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Residential crimes and neighbourhood built environment: Assessing the effectiveness of crime prevention through environmental design (CPTED)

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ABSTRACT

The objective of this paper is to assess the relationship between residential crime and the built environment that reflects the principles of crime prevention through environmental design (CPTED) at the neighbourhood level. Using crime data for Seattle, this study investigated the effectiveness of CPTED principles associated with two different space design approaches (i.e., permeable space and defensible space) with respect to reducing residential crime. For the analysis, 1407 cases of residential crime (i.e., burglaries and robberies) were extracted from the Seattle crime incidents report. To identify the spatially unbiased distribution of residential crime, an area-standardized crime measure (i.e., crime density) was used in the analysis. The regression results showed that the proportion of the residential area, the average number of building storeys, bus-stop density, street density, and intersection density was significantly related to residential crime when the model was controlled for population density, neighbourhood median household income, and the distance of the neighbourhood from the closest police station. The findings indicated that land use diversity along with improved street connectivity has an adverse effect on prevention of residential crime. Increases in bus-stop density and street density in neighbourhoods were negatively related to residential crime. The study calls for the refinement of CPTED concepts to increase the discriminative controllability of potential crime attractors/generators and preventers in the neighbourhood.

1. Introduction

Research on the geographic distribution and environmental determinants of crime has been an important area of interest in the fields of criminology, environmental psychology, and urban design and planning. Criminologists believe that crimes in urban neighbourhoods are strongly associated with demographic and socio-economic contexts (Cahill & Mulligan, 2003; Christens & Speer, 2005). From the perspective of environmental psychology, crime is considered to be a type of behaviour that is affected by physical environmental features (National Institute of Justice, 1996). Since the appearance of Jane Jacobs' book '*The Death and Life of Great American Cities*' in 1961, the relationship between crime and the built environment has been extensively investigated in the field of urban design and planning. In her book, Jacobs emphasized land use diversity and a high level of pedestrian activity as important attributes of neighbourhood safety (Jacobs, 1961). She believed that the continual use of public areas promoted by the creation of open, permeable environment[1] with mixed land uses was the most effective way of ensuring informal surveillance. The rationale of such arguments is based on the idea that the more people there are in the streets, the more opportunities there are for informal surveillance, which in turn discourages criminal activity (Greenberg & Rohe, 2007). In contrast, Newman's 'Defensible Space' theory (Newman, 1972) proposed a different approach. Although Newman found common ground with Jacobs in emphasizing surveillance in neighbourhoods, he suggested the creation of a 'defensible space', which was characterized by low-density, residential-dominated environments with restricted access to strangers. From the perspective of the 'Defensible Space' theory, if there are too many individuals in a space, the residents' abilities to recognize strangers as intruders may be diluted (Hillier & Sahbaz, 2008).

Subsequently, the research of Jacobs and Newman became the conceptual basis for a new approach to crime control known as 'crime prevention through environmental design' (CPTED) (Greenberg & Rohe, 2007; Kyttä, Kuoppa, Hirvonen, Ahmadi, & Tzoulas, 2014; Nichols, 2012). Originally used by Jeffery (1969), CPTED refers to the proper design and effective use of the built environment for reducing the fear and the incidence of crime (Crowe, 2000). In previous research on CPTED, four principles – 1) territoriality, 2) natural surveillance, 3) activity support, and 4) access control) – have been commonly considered as key concepts for modifying the built environment to reduce crime (Carter, Carter, & Dannenberg, 2003; Cozens, 2002; Kajalo & Lindblom, 2015; National Crime Prevention Council, 2003).

Among the four principles, territoriality is a design concept that delineates private space from public space and creates a sense of

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[1] Permeable environment refers to urban forms that permit movement of people or vehicles with great ease and with more choice of routes (Cozens & Love, 2009).

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Table 1
Findings of CPTED studies.

	Tested CPTED principles	Findings
Anderson et al. (2013)	Territoriality/surveillance/activity support	Crime is associated with indicators of built environment related to territoriality, surveillance, and walkability. Residential blocks have lower crime than blocks zoned for commercial or mixed use.
Brown and Altman (1983)	Territoriality	Applying territorial concepts can reduce burglary by affecting burglar's decision to burglarize.
Ratcliffe (2003)	Territoriality	Territoriality can be effective at local level and becomes less effective as the resolution grows larger.
Wortley and McFarlane (2011)	Territoriality	Two elements of territoriality, ownership and guardianship, are effective in reducing theft levels.
Hillier and Shu (2000b)	Natural surveillance/access control	Spaces with some through movement and good visual connections contribute to increasing safety.
Shu and Huang (2003)	Natural surveillance/access control/activity support	Segregated areas, allowing fewer passers-by to enter the areas, are more vulnerable to crime than integrated ones. Front door to front door visibility and the degree of road accessibility influence burglary distribution.
Welsh and Farrington (2002)	Natural surveillance	Improved street lighting has an effect on improving surveillance opportunities to prevent crime.
Poyner (1983)	Natural surveillance	The natural surveillance component of the defensible space theory is effective in controlling residential burglary, vandalism in multiunit housing, and school break-ins.
Hillier (2004)	Activity support/access control	Local movement potentials and 'intelligibility' (the difficulty/ease of finding one's way around) are negatively related to burglary and car crime.
White (1990)	Access control	Arterials with higher access levels are significantly associated with neighbourhood burglary rates when neighbourhood economic factors, instability, and structural density are controlled.
Yang (2006)	Access control	The incidence of first-time burglaries is associated with permeable street patterns. The gridiron layout is the most statistically significant predictor of burglarized residences among various street patterns.
Armitage (2010)	Access control	The analysis of the street layout of developments in UK indicates that the safest road layout is the true cul-de-sac (with the least connectivity), followed by the through road and the leaky cul-de-sac.

ownership. It is based on the assumption that people will protect their own space and respect the territory of others. The identification of intruders and potential offenders is easier in such well-defined spaces. Brown and Altman (1983), for example, examined the effectiveness of territoriality in crime prevention by comparing the territorial displays in burglarized and non-burglarized houses in residential area. They found that applying territorial concepts can reduce burglary by affecting burglars' evaluation of target's vulnerability. The validity of territoriality was also supported by findings from other studies (Anderson, MacDonald, Bluthenthal, & Ashwood, 2013; Ratcliffe, 2003; Wortley & McFarlane, 2011).

The second principle, natural surveillance, refers to the proper placement and use of windows, lighting, and landscaping to increase the possibility of observing activities occurring in the area (Peak, 2013). The primary aim of natural surveillance is to maintain potential criminals under observation. Areas can be designed to be easily observable by modifying physical features to increase visibility and by placing people and activities in configurations that maximize surveillance possibilities (BC Housing, 2014). Poyner's (1983) review of American studies testing defensible space theory, Hillier and Shu's (2000b) analysis of the relationship between crime and street configuration, and Welsh and Farrington's (2002) review of research on lighting and crime show the importance of natural surveillance in neighbourhood safety.

The third principle, activity support, aims to promote outdoor activities through the planning and location of public space for safe activities (Puget Sound Regional Council, 2014). Safe activities are expected to attract ordinary individuals, who can be part of the natural surveillance system and take action to discourage potential offenders from committing crimes (Cozens, Saville, & Hiller, 2005). Key strategies of activity support at the neighbourhood level include putting sidewalks along roads, providing public open space, and supporting public activities in key community areas (Puget Sound Regional Council, 2014). Studies examining the relationship between pedestrian movement and crime (Hillier, 2004; S. Shu & Huang, 2003) found that street layouts promoting pedestrian activity can reduce crime.

Access control, the last principle of CPTED, is a design concept that aims to reduce crime opportunities by denying potential offenders' access to crime targets and creating a heightened sense of risk in offenders (Cozens et al., 2005; Mair & Mair, 2003). It relies on physical elements, such as doors, fences, and landscaping, to keep unauthorized persons out of communities. Access control strategies at the neighbourhood level include closing off streets through traffic, applying neighbourhood-based parking restrictions, and developing other design features to create physical or psychological barriers (Cozens, 2002; National Crime Prevention Council, 2003). Previous research investigating the effect of access control on neighbourhood safety include White (1990); Yang (2006), and Armitage (2010).

Table 1 presents the main findings of CPTED research related to the four principles discussed above. Although a considerable body of research demonstrates the significance of CPTED strategies in crime prevention, there is either equivocal or insufficient evidence to evaluate the performance of the two different space design concepts: 'permeable space' and 'defensible space'. A number of studies have reported that environmental factors that promote permeable neighbourhood settings, such as better street connectivity and a mix of retail destinations, improve safety (Browning et al., 2010; Duany, Plater-Zyberk, & Speck, 2001; Hillier & Shu, 2000a). Other studies suggest that increased permeability and mixed land uses are associated with increased crime (Anderson et al., 2013; Cozens, 2008; Schneider & Kitchen, 2007; Yang, 2006) and that homogenous neighbourhoods with restricted vehicular and pedestrian access are safer (Greenberg, Rohe, & Williams, 1982; Poyner, 1983).

One possible reason for the inconsistency in the research findings may be methodological limitations associated with the measurement of crime. Many studies that investigate the relationship between crime and the built environment rely on subjective measures of crime (e.g., residents' fear of crime and perceived safety). Such measures do not explicitly mention the source of insecurity, which may lead to a misinterpretation of the results (Foster & Giles-Corti, 2008). For example, the source of insecurity is not clearly stated in questions such as "How safe do you feel in your neighbourhood?" or "Do you feel safe returning to your home?". Therefore, it is impossible to differentiate between crime-related source of insecurity and insecurity related to other sources, such as traffic accidents and animal attacks.

Using measures of crime standardized by the population is another problem that can result in distortions in the identification of the relationships between crime and the built environment characteristics of a neighbourhood (U.S. Department of Justice, 1980). Employment of a measure of crime, which is simply defined as the number of crime incidents standardized by the population in areas at different geographic scales (e.g., census tracts or census-block groups), may result in the overestimation of the magnitude of crime in areas with small populations

(i.e., urban centres or commercial-dominated neighbourhoods) and the under-estimation of the magnitude of crime in residential neighbourhoods with large populations. Inconsistency in the size of the spatial unit of analysis can also result in a biased measure of insecurity in a given area. If a measure of crime fails to identify the actual level of crime-related insecurity in an area, it would be unsound to use such a measure to assess the relationship between crime and the built-environment characteristics of neighbourhoods.

This paper's objective is to assess the performance of CPTED principles at the neighbourhood level using an objective measure of crime that is standardized by area. As an alternative to a population-standardized measure of crime, an area-standardized measure of crime facilitates the identification of the precise spatial distribution of crime. The focus of the analysis involves examining the relationship between residential crime and CPTED principles associated with the two different space design approaches: 'permeable space' and 'defensible space'. Examining the validity of the two approaches at the neighbourhood level is particularly important because reducing crimes at this level, rather than at the street or building levels, is likely to have a more significant influence on the overall safety of individual neighbourhoods and possibly of the city as a whole.

2. Methods

2.1. Study area

This study was conducted using crime report data for residential burglary occurred in Seattle. Seattle has the largest population (approximately 0.6 million) of cities in King County and the broader Seattle–Tacoma–Bellevue Metro Area, and is the 23rd most populous city in the U.S (Seattle Department of Planning and Development). Seattle's land area (215 km^2) remains mostly single-family residential use (49%), followed by parks and open space (14%), public facilities (11%), and commercial and mixed use (6%) (Seattle Department of Planning and Development, 2015).

3. Data

3.1.1. Crime data

The primary data sources for this study were the crime incidence reports filed by the Seattle Police Department. The Seattle crime incidents report data were obtained from an online data archive (data.seattle.gov) of the City of Seattle on 10 June 2015. The original crime data contained records of 14,705 crime cases that occurred in Seattle between 7 March and 8 June 2015. Of the total number of cases, 1407 cases of residential crime, including burglaries and robberies that occurred in residential areas, were extracted for analysis. Subsequently, the extracted data were transformed into a point shape file[2] using the longitudinal and latitudinal coordinates for each crime case, which were available in the original crime data.

3.1.2. Built-environment data

King County GIS datasets were the primary data sources for the CPTED measures for the built environment, which were used as the independent variables in the analysis. These datasets were obtained from the Washington State Geospatial Data Archive (WAGDA) in June 2015. Detailed information on the attributes and sources of the GIS datasets is summarized below (Table 2).

3.1.3. Neighbourhood socioeconomic status (SES) data

The SES data used to measure the control variables were adopted from 1) tract-level 2010 U.S. Census data and 2) 2010 consolidated demographics data developed by King County. This study employed two SES variables: population density and the median household income score. Population at the tract level was directly obtained from the 2010 U.S. Census. The median household income score was obtained from 2010 consolidated demographics data for King County, which were developed by King County using demographic information from the tract-level 2010 U.S. Census (King County GIS Center, 2014). The median household income score uses values from 1 to 5 (from the highest to the lowest levels of median household income), which were assigned based on the quintile classification of median household income.

3.2. Model

Using the crime data for Seattle, this study investigates the relationships between the CPTED measures of the built environment at the neighbourhood level and residential crime density. To examine these relationships, a linear regression model was designed in which the CPTED measures were regressed on residential crime density after controlling for SES variables and the proximity to the closest police station. The model was estimated using 465 neighbourhood samples that were randomly selected within the city limits of Seattle. An operational neighbourhood definition of a 500-m radius airline buffer was used as the unit of analysis. The advantages of this definition are three-fold. First, it was closer to the residents' perceptions of a neighbourhood than artificially imposed neighbourhood units, such as census tracts, zip-code areas, and transportation analysis zones (TAZs) (Coulton, Jennings, & Chan, 2013; Sohn, Moudon, & Lee, 2012). This definition can also overcome the limitations of artificially imposed neighbourhood units in analyses of the spatial distribution of crime (additional details are discussed in 2.3.1). Finally, the definition facilitates micro-level analyses of the built environment around the locations where crimes occur. The random sampling and the measurement of variables were performed using the ArcGIS 9.3 GIS software and its extensions, Xtools Pro and Spatial Analyst.

3.3. Variables

3.3.1. Residential crime density

The study focused on analysing residential crime including burglaries and robberies that occurred in residential properties. A pre-analysis of census tract-level data for residential crime in Seattle was conducted to compare the results of the spatial distribution of crime levels estimated using a population-standardized measure and an area-standardized measure. As shown in Fig. 1, the estimation of the residential crime rate using the two different measures of crime produced different results. Although the area-standardized measure of crime (the second map in Fig. 1) may produce a less biased estimate of the spatial distribution of crime than the population-standardized measure, the inconsistency in the size of the spatial unit of analysis, which is inherent in census tract-level data, may remain problematic.

To address the problems associated with census tract-level data, 'residential crime density' was estimated using a spatial unit of analysis of same size (i.e., a 500-m radius airline buffer) and was used as the dependent variable. 'Crime density' refers to an area-standardized measure of crime that estimates the total number of crimes committed within a particular unit of space (Harries, 2006; Nicolau, 1994; Zhang & Peterson, 2007). In this study, residential crime density was defined as the total number of residential crimes that occurred in a neighbourhood divided by the neighbourhood's area. To measure residential crime density over the entire study area, GIS raster data analysis techniques were used. First, the points of marking the locations of residential crimes (the first map in Fig. 2) were converted into raster data with a pixel size of 25 m by 25 m. Then, the number of crime incidents within the neighbourhood (i.e., a 500-m radius airline buffer around each pixel) was estimated. Finally, the residential crime density in the

[2] A shape file is a geospatial vector data format used in geographic information system (GIS) software.

Table 2
GIS datasets for built-environment measures.

Dataset	Data type	Attributes	Source
Parcels	Polygon shape	Parcel area	King County GIS Center
Building-assessment data	Database	Height (storeys), dominant use	King County Department of Assessments
Roads	Polyline shape	Length, centrelines of road segments	King County Department of Transportation
Parks	Polygon shape	Parcel area	King County Department of Natural Resources and Parks
Bus stops	Point shape	Bus-stop location	King County Department of Transportation
Police stations	Point shape	Police-station location	King County Sheriff's Office

neighbourhood was calculated by dividing the number of crime incidents within the neighbourhood by its area in pixels (the second map in Fig. 2).

3.3.2. Neighbourhood-level measures of CPTED

The characteristics of the neighbourhood built environment that reflect the four CPTED principles (i.e., territoriality, natural surveillance, activity support, and access control) were operationalized as independent variables using GIS techniques with a variety of GIS datasets for the built environment (i.e., parcels, buildings, roads, parks, and bus stops). After reviewing the CPTED literature and considering data availability, seven CPTED measures of the built environment were selected for the investigation. Because CPTED principles often depend on one another, the developed measures may be related to multiple CPTED principles (Ekblom, 2011). The developed measures with their related CPTED principles are discussed below.

1) Proportion of residential area to total area of the neighbourhood: this measure was estimated by dividing the total area of the residential parcels in a neighbourhood by the neighbourhood's total area. Although a neighbourhood was defined as a 500-m radius airline buffer, variation in its area could occur because bodies of water (e.g., lakes, reservoirs, and the sea) were excluded. Increasing the proportion of the residential area in a neighbourhood is expected to improve territoriality because it increases the homogeneity of inhabitants (Hillier & Sahbaz, 2008; Newman, 1972; Ruijsbroek, Droomers, Groenewegen, Hardyns, & Stronks, 2015). However, it may weaken activity support and natural surveillance because a higher activity level is associated with land use diversity (Frank & Pivo, 1994; Jacobs, 1961).
2) Average number of storeys in neighbourhood building: this measure was used as a proxy for a neighbourhood's development density. As development density increases in a neighbourhood, the sense of anonymity becomes more pervasive, which results in resident withdrawal and decreases the radius of responsibility maintained by residents (Taylor, Koons, Kurtz, Greene, & Perkins, 1995). The literature indicates that a higher density is associated with higher crime rates because it may deteriorate territoriality (Browning et al., 2010; Christens & Speer, 2005).
3) Ratio of commercial area to residential area: this measure was developed as a proxy for the land use diversity in a neighbourhood. It was estimated by dividing the total parcel area of commercial use by the total parcel area of residential use in the neighbourhood. Advocates of the permeable space approach claim that an increase in commercial developments in a neighbourhood can generate more street activity and increase the associated social control benefits of "eyes on the street" (Browning et al., 2010), which enhances natural surveillance and activity support but may have adverse effects on territoriality and access control.
4) Bus-stop density: this measure was used as a proxy for transit accessibility and was estimated by dividing the total number of bus stops in a neighbourhood by the neighbourhood's area. The literature

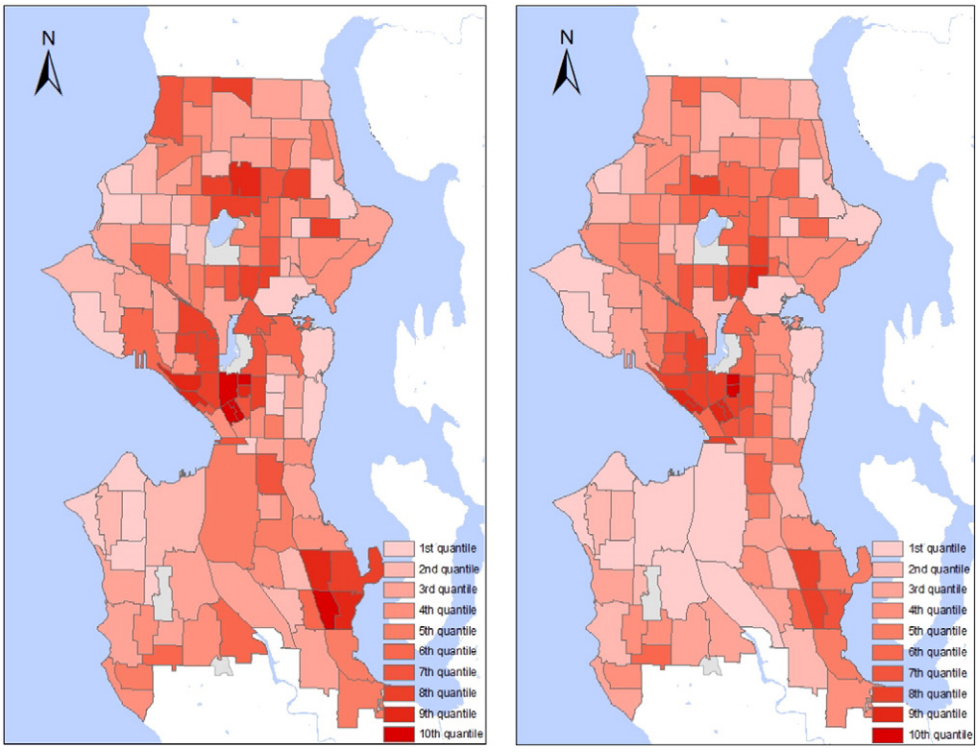

Fig. 1. Maps of residential crime rates in Seattle estimated using a population-standardized measure of crime (left) vs. an area-standardized measure of crime (right).

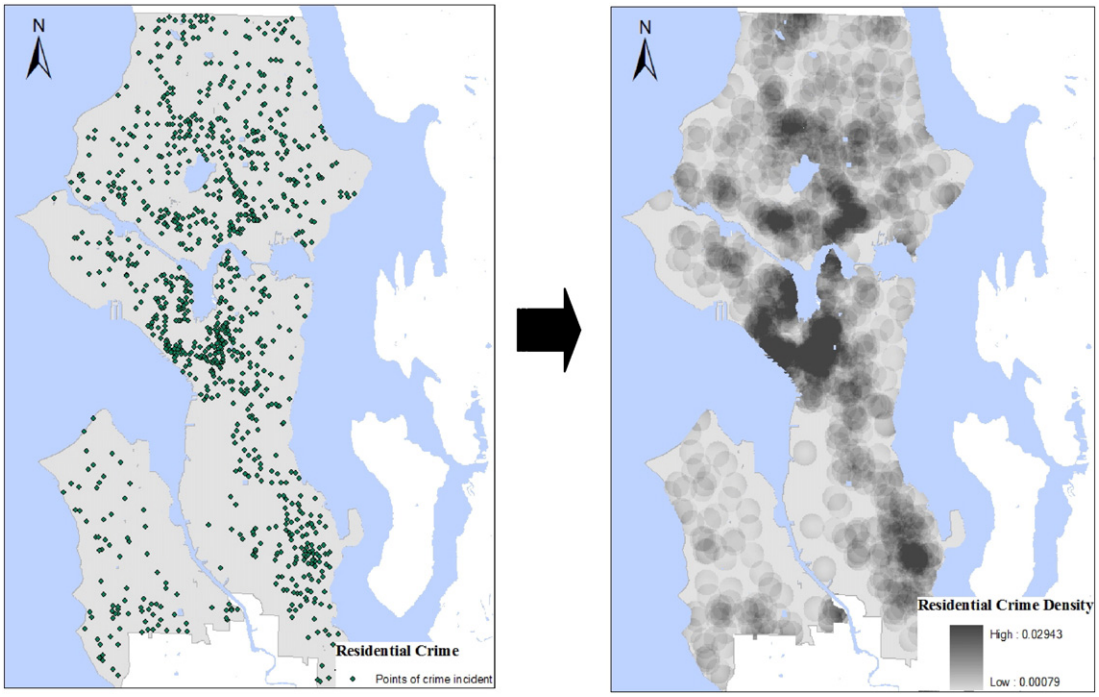

Fig. 2. GIS process of measuring residential crime density in a neighbourhood.

indicates that convenient transit access is associated with more pedestrian activities (Robert Cervero & Duncan, 2003; Chisholm, 2002; O'Sullivan & Morrall, 1996), which enhances natural surveillance and activity support.

5) Ratio of park area to residential area: this measure was estimated by dividing the total parcel area of parks by the area of residential parcels in a neighbourhood. Providing parks in a neighbourhood is a typical CPTED strategy that aims to increase activity support (Puget Sound Regional Council, 2014). It also helps enhance natural surveillance by promoting outdoor activities.
6) Street density: this measure was estimated by dividing the total length of neighbourhood streets by the neighbourhood's area. From the perspective of CPTED, improved street networks are expected to enhance natural surveillance (Jacobs, 1961; Johnson & Bowers, 2010), but they adversely affect access control because they increase a neighbourhood's permeability (Brantingham & Brantingham, 1993; Newman, 1972).
7) Intersection density: this measure also examines the effect of street networks on residential crime. It was estimated by dividing the total number of a neighbourhood's street intersections in by its area. This measure is extensively used in research to measure the connectivity of street networks (Norman et al., 2006). Generally, higher intersection density indicates higher street connectivity (Sallis et al., 2009), which is positively associated with the permeability of space. Therefore, an increase in intersection density weakens access control but enhances natural surveillance and activity support by providing a pedestrian-friendly environment (Cozens, 2008; Hillier & Sahbaz, 2008). Studies on streets configuration and physical activities report that pedestrian activities increase in the neighbourhoods with higher street connectivity (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009; Saelens, Sallis, & Frank, 2003), which may improve the opportunity of natural surveillance. However, findings from the study on crime and street configuration indicate that street networks with higher connectivity may weaken neighbourhood safety because it increases the number of escape routes that can be facilitated by offenders (Brantingham & Brantingham, 1993).

3.3.3. Control variables

The population density, median household income score, and distance to the nearest police station were included in the model as control variables. Population density was directly obtained from the tract-level data of the 2010 U.S. Census. The median household income score was obtained from the 2010 consolidated demographics data developed by King County. The research findings indicate that a higher population density and a lower level of household income are associated with increased residential crime (Cahill & Mulligan, 2003; Christens & Speer, 2005; Zhang & Peterson, 2007). The distance from a neighbourhood to the nearest police station was estimated using the GIS programme and the GIS data on police stations obtained from the King County Sheriff's Office. The literature suggests a negative relationship between proximity to a police station and residential crime because if a potential offender is within close proximity to a police station, he or she will be discouraged from committing a crime (Murray, McGuffog, Western, & Mullins, 2001; Sherman & Weisburd, 1995).

4. Results

Table 3 shows the means and standard deviations of the variables used in the analysis. The mean of 0.004 for residential crime density indicates that an average of approximately 5 residential crime cases occurs in the sampled neighbourhoods (based on a 500 m radius airline buffer). The mean population density of these neighbourhoods is 31.649 persons/ha. The average distance between these neighbourhoods and the closest police station is 2.344 km. The statistics for the CPTED variables indicate that the average number of building storeys in these neighbourhoods is 1.105 and that, on average, 46.5% of the total parcel area in these neighbourhoods is for residential use. On average, the ratio of commercial parcel area and the park area to residential area are 6.7 and 19.9, respectively. The mean bus-stop density of 0.011 and the mean intersection density of 0.040 indicate that there are approximately 14 bus stops and 50 intersections in each neighbourhood.

The regression statistics results are shown in Table 4. The base model with three control variables (i.e., population density, median household

Table 3
Variable means and standard deviations.

	Mean	Std. deviation
Dependent variable		
Residential crime density (crimes/pixel)	.004	.003
Control variable		
Population density (persons/ha)	31.649	19.461
Median household income score	3.348	1.283
Distance to the closest police station (km)	2.344	1.267
CPTED variable		
Proportion of residential area to total area	.465	.172
Average number of building storeys	1.105	.459
Ratio of commercial area to residential area	.067	.168
Bus-stop density	.011	.007
Ratio of park area to residential area	.199	.435
Street density	.416	.103
Intersection density	.040	.013

income, and distance to the closest police station) explained 37.8% ($F = 95.05$, $P < .01$) of the variance in the residential crime density in neighbourhoods. The population density and the distance to the closest police station were significant predictors of residential crime density, whereas the median household income score was not significant. In the final model, seven neighbourhood CPTED measures were added to the base model. The adjusted R-square of the final model was .518 ($F = 50.51$, $P < .01$), and the collinearity statistics (VIF) indicated that no multicollinearity existed among the independent variables. The relationships between the control variables and residential crime density remained unchanged when the CPTED measures were added. The proportion of residential area to total area, average number of building storeys, bus-stop density, street density, and intersection density were significant predictors of residential crime density after controlling for the base model variables. Residential crime density was negatively related to the proportion of residential area to total area, bus-stop density, and street density and positively related to the average number of building storeys and intersection density.

5. Discussion

Using crime data for Seattle, this study examined the relationships between residential crime and neighbourhood measures of CPTED. In the analysis, an area-standardized measure of crime (i.e., crime density) was used to identify the spatially unbiased distribution of residential crime. The regression results indicated that proportion of residential area to total area, the average number of building storeys, bus-stop density, street density, and intersection density was significantly related to residential crime when the model was controlled for population density, the median household income of the neighbourhoods, and the distance to the closest police station from these neighbourhoods.

The study has three major findings. First, it shows that land use diversity, which has been one of the key subjects of contradiction between the concepts of permeable space and defensible space, has an adverse effect on prevention of residential crime. Mixing land uses – primarily combining residential uses with commercial uses – has been supported by advocates of permeable space because, in theory, integrating businesses with residences increases street activity, resulting in the enhancement of natural surveillance (Cozens, 2008; Jacobs, 1961). For this reason, urban design strategies aimed at increasing land use diversity have been employed in some CPTED guidelines (Ministry of Justice, 2005; National Crime Prevention Council, 2003; Puget Sound Regional Council, 2014). Little empirical evidence, however, supports the effectiveness of land use mix in improving neighbourhood safety. Browning et al. (2010), who investigated the link between commercial and residential density and violent crime, showed that land use mix can reduce homicide and aggravated assault, but not robbery. As noted in their study, the relationship between land use diversity and crime may vary by offence type due to differences in the nature of the crimes. Unlike violent crimes such as homicide and aggravated assault, which can be deterred by 'eyes on the street', residential crimes such as robberies and burglaries can be amplified in areas with higher level of land use diversity as it increases familiarity with the neighbourhood among non-residents and provides opportunities for offenders to search for their targets (Hayslett-McCall, 2002; Kinney, Brantingham, Wuschke, Kirk, & Brantingham, 2008).

Second, it was found that improving street connectivity by constructing more intersections in the street network increase residential crime. The weakened level of access control caused by the enhanced street connectivity may play a significant role in negatively affecting crime prevention. Previous research examining the link between crime and street layouts consistently reported that permeable street layouts are criminogenic (Armitage, 2013; Cozens, 2008; Schneider & Kitchen, 2007); studies using Space Syntax techniques, on the other hand, found that permeability is negatively related to crime (Hillier, 2004; Shu, 2009; Shu & Huang, 2003). Although the reasons for such contradiction is unclear, one possible explanation could be that none of the research using Space Syntax techniques systematically controlled the socioeconomic factors of neighbourhoods when analysing the effect of neighbourhood permeability on crime. As noted by Taylor et al. (1995), the effects of a built environment on crime may be differentiated when the neighbourhoods' socio-economic characteristics are controlled in the analysis. Considering the significant association between socio-economic factors of a neighbourhood with crime (Cahill & Mulligan, 2003; Christens & Speer, 2005; Zhang & Peterson, 2007), it can be argued that multivariate analysis methods which control for

Table 4
Regression model results for residential crime density.

	Base model			Final model		
	Std. B	t	VIF	Std. B	t	VIF
Population density	.545	13.760**	1.170	.222	4.429**	2.410
Median household income score	−.032	−.783	1.274	−.030	−.754	1.559
Distance to the closest police station	−.188	−4.568**	1.269	−.199	−5.236**	1.392
Proportion of residential area to total area				−.214	−3.665**	3.270
Average number of building storeys				.578	10.342**	2.999
Ratio of commercial to residential area				−.003	−.070	1.561
Bus-stop density				−.086	−2.008*	2.144
Ratio of park area to residential area				−.010	−.260	1.552
Street density				−.164	−2.936**	2.981
Intersection density				.143	2.641**	2.826
R-square	.384			.527		
Adjusted R-square	.378			.516		

* $P < .05$.
** $P < .01$.

socio-economic factors produce more reliable results. The findings in this study support the claim that permeable street layouts increase a neighbourhood's vulnerability to residential crime and thus, the principle of access control based on the concept of defensible space is effective in preventing residential crime.

Third, increases in bus-stop density and street density in neighbourhoods were negatively related to residential crime. These two measures are known to encourage pedestrian activities (Robert Cervero & Duncan, 2003; Panter, Jones, Van Sluijs, & Griffin, 2010), and thus were selected as measures of activity support in this study. Although advocates of the concept of permeable space have claimed that pedestrian activity can deter the prevalence of crime (Hillier & Sahbaz, 2008; Jacobs, 1961), the relationship between walkable environment and crime has not been extensively researched. The few studies that investigated the effect of the walkable built environment on neighbourhood safety used residents' perception of crime (Foster, Giles-Corti, & Knuiman, 2010; Wood et al., 2008) instead of analysing actual levels of insecurity. Using subjective data in assessing the levels of insecurity, however, can undermine the reliability of the findings because crime is only weakly associated with the perception of crime (Foster & Giles-Corti, 2008; Kim, Schweitzer, & Kim, 2002). By employing objective crime data, this study provided evidence supporting that neighbourhood designs promoting pedestrian activities can be an effective means of enhancing safety. Considering the lack of empirical evidence showing positive association between walkable built environment and crime prevention, more research is called for to validate their relationship.

This study provided empirical evidence that certain features of built environment associated with the two space design approaches – 'permeable space' and 'defensible space' – can contribute to reducing residential crime. The negative effects of land use diversity and street connectivity on crime prevention support 'defensible space', whereas the negative relationships between residential crime and some features of built environment facilitating pedestrian activities confirm the usefulness of 'permeable space'. These mixed results regarding the effects of the two space design approaches on residential crime may be due to the subtlety and complexity of CPTED concepts (Ekblom, 2011). Since both approaches lack the specification of the targets (e.g., residents, visitors, passers-by) to control for neighbourhood safety, it is difficult to attract or repel particular kinds of people who may be potential offenders or crime preventers. For a safe neighbourhood, the environment needs to attract the 'right' kinds of people with intentions for legitimate activities. More research is in need to develop CPTED strategies that can contribute to the discriminative control of people and their behaviours in the neighbourhood. Refining CPTED concepts to manipulate the controllability of those who may act as crime attractors/generators or preventers can help reduce crime opportunities afforded by the environment.

There are methodological shortcomings in the study. First, due to the crime data collected in a relatively short time period within a cross-sectional research framework, it is limited in analysing the long-term impacts of CPTED strategies on neighbourhood crime. Second, the characteristics of victimized properties (Cozens, Hillier, & Prescott, 2001; Wright, Logie, & Decker, 1995), which are known to be significantly associated with incidents of residential burglary, were not taken into account due to the lack of building-level data. Third, the limited information on the built form of residential properties and street patterns did not allow for the consideration of the CPTED schemes that might have been adopted in the residential developments of Seattle. Lastly, quantitative methods employed in this study did not include the analysis of residential contexts, which may have played an important role in determining the effects of CPTED strategies within a neighbourhood (Reynald, 2011). Further research employing long-term crime data and analytical methods that incorporate building-level attributes of residential properties is needed to expand our knowledge of the link between crime and built environment in a neighbourhood.

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