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Street environments and crime around low-income and minority schools: Adopting an environmental audit tool to assess crime prevention through environmental design (CPTED)

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HIGHLIGHTS

- CPTED principles have been applied in school neighborhood safety.
- Multiple crime types had significant associations with CPTED principles.
- The cleanliness of streets and visual quality of buildings can reduce crime.
- Being adjacent to multi-family housing and bus stops can increase crime.
- The findings add to the evidence supporting the effectiveness of CPTED initiatives.

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ABSTRACT

Crime prevention through environmental design (CPTED) suggests an association between micro-scale environmental conditions and crime, but little empirical research exists on the detailed street-level environmental features associated with crime near low-income and minority schools. This study focuses on the neighborhoods around 14 elementary schools serving lower income populations in Seattle, WA to assess if the distribution of crime incidences (2013–2017) is linked with the street-level environmental features that reflect CPTED principles. We used a total of 40 audit variables that were included in the four domains derived from the broken windows theory and CPTED principles: natural surveillance (e.g., number of windows, balconies, and a sense of surveillance), territoriality (e.g., crime watch signs, trees), image/maintenance (e.g., graffiti and a sense of maintenance/cleanness), and geographical juxtaposition (e.g., bus stops, presence of arterial). We found that multiple crime types had significant associations with CPTED components at the street level. Among the CPTED domains, two image/maintenance features (i.e., maintenance of streets and visual quality of buildings) and two geographical juxtaposition features (i.e., being adjacent to multi-family housing and bus stops) were consistently associated with both violent and property crime. The findings suggest that local efforts to improve maintenance of streets and visual quality of buildings and broader planning efforts to control specific land uses near schools are important to improve safety in marginalized neighborhoods near schools that tend to be more vulnerable to crime. Our research on micro-scale environmental determinants of crime can also serve as promising targets for CPTED research and initiatives.

Abbreviations: CDC, Center for Disease Control and Prevention; CSA, CPTED School Assessment; CPTED, Crime prevention through environmental design; SAfETy, School Assessment for Environmental Typology; SRTS, Safe routes to school; WSB, walking school bus; *T*-COPPE, Texas Childhood Obesity Prevention Policy Evaluation.

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1. Introduction

School neighborhoods are relatively safe places for children but not immune to crime and safety concerns. Particularly in low-income and communities with greater racial/ethnic diversity, children are more likely to witness or experience violence and other forms of victimization in their neighborhoods (Sacks & Murphey, 2018). Yet, they are twice as likely to walk to school due to limited travel options compared to children in high-income and less-diverse communities (Gavin & Pedroso, 2010), which implies that efforts to improve safety and reduce crime incidents around schools serving low-income and diverse communities are imperative. Social disorganization theory has explained the geographical concentration of crime in relation to community structure, such as population density, racial diversity, neighborhood instability, and neighborhood disadvantage (Quick et al., 2018). Given that communities with lower income and diverse residents have both high rates of crime and high proportions of children walking to school, improving the structural/environmental conditions in these communities is particularly important to achieve the goals of safe routes to school (SRTS) programs aimed at promoting safe walking and bicycling to school.

Previous studies have identified a number of micro-scale environmental determinants of crime, suggesting a significant spatial clustering of crime incidents in relation to social and physical environments (Groff, 2017). For example, certain land uses and facilities, such as bars, drug treatment centers, liquor shops, and other less desirable facilities have been shown to be associated with high crime rates (Banerjee et al., 2008). Physical disorder (e.g., litter, graffiti, broken windows, and vandalism) and poor maintenance conditions not only amplify insecurity but also increase the actual incidence of crime (Doran & Lees, 2005). Crime watch or surveillance warning signs act as territorial reinforcement to increase the probability of detecting criminals and potentially reduce future crime (Donovan & Prestemon, 2012). Installation or improvement of street lighting is also reported to decrease crime by increasing surveillance of potential offenders and increasing social cohesion and informal social control (Kim & Park, 2017). These previous studies have largely been based on criminological theories such as defensible space theory, broken windows theory, and the principles of crime prevention through environmental design (CPTED) (Kelling & Wilson, 1982). These theories are among the leading frameworks guiding research on environment-crime relationships.

The aim of this study is to evaluate CPTED principles related to safety in school neighborhoods, particularly around low-income schools. This goal is accomplished by adopting four major design elements of CPTED principles: (a) natural surveillance (e.g., number of windows, balconies, and a sense of surveillance), (b) territoriality (e.g., crime watch signs and trees), (c) image/maintenance (e.g., graffiti, litter, and a sense of maintenance/cleanliness), and (d) geographical juxtaposition (e.g., bus stops, vacant land). We identified specific features among CPTED principles that are potentially correlated with crime incidents at the street segment level in order to inform evidence-based efforts targeting safety improvements to the street environment around schools.

1.1. CPTED: Theoretical and empirical foundations

CPTED is a place-based approach and evolving theory and practice to reduce fear and incidences of crime as well as to promote quality of life by creating places that are less vulnerable to crime (Armitage & Ekblom, 2018; Crowe, 2000). Although the CPTED principles and strategies have been widely used in academic research and practice, the specific terms and components of CPTED used in prior work differ (Ekblom, 2011; Gibson & Johnson, 2016). For example, Poyner (1983) proposed surveillance, movement control, activity support, and motivational reinforcement as the four principles of CPTED, while Moffat (1983) suggested six characteristics of First-Generation CPTED, which included surveillance, access control, territoriality, maintenance, activity support, and target hardening. Armitage (2013) provided additional components of CPTED including physical security, surveillance, movement control, management/maintenance, and defensible space. Cozens and Love (2015) extended a review of the development, evaluation, and applications of CPTED principles by adapting Moffat (1983)'s six principles and further including geographical juxtaposition with the recognition that the capacity of surrounding places that may influence safety and security. Many practitioners used and modified these principles in different formats, with some of them being appropriate only at certain geographical scales (Armitage & Ekblom, 2018). In our study, we adopted Cozens and Love (2015)'s framework of CPTED and used four of their seven components, including surveillance, territoriality, image/maintenance, and geographical juxtaposition. These four components were selected because they (a) aligned well with the scope of this study, (b) could be readily captured through an environmental audit, and (c) were most appropriate for our study context.

First, natural surveillance is a design strategy to maximize the visibility of people and building entrances by keeping intruders under observation. Jacobs (1961) first explained that increasing "eyes on the street" could play a central role in making a place safer and Newman (1972) further elaborated on the idea's implications for environmental design. Typical elements for natural surveillance are the building openings, doors and windows visible from streets or to neighbors, no concealment by planting or fences, open space between houses, and lighting conditions (Abdullah et al., 2013). In terms of the assessment of surveillance, Marzbali et al. (2016) measured surveillance by using the degree of visibility and the quality of lighting at the house and street levels with a five-point Likert scale, which can be easily captured through an environmental audit. Lee et al. (2016) also measured brightness of street lighting and fence removal, finding that sufficient street lighting was associated with reduced fear of crime.

Physical design enables owners/residents to develop a sense of territorial control by defining property lines and distinguishing between private and public spaces (Peeters & van der Beken, 2017). Territoriality as the design concept aims to increase residents' sense of ownership. Territoriality is not a physical spatial term but more closely related to a pattern of attitudes and behaviors responding to a physical space (Ekblom et al., 2013). However, symbolic barriers (e.g. signage) and physical barriers (e.g. fences) are commonly used in practical applications to reinforce territoriality (Armitage, 2013; Sohn, 2016). Landscaping is also one of the cues of territoriality to increase neighborhood attachment and a sense of safety (Kuo & Sullivan, 2001). Some studies adopted several features of territoriality to identify the CPTED constructs by using security systems, signs, personalization items, and landscaping. They found that these landscaping and territorial features influenced fear of crime and perceived neighborhood cohesion (Marzbali et al., 2016).

Image/maintenance is another important CPTED concept referring to physical attributes and the on-going concern for the intended users to provide clean and well-maintained places and reduce physical and social disorder. In other words, poorly maintained neighborhoods send a signal of physical decay that invite targeting crime in the community (Troy et al., 2016). Broken windows theory also posits that physical disorder, such as broken windows, graffiti, litter, vacant lands, and abandoned cars on streets, are the visible evidence of potential crime and other deviant behaviors (Wilson & Kelling, 1982). Such physical incivilities and poor maintenance were known to significantly influence perceived crime (Medway et al., 2016). Thus, several studies attempted to characterize image/maintenance as a part of CPTED domains by considering the house maintenance of exterior walls, doors, windows, roofs, and the presence of incivilities such as graffiti (Lee et al., 2016; Marzbali et al., 2016).

Although geography matters in preventing or discouraging neighborhood crime, the concept of geographical juxtaposition has been largely ignored in the CPTED literature. Geographical juxtaposition, originally coined by Newman (1972), refers to the capacity of surrounding environment and nearby land uses that offer the opportunity to commit crime. However, Cozens et al. (2019) have highlighted the importance of geographical juxtaposition, wider environment, for its role in shaping perceptions of safety. At this point, geographical juxtaposition can be applied to both within and outside the immediate crime location. Previous studies found that certain land uses (e.g., bar, liquor stores, bank, bus stop) were associated with increased crime risks (Banerjee et al., 2008). Geographical juxtaposition is related to the routine activities of the area (Cohen & Felson, 1979) and to the potential locations of crime generators and crime attractors (Brantingham & Brantingham, 1995). According to routine activity theory, crime events happen as the result of offenders, suitable targets, and the absence of guardians against crime within the area of routine activity. Similarly, crime risks can be affected by the place due to the congregation of large numbers of people (crime generators) and by the place providing potential criminal opportunities by offenders (crime attractors). There are three additional underlying CPTED strategies (i.e., access control, activity support, and target hardening) in the framework of CPTED by Cozens and Love (2015), but these domains were not included in our analysis as they are beyond our scope of this study that focuses on the physical environment at the street level.

Some criticisms do also exist regarding the interpretation and application of CPTED strategies. In particular, the elements of CPTED strategies may often conflict with one another (Armitage, 2007). For example, creating territoriality with walls or fences can help deter criminals but may also sometimes compromise opportunities for surveillance (Reynald, 2009). To date, there is a lack of empirical studies testing multiple dimensions of CPTED simultaneously (Abdullah et al., 2013). Research and practice on CPTED have also been criticized due to inconsistent measures and poor definitions within the CPTED domains, hence it has been proposed that CPTED needs to be reconceptualized and clarified (Ekblom, 2011). This lack of clarity regarding CPTED's definition has produced discrepancies in the perspectives held by different stakeholders, such as between academics and policy-makers, and between police officers and offenders (Armitage, 2018; Armitage & Monchuk, 2019). In addition, intoxicated offenders are known to be less likely to be influenced by CPTED strategies (Cozens et al., 2005). Finally, the effectiveness of CPTED should be carefully evaluated within the specific geographical and cultural contexts (Ekblom, 2011).

1.2. School CPTED

CPTED principles have been widely applied and researched in residential settings (Sohn, 2016) and commercial areas (Hunter et al., 2018). However, only in a few instances, they have been applied in school settings or neighborhoods (Vagi et al., 2018). A recent study suggested that school communities applying CPTED principles were effective in reducing youth violence (Lamoreaux & Sulkowski, 2020). Wilcox et al. (2006) explored the relationship of school crime with defensible space and CPTED principles by measuring school-specific territoriality, natural surveillance, and school image/milieu. Bradshaw et al. (2015) also developed the School Assessment for Environmental Typology (SAfETy), which applied CPTED principles to schools to measure the CPTED indicators in the school's physical and social environments, including graffiti/vandalism, appearance, illumination, and surveillance. The US Centers for Disease Control and Prevention (CDC) used CPTED to guide the prevention of school violence and developed the CPTED School Assessment (CSA) tool, which included five principles, natural surveillance, access management, territoriality, physical maintenance, and order maintenance (CDC, 2022). Vagi et al. (2018) used this CSA tool to explore school violence and safety concerns among middle school students and suggested that the CSA tool was useful for guiding school environmental modifications to mitigate violence. Prior studies on CPTED have improved our understanding of the crime risk associated with the school environment and offered valuable insights for reducing child and adolescent exposure to community violence. However, it remains unclear as to how and to what extent CPTED principles can be applied to diverse and lower-income communities near schools that tend to be more vulnerable to crime.

2. Methods

2.1. Study design, setting, and sample

This study is part of a larger project called the Walking School Bus (WSB) randomized controlled trial study in Seattle, WA, which evaluated if a WSB program increased low-income, minority children's active commuting to school and overall physical activity. The 14 study schools were selected based on having at least 75 % of the students qualifying for the free or reduced-price lunch program and having high proportions of underrepresented racial/ethnic children (average non-White: 86 %) who are exposed to disproportionately high levels of crime and health risks associated with physical inactivity.

This cross-sectional study used the street audit data from the WSB study, collected from 656 street segments located within a ¼ mile of the 14 schools with a total enrollment of 5,485 students (See Supplementary Table 1). A 400-meter was chosen as a suitable walking distance surrounding each school (McMillan, 2007). The selected street segments were located in the 55 census block groups. Each school is composed of 1–4 census block groups. The street segment in this study is defined as a segment of roadway or alley between two intersections. The average length of a street segment in our study areas is 441.7 feet (SD = 264.9 feet).

2.2. Dependent variable

The five-year (2013–2017) crime data from the Seattle Police Department were used to generate the dependent variable in this study. We used five-years of data to account for the year-to-year variation and to ensure meaningful variation across the street segments. In terms of the crime type, we focused on violent crime and property crime, because those are the most frequently reported types of crime that children are exposed to (Finkelhor et al., 2009), and they have been commonly used in previous CPTED studies (Sohn, 2016). The specific offenses we selected for this study are crimes against people (i.e., assaults, aggravated assaults, homicide, and robbery; n = 433) and crimes against property (i.e., theft and burglary, n = 2,208).

The crime incident report data included X-Y coordinates, which were used to plot each crime location using ArcMap version 10.6.1. Almost all, i.e., 98 % of the crime incidents, were located on the street segments. Among the crime records assigned to street segments, 36 % of violent crime and 11 % of property crime records were found at intersections and the remaining crimes were found at non-intersection, midblock locations. Although previous studies have excluded intersections as they were generally part of multiple street segments (Weisburd et al., 2004), we decided to include those intersection crime incidents because dropping 11–36 % of valid cases might lead to biased results and reduced statistical power. Thus, we evenly distributed crime incidents to all adjoining street segments as suggested by Kim (2018). For example, if a crime incident occurred at an intersection with four adjoining street segments, we allocated each segment 0.25 % of a crime incident.

2.3. Audit-based built environment data

To assess the micro-scale environmental qualities of the street, we adopted a modified school environmental audit tool, Texas Childhood Obesity Prevention Policy Evaluation (*T*-COPPE), because of its comprehensiveness and established reliability (Lee et al., 2013). This instrument was originally designed to measure walkability and safety of school and street environments and focused on modifiable environmental features that can be readily observed on/from public streets. The *T*-COPPE instrument included more than 150 items, such as land use,

Table 1
Descriptive statistics for independent variables and covariates at the street segment level (n = 656) and census block group level (n = 55).

Variable (description)	Frequency	Percent
Dependent variable		
Violent crime [a]	0.66	1.99
Property crime [a]	3.51	4.87
Natural surveillance		
Streetlight density (number of streetlights/ street length (mi)) a	35.94	17.60
Surveillance		
Poor or fair	220	33.90
Good	335	51.62
Very good or excellent	94	14.48
Presence of many windows overlooking street (0–10 vs 11 +)	541	83.36
Presence of many porches/balconies (0–10 vs 11 +)	55	8.47
Territoriality		
Child safety/pedestrian crossing sign	182	27.91
Bike route/bicycle-friendly sign	65	9.97
Community/cultural/religious sign	197	30.21
Crime watch /surveillance warning/home security service	497	76.23
Beware of dog sign	103	15.80
Trees in public property	471	72.24
Trees in private property	575	88.19
Image/maintenance		
Drainage problems on the street, sidewalk, or buffer	244	37.42
Unattractive items: Graffiti	224	34.36
Unattractive items: Whole or broken bottles/cans	314	48.16
Unattractive items: Cigarette/cigar butts or packages	376	57.67
Unattractive items: Abandoned cars	28	4.29
Unattractive items: Buildings with broken/boarded windows or other vandalism	19	2.91
Unattractive items: Excessive power lines	204	31.29
Sidewalk obstruction: Poles or signs	73	13.49
Sidewalk obstruction: Parked cars		
Sidewalk surface condition: Holes & cracks (none vs a little or a lot)	218	40.30
Sidewalk surface condition: Bumps & uneven surfaces (none vs a little or a lot)	210	38.82
Sidewalk surface condition: Weeds (none vs a little or a lot)	370	68.39
Sidewalk surface condition: Litter (none vs a little or a lot)	218	40.30
Air Pollution (none vs a little or a lot)	31	4.78
Noise from factories (none vs a little or a lot)	223	34.36
Cleanliness and maintenance of street/sidewalk		
Poor or fair	147	22.65
Good	439	67.64
Very good or excellent	63	9.71
Cleanliness and maintenance of buildings and gardens		
Poor or fair	128	19.81
Good	403	62.38
Very good or excellent	115	17.80
Visual quality of street		
Poor or fair	150	23.11
Good	399	61.48
Very good or excellent	100	15.41
Visual quality of buildings		
Poor or fair	150	23.58
Good	403	63.36
Very good or excellent	83	13.05
Visual quality of trees/vegetation		
Poor or fair	138	21.26
Good	404	62.25
Very good or excellent	107	16.49
Geographical juxtaposition		
Single family home	630	96.63
Multifamily housing	143	21.93
Playground, trail, and park	67	10.28
factory/warehouse /storage building/parking lot	23	3.53
Bus stop	65	9.97
Vacant/abandoned/undeveloped land	48	7.36
Vacant/abandoned building	45	6.90
Sidewalk	541	82.98
Arterial	122	18.60
Exposure Variable		
Street segment length (ft) [a]	442.32	264.34
Control Variables		
Segment-level SES (n = 656)		
Residential unit density (residential units/ 100ft of street segment length) [a]	4.47	9.17
Average property value ($/10,000) [a]	13.54	7.19
Census block group-level SES (n = 55)		
Population density [a]	13.61	7.67
Hispanic population rate	0.10	0.11
At least a bachelor's degree rate [a]	0.40	0.19
Poverty rate [a]	0.12	0.14

Note: [a] indicates continuous or count variables represented as the value of the mean and Standard Deviation (SD).

street characteristics, walking and biking conditions, adjacent buildings, and environmental perceptions, which were known or likely to be correlated with walking and safety around elementary schools. With its comprehensive auditor training procedure, the original instrument has been shown to have an adequate level of inter-rater and test–retest reliability. More details about the instrument including its development process, test methods and results, and the auditor training and certification process are included in a previously published paper (Lee et al., 2013). In this study, we selected a total of 40 audit variables that were included in the four domains derived from CPTED principles: (a) natural surveillance (e.g., number of windows, balconies, and a sense of surveillance: n = 4 items), (b) territoriality (e.g., crime watch signs, trees: n = 7 items), (c) image/maintenance (e.g., graffiti, litter, and a sense of maintenance/cleanness: n = 20 items), and (d) geographical juxtaposition (e.g., bus stops, presence of sidewalk, and arterial: n = 9 items). The descriptions of these variables are listed in Table 1. An average of 46.9 (S.D. = 19.0) CPTED street audits were conducted per school.

The audits were conducted independently by two trained staff members over three periods: from February to April 2014 for six schools, January to February 2015 for one school, and January to April 2016 for seven schools. The audit was conducted during the daytime when the weather was sunny or partly cloudy, and auditors observed the environmental conditions while walking along the street. Objective items such as land use type, presence of unattractive items, and number of streetlights were captured using absolute values, dichotomous, and categorical measures. Subjective variables such as a sense of surveillance or maintenance were rated by each auditor by using a five-point Likert-type scale (poor, fair, good, very good, excellent), which was collapsed into three scale formats ("poor or fair", "good", and "very good or excellent") in this study to account for their skewed distribution. If there were mismatched objective item recordings between the two auditors, a third researcher made the final determination based on Google Street Views. For the subjective variables, we used the average value of the two auditors' ratings.

2.4. Socioeconomic status data

As crime incidents are influenced by social disorganization, we included six control variables, socioeconomic status (SES) at street segment and census block group levels. The segment-level measures included average property value and residential housing density. The average property value variable was measured based on the single-family residential properties located along each street segment, using the 2017 King County appraisal data. The housing unit density was measured as the number of residential units per 100 feet of street segment length. For the census block group level confounders, we initially used seven variables from the 2013–2017 American Community Survey. Informed by extensive empirical literature on this topic and their correlations with either violent or property crime, we excluded racial diversity, unemployment rate, and median household income that were not statistically significant at the $p < 0.05$ level. The final variables retained in the analysis were: 1) population density, 2) Hispanic population rate, 3) rate of people having at least a bachelor's degree, and 4) rate of people below the poverty line.

2.5. Statistical analysis

We used a negative binomial regression in our study as an appropriate choice for modeling over-dispersed count variables like crime data. We also had to account for the potential clustering at the census block group level, as street segments are nested within the larger unit of census block groups, and therefore used multilevel negative binomial regressions in all our analyses. We also included the street segment length in our model as the exposure variable, allowing the counts of crime at the street segment level to be comparable because longer street segments potentially allow for more crime opportunities relative to shorter street segments.

The estimated negative binomial regression coefficients and Standard Error (SE) were calculated. In the bivariate analyses, we conducted unadjusted multilevel negative binomial regressions to see any correlation of each built environmental variable with the types of crime outcomes. We then included all significant variables ($p < 0.05$) and control variables regardless of their statistical significance in the multivariate analyses and only significant results of the built environments were reported in the final models. We also checked for the presence of multicollinearity among the independent variables and calculated the variance inflation factor (VIF). All analyses were conducted using Stata SE 15.1.

3. Results

Fig. 1 shows the distribution of violent property crime incidents

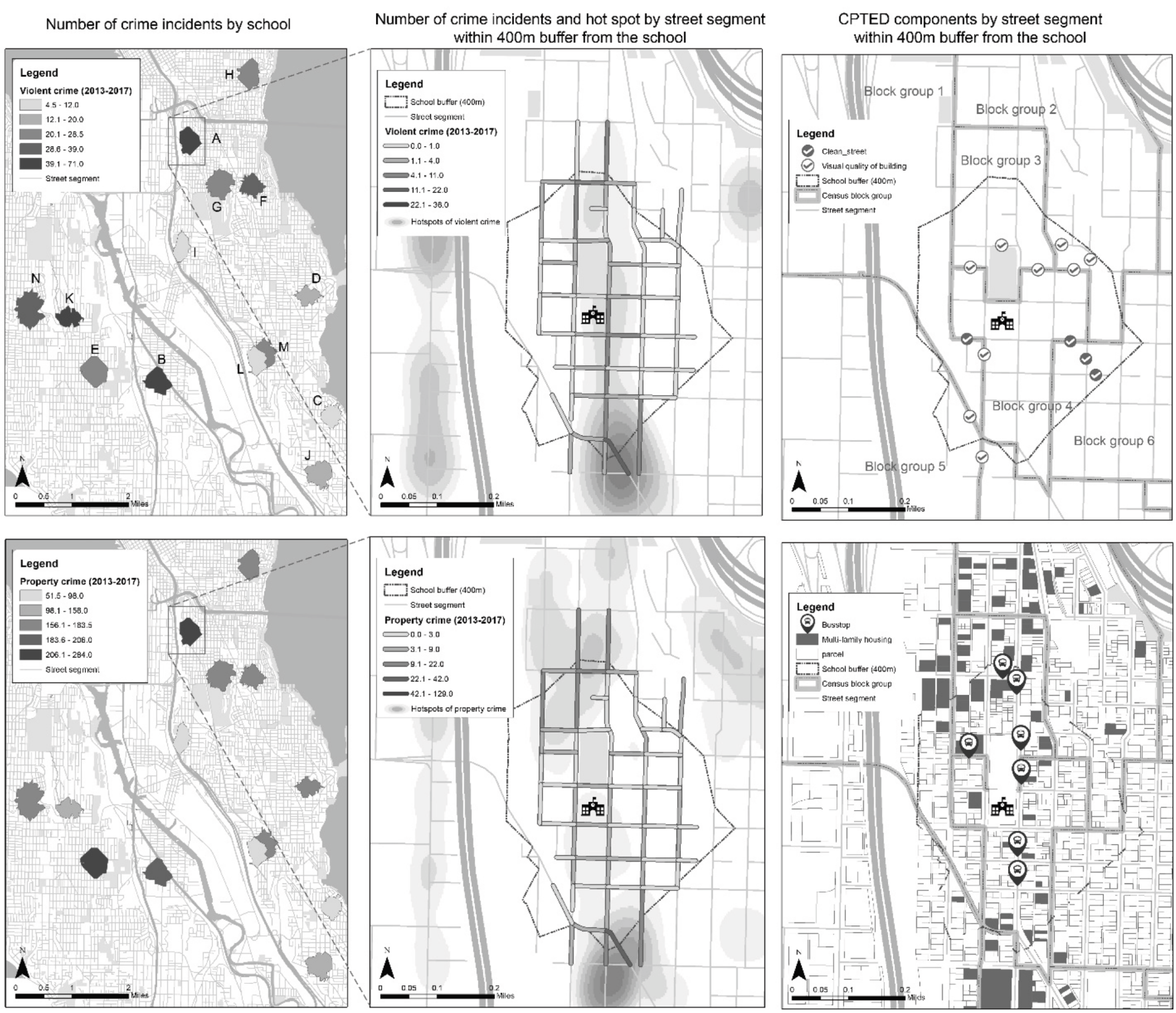

Fig. 1. Spatial distribution of violent and property crimes and CPTED variables.

across the schools and street segments. This visualization reveals that both violent and property crimes were concentrated in a certain school and street segment in responding to some items within CPTED principles. The count of crime incidents between 2013 and 2017 in the selected street segments located within ¼ miles of low-income elementary schools was over-dispersed (total violent crime: mean = 0.66, variance = 3.98 and total property crime: mean = 3.51, variance = 23.74).

Table 1 illustrates the descriptive statistics for outcome variables and built environmental variables used in the analysis. Regarding the natural surveillance domain, the street segments had a mean of 35.9 (SD = 17.6) streetlights per mile of street segment. Around 14.5 % of street segments were reported to be at the very good or excellent surveillance level. Regarding territorial reinforcement, two-thirds of the street segments had crime watch, surveillance warnings, or home security service signs and 15.8 % had beware of dog signs. In terms of trees, 72.2 % of the street segments had trees on public property and 88.2 % had trees on private property but clearly visible from the streets. In terms of the image/maintenance domain, almost all (98.7 %) street segments had one or more unattractive items such as graffiti, abandoned cars, or buildings with broken windows while only 4.8 % of the street segments were reported having a little or a lot of air pollution. Average sidewalk quality or visual quality of streets, buildings, and trees were rated as good to very good. As for geographical juxtaposition, almost all street segments (96.6 %) in our study had one or more single-family homes; 21.9 % had one or more multifamily homes; 9.9 % had bus stops; and 18.6 % of the street segments were located adjacent to arterial roads.

Table 2 shows the bivariate analysis results of the associations between built environmental factors and crime. In the bivariate model, we found that 21 and 18 built environmental factors were independently associated with violent crime and property crime, respectively ($p < 0.05$). Most natural surveillance items were significantly associated with property crime only while one item, streetlight density, was consistently associated with both violent and property crimes. The items from territoriality showed inconsistent associations with each violent crime and property crime. Specifically, crime watch, beware of dog sign, and trees in private property were negatively associated with violent crime while community signs and trees in public property were positively associated with property crime. In the image/maintenance domain, the presence of unattractive items (e.g., broken bottles, cigarette), sidewalk obstructions (e.g., poles or signs), and noise from factories were positively associated with both crime types. Cleanliness and maintenance of streets and visual quality of buildings were negatively associated with both violent and property crime. In the geographical juxtaposition domain, we found that presence of multifamily housing, bus stop, and arterials on the street segments were consistently shown to have positive associations with both violent and property crime. The presence of single-family housing and factories was negatively associated with only violent crime.

Table 3 presents the results from multivariate analyses examining the associations between built environmental factors and crime. Sidewalk obstructions, such as poles, parked cars, and litter, were excluded from the multivariate models as they were fully dependent on sidewalk presence. After adjusting for those significant variables ($p < 0.05$) selected from the binary analyses, six environmental variables retained their significant associations with violent crime and property crime. Out of the six, two environmental features from the image/maintenance domain (i.e., lower visual quality of buildings, lower cleanliness or maintenance of street) and two land use types in the geographical juxtaposition domain (i.e., presence of multifamily housing, and presence of bus stop) were consistently associated with greater violent and property crime. Additionally, crime watch sign in the territoriality domain was negatively associated with violent crime, while air pollution was positively associated with violent crime. In the natural surveillance domain, streetlight density and surveillance were positively associated with property crime. Fig. 2 shows examples of physical features

Table 2
Bivariate Analyses: Multi-level negative binomial regression model results for crime type.

	Violent Crime		Property Crime	
	Coeff	SE	Coeff	SE
Natural surveillance				
Streetlight density	0.025**	0.004	0.012**	0.003
Surveillance (ref. poor or fair)				
Good	0.059	0.179	0.336**	0.096
Very good or excellent	0.395	0.250	0.623**	0.140
Number of windows overlooking street	0.554	0.491	1.438**	0.332
Number of porches/ balconies	0.234	0.153	0.451**	0.082
Territoriality				
Child safety/pedestrian crossing sign	0.128	0.165	−0.043	0.091
Bike route/bicycle-friendly sign	0.565*	0.232	0.215	0.136
Community/cultural/ religious sign	0.188	0.169	0.269**	0.090
Crime watch/surveillance warning	−0.393*	0.172	0.136	0.100
Beware of dog sign	−0.435*	0.212	−0.049	0.110
Trees in public property	0.321†	0.187	0.190*	0.096
Trees in private property	−0.548*	0.216	0.005	0.131
Image/maintenance				
Drainage problems	0.118	0.186	0.162†	0.091
Graffiti	0.655**	0.157	0.104	0.088
Whole or broken bottles/ cans	0.457**	0.156	0.205*	0.083
Cigarette/cigar butts or packages	0.641**	0.168	0.396**	0.085
Abandoned cars	0.047	0.363	0.127	0.204
Buildings with broken/ boarded windows	0.647	0.372	0.424†	0.226
Excessive power lines	−0.019	0.210	0.322**	0.109
Poles or signs	0.886**	0.199	0.387**	0.126
Parked cars	0.006	0.238	0.278*	0.131
Holes & cracks	−0.224	0.173	0.002	0.093
Bumps & uneven surfaces	0.023	0.173	0.032	0.094
Weeds	−0.077	0.179	0.067	0.098
Litter	0.651**	0.164	0.318**	0.093
Air Pollution	1.195**	0.300	0.134	0.198
Noise from factories	1.042**	0.154	0.25**	0.088
Cleanliness and maintenance of street/sidewalk (ref. poor or fair)				
Good	−0.506**	0.175	−0.217*	0.100
Very good or excellent	−0.996**	0.336	−0.204	0.165
Cleanliness and maintenance of buildings and gardens				
Good	0.120	0.228	−0.012	0.108
Very good or excellent	−0.263	0.354	0.014	0.146
Visual quality of street				
Good	−0.129	0.191	−0.012	0.106
Very good or excellent	−0.502†	0.271	0.085	0.146
Visual quality of buildings				
Good	0.093	0.182	−0.208*	0.103
Very good or excellent	−0.593*	0.301	−0.064	0.127
Visual quality of trees/ vegetation				
Good	−0.461*	0.190	−0.022	0.109
Very good or excellent	−0.943**	0.273	0.042	0.144
Geographical juxtaposition				
Single family home	−1.066**	0.329	−0.339	0.215
Multifamily housing	1.456**	0.164	0.714**	0.091
Playground/ trail/ park	0.103	0.241	−0.168	0.137
factory/Warehouse/storage building/parking lot	0.853*	0.353	0.194	0.212
Bus stop	1.156**	0.199	0.514**	0.126

(continued on next page)

Table 2 (*continued*)

	Violent Crime		Property Crime	
	Coeff	SE	Coeff	SE
Vacant/abandoned land	−0.284	0.306	−0.034	0.159
Vacant/abandoned building	0.485†	0.265	0.197	0.154
Sidewalk	0.519*	0.237	0.215†	0.117
Arterial road	1.158**	0.161	0.344**	0.101
Control Variables				
Street segment level				
Residential unit density	0.016†	0.009	0.015**	0.006
Average property value	−0.085**	0.017	−0.023**	0.006
Census block group level				
Population density	0.033†	0.017	0.014*	0.007
Hispanic population rate	2.891**	1.127	1.302*	0.537
At least a bachelor's degree rate	−1.876*	0.736	−0.641*	0.321
Poverty rate	2.118*	0.911	0.518	0.421
Random Effect [a]	Variance Component	SE	Variance Component	SE
Census block group	0.556**	0.193	0.076*	0.036

Note: **p < 0.01, *0.01 $\leq p < 0.05$ †0.05 $\leq p < 0.1$; Coeff: Coefficient; and SE: Standard Error; [a] displays the results of multi-level models presenting the variance components (the amount of variation across the census block groups) for violent and property crime.

Table 3
Multivariate Analyses: Multi-level negative binomial regression model results for crime type.

	Violent Crime		Property Crime	
	Coeff	**SE**	**Coeff**	**SE**
Natural surveillance				
Streetlight density	–	–	0.008**	0.003
Surveillance (ref. poor or fair)				
Good	–	–	0.120	0.098
Very good or excellent	–	–	0.307*	0.140
Territoriality				
Crime watch/surveillance warning	−0.401**	0.151	–	–
Image/maintenance				
Air Pollution	0.700*	0.277	–	–
Cleanliness and maintenance of street/sidewalk (ref. poor or fair)				
Good	−0.421*	0.174	−0.272**	0.102
Very good or excellent	−0.764*	0.366	−0.209	0.170
Visual quality of buildings (ref. poor or fair)				
Good	−0.387*	0.176	−0.290**	0.101
Very good or excellent	−0.027	0.260	−0.032	0.122
Geographical juxtaposition				
Multifamily housing	0.634**	0.213	0.414**	0.109
Bus stop	0.634**	0.213	0.310*	0.143
Constant	−6.978**	0.626	−6.525**	0.500
Random Effect	Variance Component	SE	Variance Component	SE
Census block group	0.031	0.065	0.044†	0.028

Note: **p < 0.01, *0.01 $\leq p < 0.05$ †0.05 $\leq p < 0.1$; We included all significant variables ($p < 0.05$) and socio-economic status variables in the multivariate analyses; Poles, parked cars, and litter on the sidewalk variables were excluded in the multivariate models as these sidewalk obstructions were only found when sidewalk exists; Coeff: Coefficient; and SE: Standard Error.

associated with increased crime as shown in our analyses. The collinearity statistics (VIF values) of the variables included in the multivariate models were lower than 4, indicating no serious multicollinearity problems among the independent variables (Supplementary Table 2).

4. Discussion

The purpose of this study was to identify micro-scale physical features, as measured by the CPTED-based environmental audit, in relation to crime incidents near low-income and minority schools characterized by high rates of crime and violence. This study addressed two gaps in the current literature: first, it evaluated four principles of CPTED (i.e., natural surveillance, territoriality, image/maintenance, and geographical juxtaposition) at the school neighborhood level, particularly around low-income elementary schools. Little research has studied the applications of CPTED principles around low-income schools, and only a few studies adopted CPTED assessment at grounds, buildings, and interiors within the school (Lamoreaux & Sulkowski, 2020). Second, this study assessed the associations of various street environmental conditions with crime at the micro-scale level (i.e. street segments located within a 400 m from the schools). This filled a gap in the literature since existing studies had not adequately captured micro-scale environmental features and relied on larger geographical scale, such as block groups or tracts. This study's empirical results suggested the importance of CPTED in preventing crime near low-income elementary schools at the micro-scale level and offered additional evidence of the value of micro-scale CPTED approaches.

We found that several physical features associated with the CPTED principles were linked with crime around low-income minority schools. This finding can support SRTS to make it safer for students to commute to school and enhance overall safety in school neighborhoods. Especially, streets around schools are where school-aged children travel and play on the way to and from school. Several studies found that high crime rates in the neighborhood were among the major barriers to walking and physical activity among children (Jamme et al., 2018). Exposure to crime near schools was also significantly associated with students' academic performance, especially in low-income and minority schools (Sharkey et al., 2014). Thus, identifying actual crime incidents around schools and applications of relevant CPTED principles can be beneficial to practitioners and policy makers providing them with a guidance on the environmental design strategies to mitigate crimes near schools and encourage children to walk to/from school and play outdoors at/near schools. Especially in high crime school neighborhoods, school communities can also benefit from this study by educating parents and residents about the specific ways (e.g. keeping maintenance of streets and visual quality of buildings as the cues to care) to modify their surrounding environment to improve their own and their children's safety (Murray & Swatt, 2013).

The most effective predictors from CPTED principles that were consistently associated with both violent and property crimes around low-income schools came from the image/maintenance and the geographical juxtaposition domains. From the image/maintenance domain, perceived built environmental variables such as overall sense of cleanliness and maintenance of streets and visual quality of buildings remained significant in the multivariate analysis. This is consistent with other studies finding that street and landscape characteristics related to care and maintenance can help reduce crime through the "cues to care" effects (Nassauer et al., 2021). Based on the "broken window" hypothesis (the opposite of the "cues to care" concept), there were also several physical disorders, including graffiti, whole or broken bottles, cigarettes, buildings with broken windows, litter, and noise from factories, significantly associated with criminal activities in the bivariate analyses. However, these variables became insignificant after adjusting for the neighborhood structure variables (e.g., Hispanic population rate or ethnic diversity and poverty rate) and other built environmental characteristics. This is likely because larger neighborhood structural characteristics, such as poverty, play a stronger role in influencing levels of disorder (Sampson & Raudenbush, 2001). The findings implied that just removing small objective cues of physical disorder may have limited

Fig. 2. Example of significant environmental correlates of crime from the environmental audit The left top image shows streets with poor visual quality of the vegetation (48th Ave S, 2014). The middle top image shows abandoned vehicles on the street (S Spencer St, 2014). The right top image shows poorly maintained and unclean street conditions (33rd Ave S, 2014). The left bottom image shows a neighborhood crime watch sign (30th Ave SW, 2014). The middle bottom image shows public trees that can decrease surveillance (35th Ave SW, 2014). The right bottom image shows the streetlights located in areas with mixed land use near a school (S Orcas St, 2014).

impact on crime prevention, and clean/well-maintained streets and visually attractive buildings are more promising to discourage crimes in marginalized communities around elementary schools.

In the geographical juxtaposition domain, we found that street segments with certain land use types were strongly associated with criminal activity. For example, multifamily housing and bus stops were positively associated with violent and property crime even after controlling for other covariates, which is consistent with the literature (Stucky & Ottensmann, 2009). Multifamily housing and bus stops are the main land uses correlated to crime, likely because high-density residential areas and public transportation have higher concentrations of people and become crime targets. Particularly, walking next to bus stops or waiting at bus stops were frequently reported as a safety concern (Loukaitou-Sideris, 2005). While only 10 % of street segments in our school neighborhoods had a bus stop, their presence on the way to/from school was also known to be negatively associated with perceived convenience of walking among children (Zhu & Lee, 2009). Given the nature of urban school districts, particularly near low-income and minority schools, that typically contain high-density residential areas and public transportation systems, additional efforts from the school district and transit providers are needed to improve safety and facilitate adult supervision for children using streets near schools for commuting and other purposes.

For territoriality, our results showed that most of the environmental features were associated with certain crime types in the bivariate analyses but not in the multivariate analyses. For example, trees on private properties that are visible from the streets were significantly associated with lower violent crime, while trees along the public right-of-way of the streets were marginally associated with higher violent crime in bivariate analyses. However, these variables were not significantly associated with crime once we considered other built environment factors, such as land use or visual quality of the vegetation in the model. Similarly, crime watch, bicycle-friendly, and beware-of-dog signs had significant associations with crime in the bivariate analyses, but only the crime watch sign variable maintained statistical significance with lower violent crime in the multivariate analyses. Crime watch signs are known to serve as symbolic barriers and territorial cues, influencing offenders' perception of being noticed (Perkins et al., 1993). This finding suggests that installing and displaying signs featuring images of watching eyes may be a simple yet effective intervention to reduce violent crime around low-income minority schools.

It is also noteworthy that our measures of natural surveillance, such as streetlight density and the sense of surveillance, unexpectedly showed a positive relationship with the property crime while those were not significantly associated with violent crime. This finding was somewhat inconsistent with previous studies showing a positive effect of street lighting and good natural surveillance in crime reduction through increasing visibility and guardianship (Lawson et al., 2018). However, some studies found that the effectiveness of Jacobs' concept of 'eyes on the street' in reducing crime is not always valid especially in areas where neighborhood walkability exceeds certain thresholds, which could potentially lead to increased motivated offenders, increased suitable targets, and decreased capability of guardianship (Lee, 2021). Visibility of building openings from the street was also associated with increased residential burglaries by influencing offender's decision to break into buildings (Amiri et al., 2019). Chalfin et al. (2022) argued that greater visibility through increased street lighting can also help offenders find crime targets. Weisburd et al. (2014) even found that more street lighting was associated with a higher likelihood of being a crime hot spot at the street segment level, which is related to the fact that naturally more street lighting is located in busy streets with more people and traffic. It is also likely that more lights are installed in areas with greater crime incidences/concerns. Further studies are warranted to explore why and how streetlighting and surveillance are associated with increased property crime around low-income schools.

We acknowledge several limitations of this study. Importantly, our study was limited to street segments located in school areas with higher proportions of racial-ethnic minorities and households with lower incomes. Thus, the present findings cannot be generalized to dissimilar streets in other school neighborhoods. Also, the crime data did not capture whether the crime incidents involved youth and occurred on the streets or not, which could have implications for children's school travel related to these crimes. Furthermore, audit data were collected at different times from 2014 to 2016 and different months between January and April, which may be problematic for time-variant factors. For example, factors such as the presence of sidewalks and signage will likely not change, but the quality of the street environment or perceived maintenance may be influenced by the time and weather conditions when the audit was conducted. Finally, the analyses conducted here are cross-sectional, making it impossible to make conclusions about causal relationships. Future research should perform longitudinal analysis of street variability in crime trajectories to examine how changes in street design relates to changes in the crime rate over time.

5. Conclusion

Findings from our study suggested that CPTED-related street-level built environmental features are associated with crime incidents in areas along the streets in neighborhoods around schools with a high proportion of low-income and racially/ethnically diverse students in Seattle, WA. As few existing studies considered the multi-faceted CPTED principles at the school neighborhood and the detailed street-level environmental factors, our study provides additional insights on the characteristics of CPTED principles associated with crime safety around schools serving low-income and diverse populations. Particularly, four specific environmental features from the image/maintenance and geographical juxtaposition domains showed significant associations with both violent and property crime. Overall sense of cleanliness and maintenance of streets and visual quality of buildings can provide "cues to care" effects, contributing to reducing both crime types. This result highlights the importance of local efforts for improving street maintenance/cleaning and the design/aesthetics of buildings as well as the collaborative efforts among urban planning, design professionals, transportation, youth development, and criminal justice to enhance safety near schools, especially in high-risk communities. On the other hand, we found that areas with high concentrations of people, such as multi-family residential areas and bus stops, were prone to criminal activities. This can translate into increased exposure to crimes near low-income and minority schools as they tend to be located in higher density areas. Further work is needed to better understand the causal pathways between these variables, as well as an optimal development density around schools balancing adequate visual surveillance (i.e., eyes on the street) and potential crime exposure due to increased human activities.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104676.

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