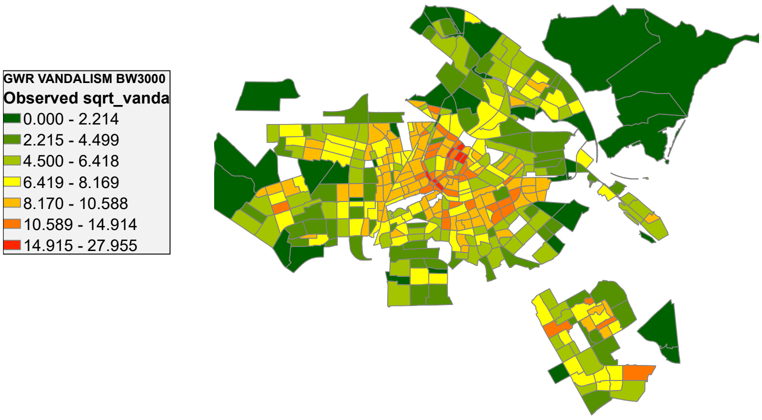
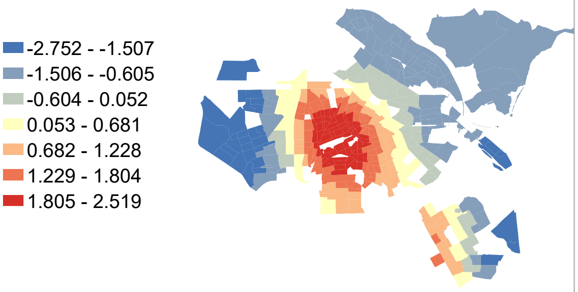


Figure 14: Observed values vandalism (square root of vandalism related crimes per square kilometer)

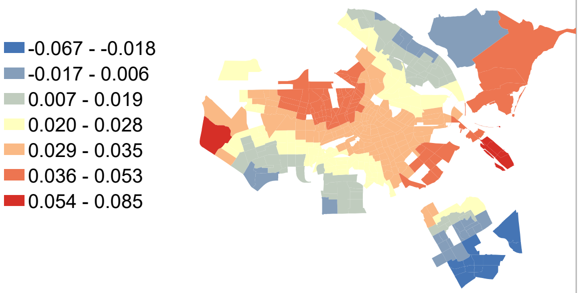
Table 19 shows maps representing the local coefficients.

Table 19: Visualization of coefficients GWR Vandalism

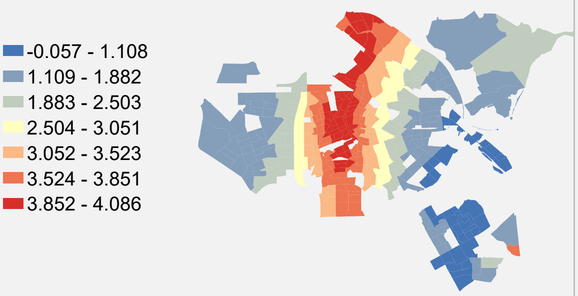
Intercept



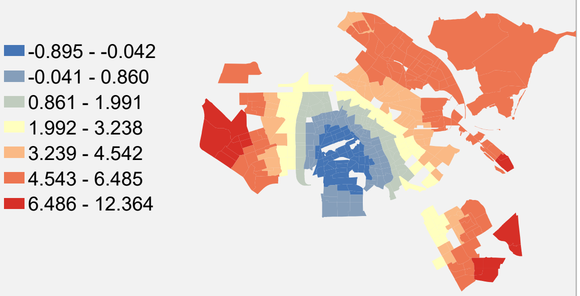
Art density



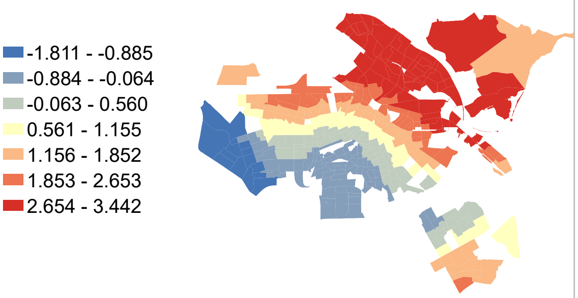
Ratio CCTV



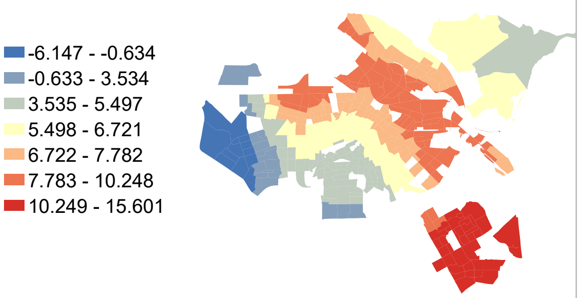
Ethnic Heterogeneity

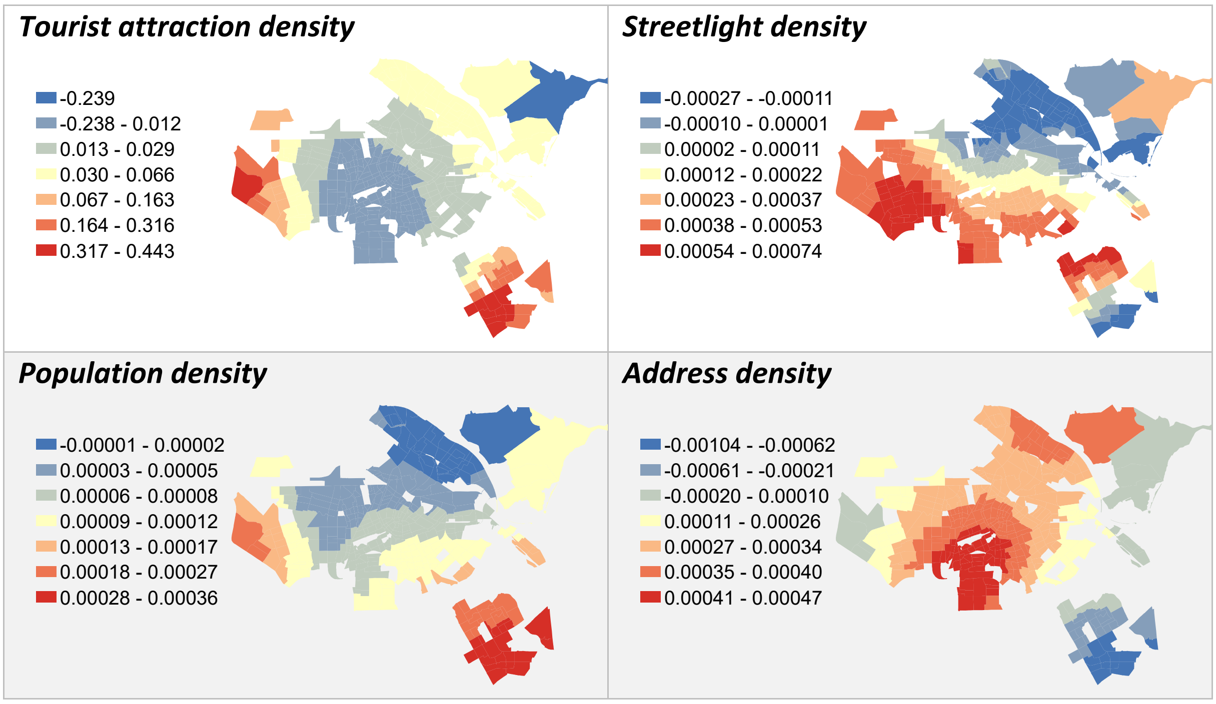


Percentage residential land-use



Percentage retail and catering land-use





The intercept seems to be the highest in the city center while the peripheral areas have lower coefficients. Arguably, the intercept might be compensating for variables which are not included, but which stimulate vandalism. The local R-squared values are also the lowest in the city center where vandalism occurs the most.

It is no surprise that the highest coefficients for artworks are located in the city center, as in the city center most artworks are present, in combination with a higher number of vandalism related crimes.

As far as the coefficients for CCTV are concerned, it is interesting to see that the coefficients are the highest in areas west of the city center. The city center still has a relatively high coefficient. Peripheral areas have a coefficient near zero.

Ethnic heterogeneity seems to be influencing the number of vandalism related crimes most in areas that also have the highest ethnic heterogeneity. So, the GWR basically enhances the effect of ethnic heterogeneity on vandalism compared to the OLS regression. This indicates that areas with a more homogeneous ethnic composition suppress the areas with a more heterogeneous ethnic composition in an OLS regression.

It is interesting to see that the coefficients of residential land-use follow the same pattern as those of retail and catering land-use, although the retail and catering land-use is more nuanced. The coefficients approach the mean, however still positive, near the city center where most vandalism occurs.

Unexpectedly, tourist attraction density has the lowest coefficients in the area where most tourist attractions are located. A possible explanation is that the tourist density is much higher in that area and that the model uses a lower coefficient in order to compensate this a little by giving the tourist intensive areas lower coefficients. In Figure 15, the contribution of the tourist attraction density to the dependent variables (coefficient * tourist density) is displayed. Figure 15 makes clear that the tourist attraction density has the highest contribution to vandalism in the city center, whereas it does barely contribute in areas outside of the city center.

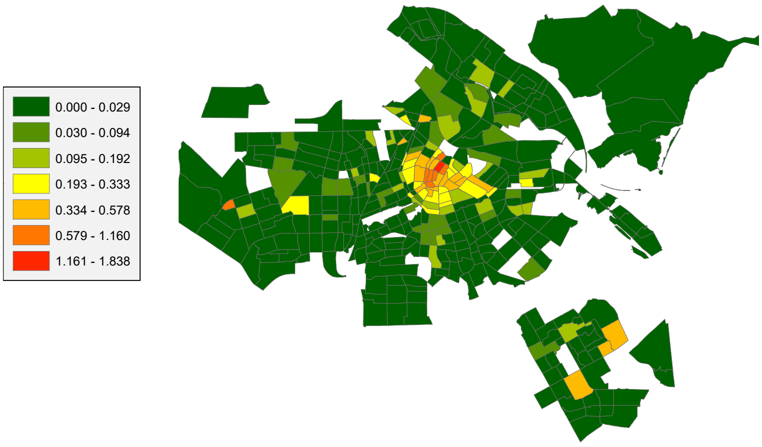


Figure 15: Contribution of tourist attraction density to the dependent variable

The highest coefficients regarding streetlighting appear to be located in areas with a relatively low amount of vandalism; the areas with most vandalism have medium to low coefficients. Some neighborhoods in the area of the city center even have negative coefficients. Which is interesting, as the OLS regression suggested that streetlighting is positively correlated with vandalism. The results of the GWR indicate that these results should be nuanced as there are areas with a high number of vandalism related crimes with a negative coefficient for streetlighting. Hence the use of a GWR provides more and better insights in the underlying mechanisms.

Like with the burglary model, where population density and address density both were included, they seem to be some sort of inverse of each other as the patterns on the maps show. It is expected that this is due to the fact that these variables are correlated. This correlation, however, is not problematic as the maximum VIF-value is 2.829.

5.3 Violent Crimes

The results of the exploratory regression for violent crimes are summarized in Table 20. It can be observed that many variables are in line with the literature.

Table 20: Variables and their sign that are included in the best specified OLS regression model of violent crimes

	ADDRESS DENSITY	POPULATION DENSITY	VACANCY RATE	STREETLIGHT DENSITY	PARKING DENSITY	RATIO CCTV	ETHNIC HETEROGENEITY	SOCIO-ECONOMIC STATUS	PERCENTAGE RETAIL AND CATERING LAND-USE	MIXED LAND-USE	R2-ADJUSTED	AICC	F-STATISTIC	STD. ERROR OF THE ESTIMATE
VIOLENT CRIMES	+	+	+	+	+	+	+	-	+	-	0.71	2044.70	98.800	3.007

The results of the ordinary least squares regression are displayed in Table 21. Again, high significance levels can be observed (all variables except the intercept are significant at a p < 0,05 level), due to the before executed exploratory regression analysis. No multicollinearity issues arise as the VIF values remain low as the highest value is 3.088. Moreover, a relatively high adjusted R-squared is achieved with this model.

Table 21: Regression coefficients violent crimes

	Coefficients	*Std. Error*	*Standardized coefficients*	*t*	*Sig.*	*VIF*
(Constant)	-.369	1.134		-.326	.745	
Parking density	.00027	.00012	-.079	-2.155	.032*	1.863
Ratio CCTV	2.792	.787	.124	3.547	.000*	1.677
Ethnic heterogeneity	7.585	1.713	.157	4.429	.000*	1.730
Percentage retail and catering land-use	18.418	1.414	.515	13.027	.000*	2.157
Mixed land-use	-2.690	.886	-.099	-3.037	.003*	1.475
Socio-economic status	-.256	.091	-.108	-2.821	.005*	2.034
Streetlighting density	.00042	.00020	.074	2.079	.038*	1.730
Population density	.00011	.00003	.156	3.291	.001*	3.088
Address density	.00038	.00008	.219	4.846	.000*	2.831
Vacancy rate	.068	.026	.087	2.562	.011*	1.574

a. Dependent variable: sqrt_VC (square root of number of violent crimes per square kilometer)
** variable significant at the p < 0.05 level*

The positive coefficient for parking places is confirming to the CPTED principle of access control. As limited parking places should improve the access control and thus less crime. The results suggest that the fewer parking places are present in the area, the fewer violent crimes occur.

Like in the case of vandalism, it is believed that the ratio of CCTV coverage is positively correlated, as CCTV cameras might have been placed because of the crime that occurred in that area. As Cerezo (2013) found that CCTV reduced crime after its implementation, it could be that in previous years, before the implementation of CCTV cameras, crime rates were higher in the specific areas. Hence, more research is needed on this matter.

Ethnic heterogeneity and the socio-economic status are perfectly in line with the literature and confirm the social disorganization theory, as ethnic heterogeneity increases the number of violent crimes and a higher socio-economic status decreases the number of violent crimes in the neighborhood.

It is believed that the percentage of retail and catering land-use is significant due to the presence of bars, liquor stores and coffeeshops (which are tolerated in Amsterdam). As Han & Gorman (2013) showed that violent crimes occur more near liquor stores. Moreover, Trimbos-instituut (2020) states that 26 to 43 percent of the violent incidents in the Netherlands can be linked to alcohol consumption. Hence, it makes sense that the percentage of retail and catering land-use is highly correlated with the violent crimes. This is also reflected in the standardized coefficient, which is higher than .500.

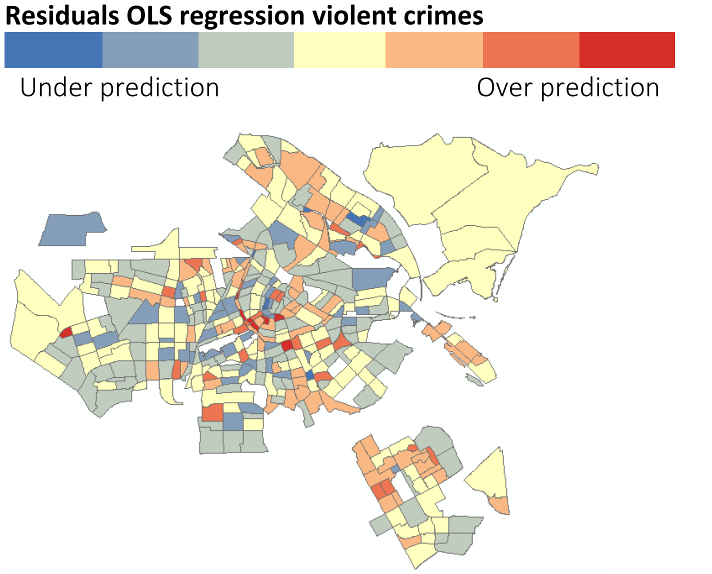
Mixed land-use is negatively correlated with violent crimes, which is supported by the literature. It is believed that this is due to increased pedestrian activity in the neighborhood. This high pedestrian activity is expected to lead to more informal surveillance.

Streetlighting has a positive sign, which is contrary to the literature. It is believed that this is due to the increased number of streetlighting in the city center and that the correlation between streetlighting and violent crimes do not represent a casual relation in this case. It is believed to be more likely that this correlation is based on the geographical position of the streetlighting.

A higher population density and the address density indicate that there are generally speaking more people in the area, meaning more potential offenders and targets for criminal behavior and thus also violent crimes. These variables also partly act as a control variable, since the crime numbers are standardized to area. Therefore, it is no surprise that these variables are positively correlated with violent crimes. The percentage of vacant dwellings is significantly correlated with violent crimes, which is in line with the findings of Cui & Walsh (2015). It is also in line with the broken window theory and the image principle of CPTED, as vacancy is often seen as the key variable of these principles/theories. Hence, it makes sense that the vacancy rate is positively correlated with violent crimes.

The residuals of the OLS regression were subject to test whether they were spatially autocorrelated. The results of this test are displayed in Table 22. The whole report regarding this test can be found in appendix 3. The results indicate that the residuals of the OLS regression are distributed randomly across the research area.

Table 22: Spatial autocorrelation (Moran's I) of the residuals of the OLS regression (violent crimes)



Fixed distance	3000
Distance method	Euclidean
Moran's Index	0.000396
Z-score	0.520
P-value	0.603

As the residuals were randomly distributed across the research area, the GWR is performed using the same variables as the OLS regression analysis. The results are displayed in Table 23 showing the coefficients and Table 24 showing the model performance. Moreover, a comparison is made with the OLS variables.

Table 23: Coefficients GWR for violent crimes model

	Coefficients			
	OLS	***GWR***		
		Lowest	***Mean***	***Highest***
(Constant)	-.369	-3.692	0.412	5.238
Parking density	.00027	-0.000801	-0.000268	0.00156
Ratio CCTV	2.792	-0.426	3.838	6.649
Ethnic heterogeneity	7.585	1.182	7.139	11.527
Percentage retail and catering land-use	18.418	-0.395	17.054	23.084
Mixed land-use	-2.690	-6.928	-3.196	2.428
Socio-economic status	-.256	-0.565	-0.233	0.188
Streetlighting density	.00042	-0.00126	0.00018	0.00159
Population density	.00011	-0.00019	0.00011	0.00049
Address density	.00038	-0.00060	0.00041	0.00083
Vacancy rate	.068	-0.014	0.081	0.160

Table 24: Model performance of GWR for violent crimes

	GWR		*Model improvement*
R^2-adj	0.803		0.094
AICc	412.99		1631.70
	Low	***Mean***	***High***
local R2	0.617	0.728	0.909

Again, as expected, the model improved by using a GWR, meaning that violent crimes, are indeed non-stationary. The GWR model improved the adjusted R-squared with 0.094 whereas the AICc value dropped by more than 1600. Looking at the local R-squared values, there are areas in Amsterdam in which 90 percent of the variance can be explained by the GWR model. Figure 16 shows the local R-squared values and in Figure 17 the observed values are displayed.

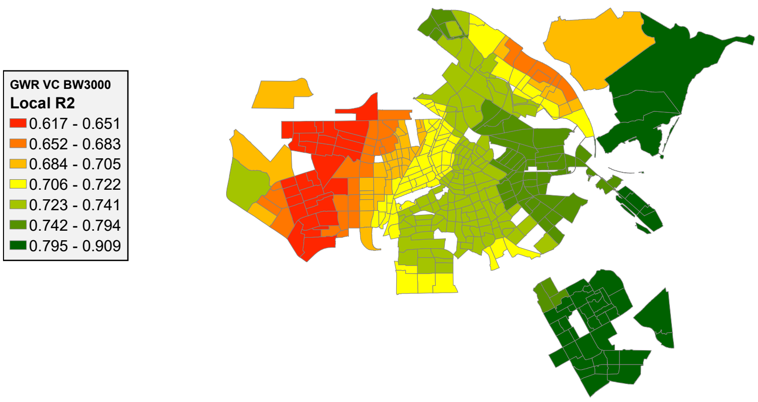


Figure 16: Local R-squared values GWR violent crimes

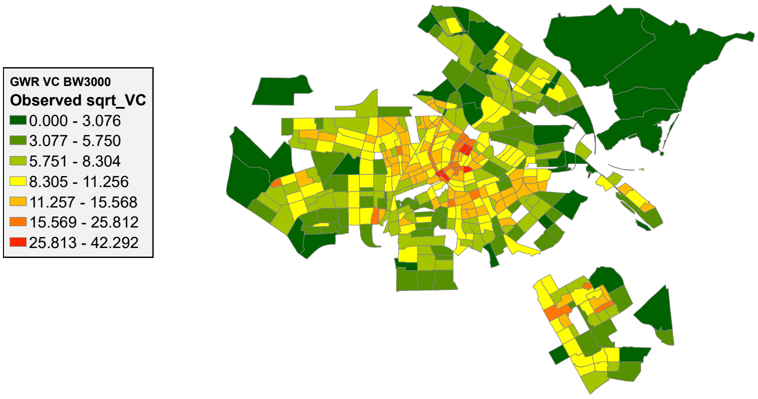


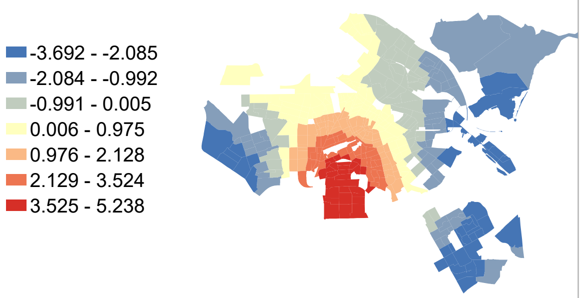
Figure 17 Observed values violent crimes (square root of violent crimes per square kilometer)

Looking at the local R-squared values, a clear division between east and west can be observed: in the east high values are present whereas in the west the lowest values are present. The city center where most violent crimes occur, has a R-squared value that is slightly higher than the mean. This clear division between east and west could possibly indicate that additional variables are of importance in the west for violent crimes as there is quite some difference in the amount of variance that is being explained in these regions. In

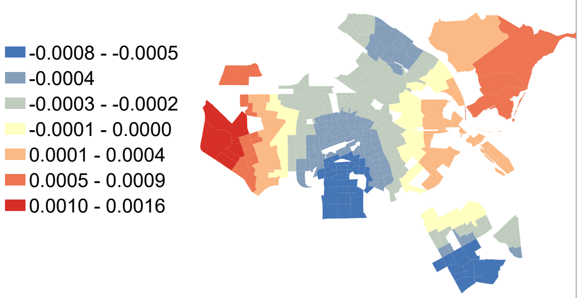
Table 25, maps representing the local coefficients are displayed.

Table 25: Visualization of coefficients GWR violent crimes

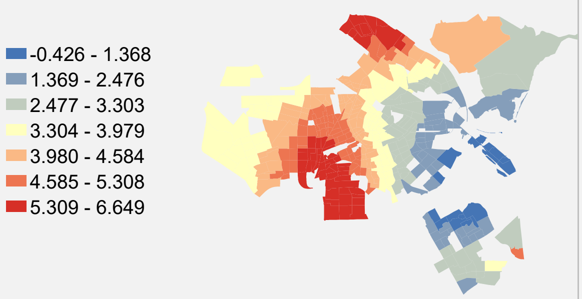
Intercept



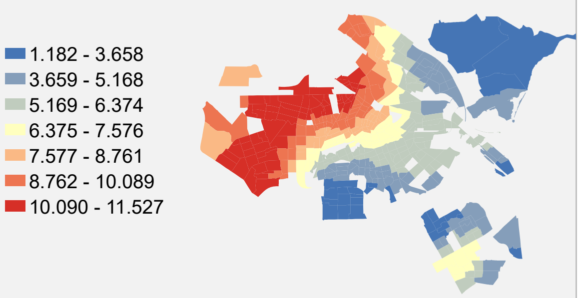
Parking density

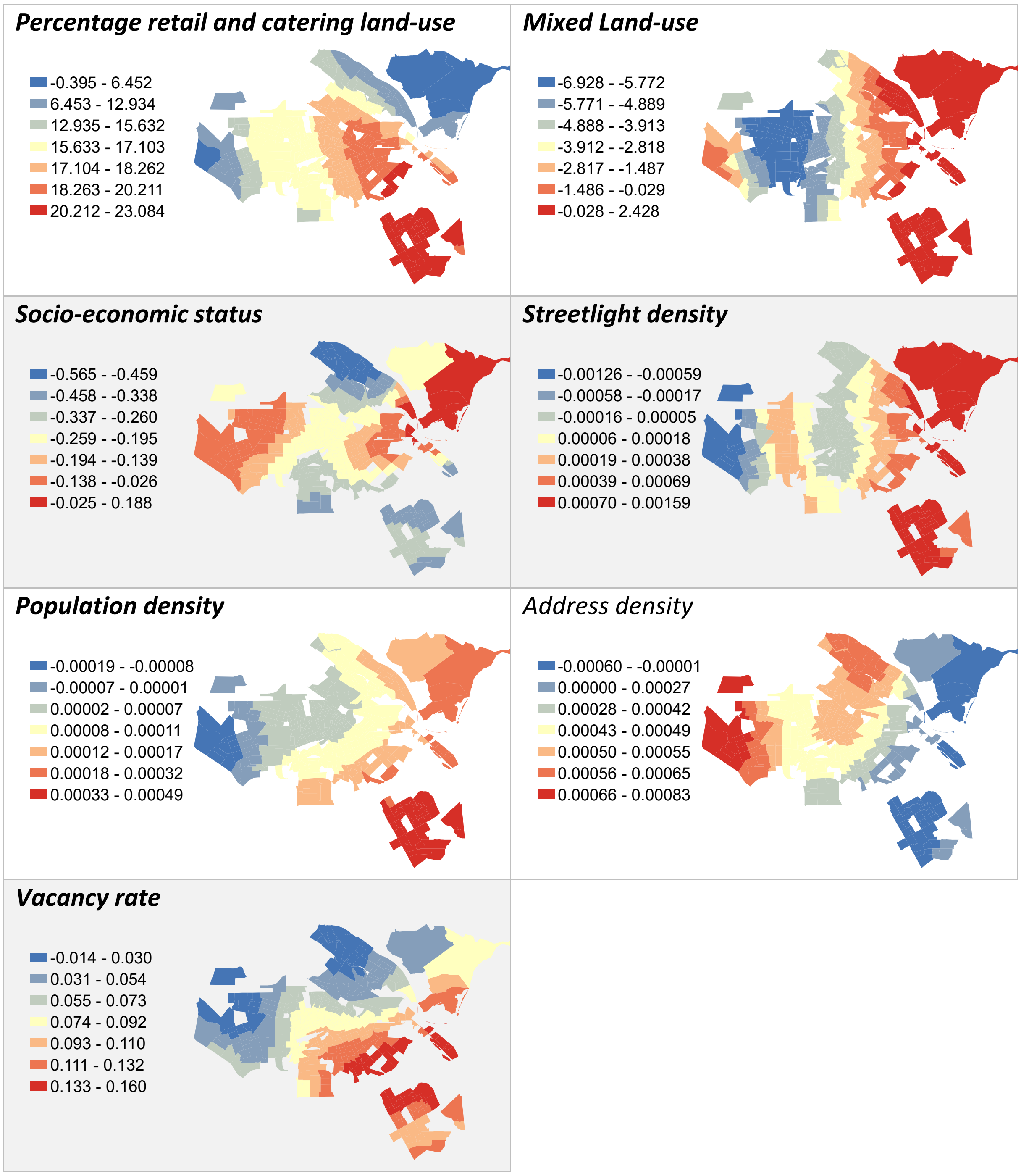


Ratio CCTV



Ethnic heterogeneity





The intercept appears to have the highest coefficient in the southern part of the city, besides the south-east region. The city center still has a relatively high coefficient whereas the rest of the city has a coefficient of zero or a negative value.

As far as violent crimes are concerned, parking places seem to be less influential in the city center. This implies that the number of parking places is of less importance in areas where most violent crimes occur, as suggested by the OLS regression. This makes sense, as the city center offers less parking places than the rest of the city. Moreover, it can be observed that in the areas that experience the least of these crimes, the influence of parking places is of more importance in explaining the number of crimes. In some neighborhoods, the number of parking places even has a positive sign. This implies that the results of the OLS should be nuanced.

The coefficient for the CCTV coverage seems to be highest in the areas where there is no to little coverage. On the other hand, the mean of the coefficients of the ratio CCTV is much higher than the coefficient of the OLS regression and considering that the grey areas have approximately the same coefficients as the OLS regression. In general, the ratio CCTV coverage has thus more influence in the GWR than in the OLS regression.

Ethnic heterogeneity seems to be influencing violent crimes the most in the west, where a high level of ethnic heterogeneity can be observed. It is interesting to note that the south-east region which also has a high level of ethnic heterogeneity has a relatively low coefficient.

The percentage of retail and catering land-use is the highest in the south-east region and the city center. The fact that the city center has a relatively high coefficient seems logical, as the city center experiences the most violent crimes and the other variables seem to have less influence in the city center. Moreover, more retail and catering facilities can be found in the city center.

The mixed land-use variable seems to have a slightly positive coefficient, although close to zero, in the east of Amsterdam whereas the other areas have a negative sign. The coefficient is smallest in the neighborhoods west of the city center.

The socio-economic status for violent crimes is easier to interpret than for the burglary model. The coefficients for the violent crimes model are, generally speaking, all negative, except a handful of neighborhoods. Neighborhoods with a socio-economic status that is above average will experience less violent crimes as the coefficient is negative and the value for the variable is above zero. The maps of the socio-economic status and ethnic heterogeneity show that they are each other's "inverse", as the maps show a similar pattern.

Looking at the streetlighting, it is interesting that the city center, with most violent crimes, has coefficients near zero, which means that the streetlighting density does not have a big influence on violent crimes in that specific area. Only in the west, there is a clear negative coefficient, whereas the rest of the research area has a positive one.

Again, like burglary and vandalism, the population density and address density seem to be compensating each other. This makes sense as both variables are related to each other. Finally, the vacancy rate seems to be most influential in the south-east part of Amsterdam, whereas the western and northern parts seem to be less influenced by vacancy. The coefficient for the city center is near the mean and the coefficients obtained from the OLS regression analysis.

5.4 Drugs and Nuisance

In Table 26 the results of the exploratory regression analysis for drugs and nuisance related crimes are summarized.

Table 26: Variables and their sign that are included in the best specified OLS regression model for drugs and nuisance related crimes

	INTERSECTION DENSITY	*POPULATION DENSITY*	*PERCENTAGE RENTED HOMES*	*VACANCY RATE*	*STREETLIGHT DENISTY*	*PARKING DENSITY*	*RATIO CCTV*	*PERCENTAGE RETAIL AND CATERING LAND-USE*	*TOURIST ATTRACTION DENISTY*	*R2-ADJUSTED*	*AICC*	*F-STATISTIC*	*STD. ERROR OF THE ESTIMATE*
DRUGS AND NUISANCE	+	+	+	+	+	-	+	+	+	0.72	2120.61	118.059	3.309

The results of the OLS regression analysis are displayed in Table 27. The relatively high R-squared value stands out, as well as low VIF values. Significance levels are in comparison to the other models a bit worse. Nonetheless, most of them are still significant at the $p < 0.10$ level.

Table 27: Regression coefficients drugs and nuisance related crimes

	Coefficients	*Std. Error*	*Standardized coefficients*	*t*	*Sig.*	*VIF*
(Constant)	-.356	.724		-.492	.623	
Intersection density	-.0042	.003	.053	1.495	.136	1.837
Parking density	-.00043	.000	-.114	-3.268	.001*	1.758
Ratio CCTV	3.875	.839	.152	4.617	.000*	1.575
Percentage retail and catering land-use	18.443	1.561	.456	11.813	.000*	2.173
Tourist attraction density	.099	.015	.249	6.809	.000*	1.944
Streetlighting density	.00043	.000	.068	1.800	.073	2.088
Population density	.00005	.000	.061	1.805	.072	1.650
Percentage rented homes	.016	.008	.054	1.955	.051	1.091
Vacancy rate	.047	.028	.053	1.705	.089	1.421

a. Dependent variable: sqrt_DN (square root of number of drugs and nuisance related crimes per square kilometer)

* variable significant at the $p < 0.05$ level

Although, not significant at the $p < 0.10$ level, the intersection density is interesting, as it still improves the likelihood of a correct prediction, otherwise it would not have been included in the model by the exploratory regression analysis. It is interesting, as it partly (not significant) confirms Hillier's (2004) statement that drug related crimes occur more near intersections.

Parking places having a negative coefficient is contrary to the literature, as the literature suggests that car parks act as a crime attractor (Newton, 2018). Moreover, a high number of parking places is argued to be weakening the access control principle from CPTED. Arguably, the cause for the negative sign is that most of the drugs and nuisance related crimes occur near/in the city center, where also the least parking places are located. It would be interesting to see whether the sign of the coefficient is also negative throughout the entire research area when using a GWR.

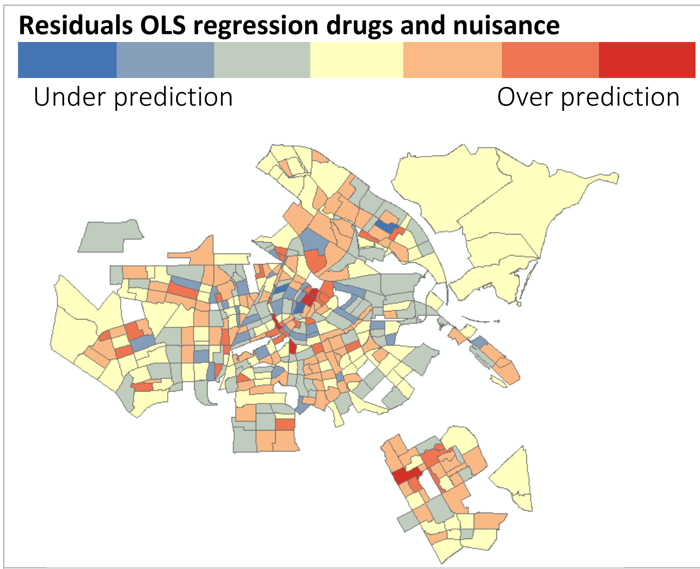
The coefficient of the ratio CCTV is again positive. It is expected that this has the same cause as with vandalism and violent crimes. The percentage of retail and catering land-use of the neighborhood is positively correlated with drugs and nuisance related crimes. Arguably, it could be that nuisance related crimes are partly committed by people that are under the influence of alcohol and/or other substances.

Streetlighting is positively correlated with drugs and nuisance related crimes. As beforementioned, the expectation is that this is due to the high number of streetlight installations in the city center. Population density is in line with the literature. The vacancy rate having a positive sign corresponds with the image principle of CPTED and the broken windows theory. Moreover, positive coefficient for the percentage of rented homes is in line with the social disorganization theory.

The residuals of the OLS regression analysis, just like the other crime types, were tested for spatial autocorrelation to make sure that the residuals were spread randomly across the research area. The results are summarized in

Table 28. The full report of this test can be found in appendix 4.

Table 28: Spatial autocorrelation (Moran's I) of the residuals of the OLS regression (drugs and nuisance)



Fixed distance	3000
Distance method	Euclidean
Moran's Index	0.00199
Z-score	0.811
P-value	0.417

In Table 29 the results of the GWR for drugs and nuisance related crimes are summarized. Table 30 shows the model performance in comparison to the OLS regression model.

Table 29: Coefficients GWR for the drugs and nuisance related crimes model

Coefficients				
	OLS	*GWR*		
		Lowest	*Mean*	*Highest*
(Constant)	-.356	-1.653	0.029	2.393
Intersection density	.0042	-0.009	0.004	0.012
Parking density	.00043	-0.00077	-0.00047	0.00031
Ratio CCTV	3.875	0.944	5.138	18.458
Percentage retail and catering land-use	18.443	0.705	18.331	31.537
Tourist attraction density	.099	-0.063	0.095	0.267
Streetlighting density	.00043	-0.00036	0.0002	0.00122
Population density	.00005	-0.000019	0.000065	0.00029
Percentage rented homes	.016	-0.015	0.015	0.049
Vacancy rate	.047	-0.023	0.068	0.118

Table 30: Model performance of GWR for drugs and nuisance related crimes

	GWR		*Model improvement*
R^2-adj	0.732		0.00839
AICc	2137.37		-16.762
	Low	***Mean***	***High***
local R2	0.453	0.721	0.840

The adjusted R-squared value increased with less than 0.01 whereas the AICc even increased when using a GWR. Taking this into consideration, it could be argued that drugs and nuisance related crimes are stationary.

Table 18 and Figure 19 respectively display the local R-squared values and the observed values. It can easily be observed that most variance is explained in areas where most drugs and nuisance related crimes occur.

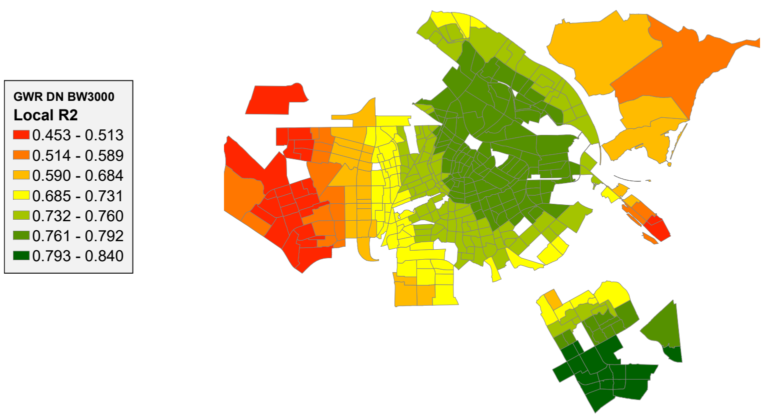


Figure 18: Local R-squared values GWR drugs and nuisance related crimes

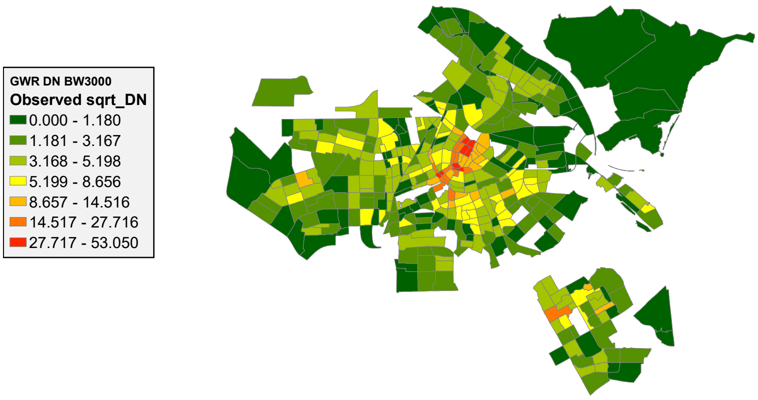
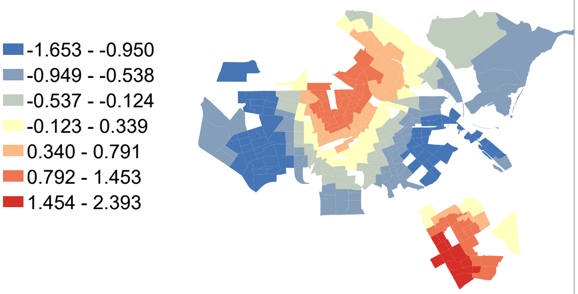


Figure 19: Observed values drugs and nuisance related crimes (square root of drugs and nuisance related crimes per square kilometer)

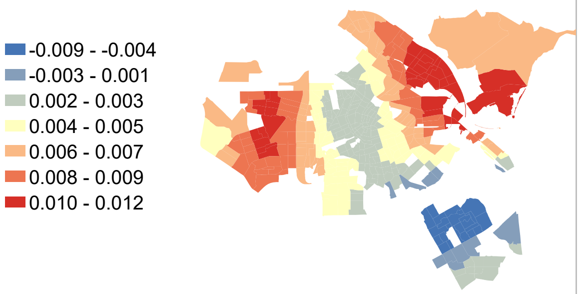
In Table 31 the coefficients of the independent variables are visualized.

Table 31: Visualization of coefficients GWR drugs and nuisance related crimes

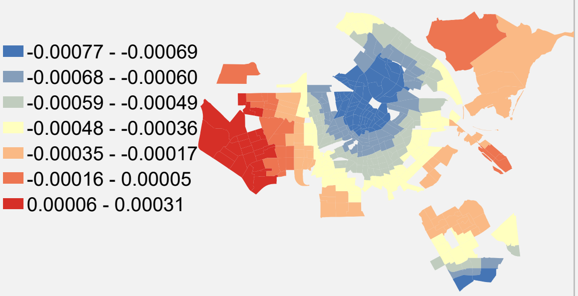
Intercept



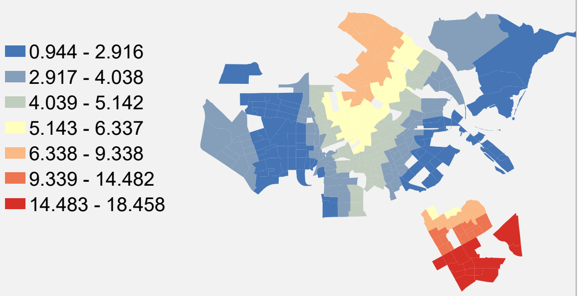
Intersection density



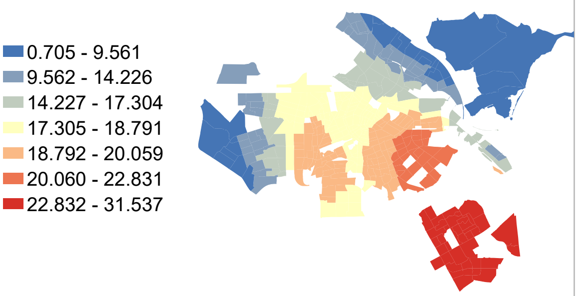
Parking density



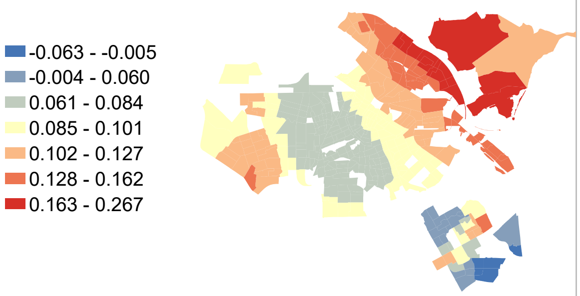
Ratio CCTV

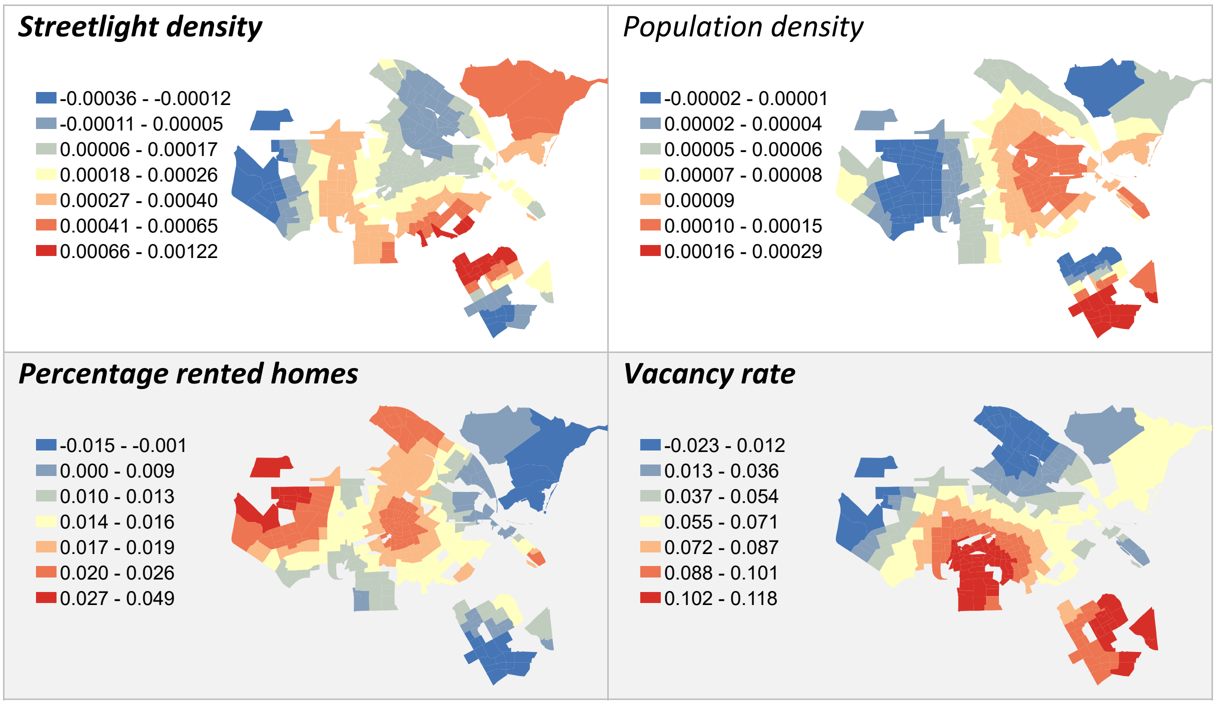


Percentage retail and catering land-use



Tourist attraction density





The intercept has the highest coefficient in the south-eastern part of the city. The coefficient of the intercept for the city center, where most drugs and nuisance related crimes occur is close to zero. Hence, it could be argued that the variables in the model predict these types of crime well.

The intersection density seems to be most influential in the west and north east part of the city. The coefficients are just above zero in the city center, which implies that the number of intersections only appear to be influencing drugs and nuisance related crimes relatively little. Outside the city center, where relatively little drugs and nuisance related crimes occur, the coefficient increases. It is remarkable that the coefficient for the parking density is negative in the areas where drugs and nuisance related crimes occur most. A similar pattern as with the violent crimes model can be observed.

CCTV has the highest coefficients in the south-east part of the city, whereas the city center and the areas that are covered by CCTV have coefficients near the mean or lower. This is a consistent pattern that also occurs for the other crime types.

Retail and catering land-use has the highest coefficient in the south-eastern part of the city, whereas the city center has a coefficient close to the mean. The tourist attraction density has, generally speaking, higher coefficients in the area where retail and catering facilities have a lower coefficient and vice versa.

Streetlighting, surprisingly, has a lower coefficient in the city center, where most drugs and nuisance related crimes occur. This implies that the effect of streetlighting that was suggested by the OLS regression should be nuanced a little.

Population density has the highest coefficient in the most south-eastern area whereas the city center also has a relatively high coefficient. In the west the coefficient is lower. The percentage rented homes has the highest coefficient in the west and the city center. The vacancy rate is most influential in the south and south east for drugs and nuisance related crimes. The city center does not have a distinctive coefficient for the vacancy rate.

5.5 Theft

In Table 32 the results of the exploratory regression analysis for theft are summarized. It is surprising that population density is negatively correlated.

Table 32: Variables and their sign that are included in the best specified OLS regression model of the crime type theft

	ADDRESS DENSITY	POPULATION DENSITY	PERCENTAGE RENTED HOMES	VACANCY RATE	STREETLIGHT DENSITY	RATIO CCTV	SOCIO-ECONOMIC STATUS	PERCENTAGE RETAIL AND CATERING LAND-USE	MIXED LAND-USE	TOURIST ATTRACTION DENSITY	R2-ADJUSTED	AICC	F-STATISTIC	STD. ERROR OF THE ESTIMATE
THEFT	+	-	+	+	+	+	+	+	-	+	0.81	2302.83	169.531	4.1226

First, the model summary shows a high adjusted R-squared value. Second, there are no signs of multicollinearity, as the VIF values remain low. Moreover, all variables including the constant are significant at the $p < 0.05$ level.

Table 33: Regression coefficients theft

	Coefficients	*Std. Error*	*Standardized coefficients*	*t*	*Sig.*	*VIF*
(Constant)	2.527	1.192		2.120	.035*	
Ratio CCTV	3.230	1.077	.084	3.000	.003*	1.653
Percentage retail and catering land-use	26.662	2.016	.440	13.227	.000*	2.310
Mixed land-use	-3.250	1.144	-.071	-2.841	.005*	1.298
Tourist attraction density	.146	.018	.245	8.144	.000*	1.882
Socio-economic status	.397	.123	.099	3.230	.001*	1.972
Streetlighting density	.0015	.00027	.158	5.618	.000*	1.651
Population density	.00012	.00004	-.100	-2.712	.007*	2.817
Address density	.00048	.00011	.165	4.352	.000*	3.002
Percentage rented homes	.032	.012	.072	2.770	.006*	1.398
Vacancy rate	.104	.037	.079	2.794	.005*	1.657

a. Dependent variable: sqrt_Theft (square root of number of Theft crimes per square kilometer)
* variable significant at the $p < 0.05$ level

These results are as expected, as pickpocketing is a major problem in the city center of Amsterdam. Pickpocketing occurs most in crowded areas, hence it is no surprise that variables regarding tourism and retail and catering land-use correlate most with theft, as touristic attractions, shops, bars and restaurant generate crowds in the city center. CCTV is expected to be correlated with theft due to its coverage of the city center, where most thefts occur.

A higher socio-economic status of the neighborhood seems to be increasing the number of thefts in the area. Two possible explanations can be identified, neighborhoods with a high socio economic status are located most in the city center where also the pickpocketing occurs most, a non-causal relationship. On the other hand, it can be reasoned that theft is a financially driven crime, and thus a neighborhood with a high socio-economic status offers more opportunities and a higher reward for theft.

The negative sign for mixed land-use is interesting as it is consistent with findings from the literature. On the other hand, knowing that most of the theft related crimes require crowds (pickpocketing) and that mixed land-use, generally speaking, increases pedestrian activity in the area, is contradictory. Arguably, the significance and the sign of the mixed land-use variable comes from other forms of theft than pickpocketing.

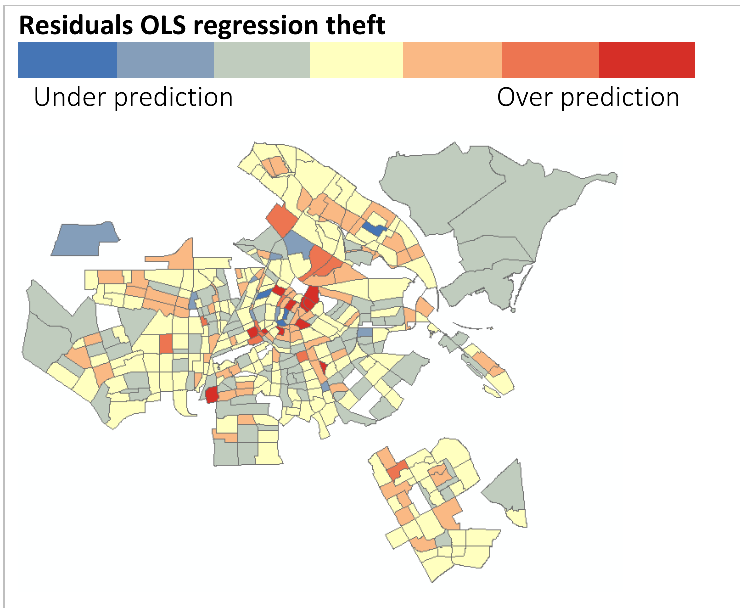
Streetlighting show a positive sign, which is contrary to the literature, as it should be increasing the number of pedestrians and thus increase the natural surveillance. However, as mentioned before that pickpocketing is the form of theft that occurs most, it makes sense as pickpocketing thrives best in crowds.

A remarkable result is the address density with a positive sign and population density with a negative sign, as both variables are related. As both variables are related. Arguably, this difference is due to the fact that theft occurs most in the city center, where most addresses are being used for corporate purposes rather than residential ones. As can be observed in Table 7 in section 3.3, the population density is relatively low in the city center.

The percentage of rented homes is in line with the social disorganization theory, whereas the number of vacant homes is in line with the broken windows theory and image principle of CPTED. Hence it was no surprise that these variables were included and positively correlated with theft.

The residuals from the OLS were tested for spatial autocorrelation. The results are summarized in Table 34. The full report can be found in appendix 5.

Table 34: Spatial autocorrelation (Moran's I) of the residuals of the OLS regression (theft)



Fixed distance	3000
Distance method	Euclidean
Moran's Index	0.000238
Z-score	0.491
P-value	0.623

As the residuals were randomly distributed across the research area, the same variables as the OLS regression were used for the GWR. Table 35 shows the coefficients of the GWR and Table 36 shows the model performance in comparison to the OLS regression model.

Table 35: Coefficients GWR for the theft model

Coefficients				
	OLS	***GWR***		
		Lowest	***Mean***	***Highest***
(Constant)	2.527	-4.269	3.677	7.783
Ratio CCTV	3.230	-1.852	4.662	17.415
Percentage retail and catering land-use	26.662	3.221	23.616	30.033
Mixed land-use	-3.250	-7.051	-3.018	3.251
Tourist attraction density	.146	-0.302	0.126	0.278
Socio-economic status	.397	-0.194	0.327	0.762
Streetlighting density	.0015	0.000	0.001	0.003
Population density	.00012	-0.00017	-0.000096	0.00019
Address density	.00048	0.00022	0.00048	0.00120
Percentage rented homes	.032	-0.023	0.018	0.073
Vacancy rate	.104	-0.044	0.147	0.319

Table 36: Model performance of GWR for the crime type theft

	GWR		*Model improvement*
R^2-adj	0.824		0.017
AICc	2298.92		3.91
	Low	**Mean**	**High**
local R2	0.622	0.795	0.865

Looking at the model improvement (Table 36), the first thing that stands out is the limited improvement of the GWR model. The AICc improvement is only 3.91 points, a small improvement. The improvement of the adjusted R-squared remains below 0.02. The question remains whether the occurrence of theft related crimes is indeed non-stationary. When looking at the local R-squared values in combination with the observed values, displayed in Figure 20 and Figure 21, it becomes clear the variance is best explained in neighborhoods near the city center, where most theft related crimes occur. Moreover, when looking at the standardized coefficients of the OLS regression, the address density, tourist attraction density and the percentage of retail and catering land-use appear to be highly correlated in comparison to the other variables. These three variables are also most present with high values near the city center. Hence, there are two explanations for the limited model improvement, namely, as beforementioned, theft is stationary. Another possible explanation is that the spatial component of the beforementioned three key variables interferes with the GWR as the model mainly focuses on the city center of Amsterdam.

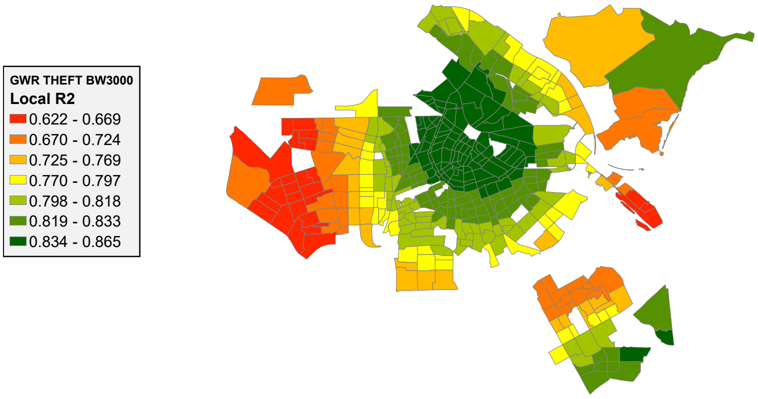


Figure 20: Local R-squared values GWR theft

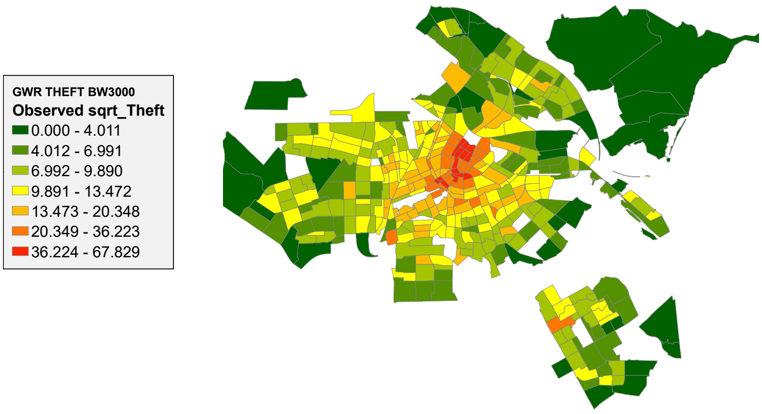
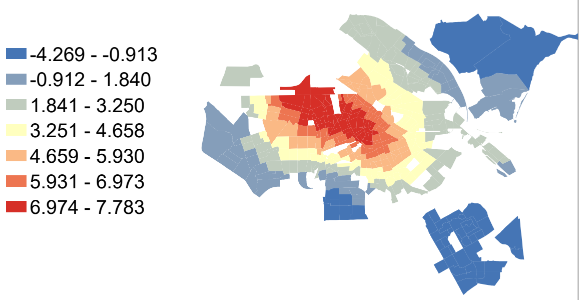


Figure 21: Observed values theft (square root of thefts per square kilometer)

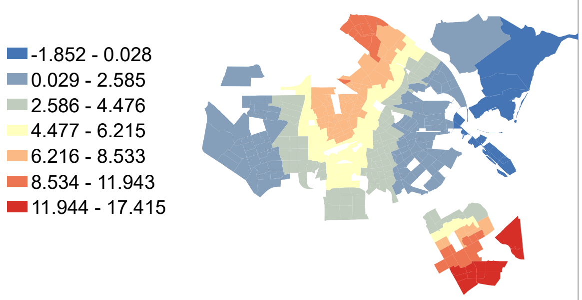
One of the advantages of a GWR is that local variations in the relationships can be observed. Where the GWR model does not improve much in comparison with the OLS model, insight can be gained as to where which variable explains more variance. In Table 37, maps representing the local coefficients are displayed.

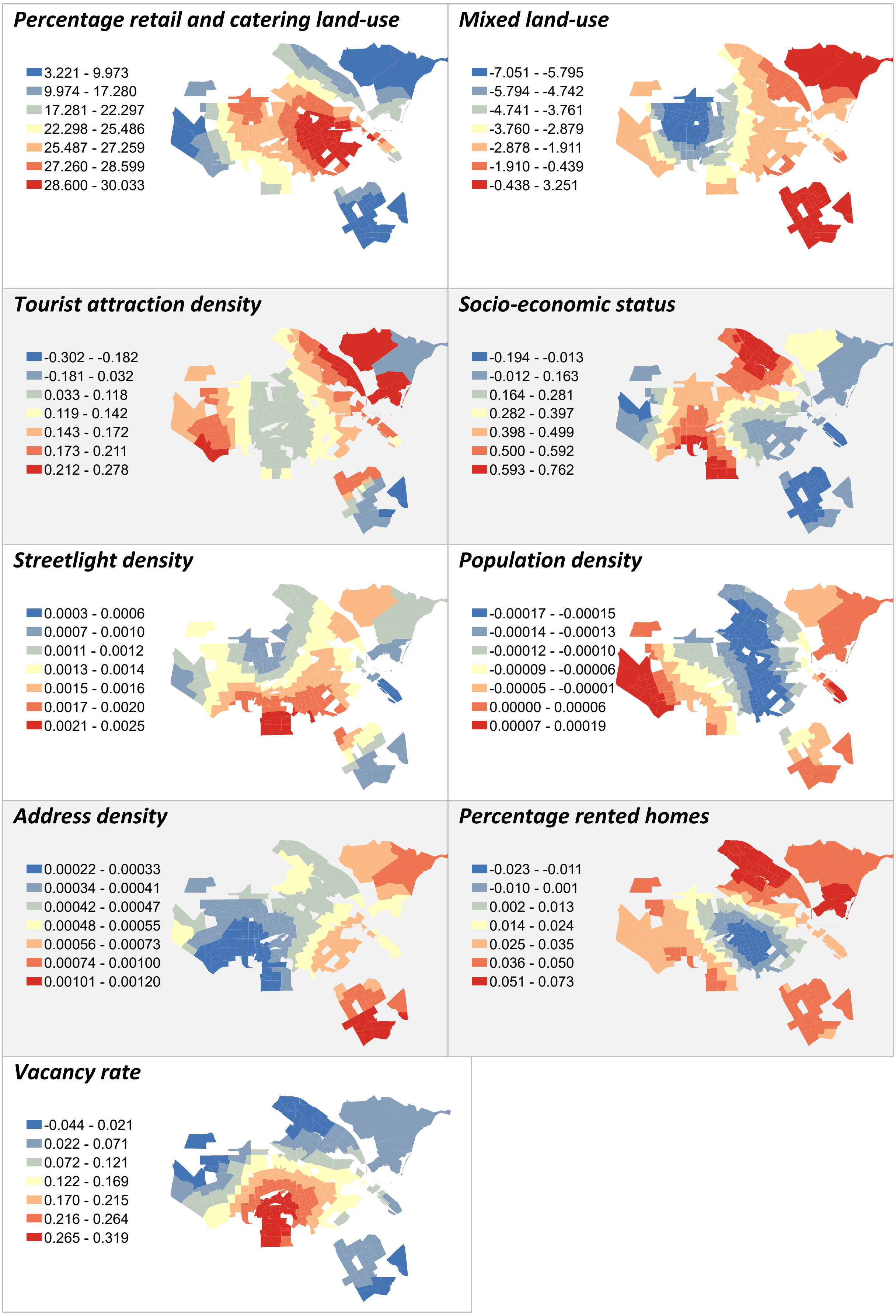
Table 37: Visualization of coefficients GWR theft

Intercept



Ratio CCTV




Percentage retail and catering land-use
3.221 - 9.973
9.974 - 17.280
17.281 - 22.297
22.298 - 25.486
25.487 - 27.259
27.260 - 28.599
28.600 - 30.033
Mixed land-use
-7.051 - -5.795
-5.794 - -4.742
-4.741 - -3.761
-3.760 - -2.879
-2.878 - -1.911
-1.910 - -0.439
-0.438 - 3.251
Tourist attraction density
-0.302 - -0.182
-0.181 - 0.032
0.033 - 0.118
0.119 - 0.142
0.143 - 0.172
0.173 - 0.211
0.212 - 0.278
Socio-economic status
-0.194 - -0.013
-0.012 - 0.163
0.164 - 0.281
0.282 - 0.397
0.398 - 0.499
0.500 - 0.592
0.593 - 0.762
Streetlight density
0.0003 - 0.0006
0.0007 - 0.0010
0.0011 - 0.0012
0.0013 - 0.0014
0.0015 - 0.0016
0.0017 - 0.0020
0.0021 - 0.0025
Population density
-0.00017 - -0.00015
-0.00014 - -0.00013
-0.00012 - -0.00010
-0.00009 - -0.00006
-0.00005 - -0.00001
0.00000 - 0.00006
0.00007 - 0.00019
Address density
0.00022 - 0.00033
0.00034 - 0.00041
0.00042 - 0.00047
0.00048 - 0.00055
0.00056 - 0.00073
0.00074 - 0.00100
0.00101 - 0.00120
Percentage rented homes
-0.023 - -0.011
-0.010 - 0.001
0.002 - 0.013
0.014 - 0.024
0.025 - 0.035
0.036 - 0.050
0.051 - 0.073
Vacancy rate
-0.044 - 0.021
0.022 - 0.071
0.072 - 0.121
0.122 - 0.169
0.170 - 0.215
0.216 - 0.264
0.265 - 0.319

The intercept has the highest coefficient in the city center, whereas the peripheral areas of the city have the lowest coefficients. Taking into consideration that the improvement of the GWR model in comparison to the OLS model is quite poor, it could be argued that theft is indeed stationary, and that the intercept of the GWR acts as a measure of distance to the city center.

CCTV coverage has, generally speaking, coefficients near the mean or slightly below the mean in areas where it is present. As this is also the case with the other crime types, it could be argued that the GWR nuanced the results of the OLS regression.

The highest coefficients for retail and catering land-use can be found in the city center. In this area, most land is covered by retail and catering facilities. This implies that the effect of retail and catering facilities is amplified when using a GWR. The effect of mixed land-use when using a GWR is considered to be the same in the city center as with the OLS regression model. In the area west of the city center, the effect of mixed land-use in reducing the number of thefts is largest. Tourist attraction density has surprisingly a relatively low coefficient in the city center where most tourist attractions are present. This may be due to the big differences in the values of the tourist attraction density of the city center compared to the rest of the city, similar to the vandalism model. The coefficients of the socio-economic status and streetlight density seem to have a more random pattern.

Population density and the address density both have relatively low coefficients in the city center. This could be explained by the big influence of the tourist attractions and the retail and catering land-use. These latter two variables also have the highest unstandardized coefficients. The percentage of rented homes also has the lowest coefficient in the city center. The vacancy rate follows a similar pattern as in the other crime types. The highest coefficients are in the south of the city. Surprisingly, that area has a relatively low vacancy rate.

5.6 Total

As some variables from the literature were not aimed at specific crimes but rather at general crime rates, the total number of crimes per neighborhood is also considered in this research. Just like with the specific crime types, first an exploratory regression analysis was performed. The results are summarized in Table 38.

Table 38: Variables and their sign that are included in the best specified OLS regression model for total crimes

	ADDRESS DENSITY	PERCENTAGE RENTED HOMES	STREETLIGHT DENSITY	TREE DENSITY	RATIO CCTV	ETHNIC HETEROGENEITY	SOCIO-ECONOMIC STATUS	PERCENTAGE RETAIL AND CATERING LAND-USE	MIXED LAND-USE	TOURIST ATTRACTION	R2-ADJUSTED	AICC	F-STATISTIC	STD. ERROR OF THE ESTIMATE
TOTAL	+	+	+	-	+	+	+	+	-	+	0.88	2650.37	287.453	6.375

In Table 39 the results of the OLS regression are summarized. Perhaps the most interesting is the high adjusted R-squared value of .877. Multicollinearity issues do not arise as, the highest VIF-value remains below 2.3.

Table 39: Regression coefficients total crimes

	Coefficients	*Std. Error*	*Standardized coefficients*	*t*	*Sig.*	*VIF*
(Constant)	2.869	2.332		1.230	.219	
Tree density	-.001	.001	-.044	-2.042	.042*	1.531
Ratio CCTV	5.413	1.665	.073	3.251	.001*	1.669
Ethnic heterogeneity	11.354	3.857	.072	2.944	.003*	1.952
Percentage retail and catering land-use	56.455	3.085	.484	18.300	.000*	2.285
Mixed land-use	-7.424	1.686	-.084	-4.404	.000*	1.189
Tourist attraction density	.212	.027	.185	7.969	.000*	1.751
Socio-economic status	.686	.193	.089	3.559	.000*	2.048
Streetlighting density	.0028	.00045	.155	6.342	.000*	1.942
Address density	.0015	.00013	.270	11.381	.000*	1.833
Percentage rented homes	.064	.019	.073	3.374	.001*	1.544

a. Dependent variable: sqrt_total (square root of total number of crimes per square kilometer)

* variable significant at the $p < 0.05$ level

It is remarkable that the number of trees per square kilometer is included for the total crime model but not for specific crime types. This could be caused by other variables that suppress the tree density for specific crime types and that the tree density is left out as other variables explain variance better for those specific cases.

CCTV again is positively correlated with crime. Like the situation with the specific crime types, it is expected that the CCTV is installed in areas with relatively high crime numbers. Hence it will not be elaborated more here.

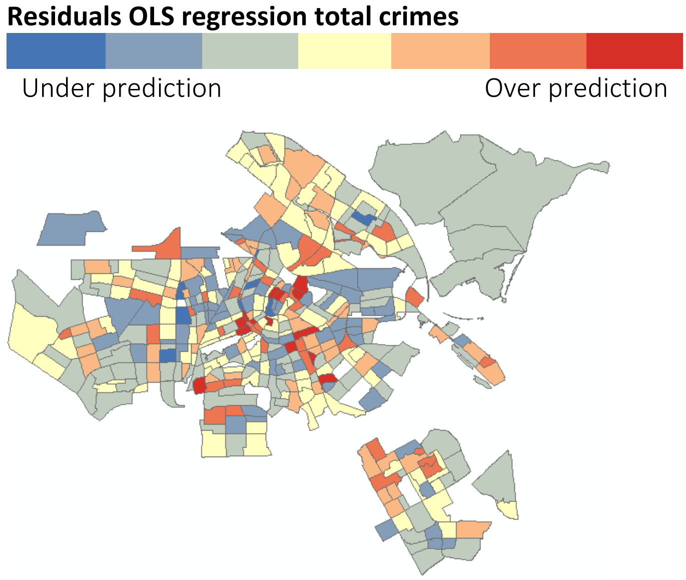
All variables originating from the social disorganization theory are significant. Ethnic heterogeneity and the percentage of rented homes both positively correlate with crime in general, which is in line with the theory. The socio-economic status has a positive sign which is contrary to the theory. It is expected that this is due to the high crime rates in the city center, which has the highest socio-economic status among the residents. The GWR should provide more insight in this matter, like it did with the burglary model.

Retail and catering land-use and the tourist attraction density both are positive, as expected. It is believed that, like the specific crime types, this is due to the high crime rate in the city center where these variables are most present. The negative sign for mixed land-use is in line with the literature and confirms Jacobs' (1961) ideas about mixed land-use.

Streetlighting being positively correlated is contrary to the literature. As mentioned with the theft model, it is expected that this is due to the high number of light installations in the city center. Moreover, as theft is the most occurring crime in Amsterdam, it is no surprise that variables included in the theft model are also included in the total crimes model. Address density is also in line with the literature, as the level of urbanization is expected to be positively correlated with crime.

Residuals were once again tested for spatial autocorrelation. The results are summarized in Table 40. The full report of this test can be found in appendix 6.

Table 40: Spatial autocorrelation (Moran's I) of the residuals of the OLS regression (total crimes)



Fixed distance	3000
Distance method	Euclidean
Moran's Index	-0.000081
Z-score	0.434
P-value	0.665

As the residuals were not spatially autocorrelated, the GWR with the same variables can be executed. The results are displayed in Table 41 and Table 42; Table 41 showing the coefficients and Table 42 showing the performance in comparison with the OLS regression.

Table 41: Coefficients GWR for total crimes model

Coefficients

	OLS	*GWR*		
		Lowest	*Mean*	*Highest*
(Constant)	2.869	-2.621	6.734408	17.414023
Tree density	-.001	-0.003	-0.001	0.003
Ratio CCTV	5.413	0.658	7.357	21.990
Ethnic heterogeneity	11.354	0.016	8.443	17.185
Percentage retail and catering land-use	56.455	22.614	55.477	64.419
Mixed land-use	-7.424	-12.564	-7.541	1.610
Tourist attraction density	.212	-0.478	0.194	0.891
Socio-economic status	.686	-0.245	0.553	1.083
Streetlighting density	.0028	0.0013	0.0026	0.0046
Address density	.0015	0.0011	0.0016	0.0036
Percentage rented homes	.064	0.006	0.042	0.126

Table 42: Model performance of GWR for total crimes

	GWR		Model improvement
R^2-adj	0.916		0.0316
AICc	555.92		2094.45
	Low	***Mean***	***High***
local R2	0.799	0.864	0.942

The model improves quite a lot in comparison to the OLS regression. What stands out are the large coefficients and their range in comparison to the specific crime types. It is expected that this is due to a larger observed value. The local R-squared values (Figure 22) in combination with the observed values (Figure 23), show that the areas with the highest crime rates also have a higher local R-squared value. It is preferable that the R-squared is highest in areas with the highest crime rates, as the upmost part of the total crimes are explained.

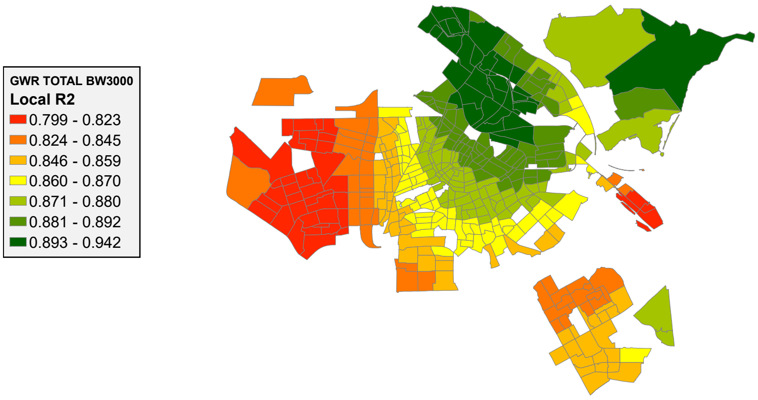


Figure 22: Local R-squared values GWR total crimes

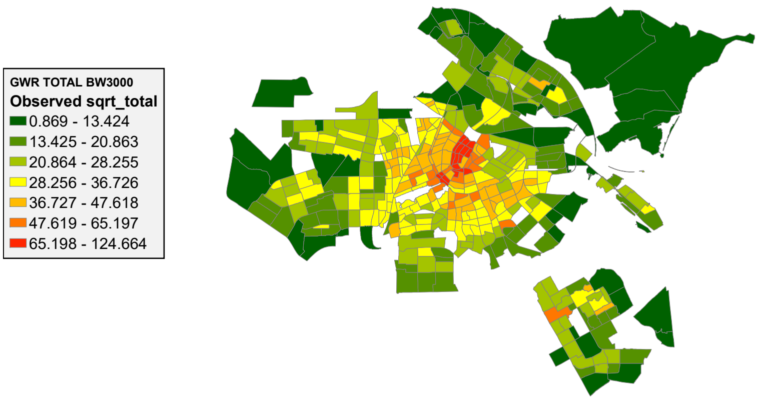


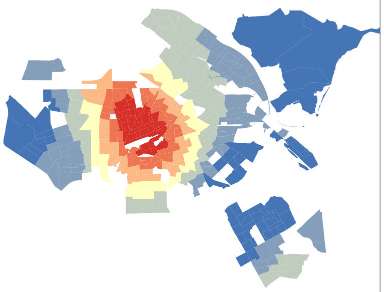
Figure 23: Observed values total crimes (square root of crimes per square kilometer)

In Table 43, maps representing the local coefficients are displayed.

Table 43: Visualization of coefficients GWR total crimes

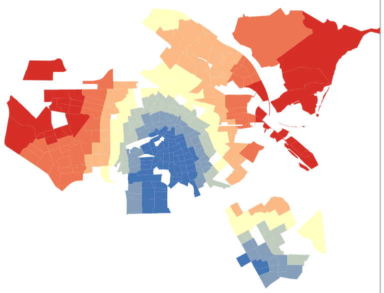
Intercept

- -2.621 - 0.504
- 0.505 - 2.626
- 2.627 - 5.023
- 5.024 - 7.978
- 7.979 - 10.956
- 10.957 - 14.154
- 14.155 - 17.414



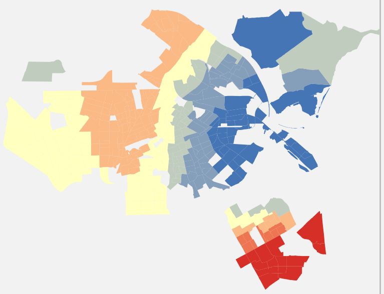
Tree density

- -0.0033 - -0.0028
- -0.0027 - -0.0023
- -0.0022 - -0.0016
- -0.0015 - -0.0010
- -0.0009 - -0.0003
- -0.0002 - 0.0008
- 0.0009 - 0.0026



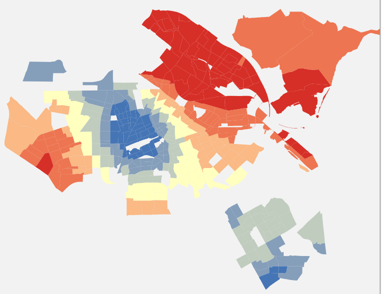
Ratio CCTV

- 0.658 - 2.656
- 2.657 - 4.674
- 4.675 - 6.644
- 6.645 - 8.485
- 8.486 - 11.312
- 11.313 - 14.807
- 14.808 - 21.990



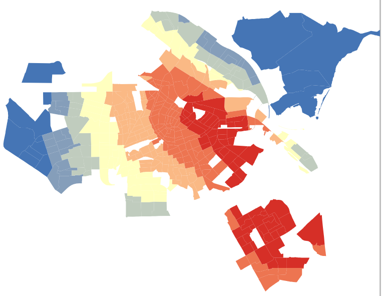
Ethnic heterogeneity

- 0.016 - 2.273
- 2.274 - 4.642
- 4.643 - 7.103
- 7.104 - 9.557
- 9.558 - 11.908
- 11.909 - 14.309
- 14.310 - 17.185



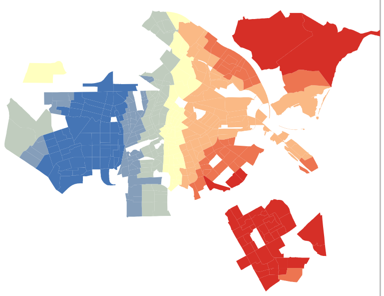
Percentage retail and catering land-use

- 22.614 - 35.259
- 35.260 - 44.215
- 44.216 - 50.627
- 50.628 - 55.105
- 55.106 - 58.270
- 58.271 - 61.033
- 61.034 - 64.419



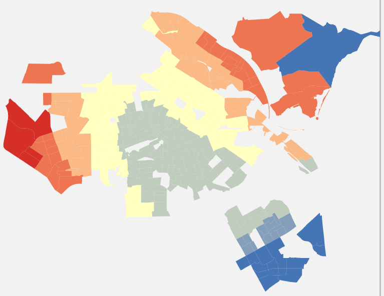
Mixed land-use

- -12.564 - -11.345
- -11.344 - -9.844
- -9.843 - -8.164
- -8.163 - -6.635
- -6.634 - -5.177
- -5.176 - -3.043
- -3.042 - 1.610



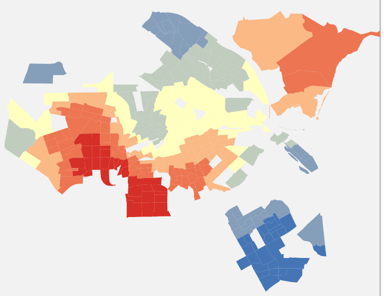
Tourist attraction density

- -0.478 - -0.099
- -0.098 - 0.085
- 0.086 - 0.185
- 0.186 - 0.236
- 0.237 - 0.317
- 0.318 - 0.450
- 0.451 - 0.891



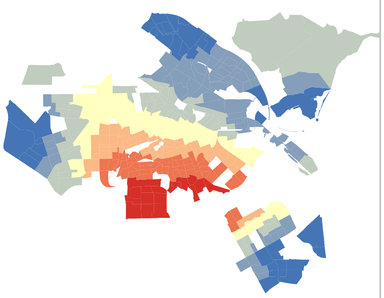
Socio-economic status

- -0.245 - 0.028
- 0.029 - 0.308
- 0.309 - 0.538
- 0.539 - 0.622
- 0.623 - 0.728
- 0.729 - 0.853
- 0.854 - 1.083



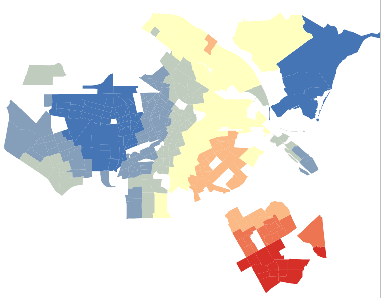
Streetlight density

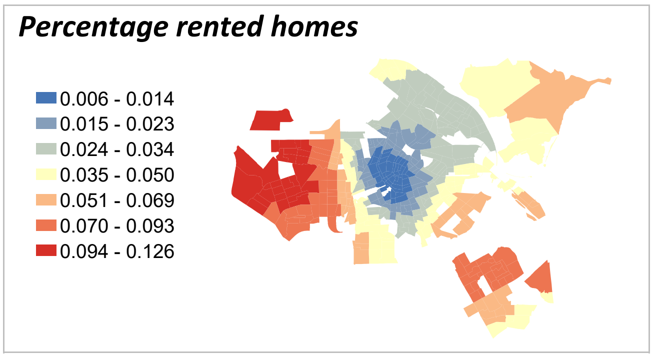
- 0.0013 - 0.0017
- 0.0018 - 0.0021
- 0.0022 - 0.0024
- 0.0025 - 0.0028
- 0.0029 - 0.0032
- 0.0033 - 0.0038
- 0.0039 - 0.0046



Address density

- 0.00113 - 0.00134
- 0.00135 - 0.00147
- 0.00148 - 0.00160
- 0.00161 - 0.00175
- 0.00176 - 0.00211
- 0.00212 - 0.00283
- 0.00284 - 0.00358





The intercept appears to have the highest coefficient in the city center, where relatively many crimes occur. Arguably, the intercept compensates for variables which are not included in the models. A coefficient for the intercept of approximately 15, in combination with the square root transformation suggests that the intercept compensates for more than 200 crimes per square kilometer per year in those areas.

A look at the coefficient for the tree density, shows that the city center has negative coefficients, whereas the peripheral areas have coefficients near zero or positive, which implies that in those areas the tree density does not seem to reduce crime at all.

CCTV has the highest coefficients in the south-eastern part of Amsterdam. In general, the areas with the highest CCTV coverage have the lowest coefficients. Similar results were obtained with the models for specific crime types.

Ethnic heterogeneity seems to have the lowest coefficients in the areas which also have the lowest values for ethnic heterogeneity. This implies that ethnic heterogeneity is even more correlated with crime. Hence, this relationship could arguably be an exponential one. The socio-economic status, interestingly, has a negative coefficient in the south-east part of the city, where the socio-economic status also has a negative value, which means that there is more crime in that specific area. The other coefficients do not seem to have a pattern in combination with the crime rates or socio-economic status of the area.

Retail and catering land-use seem to have the most influence in the city center where most retail and catering facilities are located. Hence by using a GWR the effect of retail and catering land-use amplified. Mixed land-use has the highest coefficients in the east, moving towards the west the coefficients decrease.

Address density has the highest coefficients in the south-east for the total number of crimes, whereas the city center has generally low coefficients. Streetlighting was thought to be positively correlated with crime due to high numbers of crimes in the city center in combination with a high streetlight density in that area. However, when looking at the coefficients, streetlighting appears to be most influential in the south, whereas the city center has coefficients near the mean. The percentage of rented homes has the lowest coefficients in the city center.

5.7 Discussion

Looking at the results from all models in comparison with the literature, many similarities can be observed. However, also differences are present. In Table 44 the literature is compared to the regression models per variable.

Table 44: General discussion of the results and feedback on the literature

Variable	*Finding literature review*	*Finding regression models*
Street layout	The number of intersections is expected to be positively correlated with crime, especially burglary. The number of cul-de-sacs is expected to be negatively correlated with crime.	The number of intersections indeed are positively correlated with burglary and also with drugs and nuisance related crimes. The number of cul-de-sacs did not come forward in any of the regression models.
Mixed land-use	Mixed land-uses are expected to be decreasing the number of crimes in the area, as pedestrian activity is increased, creating more ‘’eyes on the street’’	Mixed land-use indeed is negatively correlated with most crime types (violent crimes, theft and total). Burglary was positively correlated
CCTV coverage	Presence of CCTV is expected to deter criminal activity in the area. It acts as a measure of access control and surveillance.	Findings differ from the literature. Probable Is that the implementation of CCTV is the result of high crime rates in those specific areas.
Streetlighting	Streetlighting is expected to decrease crime, as it improves visibility and decreases the fear of crime, which results in more pedestrians.	Findings are contrary to the literature. It is expected that this is due to the high number of streetlighting in the city center where most crimes occur.
Artworks	Artworks are expected in increase the territoriality in the area, but also improve the social cohesion in the neighborhood and thus reduce crime.	Artworks are positively correlated with crime; the question arises whether this correlation is by chance or causation.
Greenspace	Greenspace is expected to be negatively correlated with crime.	The ratio of greenspace is positively correlated with burglary. Moreover, the number of trees is also negatively correlated with the total crime.
Parking	Limiting the number of parking places are expected to be decreasing crime, as it improves the access control principle of CPTED. On the other hand, parking places could act as crime attractor.	Parking places are positively correlated with violent crimes, which is in line with the literature on CPTED. Drugs and nuisance related crimes are negatively correlated.
Housing/ urbanization	Population density and the address density are expected to increase the number of crimes, as crime thrives in areas with a high number of residents. The vacancy rate is expected to be increasing the	Population and/or address density are included with a positive sign in all regression models, which confirms the literature. The positive sign for the vacancy rate is also in line

	number of crimes in the neighborhood.	with the literature. Population density is negatively correlated with theft.
Tourist attractions	Tourist attractions are vulnerable for vandalism. Tourism in Amsterdam generates crowds, which facilitate pickpocketing	Tourist attractions are positively correlated with vandalism, drugs and nuisance related crimes, theft and crime in general.
Ethnic Heterogeneity	Ethnic heterogeneity is expected to be positively correlated with crime.	Ethnic heterogeneity is positively correlated with vandalism, violent crimes and crime in general.
Socio-economic status	Socio-economic status is expected to be positively correlated with crime.	The socio-economic status of the neighborhood is negatively correlated with violent crimes, whereas theft and crime in general are positively correlated. Burglary is positively correlated in certain areas and negatively correlated in others.
Residential mobility/ percentage rented homes	The percentage of rented homes is expected to be positively correlated with crime.	Rented homes are positively correlated with drugs and nuisance related crimes, theft and crime in general.

As regards the CPTED principles, some conflicting findings can be observed. The number of intersections increasing crime is in line with the CPTED principle of access control, as the number of intersections increases the permeability of the neighborhood and thus weakens the access control. Mixed land-use should act as a measure to improve natural surveillance, which it does, as all the signs are negative, except for burglary. The vacancy rate is also in line with CPTED, namely the image and milieu principle; vacancy is argued to have a negative effect on the image of the neighborhood, which results in more crime. The vacancy rate is positively correlated with drugs and nuisance related crimes, violent crimes and theft. The number of rented homes, arguably, can be seen as a negative measure of territoriality, as people are more inclined to defend their own property. The percentage of rented homes is positively correlated with drugs and nuisance related crimes, theft and crime in general. Hence, variables representing all CPTED principles are in line with the CPTED strategy. However, some variables appear to be out of line. For example, CCTV, which should act as a measure of surveillance and access control, however, CCTV is positively correlated. The same goes for the streetlighting as a measure of natural surveillance, artworks as a measure of territoriality and parking places as a measure of access control.

As regards the social disorganization theory, the most interesting finding is that the variables originating from the social disorganization theory are generally in line with theory. Ethnic heterogeneity is positively correlated in all the models in which it is included. The same goes for the percentage of rented homes, which is used as a measure of residential mobility. The socio-economic status is negatively correlated with burglary and violent crimes, whereas there is a nuance in the results for burglary (see section 5.1). The socio-economic status is positively correlated with theft related crime and the total number of crimes. The socio-economic status being positively correlated with theft could be explained by the fact that theft is a financial driven crime and thus the reward is possibly higher in areas with a higher socio-economic status.

Looking at the burglary model from the GWR, the most interesting findings are the intersection density and the socio-economic status. The intersection density, although not significant, perfectly follows the empirical results of Sohn (2016) & Yang (2006). On the other hand, it is contrary to Jacobs' (1961) argument of increased permeability which should decrease crime. Socio-economic status having positive and negative coefficients is also found to be remarkable, as it suggests that burglaries should occur least in areas with a socio-economic status that is close to the mean.

The most interesting finding of the vandalism model is the high positive correlation with tourist attractions, which was initially unexpected. However, the literature suggested that this correlation does make sense (Bhati & Pearce, 2016; Merrill, 2011).The most interesting results of the violent crimes model are that a large number of variables included are perfectly in line with the literature; variables originating from the social disorganization theory, vacancy, mixed land-use and retail and catering land-use. Looking at the theft and the drugs and nuisance models the most outstanding variables included are for both models tourist attractions and the percentage of retail and catering. These variables are so dominant that they might have suppressed other variables.

When taking spatial relationships into account, it can easily be observed that for burglary, vandalism, violent crimes and crime in general, the models improve significantly. Drugs and nuisance related crimes as well as theft seem to have a limited, if any, improvement. Hence, it could be argued that drugs and nuisance related crimes and theft are stationary. Moreover, taking into account spatial variation of the coefficients provides the opportunity to observe where certain variables are more influential and where they are not.

6 Conclusion

In this research, multiple crime types were researched in regard to their relation to characteristics of the built environment and some regarding the social disorganization theory as control variables. First literature was consulted to obtain the most relevant theories and contributions on this matter. An exploratory regression analysis was performed to find the most suitable and efficient OLS regression model per crime type. The residuals of the OLS regression models were tested for spatial autocorrelation. Finally, a geographically weighted regression analysis was performed to identify spatial variations in the influence of the built environment on various crime types.

This final chapter is divided in seven parts. The scientific relevance of the research will be discussed first. Here the research questions asked will be answered. The societal relevance of the research will be discussed afterwards, followed by the limitations of the research. Implications of the methods used will be discussed next. The generalizability of the research will be discussed before moving on to proposals for further research. The chapter ends with the recommendations

6.1 Scientific Relevance

In this research spatial statistics were used to get a better understanding of the influence of the built environment in relation to crime. The following research question was asked in the introduction:

Main question:

To what extent do characteristics of the built environment and especially CPTED measures influence the amount of crimes in the neighborhoods of Amsterdam and how does this relation vary among different neighborhoods?

To answer the main question, the sub questions are answered first.

1. *How do characteristics of the built environment relate to the principles of CPTED?*

Characteristics of the built environment can all be related to the principles of CPTED. (natural) Surveillance can be achieved by increasing the number of different land-uses, intersections and greenspace. Cul-de-sacs, artworks and owned homes can be related to territoriality. The maintenance and image principle is characterized by vacancy. Finally, access control can be related to the infrastructure layout and the number of parking places. Besides the beforementioned characteristics, more variables can be related to CPTED principles, as CPTED is more a design strategy rather than a ''checklist''.

2. *What are the current crime levels in neighborhoods of Amsterdam?*

The crime levels in Amsterdam are generally speaking quite high in comparison to other Dutch cities. In general crime occurs most in the city center. Burglaries, however, occur most in a ring around the city center.

3. *How do socio-demographic and socio-economic characteristics vary among the neighborhoods of Amsterdam and how do they influence crime numbers in the neighborhoods of Amsterdam?*

It was found that socio-demographic and socio-economic characteristics of the neighborhoods vary among different areas of Amsterdam. Variables included were derived from the social disorganization theory. Ethnic heterogeneity was the highest in the south-eastern and western parts of the city. The socio-economic status was the highest near the city center and the lowest in the south-eastern and western parts of the city. The analysis found that ethnic heterogeneity does indeed influence crime, especially vandalism and violent crimes. The socio-economic status was also found to be influencing crime, however not consistently among crime types. This influence also differs throughout the research area. Moreover, the influence of the socio-economic status has even positive and negative signs within crime types.

4. *How do these relationships vary with different crime types?*

The geographically weighted regression showed that the relationships do indeed vary among different areas of the research area. This was of added value, for example, socio-economic status in the burglary model has positive and negative coefficients.

Answering the main question, it was found that that there are characteristics of the built environment that have an influence on crime. All operationalized variables except the cul-de-sac density were at least included once in the regression models. These relationships vary with different crime types. The added value of this research, arguably, is that multiple variables of the built environment are included, whereas the literature often only focusses on one specific aspect such as greenspace or infrastructure.

In general, it can be concluded that the built environment does have an influence on the occurrence of crime and that this influence differs among crime types. Moreover, different characteristics of the built environment have influence on different types of crime.

6.2 Societal Relevance

This research is concerned with preventing crime by shaping the built environment in a specific way.

Nowadays the Netherlands face a housing shortage and many new dwellings have to be built. Using the findings of this research could result in the designing of safer neighborhoods. New residential areas also need supporting facilities. Instead of concentrating them, these facilities are recommended to be spread throughout the area. As the results clearly show that crime occurs most in the city center, where many retail and catering facilities are located.

As was mentioned in the introduction, crime could be reduced by shaping the built environment in a particular way and, as a consequence, pressure experienced by the police could be lowered. Moreover, society in general benefits if there is less crime on the streets. Finally, by reducing crime in neighborhoods, real estate/land values increase, which in general is preferable.

6.3 Limitations

An important limitation/point of interest in this research is the high number of tourists in the city center of Amsterdam. It could be argued that tourism suppresses other variables from the built environment that might have come forward if there were fewer tourists. On the other hand, the excessive tourism of Amsterdam is a part of the city, and thus should be included.

In regard to the operationalization, it is wondered whether the variable of the CCTV was suitable for this research. First, the effectiveness of implementing CCTV in an area is believed to be reducing crime, however by using a form of regression, a neighborhood is only one observation among many. To adequately test the effectiveness of the implementation of CCTV, it is argued that the same neighborhood should be analyzed for several years before and after the implementation of CCTV to obtain reliable results. By using a regression analysis, this aspect is neglected as the statistical approach is different. Moreover, it is believed that CCTV is implemented because of crime and nuisance, hence it makes sense that the signs for all crime types except burglary were positive.

6.4 Method

A geographically weighted regression is always useful, if the sample consists of geographical bodies such as neighborhoods or districts, as it helps identifying local variations. Moreover, it helps understanding the key variables that were included in the models. For example, the models had some sort of bias in regard to the city center, making it clear which variables were important in what area. This bias was probably caused by the tourism in the city center. Another useful insight gained by using a GWR is, for example, the effect of the socio-economic status on burglaries. The GWR demonstrated that neighborhoods with a low socio-economic status as well as with a high socio-economic status suffer more from burglaries. Hence neighborhoods with a socio-economic status around the mean suffer the least.

Another point of interest in regard to a GWR are the variations in the intercept. The fact that there are coefficients for the intercept which are quite high, might indicate that the included variables do not explain the variance well in those specific regions. Moreover, this could imply that variables are missing that are apparent in those specific areas and that the coefficient for the intercept compensates for these missing variables.

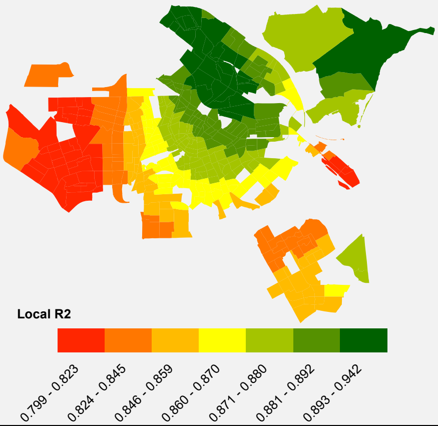
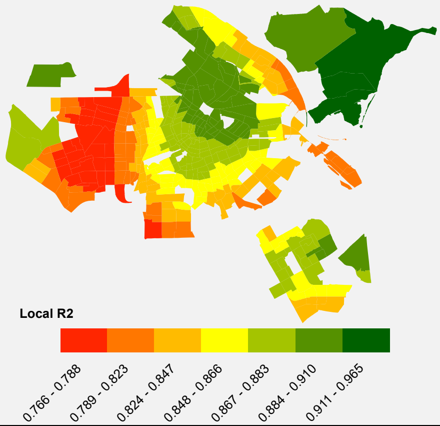
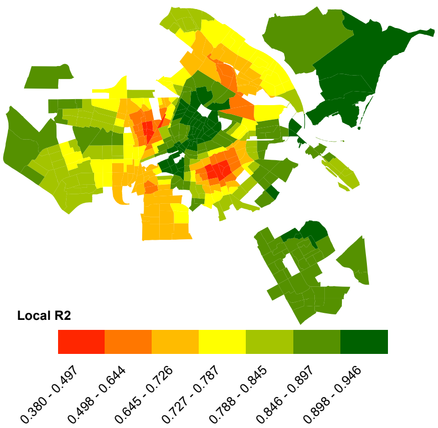
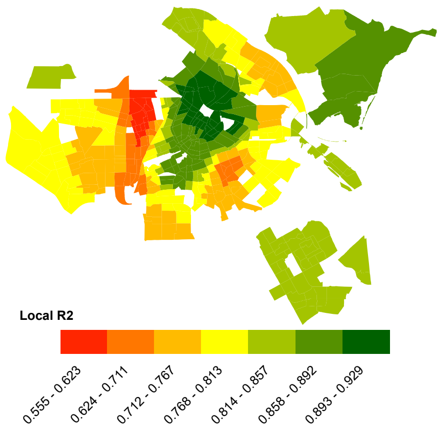
When using regression analysis, or rather statistics in general, attention should be paid to the fact that correlations do not necessarily mean there is a causal relationship. There could be an unidentified spurious relationship or even a correlation that is based on chance. In this research, the influence of artworks does not make much sense (except for vandalism). It is expected that this is due to a spurious relationship or even by chance. As there is not an explanation yet for this correlation, no conclusion should be drawn from this result.

Another important point of interest as regards a GWR is that the coefficients will be ''fitted'' to obtain a better model fit. Hence, the results of the GWR should be interpreted carefully. In line with this is the bandwidth of the kernel, which is also subject to a more critical interpretation as the smaller the bandwidth the more the coefficient will be ''fitted'' to obtain a better model fit. This variability in the bandwidth and kernel, is elaborated more in the upcoming section.

6.4.1 Kernel and bandwidth

For this research, a fixed kernel with a bandwidth of three kilometers was used. This bandwidth was determined by the minimum bandwidth of approximately 2200 meters which approached the bandwidth which is used in the literature. A slightly larger bandwidth was taken, so that every neighborhood had more than only a couple of neighbors. The minimum bandwidth for the city of Amsterdam was quite large. It is expected that this is due to the large neighborhoods in the north-eastern part of the city. Although these neighborhoods are part of Amsterdam and thus should be included in the analysis, three more analysis were performed for the total crime model, one with a smaller fixed bandwidth of 2300 meter (which was found in the literature) and two with an adaptive kernel with 50 and 100 neighbors. In Table 45 a comparison is made between these models.

Table 45: Comparison total crime models with different kernel and bandwidths

Fixed kernel		
bandwidth	3000 meter	2300 meter
R^2-adj	0.916	0.926
AICc	555.92	495.156
Local R^2		
Adaptive kernel		
Bandwidth	50 neighbors	100 neighbors
R^2-adj	0.947	0.934
AICc	292.57	565.11
Local R^2		

Comparing the model with the 2300 meter bandwidth with the 3000 meter bandwidth, no major differences can be observed. It should be noted that in the model with the 2300 meter bandwidth. In general, these two models with a fixed bandwidth show similar patterns. From the model with the adaptive kernel of 50 neighbors it can be observed that there are areas that perform significantly worse. It could be argued that this is the result of a small bandwidth.

This will fit the model more to the data. Moreover, the range in the local R-squared values indicates that this model is quite unstable over space. The same holds for the model with 100 neighbors, however, the results are more nuanced. Comparing the original model with the fixed bandwidth of 3000 meter with the model with an adaptive kernel with a bandwidth of 100 neighbors, it can be observed that the model with the fixed distance performs better on the AICc, but that the R-squared is better for the model with an adaptive kernel. However, as beforementioned, the local R-squared values seem to have a larger range for these models. Hence, it could be argued that for this research a fixed kernel is more suitable as the performance is more stable over the whole research area. The coefficients of these additional three models (the model with a fixed kernel with bandwidth 3000 meter is already reported in section 5.6) can be found in appendix 7-9.

6.5 Generalizability of the research

As regards the generalizability of the results, attention should be paid to the fact that a local form of regression was used in this research, which was based on the municipality of Amsterdam. The coefficients obtained from the GWR are neighborhood specific and are therefore difficult to generalize. The results of the ordinary least squares regression, on the other hand, are more suitable for generalizability.

Moreover, the extreme number of tourists in Amsterdam suppresses the result of other variables in the models. This results in less generalizable results for the models in which tourist attractions are included. On the other hand, it is more generalizable for tourist intensive cities. Models like the burglary model, in which no tourism is included, are more generalizable for the Dutch context. Research regarding theft and drugs and nuisance related crimes, should perhaps be done in more ordinary Dutch cities to obtain more generalizable results. However, the number of observations will probably be problematic. Hence the research area should be expanded, which will require data from multiple municipalities which in turn could be problematic.

6.6 Further research

For further research, as beforementioned, a less tourist intensive city should be researched. Such research would possibly produce more generalizable results that can also be used for other cities in the Dutch and maybe even the Western European context.

Another interesting follow-up research could be on a more micro level of analysis rather than on whole neighborhoods. Such research would require disaggregated crime statistics, which will be difficult to obtain due to European legislation on privacy. This research was dependent on available data from the Dutch police. Because of this, data was aggregated to the neighborhood level. If crime data with an exact location is available, the CPTED measures could also be analyzed at the micro level, rather than at the meso level.

Finally, as mentioned in the limitations section, the effectiveness of CCTV could probably be better researched with a different method and by comparing different time periods, from before and after the implementation for the same neighborhood.

6.7 Recommendations

When designing new urban areas, it is recommended to include as many land-uses as possible and feasible. This will lead to more pedestrian activity. Moreover, when more functions are present in the neighborhood, the population density will also decrease. Hence it is argued that areas should not contain only residential, retail and catering or business activities but a mix of all. This recommendation is also in line with new urban concepts like ''new urbanism'' or ''Transit oriented developments''. These concepts are also concerned with mixed land-use and stimulation of pedestrian activity.

As regards to policy making to decrease criminal activities in the city center of Amsterdam, it is recommended to limit the amount of retail and catering facilities in the city center, as they seem to stimulate criminal behavior for different types of crime. Research should be done to establish to what extend the retail and catering facilities can be reduced while it is still able to provide the population of Amsterdam. Limiting the retail and catering facilities, would also provide an opportunity to implement different types of land-use to increase the number of different functions. Mixed land-use will in its turn also lower the population density, which stimulates crime, as multiple functions besides residential are present in the area. Concerning tourism, it is recommended to evaluate whether the benefits of the high number of tourists outweigh the disadvantages such as crime, but also the deterioration of the city center, sustainability issues and the nuisance in general that the residents of Amsterdam experience. Limiting the number of tourists could be done by implementing a higher tourist tax or by regulating the number of hotel rooms.

Finally, as beforementioned, further research is recommended to increase the knowledge on the influence of the built environment on crime and to do this for multiple contexts and levels of analysis to get a more thorough understanding on this matter.

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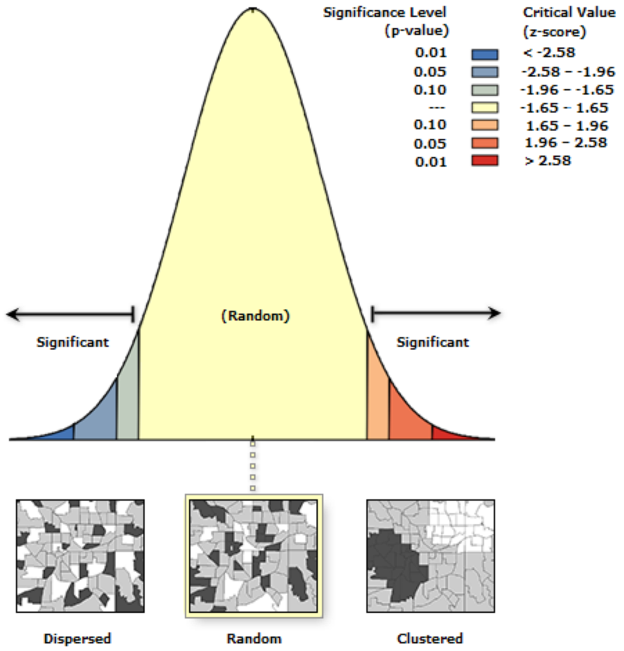
Appendices

Appendix 1: Spatial Autocorrelation Report Residuals Burglary Model

Moran's Index: 0.005360
z-score: 1.411898
p-value: 0.157980



Given the z-score of 1.41189847768, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

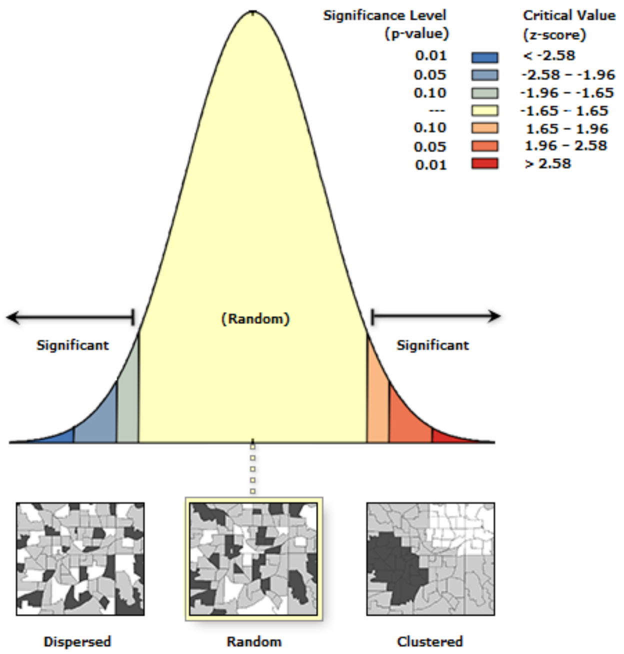
Moran's Index:	0.005360
Expected Index:	-0.002488
Variance:	0.000031
z-score:	1.411898
p-value:	0.157980

Dataset Information

Input Feature Class:	OLS_BURGLARY
Input Field:	RESIDUAL
Conceptualization:	FIXED_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	3000.0000 Meters
Weights Matrix File:	None
Selection Set:	False

Appendix 2: Spatial Autocorrelation Report Residuals Vandalism Model

Moran's Index: 0.002210
z-score: 0.855496
p-value: 0.392277



Given the z-score of 0.85549572874, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

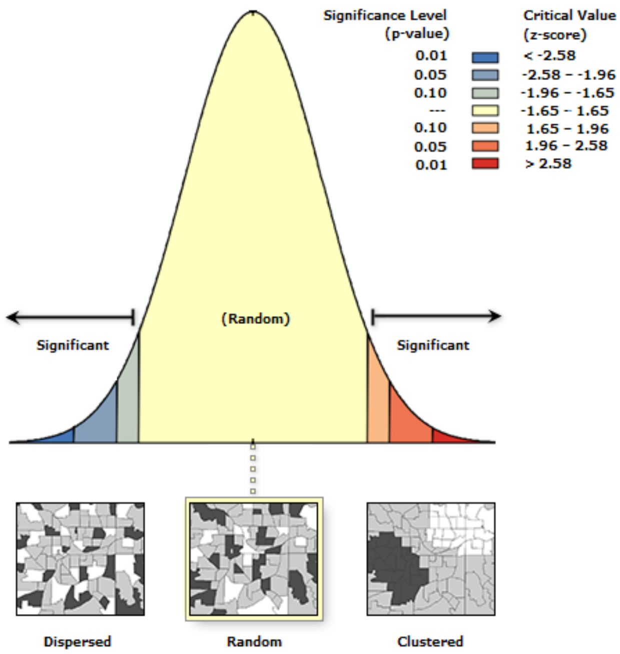
Moran's Index:	0.002210
Expected Index:	-0.002488
Variance:	0.000030
z-score:	0.855496
p-value:	0.392277

Dataset Information

Input Feature Class:	OLS VANDALISM
Input Field:	RESIDUAL
Conceptualization:	FIXED_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	3000.0000 Meters
Weights Matrix File:	None
Selection Set:	False

Appendix 3: Spatial Autocorrelation Report Residuals Violent Crimes Model

Moran's Index: 0.000396
z-score: 0.520057
p-value: 0.603024



Given the z-score of 0.52005722314, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

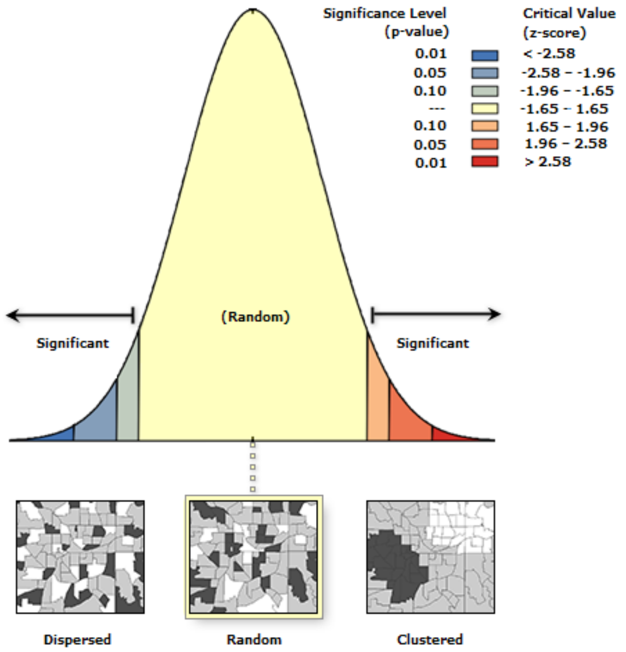
Moran's Index:	0.000396
Expected Index:	-0.002488
Variance:	0.000031
z-score:	0.520057
p-value:	0.603024

Dataset Information

Input Feature Class:	OLS VC
Input Field:	RESIDUAL
Conceptualization:	FIXED_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	3000.0000 Meters
Weights Matrix File:	None
Selection Set:	False

Appendix 4: Spatial Autocorrelation Report Residuals Drugs and Nuisance Related Crimes Model

Moran's Index: 0.001985
z-score: 0.811449
p-value: 0.417108



Given the z-score of 0.81144876471, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

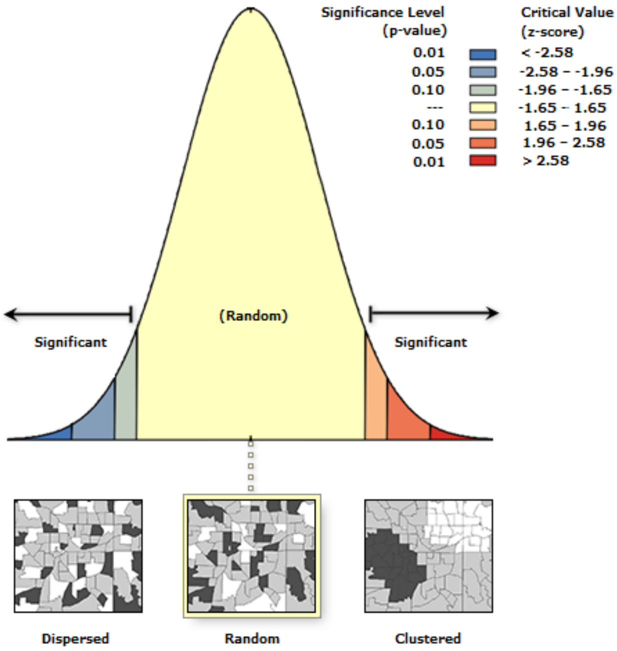
Moran's Index:	0.001985
Expected Index:	-0.002488
Variance:	0.000030
z-score:	0.811449
p-value:	0.417108

Dataset Information

Input Feature Class:	OLS DN
Input Field:	RESIDUAL
Conceptualization:	FIXED_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	3000.0000 Meters
Weights Matrix File:	None
Selection Set:	False

Appendix 5: Spatial Autocorrelation Report Residuals Theft Model

Moran's Index: 0.000238
z-score: 0.491463
p-value: 0.623099



Given the z-score of 0.49146327380, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

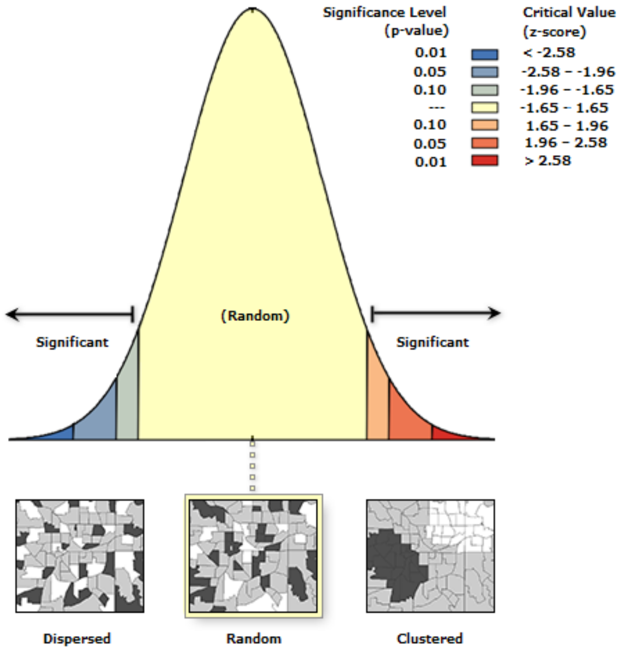
Moran's Index:	0.000238
Expected Index:	-0.002488
Variance:	0.000031
z-score:	0.491463
p-value:	0.623099

Dataset Information

Input Feature Class:	OLS THEFT
Input Field:	RESIDUAL
Conceptualization:	FIXED_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	3000.0000 Meters
Weights Matrix File:	None
Selection Set:	False

Appendix 6: Spatial Autocorrelation Report Residuals Total Crimes Model

Moran's Index: -0.000081
z-score: 0.433635
p-value: 0.664553



Given the z-score of 0.43363543236, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

Moran's Index:	-0.000081
Expected Index:	-0.002488
Variance:	0.000031
z-score:	0.433635
p-value:	0.664553

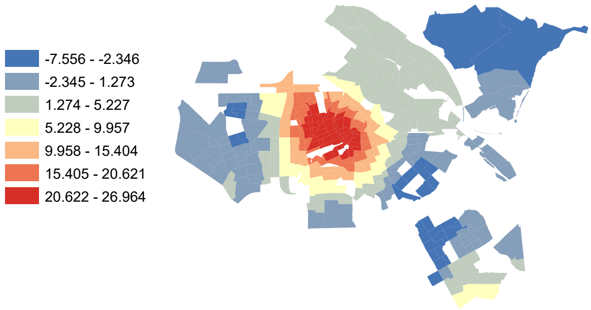
Dataset Information

Input Feature Class:	OLS TOTAL
Input Field:	RESIDUAL
Conceptualization:	FIXED_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	3000.0000 Meters
Weights Matrix File:	None
Selection Set:	False

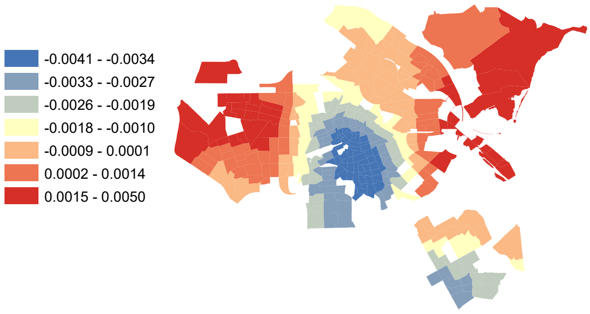
Appendix 7: Coefficients GWR total crimes fixed kernel 2300 meter

Adjusted R-squared	0.926
AICc	495.156

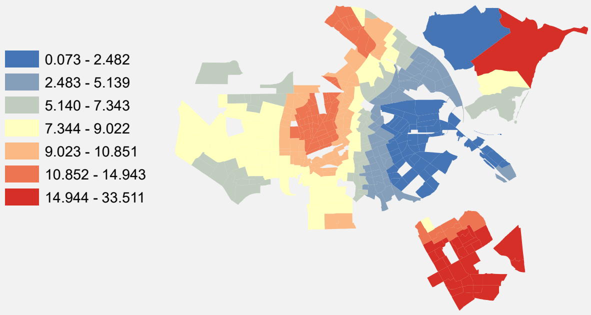
Intercept



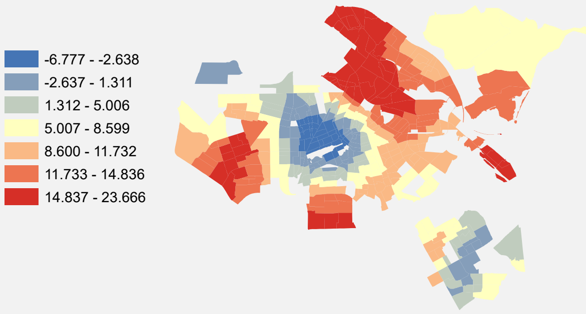
Tree density



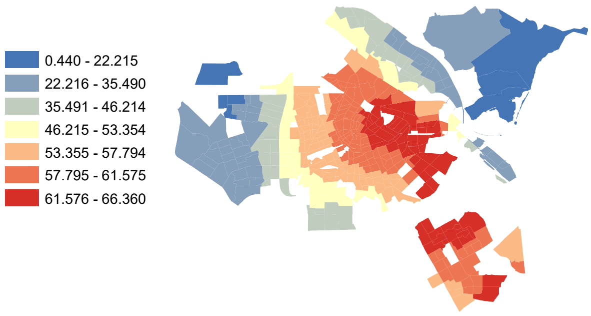
Ratio CCTV



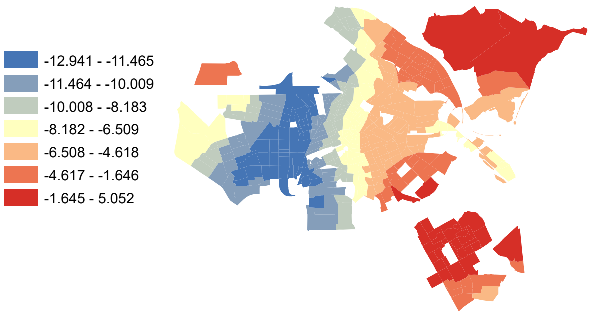
Ethnic heterogeneity



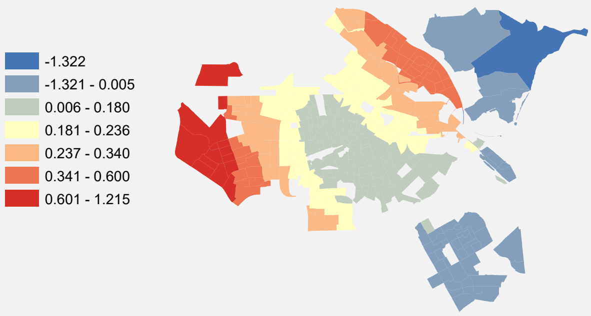
Percentage retail and catering land-use



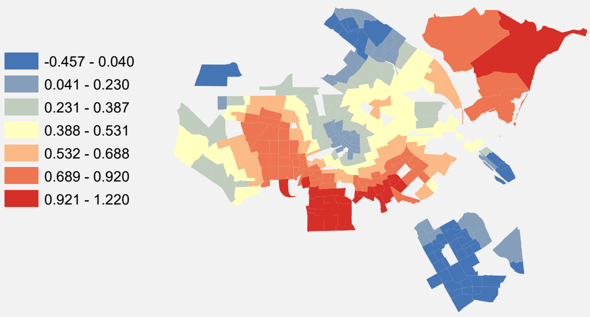
Mixed Land-use



Tourist attraction density

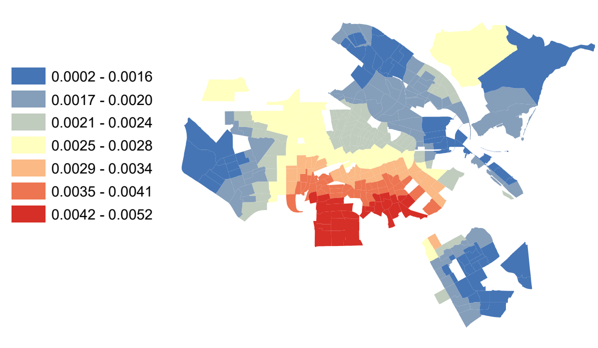


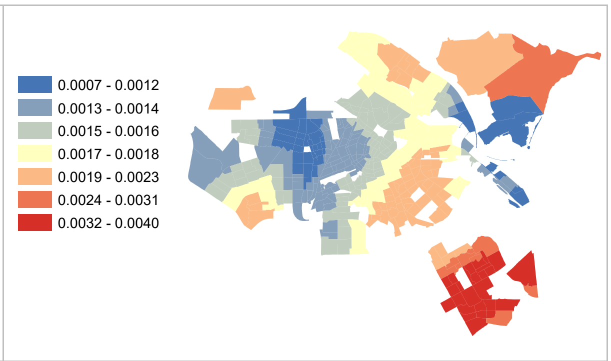
Socio-economic status



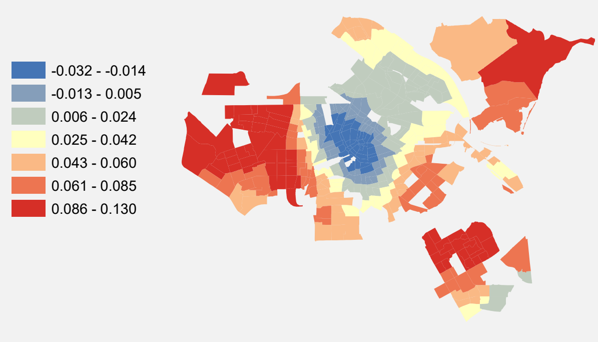
Streetlight density

Address density





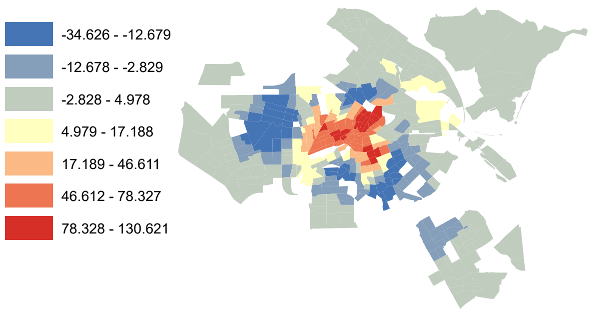
Percentage rented homes



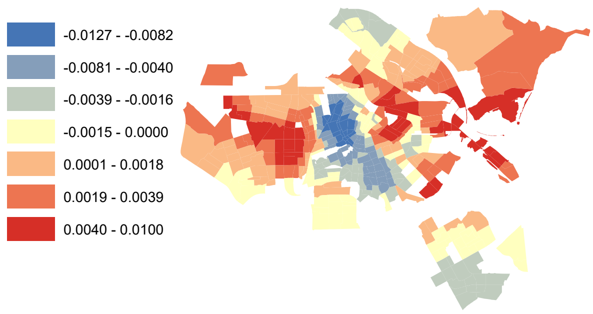
Appendix 8: Coefficients GWR total crimes adaptive kernel 50 neighbors

Adjusted R-squared	0.947
AICc	292.57

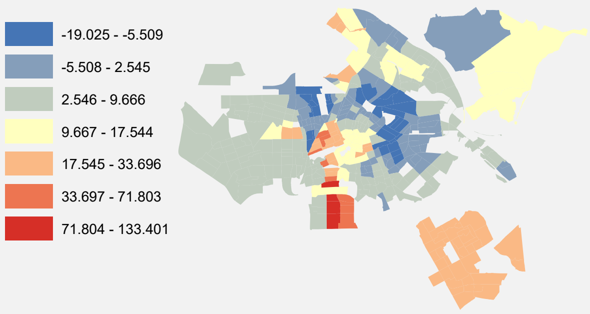
Intercept



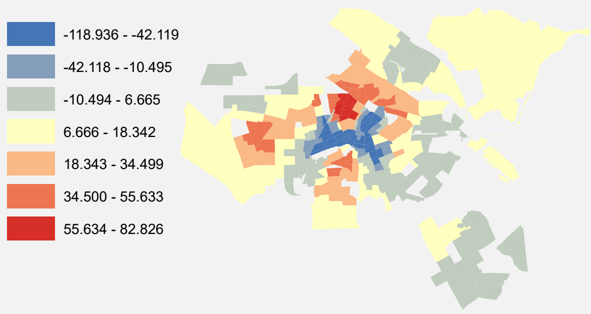
Tree density



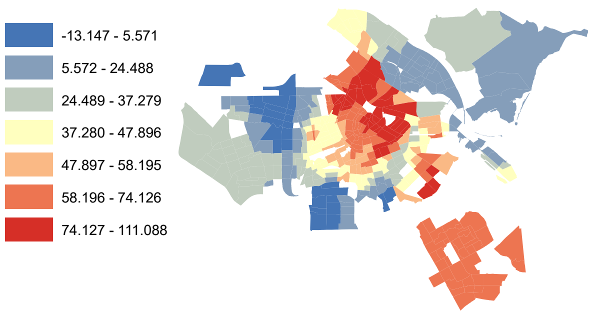
Ratio CCTV



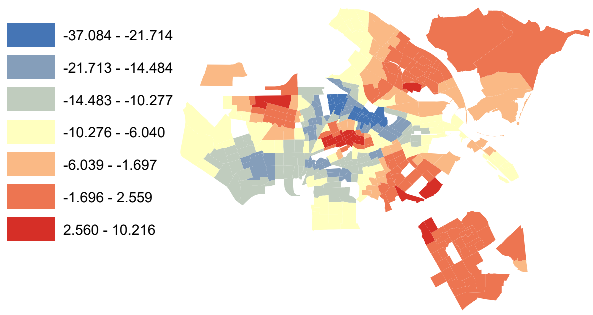
Ethnic heterogeneity



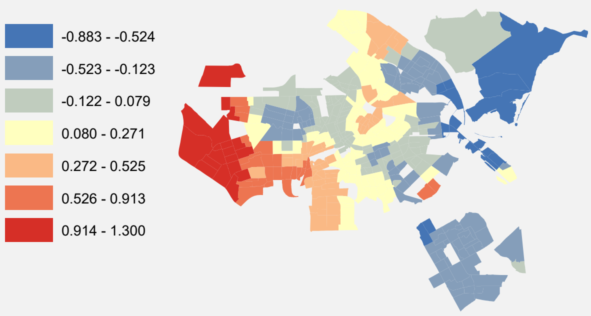
Percentage retail and catering land-use



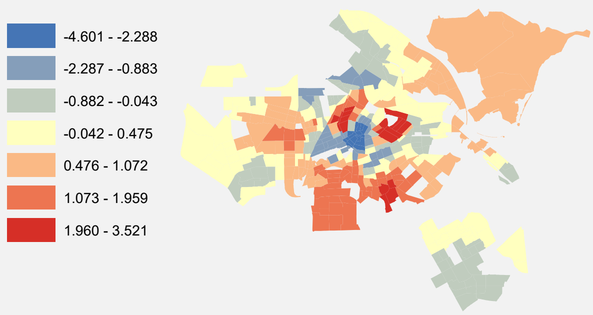
Mixed Land-use



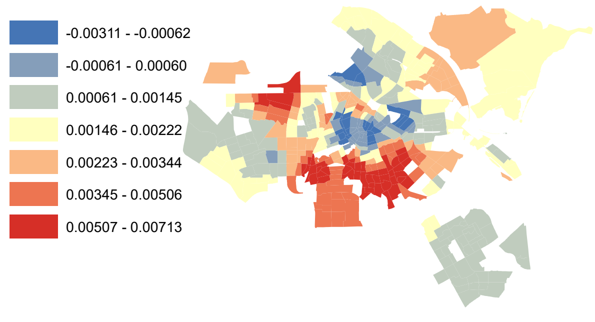
Tourist attraction density



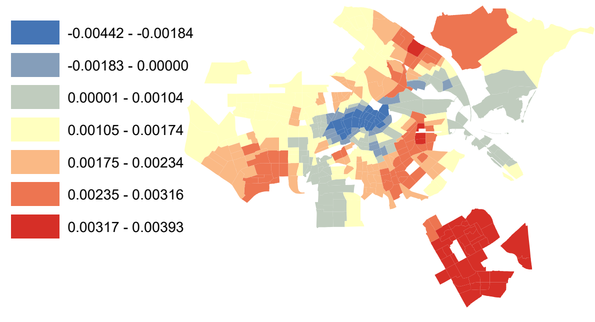
Socio-economic status



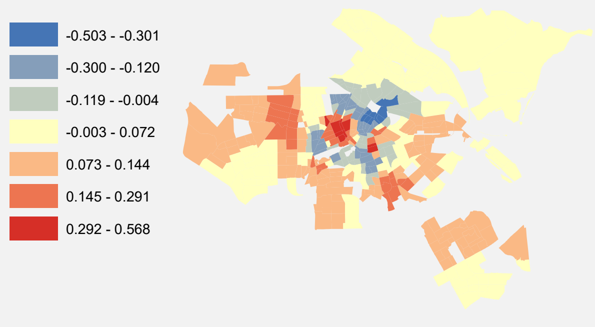
Streetlight density



Address density



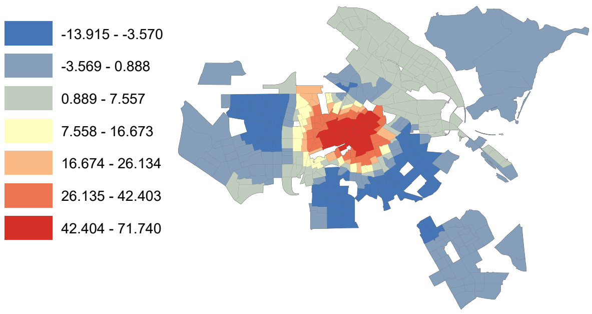
Percentage rented homes



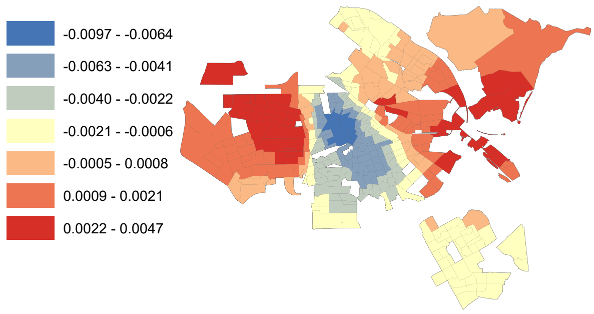
Appendix 9: Coefficients GWR total crimes adaptive kernel 100 neighbors

Adjusted R-squared	0.934
AICc	565.11

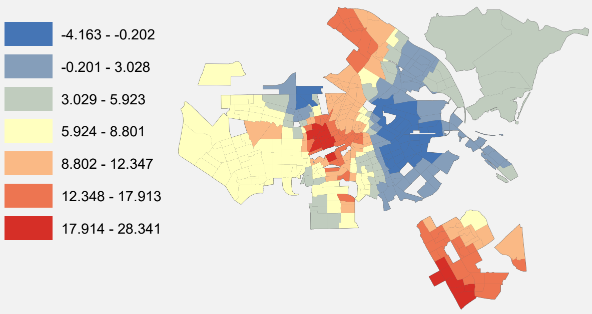
Intercept



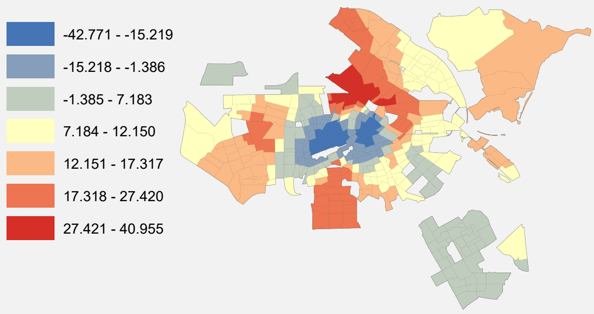
Tree density



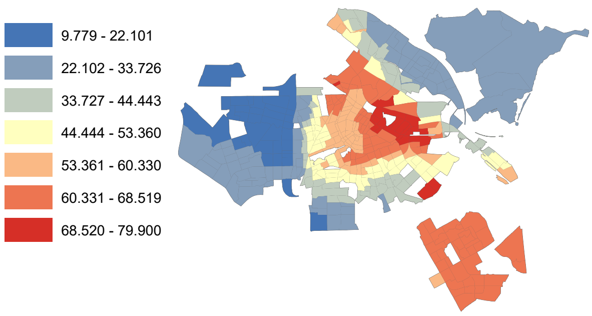
Ratio CCTV



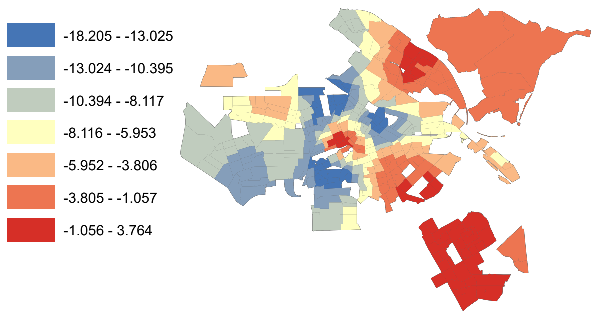
Ethnic heterogeneity



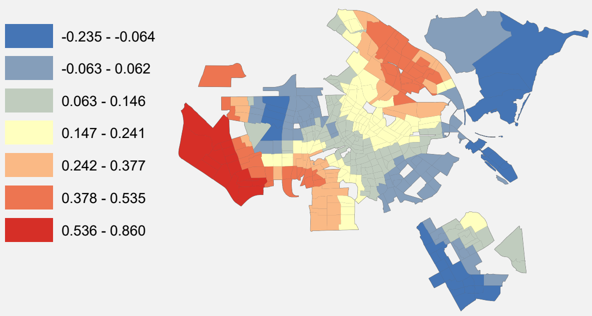
Percentage retail and catering land-use



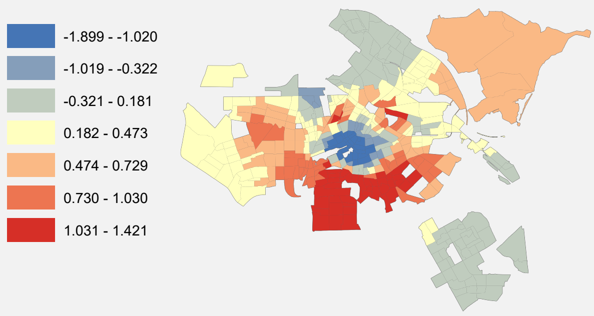
Mixed Land-use



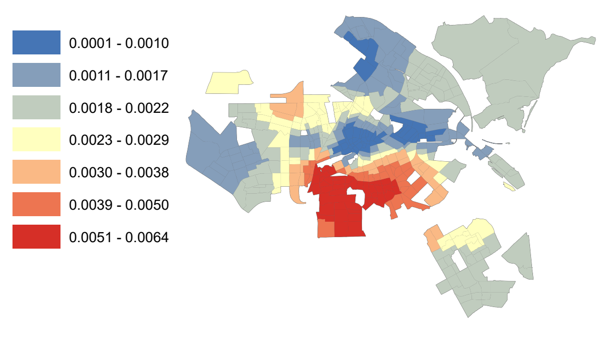
Tourist attraction density



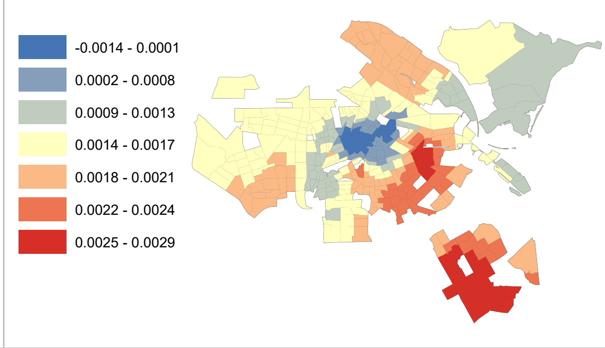
Socio-economic status



Streetlight density



Address density



Percentage rented homes