Mobility for Compact and Less Segregated cities: The Urban Plan of Expanded Center from Bogotá

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Abstract. In the urban mobility the inequalities of social, environmental, and economic urban components are reflected [1], which can be explained, for example, in the analysis of urban mobility queries, in the densely populated areas, and in the residential deficit (demographic urban components), or areas with greater attraction of travel for employment (socio-economic urban component). This study proposes to densify areas with the best mobility conditions from home to work in public transport with travel times not exceeding 20 minutes and respecting the other urban components that make viable the habitability in the expanded Center of Bogotá, according to the prescriptions of the “El Plan Urbano del Centro Ampliado de Bogotá”.

1. Introduction
The Urban Plan of Expanded Center from Bogotá (PUCAB in Spanish) [2] is a book made by the Bogotá Humana series (2015), which is about an area where the middle-high classes live. The PUCAB’S objective is to densify the downtown in 808.506 habitants (Bogota population increase for the year 2020) [3], with housing for low-class living towards the periphery far from the major employment offer, and decreasing the spatial segregated while urban mobility keeps improving with short displacements between 20 minutes from home to work on public transport due to pendulum-like tides, originated by people who live on the periphery and work in downtown. This investigation respects the geographical mark-up of the PUCAB due to other urban aspects which will then be discussed. This work gives a densifying methodology for PUCAB’s areas under mobility time restrictions.

2. Geographic limits from Bogotá’s Expanded Center.
The figure 1 shows the Expanded Center from Bogotá. It’s a big area, with 13 sub-areas of 20 total areas from the city [4].
2.1. Justifications why to densify the Center Expanded

Table 1 shows the urban equipment in Expanded Center.

Table 1. Equipment for area, population and equipment for 10.000 habitants, 2011 [4]. Source: Master Urban Plans SDM, 2011.

| No | sub-areas names | Social welfare | Health | Education | Culture | Others | Recreation and sports | Food supply | Administration | Security, defense and justice | Fairgrounds | Cemeteries and funeral services | Total | Population of year 2011 | Equipment for 10,000 habitants |
|----|-----------------|----------------|--------|-----------|---------|--------|------------------------|------------|----------------|-------------------------------|-----------|-------------------------------|-------|-------------------------|-------------------------------|
| 1  | Usaquén         | 380            | 38     | 233       | 42      | 98     | 12                     | 5          | 10             | 12                            |           | 5                             | 835   | 474773                  | 18                |
| 2  | Chapinero       | 233            | 10     | 176       | 74      | 43     | 7                      | 2          | 19             | 13                            |           | 4                             | 581   | 133778                  | 43                |
| 3  | Santa Fe        | 286            | 14     | 110       | 69      | 41     | 5                      | 6          | 23             | 33                            |           | 12                            | 600   | 109993                  | 55                |
| 4  | San Cristóbal   | 563            | 25     | 174       | 63      | 60     | 6                      | 3          | 6              | 12                            |           | 2                             | 914   | 409799                  | 22                |
| 5  | Usme            | 598            | 18     | 110       | 63      | 32     | 3                      | 3          | 6              | 10                            |           | 3                             | 846   | 382876                  | 22                |
| 6  | Tunjuelito      | 103            | 19     | 97        | 10      | 48     | 1                      | 4          | 6              | 11                            |           | 4                             | 303   | 201843                  | 15                |
| 7  | Bosa            | 430            | 27     | 178       | 45      | 41     | 2                      | 2          | 6              | 12                            |           | 5                             | 748   | 583056                  | 13                |
| 8  | Kennedy         | 464            | 33     | 372       | 87      | 109    | 6                      | 6          | 16             | 19                            |           | 4                             | 1116  | 1019949                 | 11                |
| 9  | Fontibón        | 163            | 17     | 167       | 35      | 58     | 4                      | 5          | 14             | 12                            |           | 3                             | 478   | 345909                  | 14                |
| 10 | Engativá        | 681            | 29     | 402       | 47      | 147    | 12                     | 9          | 16             | 19                            |           | 5                             | 1367  | 843722                  | 16                |
| 11 | Suba            | 532            | 21     | 429       | 78      | 130    | 21                     | 3          | 18             | 19                            |           | 5                             | 1256  | 1069114                 | 12                |
| 12 | Barrios Unidos  | 370            | 14     | 132       | 10      | 80     | 10                     | 3          | 9              | 6                             |           | 1                             | 641   | 233781                  | 27                |
| 13 | Teusaquillo     | 179            | 12     | 179       | 48      | 73     | 3                      | 2          | 27             | 10                            |           | 1                             | 9     | 543                      | 37                |
| 14 | Los Mártires    | 130            | 24     | 64         | 10      | 25     | 1                      | 3          | 4              | 16                            |           | 4                             | 281   | 97926                   | 29                |
The mean population from Bogotá is 214 inhabitants/Hectare and the city downtown has housing deficit [5]. The densification is viable in the Center Expanded where a greater amount of urban equipment is available like the table 1 shows. This area is also the safest from environmental risks like floods, landslides, and is not a biodiversity keeper zone as the periphery areas [6].

Figure 2 shows the middle-high classes living on the Center Expanded area in dark colors, and decreasing to light colors to the periphery zones; it is shown where low classes live [7], in densifying sectors far from the urban equipment available and employment offer. Discussed after.

![Figure 2. Neighborhood influence – Evaluation 2011.](image)

Source: Segregation in the urban space from Bogotá, [7]

The housing deficit on the central city area can be checked in mobility surveys [8], as figure 3 shows. The map of Bogota can be noticed, where mostly densifying housing is on the periphery areas colored with green and yellow color; being green the major travels receptor to home, and decreasing in travelling to the pink and beige areas according to the legend. In like manner, figure 4 shows the Center Expanded as work destination by the population of Bogota and people from nearby sectors from the Colombian capital city. The highest work displacements are in the direction of 26 zone [8], out of Expanded Center but near there. The legend colors interpretation is the same shown on Figure 3, being green and yellow the highest travelling reception to work (high displacements to Expanded Center), and decreasing to pink and beige with a low travelling reception to work or search for job, showing the pendulum-like tides, originated by people who live on the periphery and work in downtown.
Figure 3. Travels to home back, mobility survey 2015.
Source: Own, based on information from Mobility Survey [8].

Figure 4. Commutes from home to work, mobility survey 2015.
Source: Own, based on information from the Mobility Survey [8].
3. Methodology
Finding a difference among the areas of greatest tendency for employment location presented by PUCAB in chapter 1 and 4, this study identifies these areas before proposing short trips from home to work. The arrive to employment is the greatest objective of displacement at the city central areas according to query mobility survey. This work presents a methodology for prioritizing areas to densification under conditions of short commutes of 20 minutes from home to work in scenario of placing homes close to jobs located even out of the Expanded Center.

Another point is that Mobility Surveys are studies that determine mobility patterns according to demographic and socio-economic features of studied population in Zones of Transportation Analysis (ZAT). The priority areas to be densified under conditions of public transport trips till 20 minutes from home to work, and are delivered on this same unit ZAT. The information about commute timing from home to work is taken from these studies.

The displacements in public transport are represented in the next matrix (Figure 5), of 999 x 999 zones ZAT, the time of displacements are from the first column j (home’s ZAT) to the first line i (work’s ZAT). The number “999999” means the no-connection between two ZAT zones in public transport. For example, the commute from ZAT 167 to the ZAT 170 is in 5, 56 minutes. Here a part of the real matrix is represented because of its big size.

\[
\begin{array}{cccccc}
\text{Origin zones ZAT} & \text{ZAT} & 167 & 168 & 169 & 170 & 171 \\
167 & 0 & 999999 & 999999 & 5,56 & 999999 \\
168 & 4,19 & 0 & 999999 & 4,83 & 999999 \\
169 & 3,37 & 999999 & 0 & 999999 & 999999 \\
170 & 7,06 & 2,54 & 999999 & 0 & 999999 \\
171 & 999999 & 999999 & 999999 & 999999 & 0 \\
\end{array}
\]

**Figure 5.** Matrix times for Origin to Destination zones in public transport.
Source: Own, based on information from Mobility Survey [8].

ZAT: ID numbering of ZAT’s.
Origin Zones ZATj: Origin ZAT zone on the first column to the left.
Destination Zone i: Destination ZAT zone in the upper row.
\(T_{ij}\) (min): Matrix times from Origin zones j to Destination zones i, in public transportation.

3.1. The proposal to densify the PUCAB’s sector under the mobility condition
The proposal is to densify zones within the enlarged downtown, and to be able to cover a perimeter of job offer even outside of this sector in public transport provided that the travel takes until 20 minutes from PUCAB’s mobility condition.

The quantity of people that travel to Bogotá city was consulted in the database survey mobility [8] travel’s numbers (Column \(N_i\)), per interview moving to target ZAT zone (column B) is given below on Figure 6. For these results, the column D was filtered, reason of travel (employment = 1), and column E, destination zone ZAT (destination in Bogotá any zone = 1). This survey was taken for making the Figure 4, discussed before, to know the highest displacements to work in Bogotá (Center Expanded and city north).
Figure 6. Amount of travels or displacements for each ZAT, zone because of employment.
Source: Mobility survey [8].

“Nji”: travel’s numbers per interview moving to target ZAT zone.
“D”: travel’s reason, employment = 1.
“E”: destination zone, Bogota = 1 [9]
“B”: target ZAT zone.

The Figure 7 is a hypothetical matrix for calculating the mean time (Pj) and a coverage (Aj), to give priority on densifying areas with less time commutes from home to work on 20 minutes, and zone coverage with greater potential to attract a lot of short travels from home to work (Ni), till 20 minutes. The zones for densifying are in Expanded Center due to other urban components, but the commutes from home to work to any ZAT zone in Bogota or nearby zones that compose the Mobility Survey can be out of this sector if the travel is made in a maximum of 20 minutes. The matrix shows a zone to densify (hypothetical Center Expanded) in the first column to left with zones represented for the consecutive numbers 167 to 171, and destination zones (employment zones) are represented with the consecutive numbers 1 to 7. The real Bogota matrix has 790 destination zones and 325 Center Expanded zones.

Table 1

| Nj | D | E | B  |
|----|---|---|----|
| 3  | 1 | 1 | 568|
| 3  | 1 | 1 | 471|
| 1  | 1 | 1 | 198|
| 1  | 1 | 1 | 230|

Figure 7. Origin Matrix to destination times in public transportation.
Source: Own, based on information from the Mobility Survey [8]

\[
P_j = \frac{\sum_{j=1}^{B} T_{j,i}}{NT_j}
\]

(1)
\[
Z_j = \sum_{T_{ij} \leq 20} D_i N_i
\]

(3)

\[
A_j = \frac{Z_j \times 100}{\sum_{i=1}^{D_i} N_i}
\]

\(N_i\): travel’s amount attracted by Destination zone (i)
\(P_j\): mean commute times between origin and destination times until 20 minutes
\(Z_j\): Sum of travels attracted by Destination zones (\(N_i\)) till 20 minutes.
\(A_j\): Destination’s Percent on coverage zones, with greater employment, in commutes under 20 minutes, from each Origin zone.
\(D_i\): Total amount of Destination zones (Destination zone universe)
\(NT_j\): Total amount of \(T_{ij} \leq 20\) in commutes from each Origin zone to \(D_i\).

Example on Figure 7, to calculating \(P_j, Z_j,\) and \(A_j\) for origin zone 167:
\(P_j = (10 + 10 + 20) / 3 = 13.3\) minutes.
\(Z_j = (18 + 18 + 30) = 66\) travels.
\(A_j = (66 \times 100) / (18 + 18 + 30 + 9 + 77) = 43.42\%\).

For densifying the zones with greater reach of higher labor demand (\(A_j\)), and less mean commute time until 20 minutes (\(P_j\)) from home to work, is used the next tables 2 y 3 with the greater weight for less \(P_j\) and higher \(A_j\).

**Table 2.** Weight for time’s ranges until 20 minutes.

| Ranges | \(P_j\) (minutes) | Weight |
|--------|----------------|--------|
| R1     | Until 11       | 5      |
| R2     | 11-12          | 4      |
| R3     | 12-13          | 3      |
| R4     | 13-14          | 2      |
| R5     | >14            | 1      |

Source: Own

**Table 3:** Weight for coverage’s ranges until 20 minutes.

| Ranges | \(A_j\) (%) | Weight |
|--------|-------------|--------|
| I1     | Until 15    | 1      |
| I2     | 15-25       | 2      |
| I3     | 25-35       | 3      |
| I4     | 35-45       | 4      |
| I5     | >45         | 5      |

Source: Own
For the example, on Figure 7: The ZAT 167: $P_j$ is on range between 13 and 14 minutes (Table 2). The partial weight is 2; The coverage $A_j$ is on range between 35% and 45%, whose partial weight is 4 (Table 3). The total weight is 6 (sum partial’s weights). This final weight will give the 167 zone’s position on ranking for priority densifying. Then, the zones 168 (Final weight = 7), 169 (Final weight = 8), 170 (Final weight = 6) and 171 (Final weight = 9).

**Table 4.** Ranking ZAT zones to densify into an hipotetic sector.

| Ranking | ZAT zone |
|---------|----------|
| 1       | 171      |
| 2       | 169      |
| 3       | 168      |
| 4       | 167      |
| 5       | 170      |

Source: Own.

The PUCAB’s sector with the real times’s matrix is represented in the next Figure 8.
The green zones are those with high weight (priority) to densify under commutes mobility conditions till 20 minutes, in Public Transport; yellow zones represent a middle priority for densifying, and in the same order, pink and beige zones represent a low priority to densify into the PUCAB’s region. All of the conditions are according to the PUCAB’s pretention about times for commuting travels from home to work.

4. Discussions and Conclusions.
The Figure 9 shows a comparation of results zones between the priority for densifying by the PUCAB’s document and the present study.

![Figure 9](image)

Figure 9. Superposition of PUCAB’s specific areas to densify and the investigation’s results for short commutes in until 20 minutes. Source: Own.

Results about this study come when PUCAB’s proposal areas are superposing into this proposal study. In order, the purple areas are the higher priority for densifying, then, pink areas are the middle priority for densifying and the orange areas are the low priority on the proposals here exposed, for short commutes, till 20 minutes in public transport.

Currently, the cities are growing, and the urban staking is developing with new urban rules with the construction densifying index for cities. This study proposes to accompany the urban plans with the methodology here exposed based on mobility surveys for a better decision on densifying under time conditions from home to work in public transport according to the PUCAB’s concept about mobility.

A compact city, densified on city’s downtown, implies get ideal times till 20 minutes on trips from home to job, in public transport, satisfying citizens on urban environment [10]. The intention is to get a fair city, balanced and sustainable, on a diverse socioeconomic classis mix. It is possible that in public spaces like parks and roads, there is a promotion of communication among different social classes for creating diverse public policies [11] while improving the sustainable urban mobility.
Benefits with this proposal of reside on downtown, gifted with full urban equipment and offer's jobs, optimize the urban mobility not only for reverting the pendulum flow to the central areas from home to work, but for making the decongestion vehicular possible since the low classes are a greater sustainable transport user [12].

Take the urban equipment to periphery places, allows a bring near people’s job, however, it extends the city, creating new peripheries, around this equipment on conservation’s places and vulnerability environmental by collapse and flooding, that also won’t allow the compact city pretended by this proposal.

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