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Urban development around bus rapid transit stops in seven cities in Latin-America

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ABSTRACT

Although bus rapid transit (BRT) has become a popular transportation innovation worldwide, little is known about the built environment around the stops of these systems. A typology of urban development around 81 BRT stops in 7 cities in Latin America was developed and their daily BRT ridership examined. Primary and secondary data collected around the stops were the basis for factor and cluster analyses. Ten stop types were identified, with some types including attributes consistent with expectations of transit-oriented development areas. Other stops captured conditions prevalent in many cities in Latin America: mixed land uses, informal housing distant from activity nodes, large commercial developments, and a relative absence of green spaces open to the public. Confirming expectations, stop types with a higher transit orientation were more likely to have higher ridership than other stops such as those burdened by incompatible land uses and barriers to station access.

KEYWORDS

Built environment; land development; transit-oriented development (TOD); bus rapid transit (BRT); Latin America

1. Introduction

The emergence of bus rapid transit (BRT) has revolutionized the provision of mass transportation in cities. While BRT emulates the level of service of a rail system, it is viewed as more cost-effective and flexible. Relatively low upfront costs mean that rail-like mass transportation is now within reach of many cities across the globe. Beginning with Curitiba, Latin American cities have been leaders in BRT implementation. More than 69 cities in Latin America have invested in BRT, accounting for more than 60% of BRT ridership worldwide (GlobalBRTData 2017; Lindau 2011).

Despite the prominent role that Latin American cities have played in BRT adoption and the strengthening interest in transit-oriented development (TOD), there is very limited research describing and understanding the built environment around BRT stops. This is a notable gap given that more than 176 cities worldwide currently are planning or implementing new or expanded BRT systems (GlobalBRTData 2017). Furthermore, the strategic and operating importance of BRT's potential to guide development and its impacts on transit demand, societal equity, the environment, and public health underscore the timeliness of

understanding the environment around BRT stops. In this study, the built environment around BRT stops in seven Latin American cities is examined. A typology of the environment around stops is defined and its associated passenger demand analyzed. This allows for understanding whether BRT stops tend to be dominated by environments with high passenger activity but with limited TOD features, whether they serve well-developed areas with limited ridership and limited potential for TOD, or whether they serve areas with significant realized or future potential TOD attributes.

Understanding current development around BRT stops is important for land and transportation planning. For land development and spatial planners, the information is useful for advancing plans to support the development or redevelopment around the stops. For example, planners can identify built environment characteristics around their specific stops that need attention or improvement. Similarly, the understanding can help planners prioritize action, relative to other stops that may require delayed intervention or that may already be performing well. And relatedly, planners can also identify land management actions that are well suited to the conditions and needs of particular stops. For transportation planners, the information is useful to understand how the built environment and the transit orientation of particular stops can translate into ridership. A typology can also help planners identify comparable stops in other systems, and assess the ridership performance of their stops relative to their peers. Strategically, this information is important for determining how TOD fits within a regional growth plan, for raising awareness and engaging the public, and, ultimately, for increasing the success of the system.

2. Literature review

2.1. BRT and urban development

There has been increasing interest in coordinating land development with BRT investments. TOD describes development that is compact, and has a mixture of land uses often including residential, commercial and office uses, as well as high-quality pedestrian environments that effectively connect with transit. Development is considered transit-friendly or transit-supportive because it can concentrate demand along corridors, balance passenger flows, and create opportunities for multimodal travel. U.S. evidence suggests that TOD residents use public transportation two to five times more than other commuters, regardless of trip purpose (TCRP 2008). Other research has summarized the importance of the built environment for transit use (Ewing and Cervero 2010). Specifically, the type and configuration of local land uses around stops appear to be strong predictors of mass transit demand (Jun et al. 2015; Loo, Chen, and Chan 2010; Sung et al. 2014). At the city level, Cervero and Dai (2016) estimate that a doubling of density is associated with a 40% increase in BRT ridership. Furthermore, other work has highlighted empirically and theoretically the importance of the pedestrian environment for transit use (Brown et al. 2015; Estupinan and Rodriguez 2008). The emerging evidence does suggest that TOD can be a strategy that can complement and build on the strengths of BRT, further encouraging alternative modes of transportation, strengthening urban efficiency, and contributing to decreasing transportation-related emissions.

Other research has begun to examine potential impact of BRT on urban development. In Bogota (Colombia), the expansion of the BRT was associated with increases in urban density (Bocarejo, Portilla, and Pérez 2012). Rodriguez, Vergel-Tovar, and Camargo (2016) showed

that building activity measured as added floor area and construction permits increased after the implementation of BRTs in Bogota and Quito (Ecuador), although the effects varied based on location and land use. In Jinan (China), the oversupply of auto-oriented land uses, mid-block crossings on the corridor, lack of pedestrian infrastructure and connectivity, and parking issues were barriers to the introduction of BRT-oriented development (Thomas and Deakin 2008). In Seoul (Korea), even though the BRT contributed to increases in development density among urban centers, there were limited effects on residential property values within the influence area of the system (Jun 2012).

Most research on the urban development impacts of BRT to date has focused on examining associations between property values and access to BRT stops and BRT feeder routes. In the case of Bogota's BRT, researchers have examined the relationship between residential property values and distance to BRT corridor and feeder routes (Munoz-Raskin 2010; Perdomo et al. 2007; Rodriguez and Targa 2004). Studies using quasi-experimental research designs have produced inconsistent findings, with some studies finding property price increases of between 15 and 20% (Rodríguez and Mojica 2009) and others finding null results (Perdomo et al. 2007). The effects of the introduction of improvements to the BRT system in Seoul suggests residential property price increases between 5% and 10% for residences within 300 m of BRT stops and between 3% and 26% for retail and other non-residential uses within 150 m (Cervero and Kang 2011) while the announcement of a BRT corridor in Ecatepec (Mexico) appeared to have no impact on property values (Flores Dewey 2012).

Although BRT has had an impact on development, in most cases the potential to encourage high-quality TOD has yet to materialize. Multiple challenges have been identified including lack of funding for planning and preparation as part of the BRT investments, absence of local TOD policy, and limited local expertise (Cervero and Dai 2014).

Relative to rail, BRT is perceived to have several disadvantages in stimulating urban development. First, BRT's ability to stimulate economic development may be constrained because of its limited locational rigidity and permanence (Dittmar and Poticha 2004). Accordingly, developers and firms are assumed to be more likely to locate residential, commercial and office developments along a rail line than along a BRT line. Hensher (1999) finds this reasoning unconvincing and for proof suggests that there are not BRT systems that have been taken away. A second perceived concern is that BRT may be disfavored due to the noise, pollution, and negative image often associated with bus services. Conversely, rail has the allure of newness (Currie 2006). The stigma of bus-based services appears to be related to technological choices (diesel engines, tire choice, chassis design) that can be addressed more than inherent weaknesses of the mode. In fact, Currie (2006) cites other work suggesting that BRT users tend to have socio-demographic characteristics that appear more like users of rail markets than users of regular bus markets.

2.2. Transit-oriented development and neighborhood typologies

Researchers and practitioners have developed a variety of TOD typologies, but none have focused specifically on BRT. The literature on TOD types suggests important differences in the characteristics and types of development possible. Calthorpe (1993) identified urban and neighborhood TODs as two prominent types. Distinguishing features between both include the quality of transit service, land uses, development intensity, and urban design. The geography of these TODs could vary, from greenfield development, to infill and

redevelopment. In 2011, the state of Florida developed a similar typology that focused on center size (regional, community, neighborhood) but also included another dimension that was technology-specific (heavy rail, light/commuter rail, and BRT) (Renaissance Planning Group 2011).

By contrast, Dittmar and Poticha (2004) blend geography and urbanity in their TOD typology that includes urban downtown, urban neighborhood, suburban town center, suburban neighborhood, neighborhood transit zone, and commuter town. The same approach has taken hold in most recent applications of TOD typologies. For example, Sacramento defined TOD as urban core/downtown, urban center, employment center, residential center, commuter center, and enhanced bus corridor (Steer Davies Gleave 2009). Reconnecting America developed a typology for the San Francisco Bay Area that included regional center, city center, suburban center, transit town center, urban neighborhood, transit neighborhood, mixed use corridor (Metropolitan Planning Commission 2007). In Denver, Colorado, the Center for Transit-Oriented Development (CTOD 2008) developed a guide for station area planning that included the addition of a special use/employment district type.

Salat and Ollivier (2017) extend their typology beyond the physical characteristics of the built environment to include economic features. They propose a framework that classifies BRT stops based on the importance of the stop in the BRT network (nodal value), the quality of the features of the stop (place value) and the market attractiveness for development and redevelopment (market value). Using this framework, they examine stops in Zhengzhou, China and conduct case studies in London and New York to identify actions planners can take to increase station values for node, place, and market.

The typologies presented so far are prospective and hinge on the ability of planners, architects and urban designers to identify plausible place types based on their personal experience and professional knowledge. In contrast, an alternative approach is to use data grouping techniques such as discriminant analysis or cluster analysis to identify the types of TODs that exist currently. For example, a typology of development around 25 rail stations that had integrated development in Hong Kong revealed five types: high-rise office, high-rise residential, large-scale residential, large mixed use, and midrise residential (Cervero and Murakami 2009). Similarly, Atkinson-Palombo and Kuby (2011) used cluster analysis to develop a spatial-functional definition of station area types around Phoenix's LRT using. Employment centers, middle-income mixed-use areas, park and ride nodes, high population/rental areas, and areas of urban poverty were the types identified. Their findings confirm that station-area conditions influence the types of private and public TOD-related investments. For example, employment centers attracted public amenities that reinforced their status as major nodes, while middle income-mixed use areas and high population/rental areas attracted residential TOD and park-and-ride stations attracted mostly shopping activities.

A final set of emerging typologies led by CTOD embody not only the built environment but also an implementation or performance dimension. These typologies often become a two-dimensional matrix, with built environment types in one axis and –in the case of implementation, measures of implementation readiness in the other. Such typologies developed for Portland and Baltimore are used to guide investments and promote policy change (Deng and Nelson 2013). The performance-based typology focuses on miles traveled as the TOD performance dimension. This typology is helpful in raising awareness about the travel benefits of TOD.

In summary, researchers and practitioners have developed a variety of typologies of urban development oriented toward mass transit. These typologies provide a template that planners, often in conjunction with developers, can follow in prioritizing which stop areas to develop or redevelop. Not all stops, or even the majority, would contend for TOD priority. Rather, a selected number of stops with the right mix of activity, land availability, and market demand may be suitable for consideration for TOD investments. Although the types often tend to be aspirational, other studies have used types to describe current environments as a diagnostic tool of current conditions to identify areas of planning attention.

Taken together, these two bodies of research suggest that the built environment is important for BRT, not only for its potential to influence ridership but also for the ability of BRT to encourage TOD. Furthermore, neighborhood typologies are a promising approach to understand current built environment conditions, even if no studies have attempted to document the physical spaces in which BRT operates. This is particularly surprising given the emerging evidence about the potential for development oriented toward BRT, including the successful cases of Curitiba and Ottawa. The very rapid penetration of BRT over the last two decades suggests that examining development around BRT stops can be a helpful step in understanding current conditions and facilitating planning for BRT-oriented development. Furthermore, we expect stop types that have a strong transit orientation to exhibit higher ridership than other stops.

3. Methodology

3.1. Study sites

Data mining and analysis are used to describe the current pattern of development around BRT in seven Latin-American cities: Bogotá (Colombia), Guatemala City (Guatemala), Curitiba (Brazil), Goiania (Brazil), Guayaquil (Ecuador), Quito (Ecuador), and the Sao Paulo Metro Region (Brazil). These cities have BRTs in operation for 10 years or more; they are of considerable size, and have some basic secondary data available. Within each city, BRT stops and terminals (large transfer stations) are examined. Stations were identified based on interviews with local planners with the aim of identifying stops that were representative of other stops of the BRT system. Table 1 summarizes the population and BRT characteristics of each city. Together, these cities represent 17.6% of the world's BRT ridership and 27.5% of Latin-America's BRT ridership (GlobalBRTData 2017). Described below are the BRT terminals/stops selected in each city.

3.2. Data collection

Primary and secondary data to characterize the environment around each BRT stop were used. Primary data were collected with field visits to each stop. First, the location of stops was determined using Google Earth and a preliminary set of stops for further examination was developed. Second, the preliminary list was vetted by local planners and experts from each city and a final list of stops identified. Then, shape files showing all block polygons and their respective segments completely and partially falling within 250 m of each stop (with the exception of seven stops in Guatemala City and one stop in Goiânia, which had larger buffer areas because they covered two stops) and 500 m of each terminal were created. The

Table 1. Cities and BRTs studied.

City/metro-politan area	Population (millions) ^a	BRT start date	BRT length (km) ^b	Passen-gers per day	Regular stops		Terminals	
					Total	#Studied	Total	#Studied
Bogotá, Colombia	7.2	2000	84	1,650,000	114	5	7	5
Curitiba, Brazil	1.8	1977	81	505,000	113	9	30	7
Goiânia, Brazil	1.3	1976	27	240,000	19	6	5	5
Guatemala City, Guatemala	1.1	2006	39	210,000	18	9	3	1
Guayaquil, Ecuador	2.7	2006	33	310,000	50	8	3	3
Quito, Ecuador	1.6	1990	56	491,000	79	7	11	5
São Paulo ABD Corridor, Brazil ^d	2.2	1988	33	180,000 ^c	53	7	8	5
Total	28,725,394		353	3,586,000	446	51	67	31

^aSource: www.brtdata.org, Instituto Brasileiro de Geografia e Estatística (IBGE,(Brazil), Departamento Administrativo Nacional de Estadística (DANE, Colombia), and local governments.

^bSource: <http://www.brtdata.org/>. Calculations of length of BRT stops in Quito and Guayaquil were made by adding all corridors available in the BRT database.

^cSource: Empresa Metropolitana de Transp Urbanos de São Paulo (EMTU).

^dIncludes the municipalities of Diadema, São Bernado do Campo, Maua, and Santo André, but not the city of São Paulo.

larger catchment area for terminal stops is justified because studies of other BRT systems have found that catchment areas vary by station type (Jiang, Zegras, and Mehndiratta 2012). Furthermore, a 250 m buffer for a terminal would often not extend beyond the terminal itself because terminals require significant land for bus turnaround, garaging, and intermodal transfers. Thus, areas of 0.2 and 0.79 km² were examined for regular or simple stops and terminals, respectively. In the eight BRT stations that contained stop pairs (in Guatemala City and Goiânia) the buffer area varies from case to case.

Third, an inventory form or audit was used in the collection of primary data for each study area. The audit tool was designed to collect data at the segment or block-face level and at the block level. A segment was defined as the street segment between two street intersections. The form was designed to collect information regarding the pedestrian environment (Estupinan and Rodriguez 2008; Jiang, Zegras, and Mehndiratta 2012), land uses and development intensity (Ewing and Cervero 2010), public spaces (Calthorpe 1993), mix of housing (Cervero and Kang 2005; Du, Ma, and An 2011), and degree to which the area has been built out (Boarnet and Crane 1997). Specifically, it contained the following fields about the environment:

- pedestrians (pedestrian-only paths, pedestrian bridges, bicycle paths);
- land uses (industrial, commercial, residential multifamily, commercial-industrial, commercial-residential, institutional, vacant);
- development intensity (low, medium, high);
- the presence of public or quasi-public spaces (big-box developments, schools, hospitals, churches, libraries, markets, sports and recreational facilities);
- the presence of open spaces (green areas, parks, squares, pocket squares);

- mix of housing;
- parking (on street and off-street);
- the degree to which the area has been built out; and
- maintenance condition of the built environment and green spaces (low, medium, high).

With the exception of some stops in Curitiba and all stops in Guatemala City, all audits were conducted by a single team member, thereby ensuring high reliability. Once collected, all data were entered into a computer and a randomly picked subset of segments double checked for data entry accuracy.

Some secondary data were shared by local authorities, such as population within the buffer area. All blocks were intersected with census polygons provided. Population was apportioned to each of the blocks in proportion to the area of the block relative to the area of the census polygon. Other secondary data (e.g. distance to the city center from each stop) were calculated based on data available from transit agencies or using Google Earth and cross-checked with local planners in each city.

Overall, 10,632 segments and 2963 blocks around 82 BRT stops and terminals (Table 2) were audited. Because the surface area audited among stops was similar, comparisons of segments and blocks per stop provide information about compactness and connectivity in those areas of each city. One stop in Guayaquil had the most segments (102.1), while stops in São Paulo (ABD) had the fewest (43.1). Since segments were defined based on intersections, these figures represent road connectivity. A similar pattern was detected when examining segments per block. When examining the average number of blocks per stop, the data suggest that Guayaquil has the highest number of blocks (30.0), followed closely by Guatemala City (27.9). However, the number of segments and blocks in Guatemala City stops tends to be higher due to the paired stops having larger buffer areas. Sao Paulo and Curitiba each had 16 and 14.4 blocks per stop, respectively.

The segments examined at terminals reveal a similar story. Because the surface area audited at terminals is four times greater than for regular stops, terminals have many more segments and blocks. Guayaquil continues to exhibit high connectivity and compactness as determined by the number of segments and blocks around the terminals. Surprisingly Bogotá and Curitiba exhibit high connectivity and compactness at terminals, but all other cities have almost half the connectivity of the top three. Finally, when one accounts for differences in surface area, connectivity and compactness tend to be higher in regular stops than in terminals for all cities examined except Bogotá, which is not surprising given the footprint of terminals.

Table 2. Segments and blocks per city, for regular and terminal stops.

City	Regular stops					Terminal stops				
	#Stops	Segments	Segments/ stop	Blocks	Blocks/ stop	#Terminals	Segments	Segments/ terminal	Blocks	Blocks/ terminal
Bogota	5	316	63.2	96	19.2	5	1457	291.4	400	80.0
Sao Paulo -ABD	7	302	43.1	101	14.4	5	921	184.2	270	54.0
Curitiba	9	439	48.8	144	16.0	7	1169	167.0	311	44.4
Goiânia	6	386	64.3	123	20.5	5	919	183.8	265	53.0
Guatemala City	8	719	89.9	223	27.9	2	597	298.5	167	83.5
Quito	7	465	66.4	133	19.0	5	960	192.0	244	48.8
Guayaquil	8	817	102.1	240	30.0	3	845	281.7	246	82.0
Total	50	3444	68.9	1060	21.2	32	6868	214.6	1903	59.5

3.3. Creation of stop-level measures

Data were collected at three levels: segment, block, and stop. All analyses were performed at the stop level, so block and segment-level data required aggregation to the stop-level. At the stop level, population density (population/developed land excluding roads and the BRT stop/terminal), road segment density, and distance to the closest activity node (in kilometers) were measured. Population data were unavailable for one terminal in Guatemala City (Centra Sur).

At the block level, the overall presence of particular uses of land and development characteristics were measured. Specifically, the presence of public facilities (schools, hospitals, churches, libraries, markets, sport facilities, and markets/squares), green spaces (parks, squares, boulevards, and green areas), and pedestrian and bicycle-friendly areas (pedestrian alleys, pedestrian bridges, bicycleways, parks, plazas, and boulevards) was taken into account. At the segment level, land uses (commercial, industrial, residential, residential multifamily, industrial-commercial, institutional, vacant, and green), development density (low, medium and high), development height (low, medium and high), development consolidation (low, medium and high), whether the segment had high-rise buildings on it, and parking (on street and off-street) were measured.

For public facilities and land uses an index measuring the presence of BRT-friendliness was also developed. Commercial (with the exception of big-box developments), residential, and institutional uses were defined as BRT-friendly uses, and hospitals, libraries, and markets/squares as BRT-friendly public spaces. Additionally, for public facilities and public spaces density variables were calculated by dividing each measure by the gross area around each stop. Variables identifying the number of segments facing the BRT right of way, and the percent of segments with street and off-street parking, were also developed. Finally, "entropy" was also calculated using the formula of Cervero and Kockelman (1997) to assess the similarity in the proportion of the segments around each stop that contained commercial, residential single-family, residential multi-family, institutional, and office land uses. Entropy values range between 0 and 1, with 1 representing equal proportion among segments having each of the uses and 0 representing the presence of a single dominant land use in all segments. These 38 variables are described in Table 3.

3.4. Factor and cluster analysis

With a large number of variables (38) and a relatively low number of observations (82 stops), exploratory factor analysis was used to reduce the number of variables to a subset of latent (unobserved) variables and estimate their factor scores. Factor analysis relies on the covariance structure of the data to identify groups of variables that are most alike (Kim and Mueller 1978).

After the factor analysis a hierarchical agglomerative cluster analysis on the factor scores of each latent variable was used to determine which stops can be grouped so as to minimize within-group and maximize between-group heterogeneity (Everitt 2011). Cluster analysis determines the groupings (clusters) that form from the observations' factors scores. Ward's linkage, which minimizes the variance in the data (the sum of squares) and a Euclidean distance squared measure of similarity (Kaufman and Rousseeuw 1990) were used to identify cluster membership. To determine the final number of clusters, existing criteria were used

Table 3. Audit variable names, definitions, and geographic scale at which it they were collected.

Variable	Definition	Scale at which data were collected
Public facility index	Index of seven facility types, excluding big box development (0–7)	Block
Public facility density	Density of facilities (except big box development)	Block
BRT-oriented facility index	Index of presence of hospitals, libraries, markets/ squares (0–3)	Block
BRT-oriented facility density	Density of Hospitals, Libraries, Markets/ Squares	Block
Green areas' density	Density of # parks, squares, pocket parks, green areas, boulevards	Block
Park density	Density of # parks, squares, pocket parks	Block
NMT friendliness	Density of parks, plazas, pocket parks, boulevards, pedestrian alleys, pedestrian bridges, bicycleways	Block
Land use index	# of land uses in stop (1–12)	Segment
Commercial	% segments with commercial uses	Segment
Industrial	% segments with industrial uses	Segment
Residential single family (attached)	% segments with residential single family uses	Segment
Residential multifamily	% segments with residential multifamily uses	Segment
Mixed: Industrial-commercial	% segments with industrial-commercial uses	Segment
Vacant	% segments with vacant uses	Segment
Institutional	% segments with institutional uses	Segment
Green	% segments with green spaces	Segment
BRT-oriented land uses	Density of commercial, residential, and institutional uses	Segment
BRT unsupportive land uses	Density of industrial, industrial & commercial, and vacant uses	Segment
High density	% segments with high density development	Segment
Low height	% of segments with building heights ~1 story	Segment
Medium height	% of segments with building heights ~4 to 5 stories	Segment
High height	% of segments with building heights >5 stories	Segment
No height	% of segments with building heights = none	Segment
Low consolidation	% of segments with low development consolidation	Segment
Medium consolidation	% of segments with medium development consolidation	Segment
High consolidation	% of segments with high development consolidation	Segment
Low condition	% of segments in low condition	Segment
Medium condition	% of segments in medium condition	Segment
High condition	% of segments in high condition	Segment
High-rise development	% of segments with high-rise developments	Segment
Commercial and parking	% of segments with commercial and parking uses	Segment
Vacant and BRT	% of segments with vacant and on BRT corridor	Segment
Segment on BRT	% of segments facing BRT	Segment
On street parking	% of segments with parking on street	Segment
Entropy	Evenness in presence of commercial, residential single-family, residential multi-family, institutional, and office land uses (0–1, where 1 is even)	Stop
Distance to CBD	Distance to closest activity node in km	Stop
Population density	Population by gross stop area	Stop
Segment density	# of segments by gross stop area	Stop

(Calinski and Harabasz 1974; Duda, Hart, and Stork 2001). The resulting cluster analysis was the basis for the typology. Descriptive statistics of the factor variables in each cluster were used to interpret the cluster formed. Although subjective, the interpretation of each cluster provides a synthetic description of the development possibilities around BRT stops studied.

3.5. Ridership

Weekday BRT ridership data were collected from each city's BRT operator with three exceptions. In the Sao Paulo Metropolitan Area a private firm was hired to collect primary data for the stops in that city. For two Sao Paulo stops, the daily total is an estimate based on data

collected during two different time windows (6.5 h in the AM for Faccini stop, and 7 h in the PM for Sao Jose stop). Given the similarity between these two stops, observed hours in one stop were used to impute missing data for the other stop. Data in Goiania were obtained from the local Transport Authority and, for simple stations, from a demand study along the BRT corridor with ridership data published in a report from the State Government of Goias. Data in Quito represented total number of passengers per month for each station with daily totals estimated from them. All ridership data used represent total weekday passenger boardings.

4. Results

Descriptive statistics of the characteristics of the built environment around the stops in the seven cities and the weekday ridership data are shown in Table 4. Of note is a group of variables with high variance suggesting significant differences between BRT stops. Variables such as density of public facilities, density of green areas, density of BRT-oriented facilities, non-motorized transportation friendliness, and ridership all have standard deviations that are significantly greater than their mean. By contrast, the land use mix variables such as “land use index” and entropy have fairly high values (mean: 9.95, standard deviation 1.30; mean 0.57, standard deviation 0.18, respectively) with low variation. This confirms the high degree of land use mixing around BRT stops in Latin America, which may be reflecting a broader pattern of land use mixing throughout cities in this region.

Several observations emerged from examining the descriptive statistics. First, development intensity around stops seems to be relatively low. For example, only 8% of segments have developments of high density, but 31% of segments contain low-density development. Second, in the cities studied redevelopment as a strategy to encourage BRT-oriented development seems critical. Only 8% of segments had low levels of consolidation and 11% of them had vacant lots. Yet, almost half of the segments had development that was highly consolidated. This result suggests limited opportunities for BRT-oriented development in undeveloped, greenfield sites. Third, in terms of parking, it is remarkable that 26% of segments had on-street parking and 30% had commercial and retail activity with off-street parking. This highlights the challenge of managing parking supply (and demand) and may indicate that the environment around BRT stops often is not as friendly to pedestrians and BRT users as it ought to be. Ridership summary statistics reveal important variation across stops. Some stops have very high ridership (maximum 272,829), while others have very few riders (minimum 210; mean 31,882; standard deviation 59,009). This is to be expected given differences how the different BRT systems are designed and operated for the cities as well as the built environment around each stop. By design, our sample of stops attempts to represent the wide variety of characteristics present on the ground, which is likely to be reflected also in the ridership figures compiled.

4.1. Factor analysis results

The exploratory factor analysis of the 38 variables showed that one of the variables measuring level of development (consolidation) was not providing any new information because it was perfectly predicted by the other two consolidation variables. Population density was missing for one terminal in Guatemala City. Hence, medium consolidation and density were

Table 4. Built environment and ridership variables of BRT stops ($N = 82$).

Variable	Mean	Standard deviation	Min	Max
<i>Built environment characteristics</i>				
Facility index	2.91	1.46	0.00	6.00
Facility density	25.76	22.07	0.00	137.51
BRT-oriented facility index	0.52	0.59	0.00	2.00
BRT-oriented facility density	3.69	8.39	0.00	50.93
Green areas' density	39.27	50.56	0.00	346.32
Park density	16.06	21.46	0.00	132.42
NMT friendliness	57.06	111.58	0.00	804.69
Land use index	9.95	1.30	5.00	12.00
Commercial	0.12	0.10	0.00	0.40
Industrial	0.02	0.07	0.00	0.33
Residential single family (attached)	0.28	0.20	0.00	0.80
Residential multifamily	0.11	0.14	0.00	0.70
Mixed: industrial-commercial	0.07	0.11	0.00	0.61
Vacant	0.11	0.11	0.00	0.45
Institutional	0.06	0.07	0.00	0.37
Green	0.08	0.08	0.00	0.37
BRT-oriented land uses	66.46	66.82	1.01	314.03
BRT unsupportive land uses	25.10	20.88	0.00	98.00
High density	0.08	0.10	0.00	0.42
Low height	0.31	0.20	0.00	0.84
Medium height	0.12	0.11	0.00	0.44
High height	0.09	0.14	0.00	0.66
No Height	0.13	0.11	0.00	0.50
Low consolidation	0.08	0.08	0.00	0.33
Medium consolidation	0.24	0.19	0.01	0.91
High consolidation	0.48	0.24	0.00	0.86
Low condition	0.14	0.16	0.00	0.80
Medium condition	0.40	0.18	0.04	0.90
High condition	0.27	0.18	0.01	0.66
High-rise development	0.08	0.12	0.00	0.63
Commercial and parking	0.30	0.16	0.00	0.69
Vacant and BRT	0.02	0.02	0.00	0.10
Segment on BRT	0.09	0.05	0.02	0.25
On street parking	0.26	0.19	0.00	0.73
Entropy	0.57	0.18	0.08	0.98
Distance to CBD	5.14	3.85	0.00	15.06
Population density [†]	59.11	43.50	2.46	253.19
Segment density	368.83	197.74	61.12	1441.31
<i>Ridership</i>				
Weekday ridership	31,882.62	59,009.15	210.93	272,829

[†]For 81 Stops only as Terminal *Centra Sur* in Ciudad de Guatemala did not have population data.

excluded and the factor analysis was performed with 36 variables. Measures of sampling adequacy indicated that the correlation matrix of the 36 items was suitable for factor analysis.¹ Our data did not meet assumptions necessary to use factor extraction methods like principal components factors (which assumes communalities of one) and maximum likelihood (which assumes multivariate normality). On the basis of these results, exploratory factor analysis using the principal factor extraction method was used. The screen test criteria suggested that 11 factors be retained, while the eigenvalue >1.0 criteria (Loehlin 1987) suggested that 9 factors be retained. Nine factors were retained for a varimax (orthogonal) rotation on the basis of ability to interpret results and the magnitude of the loadings on all factors retained.

All items but three loaded $|0.4|$ or more on at least one factor, with six items having double loadings (Table 5). The four factors account for 86.1% of the variance of the 36 items. The

Table 5. Rotated factor loadings (N = 81).

Variable	Pedestrian friendly, connected green and public spaces (Factor 1)	Non-core single family attached (Factor 2)	High density residential multifamily (Factor 3)	Undeveloped land (Factor 4)	Well-maintained mixed use areas (Factor 5)	Well-maintained green spaces (Factor 6)	BRT-O public facilities (Factor 7)	Large-scale commercial development (Factor 8)	Consolidated non-industrial fabric (Factor 9)
Facility index							0.66		
Facility density	0.48	−0.42							
BRT-oriented facility index							0.74		
BRT-oriented facility density	0.97						0.54		
Green areas' density	0.93								
Park density	0.94								
NMT friendliness					0.59				
Land use index					0.45				
Commercial									−0.56
Industrial									
Residential single family (attached)		0.85							
Residential multifamily			0.82						
Mixed: Industrial-commercial								−0.60	
Vacant				0.94					
Institutional*									
Green	0.67					0.42			
BRT-oriented land uses		0.84							
BRT unsupportive land uses*									
High density			0.55						
Low height		0.66						0.46	
Medium height									
High height			0.92						
No Height									
Low consolidation	0.44			0.85					
High consolidation				0.68					
Low condition		0.42			−0.60				0.42
Medium condition					0.55				
High condition			0.88			−0.82			
High-rise development						0.52			

stability of the scale for each factor, or its reliability, is demonstrated by estimating Cronbach's alpha. Typically a scale is considered reliable if its Cronbach's alpha is 0.70 or higher, although Nunnally and Bernstein (1994) claim that values greater than 0.80 are highly desirable. The factors have average standardized Cronbach's alpha of 0.746 (ranging from 0.61 to 0.88).

The nine factors identified were interpreted subjectively based on the loadings of each item. "Pedestrian friendly, with connected green areas and public spaces" (Factor 1) represents availability of green spaces, park density, and pedestrian and bicycle friendliness. This factor is also characterized by high segment density, suggesting high street connectivity. "Non-core single family attached" (Factor 2) represents single family attached housing, located away from activity nodes, and with few public facilities. "High density residential multifamily" (Factor 3) represents the presence of high intensity residential land development. "Undeveloped land" (Factor 4) represents the presence of vacant land, sometimes facing the BRT corridor –an opportunity for potential land development.

"Well-maintained mixed use areas" (Factor 5) represents a variety of land uses, often in developments in good condition. "Well-maintained green spaces" (Factor 6) represents green spaces in areas with higher quality development. "BRT-O Facilities" (Factor 7) is a factor representing the presence of facilities available to the public, especially those that can be oriented toward BRT such as hospitals, libraries, markets and squares. "Large scale commercial development" (Factor 8), accounts for land development with medium heights, providing off-street parking and with no mixing with light industrial uses. This pattern is consistent with big box stores ubiquitous in some BRT stops and with retail activity concentrated in very small parcels. "Consolidated non-industrial fabric" (Factor 9) represents generic development that is well consolidated but has no industrial uses.

On the basis of the potential differences among terminal stops and simple stops, an analyses of whether it was appropriate to conduct separate factor analyses for these two types of stops was conducted. The factor analyses showed high coincidence when all stops were considered simultaneously, and when a separate factor analysis was done for simple stops and terminals (results not shown). Most differences emerged in "BRT-O Facilities" (Factor 6) and "Consolidated non-industrial fabric" (Factor 9), all of which seemed to be best explained by simple stops instead of terminals. For all other factors, results were almost identical. As a result, stops and terminals were pooled for the factor analysis and their resulting factor scores used in the cluster analysis.

4.2. Cluster analysis results

The performance of each stop on the nine factors (via factor scores) was combined with population density and three additional variables that did not load with any other variables in an agglomerative cluster analysis to determine which stops could be grouped. To avoid having the measurement scale influence the cluster analysis, all raw variables were standardized to have mean zero and standard deviation one (Everitt 2011). This made the variables comparable to the factor scores. The Calinski and Harabasz (1974) criteria suggested that 10 or 12 clusters resulted in the most distinct data grouping. A second test suggested that five or 10 clusters produced the most distinct groups (Duda, Hart, and Stork 2001), so 10 clusters were retained.

Summary statistics by cluster for the factors and the three raw variables are shown in Table 6. Table 7 shows graphically some of the key variables that distinguish the clusters.

Table 6. Mean values for variables by cluster type.

Variables	Cluster									
	Mixed-Use Corridor (1)	Downtown Historic Center (Quito) (2)	Residential Center (3)	Institutional Use Corridor (4)	BRT-oriented Satellite Center (5)	Nexus (6)	Guatemala City Corridor (7)	Community Center Terminal (8)	Neighborhood Center (9)	Green Area (10)
# of stops/terminals in cluster	17	1	7	12	2	11	5	16	5	5
Pedestrian friendly, connected green and public spaces	-0.29	1.87	0.23	0.15	4.57	-0.39	-0.62	-0.08	0.10	-0.15
Non-core single family attached	-0.46	-2.41	-0.25	0.17	0.52	-0.55	-1.05	0.84	1.63	-0.51
High density residential multifamily	0.34	-1.20	2.31	-0.32	-0.35	-0.64	-0.54	-0.16	-0.35	-0.46
Undeveloped land	-0.58	-0.82	0.06	0.06	-0.16	-0.39	-0.77	0.46	-0.40	2.65
High condition mixed use areas	0.70	0.01	-0.46	0.24	0.33	-0.50	-0.52	0.54	-1.35	-0.75
High condition green spaces	0.57	0.55	-0.63	-0.78	0.08	0.16	-1.03	-0.21	1.03	1.09
BRT-O public facilities	0.19	-0.37	-0.64	-1.26	0.72	-0.60	1.19	0.80	0.26	0.30
Commercial large-scale development	0.30	2.81	-0.25	0.38	-0.59	-1.34	0.74	-0.48	1.00	0.48
Consolidated non-industrial fabric	0.18	3.47	0.29	-0.19	-1.18	0.23	-1.94	0.15	0.63	-0.41
Institutional land uses	0.71	4.63	-0.46	-0.58	-0.26	-0.72	-0.52	0.17	-0.25	0.81
BRT-unsupportive land uses	-0.81	-1.20	-0.62	-0.33	-0.48	-0.07	0.50	1.29	0.13	0.48
Net population density	-0.15	-0.31	0.73	0.33	2.53	-0.76	-0.84	-0.16	1.00	-0.26

Table 7. BRT Typologies by built environment type.[†]

Mixed-use corridor	Downtown city center (Quito)	Residential center	Institutional use corridor	BRT-oriented satellite center
<div> Factor1 Factor2 Factor4 Factor5 Institutional BRT-O land use Pop density</div> <div>Mean -0.29 -0.48 -0.82 0.70 0.71 -0.81 -0.15</div>	<div> Factor1 Factor2 Factor4 Factor5 Institutional BRT-O land use Pop density</div> <div>Mean 1.87 -2.41 -0.82 0.01 4.63 -1.20 -0.31</div>	<div> Factor1 Factor2 Factor4 Factor5 Institutional BRT-O land use Pop density</div> <div>Mean 0.23 0.25 0.06 -0.46 -0.62 0.73</div>	<div> Factor1 Factor2 Factor4 Factor5 Institutional BRT-O land use Pop density</div> <div>Mean 0.15 0.17 0.06 0.24 -0.58 -0.33 0.33</div>	<div> Factor1 Factor2 Factor4 Factor5 Institutional BRT-O land use Pop density</div> <div>Mean 4.67 0.82 -0.16 0.33 -0.28 -0.48 2.33</div>
BRT-O land use: -0.42 Entropy: 0.78 Centrality: -0.46 Segment density: -0.19	BRT-O land use: -0.69 Entropy: -0.44 Centrality: -1.26 Segment density: 0.86	BRT-O land use: -0.61 Entropy: 0.26 Centrality: -0.87 Segment density: 0.17	BRT-O land use: -0.20 Entropy: -0.23 Centrality: -0.28 Segment density: 0.23	BRT-O land use: 0.92 Entropy: 0.37 Centrality: 0.21 Segment density: 3.24
17 Stops <i>Bogotá:</i> Calle 100, Marly <i>Sao Paulo:</i> Sao Bernardo, Jabaquara <i>Curitiba:</i> PC Euf Correia <i>Goiania:</i> Hgg. Praça Biblia, Lago Das Rosas, Universitária <i>Ciudad de Guatemala:</i> Acueducto/Los Arcos, Tivoli/IGSS <i>Quito:</i> Vaca De Castro, La Y, Estadio, Aeropuerto, Elby Alfaro <i>Guayaquil:</i> Universidad de Guayaquil	1 Stop – Unique Case <i>Quito:</i> Plaza Grande	7 Stops <i>Sao Paulo:</i> Getulio Vargas, Sao Bernardo do Campo <i>Curitiba:</i> Dom Pedro, Jardim Botânico, Praça da Ucrania, Silva Jardim <i>Goiania:</i> Bandeirante Oeste/Este <i>Guayaquil:</i> I.E.S.S.	12 Stops <i>Bogotá:</i> Calle 26, Ferias, Humedal Cordoba <i>Sao Paulo:</i> Nogueira, Sao Jose, Praisso, Fachini. <i>Curitiba:</i> Heitor Guimaraes <i>Goiania:</i> Novo Mundo <i>Ciudad de Guatemala:</i> Bolivar, Reforma <i>Guayaquil:</i> Florida	2 Stops <i>Bogotá:</i> Portal 80 <i>Guayaquil:</i> Mercado Caraguay

Nexus		Guatemala City Corridor	Community Center Terminal	Neighborhood Center	Green Area
Factor1	-0.39	-0.82	Factor1	Factor1
	Factor2	-0.69	-1.05	Factor2	Factor2
	Factor4	-0.34	-0.77	Factor4	Factor4
	Factor5	-0.34	-0.52	Factor5	Factor5
	Institutional Pop density	-0.08 -0.79	-0.32 -0.84	Institutional Pop density	Institutional Pop density
BRT-O land use: Entropy: Centrality: Segment density:		-0.45 -1.23 -0.66 -0.05	0.90 0.40 0.66 -0.38	1.71 -0.47 0.79 0.73	-0.50 -0.05 0.98 -0.87

11 Stops		16 Stops		5 Stops	
<i>Sao Paulo:</i> Cecom, Anchieta		<i>Bogotá:</i> Suba, Norte		<i>Bogotá:</i> Usme	
<i>Curitiba:</i> Fanny, TRE, Xaxim		<i>Sao Paulo:</i> Pinheirinho, Diadema, Sao Mateus, Ferrazopolis		<i>Quito:</i> El Recreo, Moran Valverde, Integración España	
<i>Goñánia:</i> José Hermano, Praça A, Capuava.		<i>Curitiba:</i> Portão, Cabral, Capão da Imbuia, Campo Comprido, Carmo, Sítio Cercado		<i>Guayaquil:</i> Rio Daule, Base Naval	
<i>Guayaquil:</i> Luz del Guayas, Cerros De Mapasingue, Atarazana		<i>Goñánia:</i> Drego, Padre Pelagio		<i>Guayaquil:</i> Guasmo	
<i>Quito:</i> Rio Coca		<i>Guayaquil:</i> Bastion Popular			

*Entropy, centrality, BRT-O land uses, and segment density are standardized for comparison purposes.

Recall that all variables were standardized so larger values suggest high representation of the variable in a given cluster. The first cluster included 17 stops but it is not very distinct. It is characterized by mixed use areas in high condition along the BRT corridor, with the presence of institutional land uses (public buildings, local government's agencies, universities and schools), and with little presence of industrial, industrial and commercial mixed, and vacant land uses.

The second cluster has only one stop which represents a downtown historic center, containing only one stop: Plaza Grande in Quito. The stop is located in the historic center, which was declared World Heritage by UNESCO in 1978. Government offices and the presidential house are located within two blocks of the stop. Within its catchment area are 21 pedestrian segments (including two pedestrian corridors traversing the historic center), with several facilities such as churches, hotels, small lot commercial establishments within the traditional colonial architecture (hence the high score for commercial facilities).

The third cluster includes seven stops and represents a residential center, with high density residential multifamily developments, incipient pedestrian infrastructure and public spaces, and a relatively weak BRT orientation. There are some industrial and commercial/industrial mixed uses, and few institutional land uses. The cluster contains six stops from the three Brazilian cities (Sao Paulo ABD, Curitiba, and Goiania) and one stop from Guatemala City. The fourth cluster includes 12 stops and represents an institutional use stop along a corridor, with public facilities such as schools, hospitals, churches, libraries and recreational facilities and a limited presence of institutional land uses.

The fifth cluster is a BRT-oriented satellite center including only two stops. It exhibits high population density with high presence of pedestrian infrastructure, green areas and public spaces, and BRT-O public facilities. Only two stops (*Portal 80* in Bogota and *Mercado Caraguay* in Guayaquil) belong to this cluster. These BRT stops are located far from the closest activity node, and hence the low consolidation and availability of open space. High values for pedestrian infrastructure and density are due to the presence of multifamily and single family residential land use built between the late 1970s and early 1990s that provided generous pedestrian areas and restricted use of cars.

The sixth cluster represents nexus stops. These have low scores on most variables for commercial development, density, institutional uses, multi-family units. The 11 stops in this cluster tend to be located in points where avenues and roads converge, acting as barriers between the stop and the rest of the city. For instance, the only terminal in this cluster (Praça A, in Goiânia) is located where Avenida Anhanguera, Rua Duzentos e Dez (including two more parallel roads) and Avenida Independência converge. The three BRT stops in the ABD corridor also show strong contrasts between industrial, low income housing (including some regularized and upgraded favelas). In the case of Curitiba, the three stops have industrial, commercial and residential land uses in low density. Fanny and Xaxim are on the Green Line that remains an industrial area.

The seventh cluster is composed by a Guatemala-city related corridor including five stops, with some BRT-oriented facilities but with low condition green spaces. These built environments are not consolidated and are located far from the activity areas. The eighth cluster represents community center terminals, in the sense that they have institutional land uses oriented toward BRT, some single family (attached) residential housing, and are located far from activity nodes. In fact, they are their own activity node, providing decentralized utility

and government offices closer to peripheral residents. There are 16 stops in this cluster, all of which are terminals.

Even though the ninth cluster, which includes five stops, is also characterized distinctly by having single family (attached) residential developments, it doesn't have institutional uses. Rather, the stops in this cluster have small-scale commercial development and fairly low-quality construction. This type of stop was labeled Neighborhood Center. Anecdotally, several of the stops in this cluster include self-help housing.

The 10th cluster is composed by five stops, characterized by undeveloped land high-quality green spaces, with the presence of some institutional land uses. Stops in this cluster are located far from the closest activity node. One of the stops (Base Naval in Guayaquil) is an institutional land use (navy) and next to the Airport, thereby explaining the presence of undeveloped land (large green areas). Other stops from Bogotá and Quito are located in greenfield development areas. Because of their potential growth, the stops have relative low population densities, but they contain affordable housing developments because land prices tend to be lower than in well-located areas.

Is the clustering capturing city-specific characteristics like idiosyncratic planning approaches or particular spatial structure characteristics? Results per city were examined, suggesting that, other than the Quito downtown cluster- and BRT-oriented satellite center which capture one and two stops, respectively, six other stop types have a variety of cities represented in them. The important exception to this is the Guatemala City corridor. It is possible that the newness of the system (this is the youngest of all BRTs studied) and the fact that it serves fairly consolidated parts of the city might explain why the stops cluster together. The residential center cluster has seven stops of which six are located in Brazil. This cluster may be capturing a Brazilian style of urban development and BRT planning, with a high mixture of land uses (often including incompatible land uses like residences, heavy and light industry, commercial, and institutional). It may also be that these stops represent established or consolidated areas of cities through which BRTs were built.

4.3. *Ridership by cluster type*

Having identified the clusters, their performance with respect to passenger demand is examined next. Figure 1 shows passenger demand by cluster type. The top three performing clusters represent the developments with the closest orientation toward transit identified in the data. In descending order from high to low ridership, the top three include terminal stops with a strong community orientation (cluster 8), satellite centers with high residential density (cluster 5), and the mixed use corridor (cluster 1). Of these, the first two represent more traditional nodal development, although they take advantage of their distance from activity nodes to more easily recreate some level of transit orientation by arranging land uses and public spaces to support ridership and pedestrian access. The mixed use corridor cluster represents a centrally located stop with mixed uses and an established urban fabric. This cluster embodies the traditional bus-based corridor TOD that is common in US planning circles.

The three clusters with lowest ridership embody challenging urban development conditions for supporting TOD. The third lowest cluster is the Nexus cluster, the second lowest is the Residential Center cluster, and the lowest is the single Quito stop. The low density of development is responsible for the limited ridership in Quito's stop. The other two clusters

Figure 1. Passenger demand by BRT stop type.

have built environments with poor pedestrian orientation, especially the Nexus cluster. Despite having high density residential development, the Residential Center clusters does not have a strong orientation toward transit, strongly suggesting that residential density alone will not result in high ridership. With stops in Brazilian cities and in Guatemala City, this cluster may also be exhibiting the influence of socio-demographic characteristics of residents around the stops, with middle income residents more likely to use private transportation for mobility.

As relevant as the reported ridership averages are the standard deviations not shown in Figure 1 for visual simplicity. In 6 of the 10 clusters the standard deviation was greater than the mean (in 2 of the remaining 4 clusters, the number of stops in the cluster was 1 and 2). This suggests that there is significant heterogeneity within each cluster, and indicates the importance of adjusting for other potential variables that may help explain variation in ridership.

5. Discussion

Primary and secondary built environment data in seven cities in Latin America were used to develop a typology of the built environment around 81 BRT stops. The resulting typology was examined relative to their ridership performance. Ten station types were identified, one of which belonged to Guatemala City and one type which represented a single stop in Quito’s city center. The other eight types represent a broad cross-section of stops across several cities. In synthesis, the stop types identified included: (a) multifamily developments with and without BRT orientation; (b) single-family attached housing, in some cases built through self-help and sweat equity, and with access to some commercial activity, often away from activity nodes; (c) peripheral stops with high population density, supportive pedestrian

infrastructure, and access to parks and green spaces, often away from activity nodes; (d) institutional stops with green spaces, not necessarily open to the public; (e) stops that are saddled with physical barriers set by the convergence of multiple high-volume roads, and (f) stops surrounded by big-box developments.

The BRT-oriented satellite center (cluster 5) contains BRT stops and terminals within large blocks that contain significant commercial activities, public facilities, parks and pedestrian amenities while mixing multifamily residential and single family attached housing. Together, these generate a combination that comes close to the ideal of TOD and the ridership data substantiate this finding. Other stop types with a high transit orientation also had high ridership, relative to those that were less transit oriented. Although ridership variation within each cluster is high, the results provide an indication that the attributes identified here as BRT friendly are positively associated with BRT ridership. They provide initial face validity to the typology. To contextualize the ridership data, the average weekday ridership for each of the top three clusters in the typology was greater than the ridership in the busiest stop among Boston's MBTA train system, San Francisco's BART, or Washington DC's WMATA. In fact, the cluster with the highest average ridership has more than twice the ridership of the busiest stop in each of these three US rail systems. The performance of these stop types relative to other metrics such as land prices, emissions, and affordable housing deserves additional research.

The nexus stop (cluster 6) represents stops limited by converging high-capacity roads, which is a challenge for local planners. On the one hand, stations and terminals should be located to facilitate intermodal transfers. On the other hand, this sacrifices station accessibility by local users. Terminal Praça A in Goiânia (Figure 2) is emblematic of this challenge. The high capacity roads limit access to the stop, even though there is high density residential development, a well-connected urban fabric, and destinations in close proximity to the stop. In terms of housing policy, the 9th and 10th BRT clusters embody an interesting combination in terms of distance from activity nodes and low income housing supply. These types tend to be located far from activity nodes, which may explain the presence of affordable housing. These clusters raise questions over the possible impacts of BRT on the segregation of housing and the financial burden of mobility on low income residents.

It was initially surprising to find that land use mix played a relatively muted role in our clusters. Land uses played a significant role in other typologies developed in the US (Atkinson-Palombo and Kuby 2011) and Hong Kong (Cervero and Murakami 2009). In retrospect, the high degree of mix of uses in Latin American cities (and therefore its low variation) may explain this finding. To contextualize this finding, consider entropy, a measure of evenness in the distribution of land uses. For the 81 stops average entropy of 0.57 was estimated (Table 4). For residents in five US cities (Baltimore MD, Chicago IL, Forsyth County NC, Los Angeles CA, New York NY, and St. Paul MN) Rodriguez et al. (2009) calculated a median entropy of 0.26. A similar figure was calculated by Frank et al. (2005) for a sample of Atlanta residents (GA) and Cervero and Kockelman (1997) for a sample of residents in the San Francisco Bay Area (CA). It suggests important differences in urban spatial structure that may explain the typology developed.

The approach used here is similar to other studies in terms of its use of socioeconomic, transportation and land use data to develop a typology (Atkinson-Palombo and Kuby 2011; Cervero and Murakami 2009). However, the current approach relied on richer primary data, which provides recent information of the built environment characteristics and allows for

Figure 2. BRT Terminal Praça A in Goiânia, convergence point of four arterials.

the collection of attributes like building condition and consolidation. Because some of the attributes collected are fairly subjective, reliability of the data is an important issue. In five of the seven cities, the data were collected by the same research team member, ensuring reliability. In two other cities, data were collected jointly by the research team member and a local collaborator trained in the process. In the seventh city, data collectors were trained on the application of the instrument.

6. Conclusions

Understanding current development around mass transit stops is critical for planning station areas, addressing station area needs, examining how current conditions fit within a regional growth strategy, raising awareness and engaging the public, and, ultimately, for increasing the success of the system. In this paper, the current built environment around 81 BRT stops in 7 cities in Latin America was examined. Ten station area types were identified, eight of which appear to capture general stations represented in several cities. Some stop types have attributes that are consistent with the principles of TOD. Other stop types are burdened by land uses, road infrastructure, and development characteristics that do not support BRT. Yet,

other types appear to be work in progress, with significant vacant land and development that has not fully consolidated. Finally, other stops seem to capture urban conditions that arise in many Latin American cities: self-help housing distant from activity nodes, large commercial developments –frequently of the big-box type– providing private spaces for public use and commerce but also surrounded by vast parking areas, and with a relative absence of green spaces open to the public.

Average weekday ridership statistics for each stop type was compared, suggesting that despite significant variation in the data, stations with TOD-like features tended to have higher ridership than stations with a limited TOD orientation. The latter areas are most frequently located in well-established parts of the city, where reshaping the urban fabric requires more complex land management arrangements including assembly and readjustment of land parcels, negotiating with multiple land owners, and working with existing tenants. Hence, unless the area already has a strong transit orientation, the prospect of TOD in areas of high transit demand is diminished.

The evidence provided can assist local planners in considering the type of stops in their systems and the potential similarities and differences with other stops in the region. Planners can use this information to compare their stops and identify tools and approaches taken elsewhere, with similar stops, to make the environment more conducive and supportive of transit use and access. Furthermore, based on our findings planners can also examine the potential implications of their stop characteristics on BRT ridership, understanding that other factors beyond the environment around the stop are likely to also influence observed demand.

It is important to reiterate that the built environment examined around stops describes conditions at the time the data were collected. Whether the conditions identified are the result of the BRT remains to be determined. Anecdotal evidence is contradictory, even within single cities (Gakenheimer, Rodriguez, and Vergel 2011). In some cases, like Curitiba, such environments are likely the result of deliberate planning and hence associated with or partly induced by the BRT. In other cases, the systems fairly new and hence fewer development projects are likely to be reflected on the ground. At play are market and regulatory forces that determine the outcome of development and regeneration. For example, the attractiveness of properties for further development can change as development regulations are updated. Changing allowed land uses, relaxing density caps, or reducing parking requirements are ways to further leverage the development potential of parcels close to mass transit stops. This coordinated strategy between land use and transportation is the cornerstone of TOD.

Three next steps arise naturally from the research. The first one is to consider how the types perform in terms of pedestrian activity, land values, and affordability. This will allow one to identify types that are performing better than others, and thus more desirable from a planning perspective. The second step is to consider the causal factors that have led to the current stop types. Was it a deliberate and coordinated strategy to transform a neighborhood or corridor, accompanied by land management and regulatory instruments? Or was it a lack of consideration or neglect about the built environment? Or that the BRT was built on neighborhoods that were highly consolidated? Understanding the stop- and corridor-level actions (and inactions) that accompanied a BRT investment will be helpful in identifying the tools necessary to encourage BRT-oriented development. The third step involves following the

descriptive analysis of ridership with statistical models aimed at adjusting for other potential explanatory variables and attempting to disentangle cause and effect.

Results regarding satellite centers and peripheral community centers are intriguing for their high access to green space, related population density, availability of community services, and high ridership. These types evoke clustered residential developments in outlying areas described in other transit-oriented cities: From Stockholm's suburban centers established in the second half of the twentieth century, to Hong Kong's development built around rail axes. They embody the potential and benefits of polycentric development, with balanced flows across centers and considerable internal trip capture. Yet, they also represent further peripheral growth, away from existing center and activity. Under the lax land planning and enforcement conditions prevalent in Latin America (in contrast to Stockholm or Hong Kong), these peripheral magnets of activity may induce additional unmanaged growth, further undermining the promise and potential of TOD. Ultimately the trade-offs inherent in the station types described here reflect the Herculean task that BRT designers often confront: maximizing ridership and land development potential, while ensuring that the system remains within certain physical and resource constraints. By providing a typology of the built environment around BRT, this study not only provides a description of the status quo, but also contributes to the benchmarking and imagination of planners and urban designers in other cities, so that they can identify the type of development around BRT that they could aspire to achieve or avoid.

Results are also important for planners considering the prospect future conditions around BRT systems being planned. Cervero (1998) argues that a successful urban development vision must precede and guide transportation investments, and that pro-active planning is necessary if sub-centers around transit stops are to take place. Burgeoning TOD typologies in the US are predicated in part on their ability to support long term TOD planning. For example, the Denver typology was critical to create a land use vision for the existing and forthcoming light rail station areas. The typology developed in this study focuses heavily on land uses and the built environment, partly because of its relevance to TOD. Yet a limitation is that the social dimensions of TOD are missing from our analysis. Poverty, housing tenure, and safety are also important determinants of whether an area is attractive for additional public or private investment.

Note

1. Bartlett's test of sphericity $\chi^2 = 2768.787$, $p < 0.000$; Kaiser-Meyer-Olkin measure of sampling adequacy = 0.597.

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