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Risk Terrain Modeling and Socio-Economic Stratification: Identifying Risky Places for Violent Crime Victimization in Bogotá, Colombia

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Abstract This research focused on the effect of the built environment on Bogotá's violent crime by using the Risk Terrain Modeling (RTM) technique. The current study used 17 ecological variables, including micro-level data on the spatial distribution of socio-economic strata, and the location of an array of businesses and other features of the landscape. As suggested by the results of this study, the spatial distribution of violent crime in Bogotá is highly correlated with the allocation of socio-economic strata throughout its geography. A statistically valid RTM analysis identified the micro-level risk factors associated with three types of violent crime incidents, namely homicide, assault, and theft incidents. These results suggest that future violent crime incidents are more likely to occur at a reduced number of high-risk micro-places. Moreover, while homicide and assault incidents were more likely to cluster within the poorest areas of the city, theft incidents presented a higher risk of victimization near the city center, where economic activity and suitable targets concentrate. This study offers a unique account regarding the effect of socio-economic segregation on violent crime victimization across Bogotá's geography and within different socio-economic strata classifications.

Keywords Risk terrain modeling · Crime analysis · Urban segregation

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Introduction

Bogotá is Colombia's financial and political center and Latin America's 4th largest city, following the megacities of São Paulo, Mexico City, and Lima. A megalopolis with a population consisting of approximately 8 million people, similar in size to New York City (Beckett and Godoy 2010). Bogotá has suffered the consequences of a long-standing armed conflict over the last few decades, sustained by confrontations between government forces and drug trafficking groups or other organized criminals (Beckett and Godoy 2010). While Colombia's violent crime rate in the 1970s was similar to other countries in the region, in the 1980s and 1990s the violent crime rate more than tripled and became one of the highest in Latin America (Gaviria et al. 2010).

Even though Bogotá remained somewhat insulated from the widespread conflicts that occurred in Colombia's rural areas, the city soon became affected by the massive migration of internally displaced people from these areas. As a result, the city's population experienced an exceptional increase over the last decades (Beckett and Godoy 2010). The situation became unsustainable in the 1990s as people massively fled entire villages that had become un-habitable by war, organized crime, and violence (Gaviria et al. 2010). Not surprisingly, Bogotá struggled to assimilate such an unprecedented migration flow, largely mismanaged by public authorities at the time.

Bogotá's recent history of violence and crime offers a unique opportunity to assess the specific locational factors that attract and generate criminal opportunity within its borders. This article hypothesizes micro places, in particular locations ascribed across certain socio-economic stratum in Bogotá, are correlated with varying risks of violent crime victimization. Having this objective in mind, this study uses Risk Terrain Modeling (RTM) to identify what places are at a higher or lower risk of violent crime victimization. Thus, and aiming to produce actionable information to improve Bogotá's public safety, this study offers a comprehensive account of the main environmental factors of vulnerability and exposure to crime (Kennedy and Caplan 2012).

Background on Bogotá, Colombia

Over the 1990s decade, the situation in Bogotá dramatically worsened as the city was plagued by terrorist attacks, kidnappings, and one of the highest homicide rates in the world. The lack of proper social services and a notoriously inefficient transportation system further increased social tensions throughout the city (Gaviria et al. 2010). According to Moser et al. (2005), the loss of values and traditions of social order, high consumption of alcohol, impunity, the lack of credibility on justice and police institutions, attitudes favoring violent forms of conflict resolution, inappropriate treatment of violence in the media, and the presence of gang and other armed groups were the main factors explaining the dramatic increase of violence and crime.

Yunda (2017) found that Bogotá's severe demographic changes, beginning in the 1950s, intensified the polarization between established urban elites and new rural migrants. A process which deepened urban segregation, with pockets of wealth and poverty concentrating in few areas of the city (Thibert and Osorio 2014). As a result, Bogotá's urban landscape now

presents a clear fragmentation between wealthier communities concentrated in the northern parts of the capital, and poor rural migrants predominantly located in the southern parts of the city and the periphery. It is particularly in the southern sections of the city, where Llorente et al. (2001) found that homicide incidents tend to cluster. According to their research findings, 20% of all homicides in Bogotá take place in just 21 sectors, mostly located in the southern parts of the city. Thus, suggesting that Bogotá's spatial crime risk variation is highly correlated to the macro spatial distribution of social class and economic status.

According to Colombia's National Statistics office (DANE), the classification of Bogotá's residential units in different stratum has its origin on the need to improve access to public utilities through a redistribution mechanism. Under this system, citizens living in the highest stratum of the city subsidize, through a surcharge, households living in the lowest stratum parts of the city, who receive a discounted rate for their utilities. The stratification of Colombia's residential units began in the 1980s through the Colombian Law of Public Services. This methodology to stratify household units is based in three main environmental factors: the state of the house (e.g., size of yard, type of façade, etc.), the immediate built environment (e.g., type of sidewalk, type of street, etc.), and the urban context (i.e., neighborhood location).[1] The unit of analysis is the street block and the unit of observation is the block side. Thus, it could be stated that Bogotá's stratification system is mainly based on an assessment of the physical characteristics of dwellings and their immediate local built environment. However, as noted by Uribe-Mallarino (2008), while socio-economic stratification in Bogotá was purposely created to classify Bogotá's household units and to ensure the redistribution and solidarity among Bogotans, the reality is that strata has become de facto a synonym of social class and economic status. Similarly, Thibert and Osorio (2014) noted that Bogotá's socio-economic stratification system designed to target subsidies toward the poor, effectively identifies parts of the city as poor, middle-income or rich.

The following passage clearly defines strata in Bogotá's popular culture[2]:

> "The strata have a georeferenced component attached to them, but this one is not linked to the administrative divisions of the city. Instead, it is a notion with two distinctive realities, one is social and the other geographic. Its social aspect is based on a hierarchical definition, while its geographic component refers to a place. Everyone knows what stratum they belong to, not only because it appears printed on every month's utilities bill but because it is one of the first questions that you ask when buying or leasing a new house."

Clearly, 'location matters' in Bogota, and has for many decades. This is true of residential preferences, and also for public safety and security. However, a major shift occurred over the administrations of Mayor Antanas Mockus (1995–1997, 2001–2003) and Mayor Enrique Peñalosa (1998–2000, 2016–incumbent[3]). Mayor Mockus introduced a new approach to fighting crime and violence that combined improvements in public health and the reclaiming of public spaces, while introducing important changes in the social justice system (Moser et al. 2005). For instance, among the measures introduced by the district administration to curb

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[1] http://www.dane.gov.co/files/geoestadistica/estratificacion/Tipo1.pdf
[2] Original Spanish passage: "Estratificación social en Bogotá: de la política pública a la dinámica de la segregación social (Uribe-Mallarino 2008, pg. 150)
[3] As of January 2018.

violence were to improve access to the judicial system, reduce alcohol consumption, new youth programs to protect the most vulnerable, and the recovery of public spaces such as parks (Moser et al. 2005). For example, the "Carrot Law" (Translated from Spanish: Ley zanahoria) imposed a curfew on alcohol sales from 1 AM, and a rush hour restriction driving private vehicles in the city (Moser et al. 2005; Soares and Naritomi 2010). Moreover, following Mockus,' success story reducing Bogotá's crime rate, Mayor Peñalosa launched an ambitious public space recovery program to regain public spaces. From the improvement of public transportation with the creation of a bus-based transit system, to the rehabilitation of a deteriorated downtown avenue into a vibrant pedestrian zone; Peñalosa's environmental approach to development was considered a success story. As a result, Bogotá's homicide rate dropped from 80 deaths per 100,000 people in 1993 to 20 deaths per 100,000 people in 2007 (Gaviria et al. 2010). Nowadays, the homicide rate in Bogotá is substantially lower than that of Caracas, Rio de Janeiro or even Washington D.C., but still higher compared to cities like Santiago de Chile or Miami (Soares and Naritomi 2010).

Among the first to measure the spatial distributions of crime in Colombia are Gaviria and Vélez (2001). Their research findings support the argument that rich households are more likely to be the victims of property crimes and kidnappings, while the poor are more likely to be victims of homicide and domestic violence. Llorente et al. (2001) offer a detailed account on the spatial distribution of homicide incidents in Bogotá, finding violent homicides are clustered in a few sectors of the city with established criminal structures that result in other forms of localized violence. Still, their research was limited at describing why criminal incidents tend to cluster at some locations and not others throughout Bogotá's geography. This study aims to fill the theoretical and empirical gaps by presenting a detailed account on the main locational factors driving crime in the Colombian capital's violent crime problems. It does so by offering a detailed account of the most significant environmental risk factors leading to violent crime victimization. These risk factors were identified and measured through the use of Risk Terrain Modeling, a spatial risk assessment technique developed by Joel Caplan and Leslie Kennedy at the Rutgers Center on Public Security (Caplan and Kennedy 2016). Moreover, and through the use of RTM, this study tested the predictive capacity of RTM to identify the locations in which violent crime incidents are more likely to emerge in the future.[4]

Introduction to the RTM Technique

Risk Terrain Modeling (RTM) diagnoses features of a landscape that interact to create unique behavior settings for crime (Caplan and Kennedy 2016). RTM builds on extant research demonstrating a relationship between crime and certain environmental features, such as bars, restaurants, and public transportation stops (e.g., see Bernasco and Block 2011). The probability of crime is estimated with RTM by testing the spatial influence of such features, and their spatiotemporal confluence at places within a jurisdiction (Caplan 2011). RTM incorporates principles of environmental criminology (Wortley and Mazerolle 2008) and risk assessment (Kennedy and Van Brunschot 2009), and it is rooted in the idea that criminal behavior is

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[4] The results to this study were originally presented in June 2015 at a colloquium organized by the World Bank, to a select number of local stakeholders, including transportation managers, city hall officials and local NGOs in the city of Bogotá.

influenced by the physical environment's (Brantingham and Brantingham 2008) crime generators and crime attractors (Brantingham and Brantingham 1995), all of which is discussed in the next section.

To more simply understand Risk Terrain Modeling, consider a place where children repeatedly play, if we focus only on the kids, we would miss the presence of swings, slides, and open fields, that is, what we might define as a playground, that attract children to this location instead of other locations that are absent such entertaining qualities. Features of a landscape are influencing and enabling playful behavior. With this in mind, RTM was developed to identify the risks that come from features of a landscape and model how they co-locate to create unique behavior settings for crime (Caplan and Kennedy 2016). That is, to answer *why* certain areas have more crime than others. RTM extends empirical investigations from the crime incidents to the contexts in which these incidents emerge or persist. Knowing what spatial risks are connected to crime allows crimes to be forecast in an area even if they have not occurred previously, and to incorporate Bayesian probability into crime analysis. To-date, RTM has been used worldwide in a number of different settings, from urban, suburban, and rural jurisdictions to analyze different problems, from drug, property and violent crimes to international trafficking.

RTMDx software is used to run risk terrain models. The software, produced at the Rutgers Center on Public Security, applies a precise set of statistical tests (see Caplan et al. 2013) in evaluating the relative importance of spatial factors in influencing crime outcomes. It begins by building an elastic net penalized regression model assuming a Poisson distribution of events. It does this using cross-validation. Then it further simplifies the model in subsequent steps via a bidirectional stepwise regression process (Poisson and negative binomial) and measures the Bayesian Information Criteria (BIC) score. The best model with the lowest BIC score between Poisson and negative binomial distributions is selected. RTMDx outputs are tabular and cartographic; for each significant risk factor, tabular outputs include a relative risk value (RRV), which is the exponentiated factor coefficient (i.e., relative weight), and the optimal operationalization and distal extent of spatial influence. A risk terrain map is also produced to show high-risk places throughout the study area.

Crime Generators, Crime Attractors, and Neighborhood Disadvantage

The spatial characteristics of crime have continued to be explored since the early works of Quetelet and Guerry. Environmental Criminology is an area of research and practice focusing on the spatial and temporal characteristics of crime, often comprised of three theories: routine activities theory (RAT) (Cohen and Felson 1979), rational choice theory (Cornish and Clarke 1986), and crime pattern theory (Brantingham and Brantingham 1993). RAT posits criminal opportunities come about when motivated offenders converge in time and space with suitable targets lacking capable guardianship. General routine activities, such as school and work, could influence the likelihood of the three elements converging and creating criminal opportunities. Rational choice argues, when considering the decision to commit crime, offenders weigh the risks and rewards associated with the opportunity.

Building from the prior two theories, crime pattern theory examines daily behavior patterns through activity spaces, such as nodes, paths, and edges (Brantingham and Brantingham 1995). In short, nodes are spaces where people spend a great deal of their time (e.g., home), paths are the routes taken between different nodes (e.g., path from home to school to work),

and edges are physical or social boundaries between different areas. Often influencing crime at activity spaces can be the presence of crime generators and crime attractors (CGAs). While the distinction of the two types is not made in the current study, and because generators could be attractors (vice-versa), the presence of CGAs contribute to creating criminogenic environments by drawing people to their locations for routine activities and/or draws offenders to their locations for the criminal opportunities. Examples of CGAs include: schools (Roncek and Faggiani 1985), bars (Ratcliffe 2012; Roncek and Pravatiner 1989), bus stops (Levine et al. 1986), and hotels (Bichler et al. 2013; LeBeau 2011). Each of these types of establishments is argued to increase the likelihood of crime based on the nature of their type of place.

Environmental criminology has extended the greater knowledge of spatial and temporal characteristics of crime. While often focusing on the micro-level, to identify greater variation, there is another area, often referred to as neighborhoods/communities and crime, focusing on the larger neighborhood context. It is within the neighborhood context that could lead to various levels of crime. The neighborhoods and crime framework was guided by early immigration assimilation arguments by Thomas and Znaniecki, ecological arguments of Park et al. (1925), advancements by Shaw and McKay (1942), and enhanced by Sampson (2012). Often nested in a social disorganization framework (Shaw and McKay 1942), neighborhoods described as being socially disorganized, commonly measured through residential instability, poverty, and racial heterogeneity, have a confusion of what are acceptable social norms and become isolated from mainstream society. With the lack of social norms, there comes an inability to regulate behaviors through traditional formal and informal social controls, often resulting in crime.

While the two areas, environmental criminology and social disorganization, are discussed and examined separately in research, there are limited studies including both into RTM research (Drawve et al. 2016b; Piza et al. 2017). Drawve et al. (2016b) developed an aggregated neighborhood risk of crime measure (ANROC), created through RTM, to predict neighborhood crime rates while accounting for neighborhood measures, concentrated disadvantage and stability. They found ANROC, concentrated disadvantage, and stability to all be significant predictors of neighborhood crime rates, which accounted for about 58% of the variance explained. This provided an example of how a measure rooted in environmental criminology could be integrated into neighborhoods and crime research. Furthermore, Piza et al. (2017) found the effect of risk factors' spatial influences for motor vehicle theft and recovery varied based on the level of neighborhood disadvantage (i.e., interaction effects). As discussed by Piza et al. (2017, p. 3015), "The significance of the interaction terms supports the notion of Environmental Criminology and Social Disorganisation as complementary, rather than competing, theoretical perspectives." Integrating social concepts and measures into environmental criminology based research could further our understanding of dynamic criminogenic environments.

Therefore, it is through the combination of these two major theoretical frameworks that this study tests the locational factors that attract and generate violent crime incidents in the city of Bogotá. RTM is used to measure the spatial correlation between a series of features of the landscape and how these collocate in time and space with violent crime incidents. The novelty of this approach lies in the use of Bogotá's micro-level stratum data within RTM, both as an environmental factor and as a proxy to socio-economic status. Thus, supporting previous research done by Drawve et al. (2016b) and Piza et al. (2017) on the benefits of combining the use of social disorganization and environmental criminology theories.

Data and Methods

The study setting for this analysis is Colombia's capital and Latin America's fourth largest city, the city of Bogotá covers an area of approximately 1518 sq. km (613 sq. miles), of which 320 sq. km (123 sq. miles) comprises the city's urban area (Beltrán 2005). For the purpose of this study, only Bogotá's urban space is analyzed and discussed in this paper. This analysis had three main objectives: first, to present a comprehensive account on the main environmental risk factors driving violent crime outcomes in Bogotá, second, to measure the spatial influence of socio-economic segregation over crime incidents, and third, to test the predictive capacity of RTM to forecast future crime outcomes in Bogotá. As shown in Table 1, a total of 17 environmental risk factors were identified for this analysis. All geo-referenced data was directly obtained from the World Bank' regional office in Bogotá and the Capital District's Spatial Data Infrastructure (IDECA). Moreover, disaggregated violent crime data for assault, theft, and homicide incidents for calendar years 2012 and 2013 was facilitated by the Fundación Ideas para la Paz (FIP).[5]

To better understand the risk posed by certain places, this study evaluates the spatial influence of the built environment on violent crime outcomes. As suggested by Caplan (2011), understanding the spatial influence includes evaluating the effects of distance or density of criminogenic features on crime occurrence. Having this objective in mind and to depict the spatial distribution of risk, Bogotá's jurisdiction was divided as a continuous surface GRID of 75 m-by-75 m cells ($n = 76,766$). The resulting GRID cells are the units of analysis to this study, and approximate half the size of an average city block, or half of 150 m. Previous research by Kennedy et al. (2015) suggests that crime-prone places typically encompass a few city blocks where recurring incidents tend to cluster in time and space. Thus, "risky places" were identified by the presence (or absence) of potential environmental factors within 3 street blocks, or 450 m, from the location where violent crime incidents occurred over the year 2012.

The classification of low and high socio-economic strata units derived from the distribution of income associated with each stratum. The stratification system in Bogotá operates on a scale of six differentiated stratum levels, in which stratum 1 households are considered to be worst-off (i.e., have a lower income level) than stratum 6 residents, having a higher purchasing power. According to Bogotá's 2011 Multipurpose Survey[6], the average monthly income per household living in stratum 1 to 3 was approximately 1.83 million Colombian Pesos (approx. USD 600[7]), while the average income for stratum 4 to 6 households was 8.1 million Colombian pesos (approx. USD 2,700[7]), or more than four times higher than the first sub-group. City-wide, the average monthly income was 2.85 million Colombian Pesos (approx. USD 950[7]), higher than the average income reported for stratum 1 to 3 over the same year. Therefore, and based on the income disparities, this study grouped stratum 1 to 3 lots as representative of Bogotá's households living below the average city income, while stratum 4 to 6 were categorized as high stratum, or above average. Regarding the city's population distribution per stratum, as much as 85% of Bogotá's population reportedly lived in stratum 1 to 3, while households living in stratum 4 to 6 only represented 14% of the city's

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[5] FIP calculations based on data from the Colombian National Police. All crime data was geo-referenced using the WGS84 reference coordinate system.
[6] http://www.sdp.gov.co/portal/page/portal/PortalSDP/InformacionTomaDecisiones/Estadisticas/Bogot%E1%20 Ciudad%20de%20Estad%EDsticas/2011/DICE115-CartillaEncuesMultipropos-2011.pdf.
[7] Currency exchange rate between Colombian Pesos (COP) and U.S. Dollars (USD) as of August 2017.

Table 1 List of potential risk factors

Environmental factors	N	Operationalization	Spatial influence
Banks	1170	Proximity and density	Up to 450 m (3 increments of 150 m)
Community kitchens	320	Proximity and density	
Higher education centers	151	Proximity and density	
Hotels	413	Proximity and density	
Tourist areas	2024	Proximity	
Tourist attractions	306	Proximity and density	
TransMilenio stations	145	Proximity and density	
Drugstores	2526	Proximity and density	
Medical clinics	10,554	Proximity and density	
Motor vehicle bridges	2834	Proximity	
Pedestrian bridges	2399	Proximity	
Public hospitals	107	Proximity and density	
Public library	20	Proximity and density	
Schools (only private)	1577	Proximity and density	
Schools (only public)	920	Proximity and density	
Low strata	1,251,403	Proximity and density	
High strata	423,579	Proximity and density	

total population during the year 2011.[8] Centroids were generated for each individual parcel unit, originally represented through the geometrical form of polygons, throughout Bogotá's urban landscape, each of which is representative of a specific stratum level. Thus, allowing us to measure the micro-level spatial influence of the different existing stratum levels against the location of violent crime events. This is an important advancement on the use of the RTM technique, as this is the first time that a study includes micro-level stratum data within a Risk Terrain Model. This classification allowed controlling for variations on socio-economic segregation within the city of Bogotá. More importantly, these indicators are relevant to the discussion on whether or not high levels of inequality are significantly correlated with the presence of violent crime incidents.

In this analysis, we used the RTM Diagnostics software (RTMDx). A total of 186 variables[9] were generated and tested as "potential risk factors", of which six risk factors were selected as having spatial associations with homicide incidents, 11 risk factors were selected for assault events, and a total 14 aggravating factors for theft victimization.

Moreover, and to compare findings, this study utilized the predictive accuracy index (PAI). Developed by Chainey et al. (2008), this technique allows for comparison of different spatial analysis techniques on their ability to predict future crime events accurately. Other studies have already compared RTM to different techniques using this approach (see Drawve 2016; Drawve et al. 2016a; Dugato 2013). The PAI is calculated with the following formula: (number of crimes in hotspot/overall number of crime) / (area of hotspot/total study area). In the current study, three comparisons were made: high-risk places (RRS values of +2SD from the mean), hot spots for crime (KDE[10] values of +2SD from the mean), and locations where high-risk places overlap with hot spots of crime.

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[8] Note that 1% of the city's population lived in non-stratum designated units.
[9] (14 factors * 2 operationalizations * 3 blocks * 2 "half increments") + (3 factors * 1 operationalization * 3 blocks * 2 "half increments") = 186 variables.
[10] The cell size was 75 m, similar to RTM, and the search radius was set to 450 m. Thus, assuming the maximum spatial influence used with RTM.

Results

According to the results of this study, the locational effect that socio-economic segregation has on violent crime incidents presents variations between different violent crime outcomes. For instance, socio-economic segregation was highly correlated and significantly increased the risk of victimization for homicide incidents in the year 2012. In Table 2, results suggest that locations within 75 m (approx. 246 ft.) to low strata units had a risk of victimization more than six times higher than that of any other place within the city of Bogotá. It is important to note that high strata locations, where more affluent households live, did not appear to be significantly correlated to the location of homicide incidents. This does not speak to the affluence of the homicide victims or offenders, because the study focused on places, not people. However, it does give strong support to the hypothesis that socio-economic segregation has a significant effect over the location of homicide incidents. Moreover, locations with a high concentration of community kitchens, public schools, and public hospitals, all appeared to have a significant spatial association with the location of homicide incidents. A common denominator to all these significant risk factors is that they all embody a series of public services commonly delivered to the most vulnerable population. Therefore, reinforcing previous research suggesting that the concentration of socially disadvantaged is correlated with a higher risk of violent crime victimization (Drawve et al. 2016b).

Similarly, locations within close proximity to low strata areas were at a higher risk of assault incidents, with a relative risk of victimization more than five times higher than any other location. However, and contrasting with the results from the previous model, locations with a concentration of high strata units were, as well, a significant risk factor to this model. Still, the risk presented by the location of richer households was comparatively much lower, with a

Table 2 Risk terrain results disaggregated by violent crime type for calendar year 2012

Risk factor	Homicide		Assault		Theft	
	SI/O	RRV	SI/O	RRV	SI/O	RRV
Socio-economic variables						
Low strata (below average)	**75 (P)**	**6.4***	**75 (P)**	**5.09***	75 (P)	1.89
High strata (above average)	–	–	225 (D)	1.53	225 (D)	1.87
Environmental variables						
Banks	–	–	225 (P)	1.43	150 (P)	1.99
Community kitchens	450 (D)	2.24	450 (P)	1.5	–	–
Drugstores	75 (P)	1.65	150 (P)	1.56	**450 (P)**	**2.57***
Higher education	–	–	–	–	450 (P)	1.28
Hotels	–	–	225 (D)	1.34	300 (D)	1.57
Medical clinics	300 (P)	1.36	450 (P)	1.51	375 (P)	1.85
Public hospitals	450 (P)	1.47	450 (P)	1.39	450 (P)	1.16
Public libraries	–	–	–	–	450 (P)	1.23
Schools (only private)	–	–	–	–	375 (P)	1.28
Schools (only public)	450 (D)	1.48	375 (D)	1.39	450 (D)	1.19
Tourist areas	–	–	450 (P)	1.29	450 (P)	1.26
Tourist attractions	–	–	–	–	450 (D)	1.45
TransMilenio stations	–	–	225 (D)	1.3	300 (P)	1.28

"O" stands for operationalization, (P) for proximity and (D) for density values. "SI" stands for spatial influence (in meters). RRV stands for relative risk value

* Most significant risk factor (highest risk score)

relative risk score of only 1.5, than that of the lower stratum households of Bogotá. Therefore, indicating that socially disadvantaged strata, or low strata areas, were at a higher risk of victimization for assault. Other significant risk factors to this model included the location of banks, medical clinics, and drugstores, all posing a higher risk of victimization for assault incidents.

In regard to the third RTM model for theft incidents in 2012, the effect of socio-economic segregation differed when compared to the previous two models on homicide and assault incidents. According to the results, the relative risk presented by high or low stratum units was significant but not determinant at explaining the occurrence of theft incidents in Bogotá. Instead, proximity to locations with drugstores or banks was associated with an increase in the risk of victimization. Thus, it can be assumed by these results, that the spatial distribution of theft incidents in Colombia's capital responds to a different locational pattern than that of homicide and assault incidents. While homicide and assault incidents tend to cluster near locations where low strata housing is present, theft incidents are more widespread through both strata.

As shown on Fig. 1, the spatial distribution of theft, and that of assault and homicide incidents differs as does the relative risk of victimization for each of these violent crime types. The central neighborhoods in the city of Bogotá presented in the year 2012 a higher risk for theft victimization, due to the opportunity presented by the combination of suitable victims and economic activity. The RTM depiction for homicide and assault incidents present a very different spatial pattern over the same year, as risk spreads between the south and western parts of the capital, where the most vulnerable concentrate. It is therefore possible to establish a spatial correlation between socio-economic segregation in the city of Bogotá and the wide-spread risk of victimization for homicide, and to some extent, assault incidents. This relation-ship did not present the same locational pattern in regard to the spatial distribution of risk for theft incidents.

To test the predictive capacity of these three RTM models, the location of future crime incidents was compared against places identified as posing a higher risk of victimization. As suggested by Caplan and Kennedy (2016, p. 27), "very accurate place-based forecasts can be made when the attractors of criminal behavior are diagnosed with RTM." In a recent publication by Dugato et al. (2017), RTM predicted that up to 85% of 2012 mafia homicides in Naples occurred in 11% of the city's area identified as posing the highest risk. Based on the results of this study and supporting previous findings, RTM accurately predicted the micro-level location of vulnerable places that attract and generate risk throughout Bogotá's jurisdiction, which allowed for 2013 crime prediction. For instance, the top 5% cells with the highest relative risk score (3839 out of 76,776) effectively predicted 29% (5410 out of 18,838) of all theft incidents occurring during 2013 in the city of Bogotá. In other words, nearly one-third of all theft incidents that took place in 2013 had its origin in an area comprising just 5% of the city's land posing the highest risk for future theft incidents. Similarly, the top 5% cells with the highest risk for homicide incidents witnessed 18% (158 out of 898) of all homicide events taking place in the city. Finally, and based on the RTM results for assault incidents, 20% (1567 out of 7947) of all assault events that occurred during 2013 were located in the top 5% cells posing the highest risk.

Finally, a comparison was made using the PAI values for high-risk places, hot spots, and the combined action of high-risk places and hot spots, to accurately predict the location of future crime events. The interpretation of PAI results is straightforward, the higher the value, the greater the accuracy when comparing across techniques (Chainey et al. 2008). In regard to the
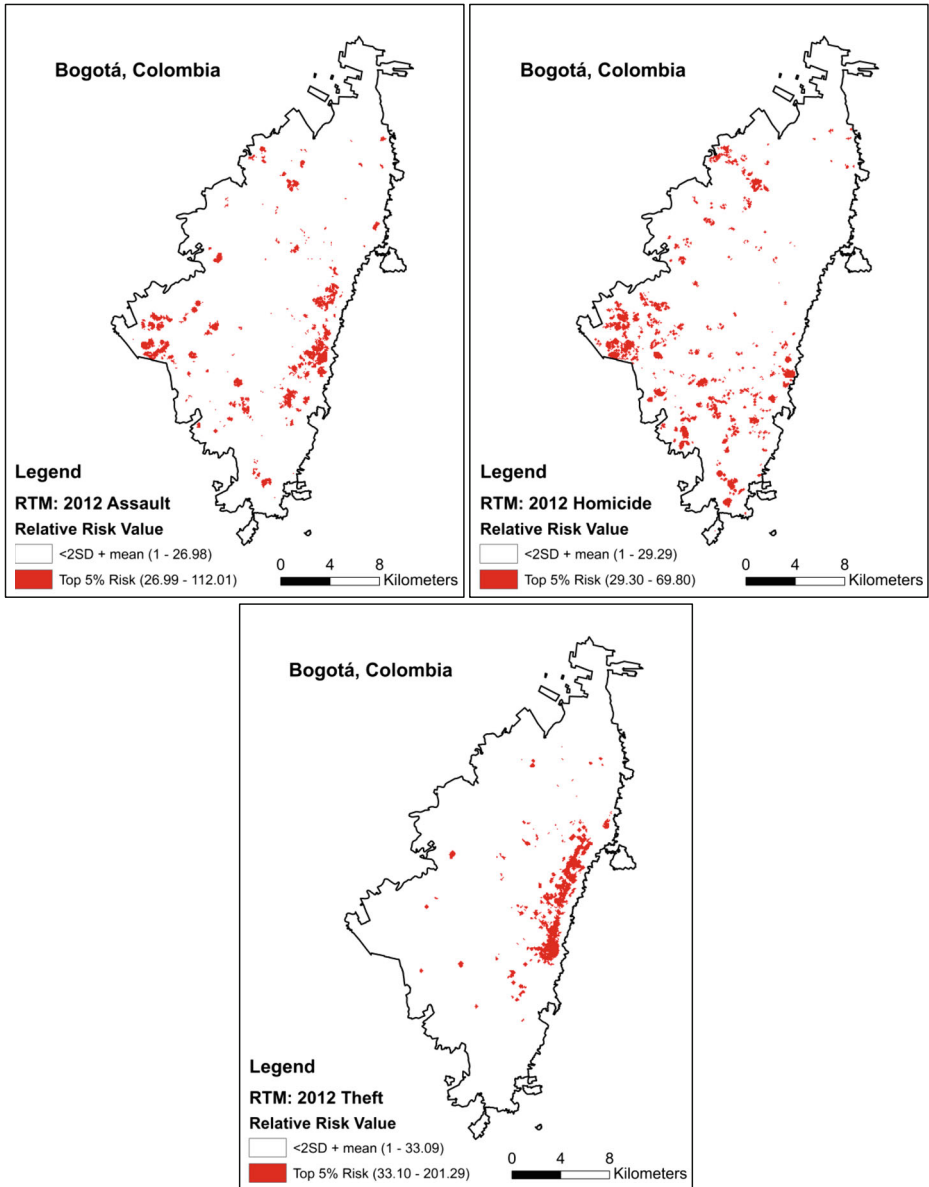
Fig. 1 Highest risk places for violent crime incidents by crime type for calendar year 2012

theft model, PAI values of 7.42 were found for high-risk places, 8.22 for hot spots, and 9.96 for locations where high-risk places intersect with hot spots. For example, using the joint utility revealed that 1492 cells intersected in an area comprising 8.4 sq. km (approx. 1.9% of Bogotá's study area), predicting 19% (3647 events) of all theft incidents. Then, for Bogotá's assault model, PAI values of 3.57 for high-risk places, 4.76 for hot spots, and 5.85 for all places where high vulnerability and exposure to past crime intersected. In other words, the combined effect of high-risk places and exposure to past crime events increased the overall

accuracy for predicting future assault incidents by 23%. Lastly, the homicide model had PAI values of 3.53 for high-risk places, 6.43 for crime hot spots, and 6.47 for locations where high-risk places overlap with crime hot spots. These results suggest that future crime incidents are most likely to emerge at places where high vulnerability (based on the presence of a series of environmental risk factors) and recent exposure to crime (hot spots) are on display (Kennedy et al. 2015).

Discussion

The results of this study confirm the initial hypothesis, noting that micro-places in the poorest areas of Bogotá are at a higher risk of homicide and assault victimization. That is not the case for theft incidents, which appear to be spatially associated with the location of banking centers, tourist-related activities, and medical clinics. Thus, suggesting that homicide and assault incidents are more "expressive types of crimes", while theft events seem to follow what could be considered a "routine activities approach" (Cohen and Felson 1979). As noted by Llorente et al. (2001), the presence of criminal structures in certain areas of the city could explain the clustering of homicide and assault crimes in the poorest areas of Bogotá. Similarly, and as discussed by Cohen and Felson (1979, p. 590), the presence in time and space of "likely offenders, suitable targets, and the absence of capable guardians" can explain the concentration of theft incidents in Bogotá's central districts. Moreover, these findings demonstrate the value of the joint utility of RTM and hot spot analysis techniques when responding to questions of "where to go" and "why", bringing valuable insights to the tailoring of crime reduction strategies. Through the use of RTM, it is possible to predict stagnant crime clusters, and to anticipate the emergence of new hot spots in similarly risky locations, even if crime has not occurred there yet (Caplan and Kennedy 2016). Based on the results of this study, both RTM and hot spot analysis have value and varying degrees of predictive accuracy. Thus, special attention should be paid to the utility that their combined use has for operational practices, risk reduction, and crime prevention.

RTM has more commonly been utilized in research to examine the spatial characteristics surrounding multiple crime types (e.g., Caplan et al. 2017; Drawve and Barnum 2017). Although this has been beneficial in applying RTM across crimes, there is limited research (e.g., Dugato 2013; Dugato et al. 2017) examining the ability to predict crime outside of the United States. The current study builds on extant RTM research by examining the ability to predict violent crime in a diverse study setting such as Bogotá.

Additionally, the current study included a stratum measure at the micro-level. The limited research including social measures with RTM are typically bound to aggregate social data at the neighborhood-level (e.g., Drawve et al. 2017; Piza et al. 2017). The ability to account for social differences at the micro-level allowed for inclusion of the stratum measure in RTM, and as seen in the results, low strata was a significant predictor for each crime type. More specifically, the low strata risk factor had the highest RRV for the homicide and assault analyses. By including social measures at the micro-level, RTM not only indicated if the strata measures were significant but also the environmental factors in the same model (i.e., simultaneously included social and physical measures). Moreover, the current study increases the support for the ability of RTM to significantly predict future crime, while examining violent crime in a city not previously studied with RTM.

As with other studies using crime data, underreporting, poor quality of records, and bias arising from police data collection methods can all potentially have a negative effect over the results from this study (Fajnzylber et al. 2002). Moreover, future research should control for micro-level risk assessments within strata, rather than citywide analyses across all strata areas. A strata-specific study will allow determining the locational effect of the built environment within particular strata sections, effectively controlling for the social characteristics of entire sections of the city. Also, a neighborhood-level analysis would bring valuable information on the neighborhood-specific characteristics leading to crime. Finally, the stark income differences discussed in this study among Bogotans and across stratum suggests the need to control for inequality, commonly an aggregate social measure, to determine the association with crime outcomes.

Conclusion

Latin America continues to be one of the world's most violent regions. According to Soares and Naritomi (2010), the occurrence of deaths due to violence is much more common in Latin America than in any other region on the planet: it is roughly 200% higher than in North America and in the Western Pacific and 450% higher than in Western Europe. This is a dramatic situation urging local and national stakeholders to take decisive steps to curve violence and crime in the region. In this analysis, we proposed the use of RTM as a tool to effectively identify risky micro-places and develop the necessary long-term strategies to reduce and mitigate risk. Still, we acknowledge that violent crime does not occur in a vacuum, as it is also the result of unique social, economic, and structural factors. For instance, high levels of socio-economic inequality have been linked to an increase in the risk of violence and violent crime, fueled by feelings of frustration and dissatisfaction (see Agnew 1999; Blau and Blau 1982; Krahn et al. 1986; Hipp 2007). Thus, the importance to include social measures to control for the unique context under which crime is most likely to emerge.

Having this objective in mind, the current study empirically demonstrated the spatial association between the concentration of the socially disadvantaged and the risk of violent crime victimization in the city of Bogotá. This relationship holds and is significant in the case of homicide and assault incidents, which are predominantly clustered near low strata sections. However, the case for theft incidents presents a different reality, as strata becomes a less significant predictor for victimization. Instead, theft incidents tend to be spatially associated with the presence of suitable victims and economic activity in Bogotá's central neighborhoods.

Moreover, this research has focused on improving the understanding of the physical and social characteristics related to multiple crime types. This is particularly relevant as results hold across property and violent crime types when utilizing RTM to predict 2013 crime counts. Also, the significant variation of risk factors displayed across different crime types illustrates the varying effect of the built environment on violent crime incidents. All of which ultimately indicates that "location matters" in the city of Bogotá, and that identifying the spatial effect of the built environment within its local socioeconomic context is fundamental to address the location of future crime events.

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