What makes a city vital and safe: Bogotá case study

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1 Introduction

By 2030, 9% of the world's population is expected to live in just 41 mega-cities, each of these accommodating more than 10M inhabitants. Thus, cities are playing an increasingly critical role in human society, as essential centers for innovation, tolerance, novelty, and economic prosperity but they are also facing challenges ranging from traffic and pollution to poverty and criminality. Moreover, urban areas allow for a more efficient use of resources and foster exchanges of ideas and knowledge creation. A fundamental research question that urban planners, sociologists, economists, and policy makers are investigating is related to the ingredients for a *vital*, *safe*, and *liveable* urban life.

The urban activist Jane Jacobs in *The Death and Life of Great American Cities*,[1] one of the most influential books in city planning, introduced the urban physical environment (the *urban fabric*) as an essential factor for urban vitality and urban safety.[2] As the book title states, Jacobs dealt with the lifecycle and complexities of growth and decline of American cities. In its most basic form, her argument was that death was triggered by elimination of pedestrian activity (*e.g.*, by highway construction, large-scale development projects, etc.), and that life was created by the presence of pedestrians at all times of the day.

She argued that, to promote urban life in large cities, the physical environment should be characterized by *diversity* at both the district and street level. Diversity requires four essential conditions: (i) *mixed land uses*, that is, districts should serve more than two primary functions, which would attract people who have different purposes; (ii) *small blocks*, which promote opportunities for contact among people; (iii) *buildings diverse in terms of rent and utility fees*, which make it possible to mix high-rent and low-rent tenants; and (iv) sufficient *dense concentration* of people and buildings.

She also emphasized *natural surveillance* as a key deterrent for fear and crime: as people are moving around an area, they will be the "eyes on the street," able to observe what is going on around them.[3]

However, these conditions have not been empirically tested until recently, mainly because it is difficult to collect data about "city life". A notable example of these recent collection efforts is the city of Seoul, which last year collected pedestrian activity through surveys at an unprecedented scale, with an effort spanning more than a decade, allowing researchers to conduct the first study successfully testing Jacobs' conditions. Here, our team proposes a valuable alternative to the lengthy and costly collection of activity survey data: mobile phone data or call detail records (CDRs). In this investigation, we are extracting human activity from CDRs and collecting land use and socio-demographic information from sources such as the census and Open Street Map. This approach was recently tested on six Italian cities. Although these cities are very

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[1] Jacobs 1961.
[2] Jacobs 1961.
[3] Doeksen 1997; Jacobs 1961.

different from the places for which Jacobs' conditions were originally delineated (i.e., great American cities) and from the places in which they were recently tested (i.e., the city of Seoul), we find Jacobs' conditions to be indeed associated with vital urban life. In this project, we propose to extend our study to Bogotá with the goal of predicting vitality, safety, and liveability (*e.g.* poverty levels, life satisfaction, etc.). Our methodology promises to have a great impact on urban studies, not least because, if replicated, it will make it possible to test Jacobs' theories around the world.

1.1 Urban life and behavior data

1.1.1 Mobile phone activity

We use mobile phone data from the Telefónica network in Colombia. Every time a mobile phone places or receives a call or message, the mobile towers carry the communication record details about the activity and relay it to the network operator. Each activity is stored in the form of a call detail record (CDR), which typically includes information such as the type of communication (call or SMS), the timestamp and duration, the identifiers of the towers where the communication began and ended, the source and destination telephone numbers (typically encrypted for security/privacy reasons), and additional information about roaming and other operators that were involved in the communication.

The CDR datasets we have access to include approximately 7 billion anonymized records, attributable to over 800 antennas tracking communication activity of up to 25 million unique users per day. This data set only contains metadata, and never the actual content of the communication.

1.2 Structural data

1.2.1 Spatial data

Bogotá, the capital city of Colombia, is divided into 20 localities, each of which contains between 1 to 12 zonal planning units, known as Unidad de Planeamiento Zonal (UPZ) in Spanish. In total, there are 113 UPZs. Each UPZ, in turn, is divided into neighborhoods, which are themselves composed of a set of blocks.

In addition to the UPZ scheme, Bogotá also has spatial divisions defined by the national census. The designations used by the census are (from largest to smallest): urban sector, urban section, and block. A sector is a cartographic census division, roughly equivalent to a neighborhood (especially for large cities), and comprising between 1 and 9 sections. Each section is composed of approximately 20 contiguous blocks, all falling within the same sector. Finally, a block is a lot of land, built or unbuilt, bounded by public paths, roads, crosswalks, etc. Blocks may also be bounded by a natural feature such as a river, stream or channel, as long as it is permanent and easy to locate in the field.

Our main source of spatial data for this analysis is the Capital District's Spatial Data Infrastructure dataset, known as Infraestructura de Datos Espaciales del Distrito Capital (IDECA) in Spanish. Its function is to facilitate the access to geographic information about Bogotá and support its social, economic, and environmental development.

The IDECA dataset used for this study is a compilation of 10 spatial datasets which cover the following topics: buildings, lots, blocks, localities, land use, points of interest, strata, transport nodes, cycling trails, and road network. They are described in more detail in Table 1.

1.3 Socio-economic and crime data

The main sources for socio-economic and crime data are the National Statistics Office of Colombia, known as Departamento Administrativo Nacional de Estadística (DANE) in Spanish, and the National Police of Colombia. We use the population census and multipurpose survey from DANE and crime data from the National Police.

1.3.1 Census data

We used census data from the last census held in Colombia in 2005, and the population projections made by DANE for 2015. The Secretary of Planning of Bogotá, using DANE's projections, issued projections of the 2015 population of Bogotá by UPZ. From the census, we have access to socio-economic data at the block

Table 1: Topics of the IDECA datasets

Topic	**Type**	**Description**
Building	polygon	Buildings with permanent cover associated with a lot for protection against weather of people, animals, or property.
Lot	polygon	Minimum geographical unit on which is located one or more properties, urban or rural.
Block	polygon	Geographical area where a set of lots are grouped with or without construction and are delimited by public spaces and/or a natural features.
Locality	polygon	District division of territory, taking into account the social characteristics of its inhabitants and according to the distribution of powers and administrative duties assigned by the District Council.
Land use	polygon	Description and coverage of the qualified uses of each current building per lot in Bogota
Points of interest	point	Designated geographical features or qualities. These represent important elements of the landscape, providing an essential reference system for location. Points of interest have a geographical name and an area of action with well defined limits.
Strata	polygon	Classification system of residential property, which takes into account the level of income of the owners, the provision of public services, location, and other characteristics.
Transport nodes	point	Points of concentration and transfer of the different modes of transportation, both for cargo and passengers.
Cycling trails	line	The route of each road permanently assigned to bicycle traffic, properly marked and delimited, separated from a vehicle roadway by barriers or on a dedicated roadway or other authorized place.
Road network	line	Paths of the roadways (street, avenue, boulevard, highway, etc) of the city.

Table 2: Chapters of the EM dataset

Chapter	Type	Description	Variables
A	Dwellings	This table contains identification data	6
B	Dwellings	This table contains data on dwellings and their environment	53
C	Households	This table contains data on household living conditions	155
D	Households	This table contains data on public services and ICT	67
E	Persons	This table contains data on family structure and demography	60
F	Persons	This table contains data on health	123
G	Persons	This table contains data for comprehensive care for children below 5 years	70
H	Persons	This table contains data on education	134
I	Persons	This table contains data on ICT	83
J	Persons	This table contains data on participation in social organizations and networks	46
K	Persons	This table contains data on labor market	133
L	Households	This table contains data on perception of living conditions and institutional performance	120
M1	Households	This table contains data on expenditures on food and non-alcoholic beverages and other expenses	131
M2	Households	This table contains data on other expenses	240

level. In Bogotá, this census was conducted in 1,931,372 households, distributed across 37,473 blocks, and includes 6,778,691 people. The projections estimate a rise in Bogotá's population to 7,878,783 people in 2015.

1.3.2 Multipurpose Survey

The Multipurpose Survey, known as Encuesta Multipropósito (EM) in Spanish, was performed in 2014 by DANE, and financed by the Secretary of Planning of Bogotá. Its objective was to obtain statistical information on social, economic, and environmental aspects of urban households and residents of Bogotá. The survey is organized into 14 chapters, which are summarized in Table 2. DANE uses the EM to derive income data, multidimensional poverty indices, and subjective poverty indices, among others. The information from this survey is statistically representative at locality level (which is less granular than the UPZ).

1.3.3 Crime data

The criminal cases dataset includes geo-located and timestamped records of reported crime in Bogotá. It consists of 27,863 criminal cases for homicide and theft (burglaries of commercial property, burglaries of houses, and robberies) for 2014. Specifically, the dataset includes the category and subcategory of the crime, the longitude, latitude, and address of where the crime was reported to have occurred, and the responsible police department.

2 Methodology

Our approach leverages data from public (*e.g.*, national census, household survey, cadastral data) and commercial entities (*e.g.*, Foursquare) to infer *urban diversity* as per Jacobs' four conditions. Our goal is to study the relationship between *urban diversity* and crime, *urban vitality* and poverty. For criminality and deprivation we use conventional sources (police and official statistics data, respectively). For *urban vitality* we use mobile activity from call detail records as a proxy.

Next, we define Jane Jacobs' *urban diversity* metrics for each UPZ (see section 1.2.1 on page 2). Finally, we describe the regression models that we used to meet our goals.

2.1 Jacobs' metrics

We extracted several variables to quantify the four *urban diversity* conditions described by Jacobs (see Section 2.1). Most variables are not normally distributed. Density measures are computed with surface area in m^2, and closeness measures are the inverse of the distance (1/m).

2.1.1 Land use

We computed Land Use Mix (LUM)[4] in district i as:

$$\text{eq:`}_i = -\sum_{j=1}^{n} \frac{P_{i,j}\log(P_{i,j})}{\log(n)} \tag{1}$$

where $P_{i,j}$ is the percentage of square footage with land use j in district i, and n is the number of possible land uses (in our case, $n = 3$). If district i's land is dedicated to one use only, then LUM_i is zero; instead, if the land is used equally in all n ways, then LUM_i is one. The higher LUM_i, the more mixed i's land use. We defined the three land uses as follows, with reference to Manaugh:[5] the first land use is "residential"; the second includes the categories "commercial", "institutional and governmental", and "resource and industrial"; and the third includes "park and recreational" and "water".

Since well-managed parks might function well as hubs for pedestrian activity, we defined the average distance from the nearest small park (area smaller than 1 km^2) for each district i:

$$\text{Closeness to SM}_i = (\frac{1}{|B_i|}\sum_{j\in B_i}(j,(j,SM)))^{-1} \tag{2}$$

where B_i is the set of blocks in district i, (j, Y) is a function that finds the geographically closest element in set Y from block j's centroid, SM is the set of small parks, and (a, b) is the geographic distance between two elements' centroids a and b.

We also computed the Residential/Non-Residential (RNR) balance in district i as:

$$\text{RNR}_i = 1 - |\frac{Res_i - NonRes_i}{Res_i + NonRes_i}| \tag{3}$$

where Res_i is the area occupied by residential buildings in district i, and $NonRes_i$ is the area occupied by non-residential ones. The higher RNR_i, the more balanced the district in terms of residential *vs.* non-residential uses.

To go beyond horizontal land use and look at vertical development, we computed the average number of floors per building in district i and called it 'housing types' (as Sung[6] did):

$$\text{Housing types}_i = \frac{\sum_c h_{c,i}\cdot z_c}{\sum_c h_{c,i}} \tag{4}$$

[4] Cevero 1989.
[5] Manaugh and Kreider 2013.
[6] H. Sung and Cheon 2015.

where $h_{c,i}$ is the number of buildings that are in height category c in district i, and z_c is the number of floors corresponding to height category c. The sums were repeated over all height categories.

The previous definitions have characterized spatial use in terms of land use and building use. However, activities are important too. Jacobs argued for mixing primary uses so that people are on the street at different times of the day. To characterize spatial use in terms of activities, using Foursquare data, we determined whether each place is used daily (*e.g.*, convenience stores, restaurants, sport facilities) or not. Based on that, we defined

$$\text{Closeness to Daily}_i = (\frac{1}{|B_i|}\sum_{j\in B_i}(j,(j,D)))^{-1} \tag{5}$$

where D is the set of places that are used daily, and B_i is, again, the set of street blocks in district i (see equation 2).

Also, not all activities are equal. There are activities that are more 'social' than others. To capture that, we refer to the concept of *third places*. These are defined by Oldeburg[7] as the "great, good places" that foster community and communication among people outside the home (the first place) and work (the second place): "they are places where people gather primarily to enjoy each others' company". Third Places function as unique public spaces for social interaction, providing a context for sociability, spontaneity, community building and emotional expressiveness.[8] Therefore, we computed:

$$3^{rd}places_i = \frac{|3^{rd}\text{places}_i|}{|\text{places}_i|} \tag{6}$$

We determined whether a place is a third place or not by following the 4-category classification proposed by Jeffres *et al.*[9] Third places fall into these four categories: *eating, drinking and talking* (*e.g.*, coffee shops, bars, pubs, restaurants, and cafes); *organized activities* contributing to social capital[10] (*e.g.*, places of worship, clubs, organizations, community centers, and senior centers); *outdoor* (*e.g.*, plazas and parks); and *commercial venues* (*e.g.*, stores, malls, shopping centers, markets, beauty salons, and barber shops).

2.1.2 Small blocks

Jacobs listed the presence of small blocks as the second necessary condition for diversity. Small blocks are believed to support stationary activities and provide opportunities for short-term and low-intensity contacts, easing into interactions with other people in a relaxed and relatively undemanding way. Specifically, she stated that "lowly, unpurposeful and random as they may appear, sidewalk contacts are the small change from which a city's wealth of public life may grow". She criticized super-blocks and rectangular blocks, which constrain urban mobility with high travel distances and limited opportunities of cross-use.

The easiest way to identify small blocks is to compute the average block area among the set B_i of blocks in district i:

$$\overline{\text{Block area}}_i = \frac{1}{|B_i|}\sum_{j\in B_i} j \tag{7}$$

Since a district with high intersections density is likely to contribute to random contacts, we also computed:

$$\text{Intersection density}_i = \frac{|\text{intersections}_i|}{i} \tag{8}$$

Finally, since block size is distributed as a power law $P(A) \sim \frac{1}{A^r}$ with $r \sim 2$, we characterized a district i by its average shape anisotropicity[11] of the blocks B_i within it:

$$\text{District anisotropicity}_i = \frac{1}{|B_i|}\sum_{j\in B_i}\Phi_j \tag{9}$$

[7] Oldenburg 1989.
[8] Oldenburg 1982.
[9] Jeffres et al. 2009.
[10] Putnam 2001.
[11] Louf and Barthelemy 2014.

where Φ_j is the ratio between the area of the block j and the area of its circumscribed circle $\mathcal{C}_j$:

$$\Phi_j = \frac{j}{\mathcal{C}_j} \tag{10}$$

The quantity Φ_j is always smaller than one, and the larger its value, the less anisotropic block j, the more opportunities for contacts the block creates.

All of these metrics were computed using the district *net area*$_i$, which excludes unpopulated patches such as rivers and natural parks.

2.1.3 Buildings Diversity

Jacobs stressed the importance of having diverse buildings in a district. If a district has only new or desirable buildings with high rents, then it would have only enterprises or individuals that can support the high costs. If it has ordinary or less desirable buildings too, instead, it would be able to incubate new small enterprises, or mix persons of different status that cannot afford high rents, and that will benefit the local economy in the long run. As Jacobs stated: "If the incubation is successful enough, the yield of the building can, and often does, rise".[12]

In Colombia they have a fiscal policy which classifies buildings in different regimes of tax payments for utilities and rents, which is called stratum. Stratum classifies buildings in a scale from 1 to 6 where 6 is for most expensive locations.

It is not yet clear how this data will be treated, but we should look at stratum average and its standard deviation to have an idea of building diversity in each district.

2.1.4 Concentration

Jacobs' fourth and final condition is about having concentration of buildings and of people. We computed two sets of concentration measures: one for people, and the other for buildings.

First, population density measures were calculated dividing the number of people by the district's net area.

$$\overline{\text{Population density}_i} = \frac{|\text{Population}_i|}{i} \tag{11}$$

To add to this people-based concentration measures one building-based measure, we computed:

$$\overline{\text{Buildings density}_i} = \frac{|\text{Buildings}_i|}{i} \tag{12}$$

which is the total number of buildings divided by district area.

Finally, as we have done previously, to go beyond people and buildings and look at activities, we computed:

$$\text{Density of daily places}_i = \frac{|\text{daily-use places}_i|}{i} \tag{13}$$

$$\text{Density of non-daily places}_i = \frac{|\text{non-daily-use places}_i|}{i} \tag{14}$$

These two quantities are not totally uncorrelated since not all places can be classified as being fully daily *vs.* non-daily.

2.1.5 Vacuums

Border vacuums are places that act as physical obstacles to pedestrian activity. For instance, parks can be a hub of pedestrian activity, if efficiently managed,[13] but they could also be deplorable places in which criminality flourishes (especially at night). In a similar way, the proximity to expressways may discourage

[12] Jacobs 1961.
[13] Jacobs 1961.

pedestrian activity or may effectively connect different parts of the city. This is what Jacobs called "the curse of border vacuums".

Therefore, we needed to identify large areas with single use. From IDECA, we took parks, fast transit zones, rivers, and highways. That extraction allowed us to build the sets of large parks LP, highways H and water areas W.

To verify the impact of a type of vacuum area, say, that of large parks on a district, we calculated the average distance between a district's block (i.e., smallest area surrounded by street segments) and its closest large park (*cf.*. eq. 2):

$$\text{Closeness to LP}_i = (\frac{1}{|B_i|} \sum_{j \in B_i} (j, (j, LP)))^{-1} \tag{15}$$

where $(j, (j, LP)$ is the distance between block j and its closest large park. The sum of distances is done over all blocks in district i (B_i is indeed the set of district i's blocks).

In a similar way, we computed the average distance between a district's block and its closest highway, and its closest water area:

$$\text{Closeness to H}_i = (\frac{1}{|B_i|} \sum_{j \in B_i} (j, (j, H)))^{-1} \tag{16}$$

$$\text{Closeness to A}_i = (\frac{1}{|B_i|} \sum_{j \in B_i} (j, (j, A)))^{-1} \tag{17}$$

where H and A are the sets of highways and of water areas.

2.2 Human Activity from Mobile Data

As has been extensively done in previous work, we used CDRs as a proxy for *people dynamics* and hence *urban vitality*.[14]

To roughly estimate the number of call and SMS events that fell into each district, we represent the urban space as a set of 2-dimensional, non-overlapping, and non-convex polygons. These polygons come from a Voronoi tessellation based on positions of the radio base stations. In order to estimate the number of mobile phone events $S_i(t)$ in each district i at time t, we counted the number of mobile phone events over all polygons v's that fell into district i over a certain time period:

$$S_i(t) = \sum_v R_v(t) \frac{A_{v \cap i}}{A_v - A_{v \cap W}} \tag{18}$$

where v is a polygon, and $R_v(t)$ is the number of call and SMS events in v at time t. The count of call and SMS events is weighted by $\frac{A_{v \cap i}}{A_v - A_{v \cap W}}$, which is the proportion $\frac{A_{v \cap i}}{A_v}$ of v's area that falls into district i ($A_{v \cap i}$ is v's area that falls into district i, and A_v is v's total area). From v's total area we removed sea areas denoted by W (*i.e.*, we removed $A_{v \cap W}$).

Finally, having $S_i(t)$, we computed a district's *activity density* as the average number of call and SMS events throughout a typical business day, divided by the district's area. The normalization of surface area makes it possible to compare the activities of districts of different sizes.

2.3 The regression model

Our goal is to model the relationship between each district's structural diversity (characterized by Jacobs' conditions) and: (i) the district's activity density; (ii) the district's crime density; and (iii) the district's poverty (deprivation) level.

We evaluate these relationships by means of an Ordinary Least Squares (OLS) model.

Since most of the regression variables were skewed, we first transformed them. More specifically, we log-transformed activity density using the natural logarithm, and transformed the structural diversity metrics

[14] De Nadai et al. 2016.

using the Box-Cox method.[15] To avoid over-fitting, we split the data into a training set (75%) and a test set (25%), and repeated our measurements 1000 times using a shuffle split cross-validation.

Specifically, we create six linear models. We create five models, one for each of the five metrics by Jacobs as independent variables (*i.e.*, we separately analyze land use, small blocks, buildings diversity, concentration, and vacuums). These models have each of the three aspects(activity density, crime density, and poverty level) as the dependent variable. The resulting coefficients of significant variables, for the criminal activity are shown in the tables bellow (Table 3 & Table 4). The other studied variables are in progress, but we put the crime variables as an example of outputs.

		Coefficient	z-Statistic	Probability
	Land use mix (1)	-0.228	-3.6457	0.000
	Residential *vs.* Non-Res. daily use (3)	-0.461	-5.130	0.000
	Residential *vs.* Non-Res. non daily use (3)	0.419	4.301	0.000
	Housing type std	0.212	3.00	0.002
1.2	Third places	-0.157	-2.813	0.004
	Daily places density	0.330	4.159	0.000
	Buildings density	0.336	5.437	0.000
	Closeness small parks	-0.277	-4.002	0.000
	Closeness highways	-0.190	-2.892	0.003
	$Pseudo - R^2$	0.71		

Table 3: Linear regression model that predicts the number of robberies in each UPZ.

		Coefficient	z-Statistic	Probability
	Land use mix (1)	-0.228	-3.6457	0.000
	Residential *vs.* Non-Res. daily use (3)	-0.327	-2.67	0.007
	Residential *vs.* Non-Res. non daily use (3)	0.272	2.72	0.006
	closeness daily buildings	0.486	5.550	0.000
1.2	Housing type avg.	-0.571	-7.53	0.000
	Third places density	0.488	5.499	0.000
	Average block size	-0.191	-2.231	0.025
	Daily places density	-1.141	-5.20	0.000
	Non daily places density	1.038	4.473	0.000
	Buildings density	1.013	14.309	0.000
	$Pseudo - R^2$	0.90		

Table 4: Linear regression model that predicts the number of homicides in each UPZ.

3 Results & Discussion

These results are very preliminary and not represent a final conclusion of this work. However, these preliminary results show a first approximation of the problem. Table 3 presents the results of the linear regression model that predicts the number of robberies in each UPZ. The table presents all coefficients that are statistically significant. A preliminary interesting result is the coefficient on LUM implies that, for the same levels of the rest variables in the model, districts that have a higher mixed land uses have 22.8% fewer robberies than districts with lower mixed land uses. The results also suggest that fewer robberies occur in Bogotá when:

– daily use of districts is more residential than non-residential;
– there are more third places in the districts than primary and secondary places;
– districts are closer to small parks;
– districts are closer to highways.

[15] Box and Cox 1964.

Regarding this last coefficient, the negative sign was not expected..
Table 4 presents the results of the linear regression model that predicts the number of homicides in each UPZ. Likewise Table 4 presents only the coefficients that are statistically significant. The results also suggest that more homicides occur in Bogotá when:

– non daily use of districts is more residential than non-residential;
– districts are closer to daily buildings;
– high density is present in third places;
– high density is present in non-daily places;
– there is a concentration of buildings density.

These first approximations are open for discussion to new ways to study and observe urban policy in different cities. The new granularity of data available with the combination of accessible CDRs, allows testing old and new questions that could make us rethink our models and ways of urban policy-making.

Glossary

CDR call detail record

DANE Departamento Administrativo Nacional de Estadística

EM Encuesta Multipropósito

IDECA Infraestructura de Datos Espaciales del Distrito Capital

LUM Land Use Mix

UPZ Unidad de Planeamiento Zonal

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