Towards a Theory of Distributed Attraction: The Effects of Street Network Configuration upon the Distribution of Retail in the City of Buenos Aires

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Martin D. Scoppa

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Towards a Theory of Distributed Attraction: The Effects of Street Network Configuration upon the Distribution of Retail in the City of Buenos Aires

Approved by:

Dr. John Peponis, Advisor
School of Architecture
Georgia Institute of Technology

Dr. Steven P. French
School of City and Regional Planning
Georgia Institute of Technology

Dr. Sonit Bafna
School of Architecture
Georgia Institute of Technology

Dr. Anne Vernez Moudon
College of Architecture and Planning
University of Washington

Dr. Lars Marcus
School of Architecture
KTH, Royal Institute of Technology, Sweden

Date Approved: December 14, 2012

To my wife

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Summary

This dissertation tests the proposition that the spatial structure of street networks affects the distribution of urban land use. Specifically, it examines patterns of commercial land use utilizing parcel based data on retail and service businesses location. While previous studies report a correlation between spatial structure and patterns of commercial land use, these studies do not typically control for the effect of key variables likely to contribute to the spatial distribution of retail and service establishments. In order to redress this balance, and using the City of Buenos Aires as a case study, this dissertation studies the correlation between commercial land use frontage and street connectivity measures, while controlling for street widths, density of population and employment, interstore externalities, zoning regulations, and distance to transit stations. Buenos Aires is chosen for its regular plan radiating from a well-defined CBD, a plan which would be expected to conform to standard urban attraction models of retail location. Results of multiple regression models indicate that, after controlling for these variables, measures of street connectivity account for key aspects of the distribution of retail, including linear distributions along major radial and peripheral streets at a distance from the CBD. Thus, the dissertation supports the thesis that "urban attraction" should not be conceptualized in terms of distances from a unique central location, or a number of central locations, but rather in terms of a model of distributed centrality governed by the structure of street networks.

Chapter 1

Introduction

This thesis examines the relationship between the spatial structure of streets and the presence of retail frontage. Connectivity is treated as a major dimension in addressing the spatial structure of streets. Retail frontage on the other hand, is measured as the estimated proportion of the retail parcels' boundaries which directly face a street segment.

Retail is an important land use in all urban environments. Thus, this thesis can be read as a contribution to a better understanding of the relationship between the spatial structure of streets, and patterns of land use. The choice of retail frontage as the focus of the study, however, reflects the understanding that retail contributes not only to the urban economy, but also to the urban liveliness and to the character of urban spaces. This has to do with the fact that the presence of retail frontage, particularly when concentrated in a particular location, attracts people from various ranges of distance, intensifying local patterns of movement –particularly pedestrian movement–, and favors the encounter of people with different interests or lifestyles, depending upon the range of retail opportunities offered. In addition to liveliness, this has other side effects, including a sense of safety arising from the presence of "eyes on the street" (Jacobs, 1961). In short, interest in the relationship between the spatial structure of streets and the distribution of retail frontage is informed by the significance of the latter as a dimension not only of urban function but also of urban culture.

The classical theory of the distribution of retail includes a fundamental distinction between retail streets, which act as attractors, and residential streets, which act as providers of a potential customers. The concentration of retail in one area, or the presence of specialized retail which cannot be found elsewhere, is thought to create “urban centers” or “central places”. The distribution of these centers over the area of the city is thought to be a function of the distribution of population (which indexes likely demand), the frequency with which shopping occurs (shopping for food, for example occurs much more frequently than shopping for furniture) and the structure of accessibility (which determines how far and how fast people are able to travel to satisfy retail needs).

The concentration of retail in centers is thought to produce economies of different kinds, ranging from the ability to satisfy several shopping needs with essentially one trip, to the success of each shop thanks in part to the presence of potential clientele attracted by other shops. Centers are organized hierarchically such that small centers responding to more frequent and more local demand are nested between larger centers responding to less frequent and more global demand. Classical theories of retail location are reviewed in chapter two.

However, in many cities, including the one to be studied here, shops are almost ubiquitously distributed. What varies is the intensity of their presence in different areas, or along different streets. In this context, it is of particular interest that classical theories of retail location have recently been augmented by the introduction of what could be called 'distributed' or 'generalized' gravity models. These emerging new models, make no prior theoretical assumption about a dichotomy between retail streets and residential streets, nor about the presence of a hierarchy of centers that *attract* clientele from ranges of distance. Rather, they suggest that street networks, by virtue of the structure of connectivity, can theoretically distribute opportunities for retail throughout the urban fabric, as a function of accessibility (how easily each location can be approached from surrounding locations at varying ranges of distance) and intelligibility (how easy it is to find the way to a location from a cognitive point of view). In all systems other than an infinite regular grid not found in real life, accessibility and intelligibility are unevenly distributed leading to degrees of likelihood that a location is suitable for retail.

The significance of the emerging distributed gravity models is that they treat distribution of retail as intrinsic to the spatial structure of urban street networks. They suggest a mutual implication between form (in this case the spatial structure of street networks) and function (in this case the presence of retail). By contrast, classical gravity models begin by supposing a homogeneous space of equivalent locations and distances, proceed to establish the likely distribution of centers given the distribution of population, and only then, if at all, do they treat actual physical form on the ground as a constraining factor.

Despite the growing number of studies linking properties of street connectivity to the distribution of commercial land use, few, if any, have considered the effects of some key fundamental variables that might have an impact on the distribution of commercial land use. Among them is street widths, a particularly important descriptor of the spatial characteristics of the built environment that is likely to impact the capacity to accommodate movement. Other, even more significant variables that will be included in this study, but are not present in recent related literature, are the regulatory framework (zoning ordinances), the distribution of population and employment, and the transportation infrastructure.

This study is intended to contribute to the emerging field of 'distributed gravitation', first, by providing a new case study by which to evaluate the value of these new models; second, and most important, by bringing into the model variables that have been omitted in the studies conducted so far, even though intuition suggests that they are most likely have a key role. By bringing these variable into the model, this study is not challenging the importance of street connectivity and its structure. On the contrary, the aim is to show that the premises of emerging distributed gravitation models, namely that the structure of connectivity affects the distribution of land uses, survive intact when other variables are factored-in.

The city of Buenos Aires is selected as a case study for four reasons. First, it is an almost ideal example of a central core, radial growth, city. As such, it would be expected to conform to traditional location models, with the main center of retail coinciding with the center from which major streets radiate. Preliminary analysis (Scoppa, 2009) has revealed that distance from globally as well as locally well-connected streets to be as important as distance from center, thus indicating that the distributed model has explanatory power even when urban form seems to privilege the posits of classical models. Second, detailed and reliable parcel based land use data is available, linked to equally detailed information about zoning, characteristics of buildings, the distribution of population, and transportation infrastructure. Third, Buenos Aires is typical of a large family of Latin American, as well international cities where shops are broadly distributed over the urban fabric. Thus, conclusions reached have a likelihood to be generalizable to other cities that encourage a wide distribution of retail over their urban fabric. Fourth, Buenos Aires is an almost ideal case of a grid-based city. Regular grids are a common form in Latin America as well as in North America, so the results will also have a wider value from the point of view of urban morphology.

From a theoretical point of view, the underlying aim is to better understand the city as a material artifact, whose spatial configuration acts as a long term structuring factor impacting the distribution of land uses and centrality. From a practical point of view, this study provides a more precise analytical framework, allowing for the study of street network properties, not just in terms of averages per unit of area, but at the level of individual streets and block faces. More knowledge on these relationships is necessary in order to build tighter links between urban planning and urban design.

1.1 Outline

Theories and research on the location of centers and their qualities, the distribution of retail land use, and methods by which to delimit market areas, are reviewed in the first sections of Chapter 2. These studies are defined as classical retail location theories, and include Central Place Theory, Bid Rent Theory and Spatial Interaction Theory. Following these classical approaches to the subject of retail location, we will introduce later refinements which focused on consumer behavior, multipurpose shopping trips and the clustering of retail activities. At this point, and considering that the key works addressing centrality and retail location studies have been presented, the review will focus on studies of accessibility within city planning, and qualitative studies of the urban retail structure, including urban morphology research. The last sections of Chapter 2, will introduce distributed gravitation models, which as presented above, constitute an alternative approach to the understanding of retail location in urban areas.

Chapter 3 introduces the materials and methods used to study the distribution of retail in the City of Buenos Aires. The chapter will introduce the main characteristics of this city, and the geographic information used in order to calculate the dependent variable, retail frontage, and the independent and control variables. The distinction between independent and control variables is aimed at highlighting the focus on street connectivity measures in this thesis. As we have noted, configurational models have seldom controlled for the impact of alternative variables describing characteristics of the built environment that study the distribution of retail.

In Chapter 4, the results of statistical analyses are presented and discussed. Two scales of analysis will be introduced. First, is the detailed scale of the street segment; the second, is based on the aggregation of street segments into larger units, which correspond to the City's named streets. At both scales, the first series of analysis is based on the study of bivariate correlations between the dependent variable, retail frontage density, and the independent and control variables. After these initial studies, which provide information about the sign and strength of these relationships, we proceeded to build multiple regression models, allowing us to analyze the combined effect of the independent and control variables in the distribution of retail. Conclusions and the discussion of the findings are reported in Chapter 5.

Chapter 2

Literature review

Early studies on retail location date back to the 1930's. Since then, several theories and models developed, providing the foundations by which to understand regularities in the distribution of retail land use. While originally a matter of study in the fields of geography, urban economics and city planning, the study of the urban spatial structure –as is defined by the geometry of the street networks–, provided additional insights which might contribute to these models. The value of this latter research, lies in its ability to inform about the role of street networks' connectivity and configuration in distributing access, and the impact of this variable on the location of commercial land use. This chapter will discuss classical theories and models addressing centrality and the location of retail, the evolution of this field, and the emerging street connectivity and configuration approach to this subject.

2.1 Classical retail location theory.

Spatial regularities in the location and composition of urban and regional centers began to be systematically analyzed in the early 1930's. Linking economic theory to observed regional and urban spatial patterns, W. Christaller (Christaller, 1933), R. Haig

(Haig, 1926), and W. Reilly (Reilly, 1931), provided the theoretical framework for much of the following research on the location, size, spacing, and functional composition of centers. While published early in the last century, these studies did not receive widespread attention from the academic community until the quantitative revolution in geography in the 1960's. However, once brought into light, the theories advanced by these authors –respectively, Central Place Theory, Bid Rent Theory, and Spatial Interaction Theory– proved to be highly influential in following research on the location of retail land use.

While the theories we will discuss in the following sections might seem outdated, as much of the literature reviewed encompasses works published decades ago, a review of more recent literature allows us to conclude that these theories and models are still in use, and that alternative approaches have been only relatively recent. Among the most notable recent contributions, we find the application of fractal geometry to the modeling of urban growth and centrality emergence (Batty 1994, Batty and Longley 1994), and the New Economic Geography theories developed by leading scholars in the field of economics (see for example Fujita, Krugman, Venables, 1999). While these latter studies are undoubtedly relevant, demonstrating the evolving nature of this field, an in-depth discussion of their qualities lies beyond the scope of this thesis. This is the case, for the classical approach is particularly useful in analyzing the City of Buenos Aires, while, on the other hand, the amount of research based on classical theories is significantly larger and has been more widely applied than that of the emerging new approaches. The review of the literature thus, will be focused on the classical approach to the spatial aspects of economic activity, discussing both cornerstone theories and their evolution.

2.1.1 Central Place Theory.

Central Place Theory (CPT) is perhaps the most well-known and extensively discussed theory of spatial location. Called "*the cornerstone of human geography, for it explains how economic dependence within the hierarchy of cities translates into their location"* (Batty, 1994), it remains until today a fundamental theory in all disciplines interested in the spatial distribution of centers in cities and regions. Despite recent criticism, noting that CPT is an appropriate *descriptor* of the spatial distribution of economic centers, but fails to address the *emergence* of these centers (Fujita, Krugman, Venables, 1999, p.27; Krugman, 1997, p.40), it still constitutes a fundamental model by which to understand why centers of different size and composition exist, and why they locate where they do. Central Place Theory addresses the question of why goods and services are produced and offered at a few necessarily central points, in order to be consumed at many scattered points (Christaller, C.W. Baskin trans., 1966, p.19).

In order to address this question, Christaller developed a model which assumed a population of rational, fully informed, utility maximizing individuals, evenly distributed over an equally simplified spatial context. Featureless plains replacing the complexities of urban and geographical space, were favored in Christaller's model for they simplified the measurement of transportation costs. Given that the total price a consumer pays for a good is a function of its price at the store, plus the transportation costs incurred in reaching the supply point, the measurement of straight line distances over featureless plains simplified the calculation of the total costs of acquiring a needed or wanted good. Central Place Theory indicates then, that as a consequence of increasing transportation costs, demand for a good will gradually decline, as distance to the point of supply increases. Demand will continue to fall, until it reaches zero; the point at which the cost of overcoming distance, affects the price of a good to such extent, that the consumer is unwilling to buy it. The maximum distance consumers are willing to travel, established the "range" of a good, the first of two key variables in CPT.

The second being the "threshold" of demand, i.e., a threshold of minimum sales which needs to be exceeded in order for a good to be supplied. Goods with high thresholds and high range (e.g., high-priced, infrequently purchased goods, like furniture or jewelry) are able to capture consumers from further locations than those with low threshold and range (e.g. low-priced, frequently bought goods like groceries), given that the transportation costs do not have as much impact on the final price of these goods. Based on these premises, and considering that goods could be sold at a profit if the range exceeds the threshold, thus creating an incentive for stores to open, a hierarchy of centers could be constructed. The hierarchy of centers proposed by Christaller, and the transportation routes linking them, is presented in figure 2.1 below.

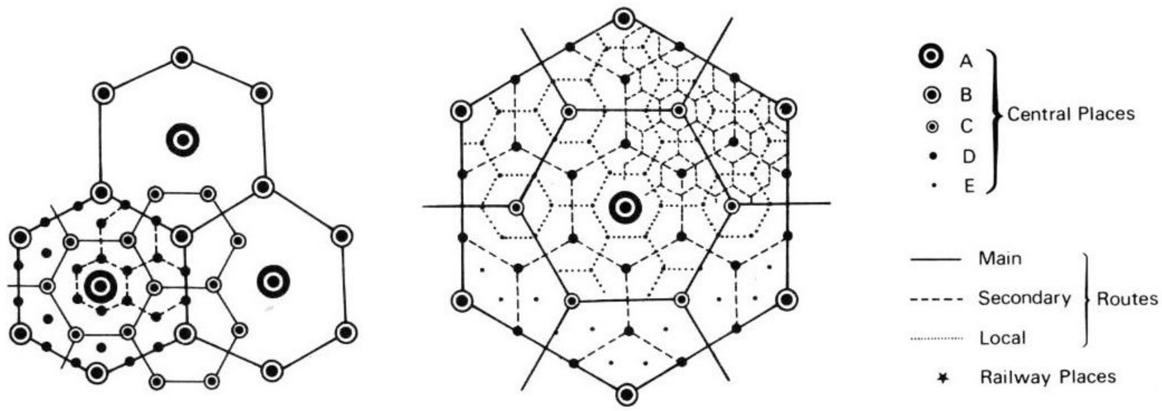


Figure 2.1 *– Marketing Regions in a system of Central Places (reproduced from Potter, 1980, p.66).*

According to the diagram presented in Figure 2.1, central places of type A, the highest in the hierarchy, would accommodate high and low order goods, while places of type E, with the smallest market areas, would only accommodate low order goods, relying on centers up in the hierarchy for higher order goods. Consequently, the functional composition of centers determined their position in the hierarchy. However, it is important to note that the arrangement of centers in the assumed plain, and their corresponding hexagonal market areas, represent *optimums* for each single good studied. In other words, the location of firms in this model is as advantageous as possible, every consumer receives service, market areas are as small as possible, and the boundaries of the market areas define points of consumer indifference. Additionally, while each store in CPT had the monopoly over its market area –for competing activities would be equidistantly distributed– free entry conditions (the ability of competitors to enter the market at any time) guarantees that abnormal profits disappear.

A notable shortcoming of CPT worth discussing given the scope of this thesis, is that relative to the network of transportation routes required to connect the centers in the proposed hierarchy. In particular, transportation inefficiencies arise when attempting to connect centers of the highest order (A-places), given that straight line routes would bypass second order B centers, located at the vertices of the A-places hexagonal market areas. This transportation inefficiency, led to Christaller's rearrangement of, in this example, B-type centers, which were placed on the midpoints of the sides of the market areas of A-type centers, instead of at the vertices.

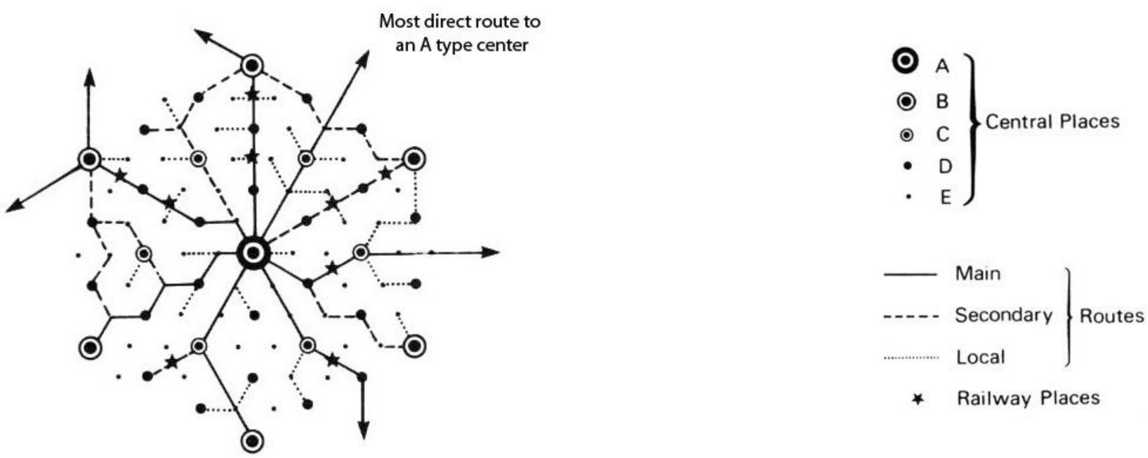


Figure 2.2 *– Inefficiencies in the transportation network (Reproduced from Potter, 1980, p.66).*

However, this change modified the progression at which higher order centers' market areas contained lower order subcenters, resulting in a clash between the principle of efficient market area delimitation, and the principle of efficient transportation. In

Christaller's view however, the transportation principle would be subordinate to the marketing principle, given that:

> "*Since the marketing principle is clearly dominant in determining the distribution of the central places in Southern Germany, we may say, generally then, that the marketing principle is the primary and chief law of distribution of the central places. The traffic and the separation principles are only secondary laws causing deviations; these laws are effective in practice only under certain conditions*." (Christaller, C.W. Baskin trans., 1966, p.192).

As Central Place Theory was originally conceived to study centers in a regional context, the application of its principles to the study of the urban retail structure, required several –mainly scale related– refinements. These were introduced in the early 1960's, eminently by Brian J.L. Berry, who adapted CPT's principles to the study of the urban case (Berry, 1963, ch.2, pp. 42-58; Berry, Parr, 1988).

In a painstakingly detailed study of the retail structure of Chicago, Berry relaxed several of assumptions of the original CPT model; in particular, those of an evenly distributed population, identical socio economic composition, and similarly identical purchasing power. As a result, and observing that the principles of threshold and range would still work under these more realistic conditions, the regularity of the nested hierarchy of hexagonal market areas would be distorted, resulting in a pattern similar to the one shown in Figure 2.3 below.

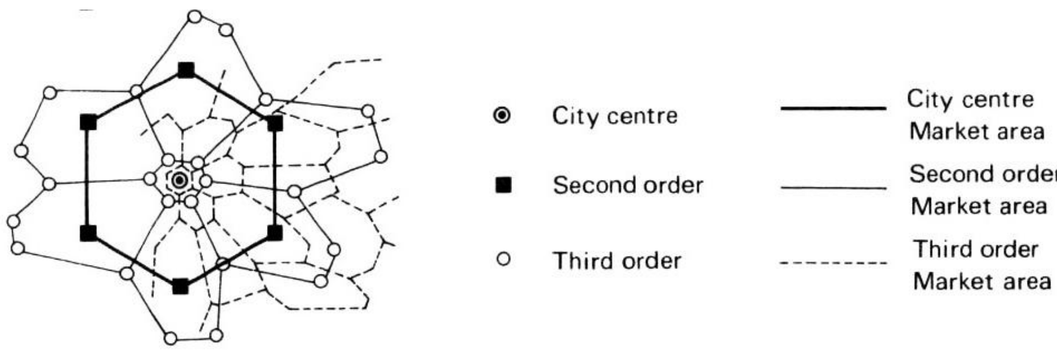


Figure 2.3 *– Impact of relaxing the equal population density assumption on market areas (reproduced from Potter, 1980, p.68).*

Still, a hierarchy of nested centers would be defined, with the CBD at the top of the scale, and followed by lower order nucleations appropriately named to reflect the urban structure of central places. However, besides this arrangement of centers in CPT fashion, a fundamental element in Berry's study of the urban retail structure, was the identification and discussion of retail ribbons, and the emergence of specialized areas characterized by functional similarities. The proposed model, shown in Figure 2.4, acknowledges two fundamental issues which were beyond the scope of the original CPT model.

The first, is the existence of morphological variations in the urban retail structure, where, while some centers are visibly compact, others string out along main arteries, making it difficult to think of them as discrete –or more accurately, dimensionless– entities. Second, it recognized the presence of functionally specialized areas or, in other words, recognized the observable clustering of competing –not just complementary–

activities found in many cities. As we will focus on clustering in particular further in this review (please see section 2.2, and special accessibility), let us for now concentrate on the importance of streets, and street intersections, in creating appropriate conditions for the location of retail.

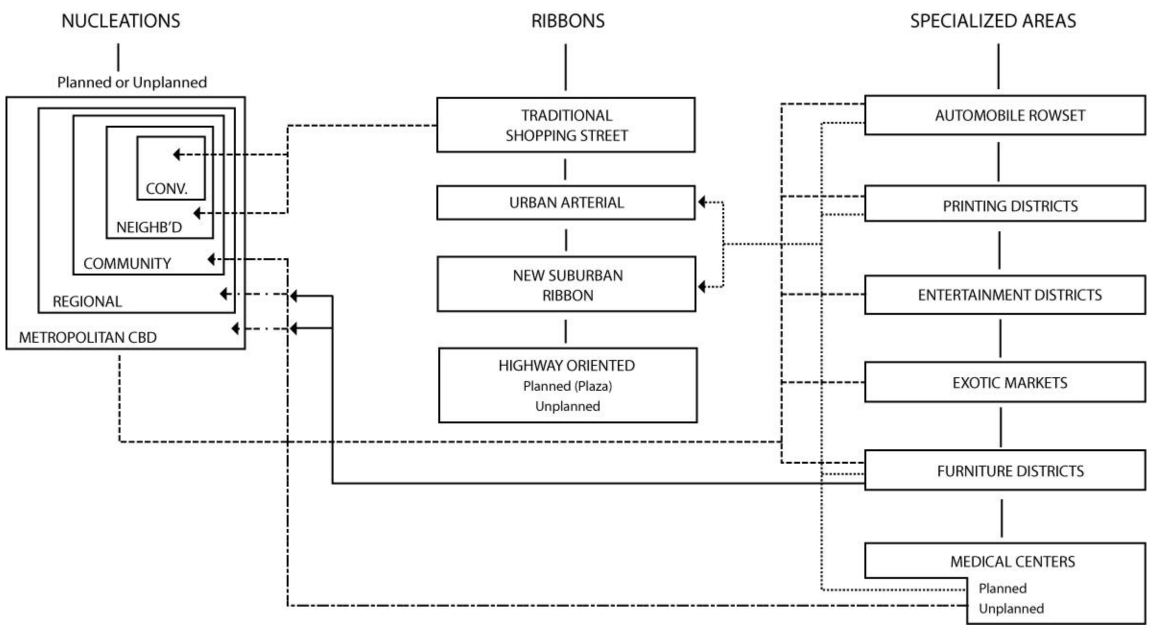


Figure 2.4 *– Berry's classification of urban businesses configuration. From Berry 1963, p.46.*

Studying Chicago's structure of radial and ring roads –a layout that is not fundamentally different from that of the City of Buenos Aires–, Berry noted that accessibility differentials from sites to consumers, were reflected in variations in land values. Citywide, and paired to a generalized outward decline in land values at increasing distance from the CBD, there were ridges of higher land values along radial and ring routes, as well as land value peaks where these ring and radial routes intersected. Higher land values at the intersection of radial and ring thoroughfares, were characteristic of spatial concentrations, or nucleated centers. Retail ribbons on the other hand, followed the higher land value ridges on main routes extending radially from the CBD, and the higher land values found on ring routes; places with high "arterial accessibility". The empirical investigation on the effects of accessibility on the location of retail, was based on the detailed study of urban thoroughfares intersections, which Berry termed "points of general accessibility".

Notably, Berry's analysis of points of general accessibility, was based on two variables which are remarkably close to those studied in urban street configuration research, as well as variables used in this thesis. The first, was the intensity of pedestrian traffic, a variable that has been studied in depth, particularly in space syntax research, and discussed from section 2.4 onward. Second, is the evaluation of commercial land use values using price per linear foot of frontage, a variable closely related to our study's variable "retail frontage density". Berry's analyses, revealed a sharp decline in pedestrian movement at increasing distance from the studied intersections, which was highly correlated to a fall-off in dollars-per-foot-of-frontage values. His work, established a valid link between accessibility, land values, and the morphology of urban retail patterns. Notably, he also commented on the liveliness that characterizes commercial centers, subcenters and lineups.

Both Christaller's work, and Berry's application of CPT principles to the intra-urban case, have generated an immense amount of research. A review of more recent literature indicates that this theory and these models continue to influence research, and that they are paradigmatic elements in human geography, urban economics and city planning (Potter 1982, Lord and Guy 1991, Borchert, 1988, 1998; Brown, 1993; DiPasquale, Wheaton, 1996; Krugman, 1997; Fujita, Krugman, Venables, 1999). The importance of CPT and Berry's work as a general framework in which to inscribe this thesis lies, first, in the classification schemes they provide for a basic understanding of the distribution and characteristics of centers and the location of retail; second, because of the insights they provide in terms of the role of accessibility and street networks as mediators between supply and demand in the built environment.

2.1.2 Monocentric city model of land use.

Central Place Theory provided the foundations by which to understand the spatial distribution of a hierarchy of centers, and the estimation of the extent of their market areas. Later modifications of the regional scale model, permitted the study of intraurban patterns of retail location, and the morphological and functional variations present in urban areas. Berry's study of points of general accessibility and their impact on the location of retail, provided valuable insights by which to understand these variations, addressing centers and retail ribbons as they relate to the urban street network, and the structure of accessibility. While the study of land values at "points of general accessibility" directly studied the relationship between the street network and the location of retail, the overall organizing effect of accessibility and land values in the distribution of urban land use was not formally developed. The general model linking accessibility and land values, to the structure of urban land use, was the focus of the classic –or monocentric city– model discussed in this section.

The German tradition of spatial analysis provided, as with Christaller's work, the basis upon which the classical economic model of urban land use was developed. The early 19th century study on the distribution of land uses surrounding an isolated agricultural town by von Thünen (von Thünen, 1826), would prove, almost a hundred years later, to be an appropriate framework by which to tackle the distribution of land uses in an urban setting. Assuming, as has been generally the case, a flat plain where travel is equally easy in all directions, von Thünen focused on the allocation of agricultural land surrounding an isolated town, so that the combined costs of producing and transporting a given supply of food to the town market was minimized. Unplanned competition among farmers and landowners, each acting in their perceived self-interest, would define a distribution of land uses, determined by the tradeoff between land rents and transportation costs.

This model indicates that given the increasing cost of transporting goods to the town, the amount of rent farmers can afford at increasing distance from the town center will decrease, giving rise to a concentric pattern of land uses. In the first ring, hard to transport, perishable, and high frequency purchased products like dairy goods would pay more in land rents, given their need for daily trips to the town center and the savings involved by locating closer to it. The intermediate ring would be occupied by crops, which can resist longer term storage, and require less frequent trips to the market than dairy goods. Finally, land at the edge of the town would be dedicated to livestock grazing, as the ability of herding the animals to the market would result in lower transportation costs. This mechanism of agricultural land allocation, constituted the base on which early models of urban land use developed, as was the case with Robert Haig's Bid Rent Theory (Haig, 1926a, 1926b).

Haig stated that the center of the plain –now the city's CBD–, and thus the most accessible location, procured benefits to economic activities seeking access to sources of labor, and to consumers for the goods they produce. As different economic actors benefit from locating at the center of the plain, a bidding process for an inelastic supply of land (meaning that an increase or decrease in the price of land will not result in a corresponding increase or decrease of its supply) was initiated, ensuring that land was put to the 'highest and best use'. In other words, demand for land was based on the profit maximizing decisions of firms, and the utility maximizing decisions of households. While firms value the central location because the CBD concentrates the transportation infrastructure by which to ship the goods they produce, as well as access to a large pool of laborers, households value proximity to the CBD –in this model, the main and only location of employment–, in order to reduce commuting costs. Land uses that cannot make the most efficient -profitable- use of a given site are outbid and forced towards peripheral locations. As a result, land uses distribute across the plain in an annular pattern, with offices and retail located at the center, and industrial and residential uses in the following rings, mirroring their rent paying abilities.

The most notable contribution to Haig's work was made by W. Alonso (Alonso, 1964). This author's studies would also rely on featureless plains, uniformly priced travel and utility maximizing individuals for their models, not modifying Haig's original assumptions. Specifically, Alonso's bid rent curves, built for each land use category, described the willingness of individuals and firms to pay for accessible locations. In particular, the steepness of the curves' slopes, reflected the sensitivity of each land use with respect to accessibility. As a result, four characteristics are observable in the monocentric model as was formulated by Alonso. These are: 1) the segregation of land uses in concentric rings, with offices in the CBD, manufacturing in the middle ring, and residences in the outer rings, 2) the decay of land prices at increasing distance from the CBD 3) the decay in the land use built density with distance from center and 4) the location of retail in the city center, outbidding offices for ground floor space, given their need to be directly accessible to passing trade.

In Figure 2.5 below, von Thünen's agricultural model and the urban model are presented side by side, and the bid rent curves describing the location of each land use can be clearly seen. In both cases, the models address a monocentric structure case. We should add that, in general, the main determinant in studying accessibility, has been distance to the CBD, although Alonso recognized that the geometry of the street network could distort the pattern of concentric rings (Alonso, 1964 pp.130-134), and so could zoning ordinances and geographical and infrastructural barriers (Alonso, 1964 pp.117-125). Still, in terms of their handling of the built environment, these models have operated at a larger, aggregated, scale, where the detailed characteristics of the street network were not taken into consideration. Accessibility was measured in terms of Euclidian distance to the CBD, or center of the urban agglomeration.

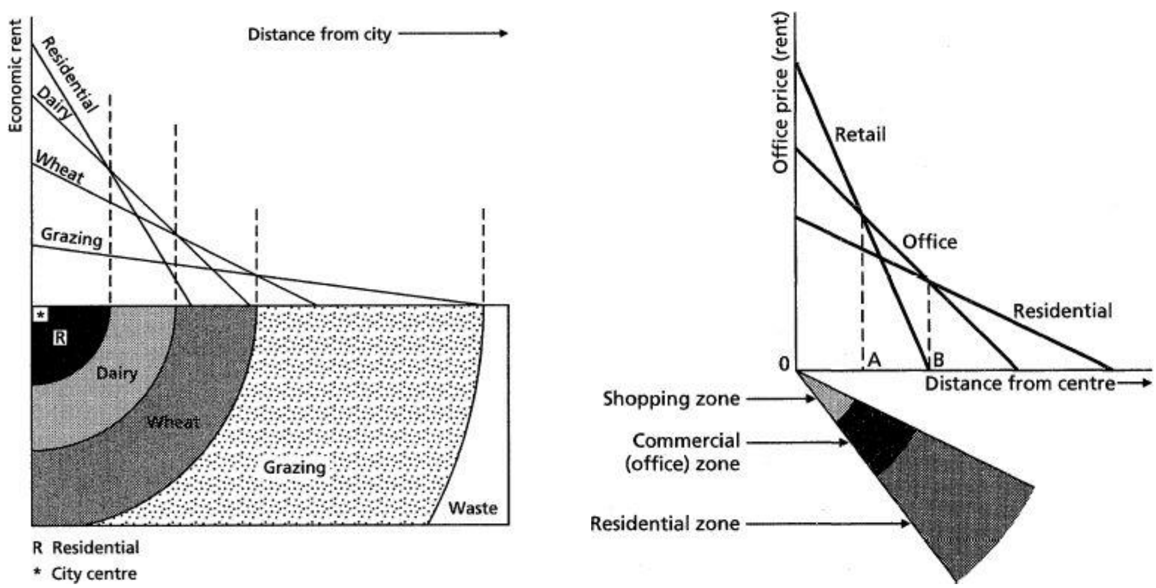


Figure 2.5 *– Bid rent curves. Left, von Thünen's agricultural model. Right, Alonso's urban land use model*

As fundamental as the monocentric city model of land use is, we should note that lately, it has been questioned for its inability to address contemporary urban land use patterns. This criticism has to do with the progressive shift towards polycentric urban development patterns (Ladd, Wheaton, 1991; Berry, Kim, 1993). While this criticism is in many cases justified, the monocentric city model still provides a valuable framework by which to understand the fundamental economic mechanisms driving the location of retail, and the important role played by accessibility in explaining land use patterns. Moreover, given the strong monocentric structure of the City of Buenos Aires –which will be quantitatively studied in the following chapter– the introduction of this model was deemed relevant and appropriate. This model still provides a valuable foundation by which to understand the land use patterns in this city.

2.1.3 Spatial Interaction Theory.

Spatial Interaction Theory constitutes the theoretical base on which gravity models of retail developed. Its main focus, is on the delimitation of market areas, and represents a first attempt in the modeling of consumer patronage behavior. Also originally addressing the regional scale, Spatial Interaction Theory, states that consumers evaluate their shopping destinations, not based on shortest travel distances to the nearest source of supply like in the scenario set forth by Central Place Theory, but through a more complex process involving the weighting of alternatives. W. Reilly, regarded as the architect of gravity modeling, postulated in analogy to Newtonian physics that consumers select the centers they patronize based on an attraction, or pull, directly proportional to the 'mass' of the destination, and inversely proportional to the squared distance to it (Reilly, 1931).

Reilly's work, analyzed consumer patronage in an intermediate location between two competing cities. The application of equation 2.1 below, allowed for the calculation of the proportion of trade captured by each of these cities, which were characterized by their population sizes, and their distance to the intermediate location being studied. As

Christaller in Central Place Theory, Reilly measured straight line distances across featureless plains.

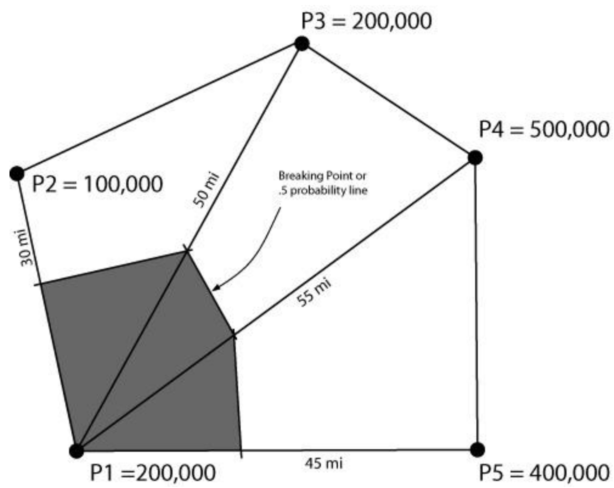
$$\frac{T_a}{T_b} = \frac{P_a}{P_b}\left[\frac{d_b}{d_a}\right]^2 \quad \text{equation 2.1}$$

Where T_a and T_b, represent the proportion of trade drawn to places a and b, P_a and P_b represented their respective populations, and d_a, d_b, the distances involved.

However, the most widely used method in defining the extent of market areas, was based on a modification of Reilly's original formula by Converse (Converse, 1949). Converse's 'break-point' formula, derived from equation 2.1, allowed for the calculation of the point at which the trading influence of each city was equal. Measured along the straight lines that connected the locations in question, the formula permitted the construction of polygons defining the boundaries of the market areas of each town. Knowing the population and characteristics of the centers, and the distance between them, the formula presented in equation 2.2, could be applied to estimate the market area of any given center, while considering, in successive steps, each of the alternative competing destinations.

$$D_b = \frac{D_{ab}}{1+\sqrt{P_a/P_b}} \qquad \text{equation 2.2}$$

Where: D_b is the breaking point between city A and retail shop/city B in miles from B, D_{ab} is the distance separating city A and City B, P_a is the Population of City A; and P_b is the Population of City B.



$$D_2 = \frac{D_{1\text{-}2}}{1+\sqrt{\frac{P_1}{P_2}}} = \frac{30}{1+\sqrt{\frac{200{,}000}{100{,}000}}} = \mathbf{12.4}$$

$$D_3 = \frac{D_{1\text{-}3}}{1+\sqrt{\frac{P_1}{P_3}}} = \frac{50}{1+\sqrt{\frac{200{,}000}{200{,}000}}} = \mathbf{25.0}$$

$$D_4 = \frac{D_{1\text{-}3}}{1+\sqrt{\frac{P_1}{P_4}}} = \frac{55}{1+\sqrt{\frac{200{,}000}{500{,}000}}} = \mathbf{33.0}$$

$$D_5 = \frac{D_{1\text{-}5}}{1+\sqrt{\frac{P_1}{P_5}}} = \frac{45}{1+\sqrt{\frac{200{,}000}{400{,}000}}} = \mathbf{26.3}$$

Figure 2.6 *– Application of the breakpoint formula as presented by Huff (Huff, 1964).*

The application of this formula in the demarcation of the trade area of a center, considering its size and distance to competing centers is presented in figure 2.6 above, as was discussed by Huff (Huff, 1964). The introduction of probability curves by Huff (Huff, 1962, 1964), the most prominent contributor to the original Spatial Interaction Theory, approached this subject, and advanced a method by which to more realistically demarcate market areas, allowing them to interweave and overlap. In this case, the point of indifference was found at the point of equal probability that a customer would patron one location or another. Huff's contribution, in mathematical form, is presented in equation 2.3, while the resulting probability surface, showing equal probability contours is presented in Figure 2.7. Huff's method, we should note, simultaneously considered the attractiveness of all possible alternative destinations, as indicated by the summation operation in the denominator of equation 2.3.

$$P(C_a) = \frac{P_a/D_a}{\sum_a^n P_a/D_{ab}} \qquad \text{equation 2.3}$$

Where: $P(C_a)$ is the probability of a consumer at point A traveling to shopping destination B, P_a is the size of shopping destination A, in sq. feet., D_a is the distance between origin A and shopping destination B; and P_b is the Population of City B.

The application of the probabilistic method developed by Huff, and the consideration of all accessible destinations, would be particularly suited for the study of the intraurban case. This is the case, for it more appropriately deals with the urban retail environment, where population densities increase, and shopping opportunities are more numerous.

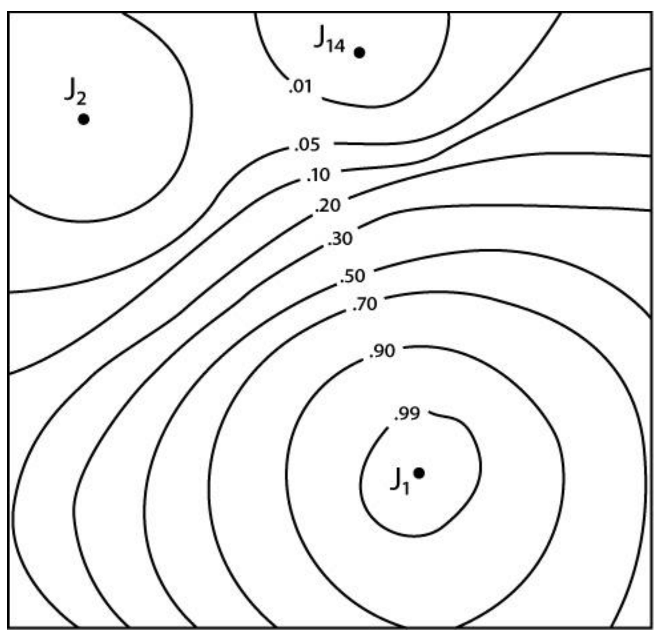


Figure 2.7 *– Probability contours which result from applying equation 2.3. From Huff, 1964.*

A large number of studies have applied the principles of Spatial Interaction Theory in studying retail location, and market area boundaries (Goldstucker et al. 1978; Rogers 1984; Gosh, McLafferty 1987; Okoruwa et al., 1988; Roy, Thill, 2003; for an in-depth discussion see for example Fotheringham and O'Kelly, 1989). As it stands, Spatial Interaction Theory is one of the most prolific theories used in retail location and market area analysis.

As we have seen, classical gravity models require previous knowledge of the spatial location of supply and demand points. While supply points constitute the trip destinations, the consumers' location –i.e., the demand points–, constitute the trip origins. The tradeoff between attractiveness, and the dampening effect of distance, determines the probability of consumers visiting either of several shopping destinations available to them. Thus, the interaction between supply and demand, is evaluated once these two elements have been spatially located.

2.2 Refinements. Consumer Behavior, Multipurpose Shopping and Clustering.

The theories presented so far, and the models they support, constitute the foundations upon which a large majority of the work on retail location developed. As such, they were the necessary stepping stones for the development of more refined analyses. Particularly, those addressing aspects of consumer behavior, the characteristics of shopping trips, and the economic mechanisms that lead to clustering. The examination of these theories and models is the subject of this section.

Classical theories have, in general, assumed that cities and regions are populated by "economic men"; fully informed, rational decisions makers, who are also perfectly aware of the structure of the retail environment. In other words, the classical theories discussed so far –with the exception of Huff's probabilistic approach– are normative in their ethos, and adopt an aggregate and almost mechanical view of consumer behavior. However, contemporary studies to these theories, argued that these assumptions were gross behavioral simplifications, and called for the adoption of alternative views to the optimizing behavior of the individuals populating classical models.

Among these studies, we find the work of Simon and Pred, who noted that consumer behavior would be more properly addressed through the notion of satisfaction (Simon, 1957, Pred, 1967). Under this revised assumption, consumers would search for *satisfactory* outcomes, not *optimal* ones. The focus of this emerging field of analysis, was summarized by Thompson when arguing that:

> *"The fundamental factor affecting the geographic distribution of retail trade is the manner in which consumers organize their perceptions of the external environment with which they are faced. Adoption of this hypothesis forces the empiricist to abandon his preoccupation with objective phenomena and necessarily to focus on the more subjective aspects of human behavior."* (Thompson, 1966, p.17).

Thompsons' words, remind us that not all consumers are equal. They have, as intuition and experience suggest, different motives, values, and desires, as well as different incomes, time budgets, and propensity and ability to travel. Behavioral and subjective elements, slowly begun to be considered along the objective factors discussed so far, particularly accessibility to, and the presence of, retail outlets and centers.

One of the earliest contributions to the study of consumer behavior and its impact on the structure of the retail environment was proposed by Rushton, who advanced the notion of "revealed space preferences" (Rushton, 1969). This work, focused on decoding consumers' rules of spatial choice which, when applied to a unique distribution of spatial opportunities (retail centers), could be capable of generating spatial behavior patterns similar to those empirically observed. Rushton argued that these rules of spatial choice should be applied instead of descriptive statistics of actual behavior, given that these statistics were based on knowledge of the spatial system that they sought to generate. In other words, and using CPT as the case in point, he noted that spatial behavior patterns would have adjusted to the system of central places, just as much as the distribution of central places adjusted to spatial behavior. Given this interdependence, movement patterns, or travel behavior, could be thought as the complement of location for *"travel behavior is in part determined by the arrangement of facilities, and in part determines that arrangement"* (Nystuen, in Rushton, 1969). It is clear then, that the emerging behavioral approach questioned the very foundations of classical models, especially its cornerstone theory, CPT. Behavioral studies, reexamined the assumption of single purpose trips to the nearest center, and their findings, as we will see, proved to be particularly fruitful in gaining a better understanding the spatial dynamics guiding retail location.

Early research by behavioral geographers found that consumers neither always patronized the nearest centers, nor did they make single purpose trips to them. In particular, it was noted that the functional complementarity of centers, provided opportunities for purchasing several goods in single trip, saving the consumers time and transportation costs (Golledge, Rushton and Clark, 1966; Rushton, Golledge and Clark, 1967; Eyles, 1971; Fingleton, 1975). In other words, the co-location of complementary activities in retail centers, offered the opportunity for consumers to engage in multi-stop, multipurpose shopping trips. This more complex, but clearly more realistic behavior, affected the posits of CPT in at least two important ways. First, when engaging in multipurpose shopping trips, consumers were inclined to bypass near low order centers, favoring more distant but better appointed ones, which offered them higher satisfaction in compensation for their longer trip. Second, it was noted that identical goods would not have identical ranges, as CPT sustained. This was the case, for centers higher in the hierarchy, with higher levels of shop complementarity, offered more opportunities for multi-stop shopping, so that the range of a good sold in a higher order center tended to be larger. The range of a good thus, would not only depend on its intrinsic qualities, but also on the characteristics of the center from which it was sold (Clark and Rushton, 1970; Timmermans, 1979a; Ghosh, McLafferty, 1984).

These studies' findings, and the overall limitations of CPT they revealed, paved the way for a change in focus in the study of the mechanisms that drive the urban retail structure. Consumer behavior and multipurpose shopping, and their impact on retail location patterns, have since then been tackled with considerable vigor by urban geographers and closely related disciplines. While multipurpose shopping modeling constitutes in itself an area of intense research, studies of shopping behavior have also concentrated on the development of general models addressing the consumers' decision to patronize a given center. In this respect, discrete choice models are an example of further contributions from economic theory and econometrics to the study of consumer behavior, and the analysis of urban centers' performance and viability. Discrete choice analyses, we should note, address the selections made by economic actors given a number of mutually exclusive potential choices available to them.

In the particular case of the urban retail environment, Di Pasquale and Wheaton note that under discrete choice theory, consumers will face the option of visiting one center, and one center only, out of the available centers in an city (Di Pasquale, Wheaton, 1996, pp.140-143). In practice, these models begin by subdividing cities and metropolitan areas into smaller zones (generally census tracts or other census defined units), for which detailed information on the main determinants of buying potential –total number of households, and their corresponding income– is available. In a following step, centers are spatially located, and the their desirability is evaluated using numerous variables, such as store mix, availability of parking, degree of enclosure, and pricing levels. Finally, the cost incurred by consumers in traveling to these centers is evaluated, using travel data from local or state transportation planning agencies. With all these data, the utility –satisfaction– derived from visiting each center is calculated for each zone, to later calculate the probabilities of visiting a given center in light of the overall utility it provides. These models' main output, is the total estimated patronage of each center, allowing for the evaluation of the likely impact of planning policy regarding new centers, or the introduction of changes in existing ones.

However, while we have so far discussed the implications of consumer behavior in economic and policy analysis of centers performance, we have not yet addressed the impact of behavioral factors on their functional composition. In CPT, we should remind the reader, the composition of centers was based on the assumption of single purpose trips to the nearest center, which, depending on its hierarchy, would house a larger or smaller number of *complementary* stores. *Competing* stores on the other hand, would be equidistant, and would have the monopoly over their market area. However, when considering multi-stop, multipurpose shopping behavior, the concentration of complementary activities in centers, gives rise to demand externalities; a factor which was not considered in Christaller's model. Demand externalities, we should clarify, refer to consumer spillovers which benefit store owners, and constitute an incentive for the clustering of retail. This is the case, for the co-location of complementary stores –which allows consumers to conduct efficient multipurpose trips and save in transportation costs–, provide for increased customer traffic, increasing the likely demand of stores which locate in close proximity to one another. In the case of planned purchases, a multipurpose trip will find consumers visiting more than one shop in a center, but also, the co-location of activities that characterizes centers might induce additional unplanned purchases which would otherwise require additional trips. Consumer behavior, particularly the transport costs saving behavior of consumers, are also a cause of demand externalities, a factor that has been found to produce of higher levels of clustering than is predicted by CPT (Eaton, Lipsey, 1982; West, Hohenbalken, Kroner, 1985).

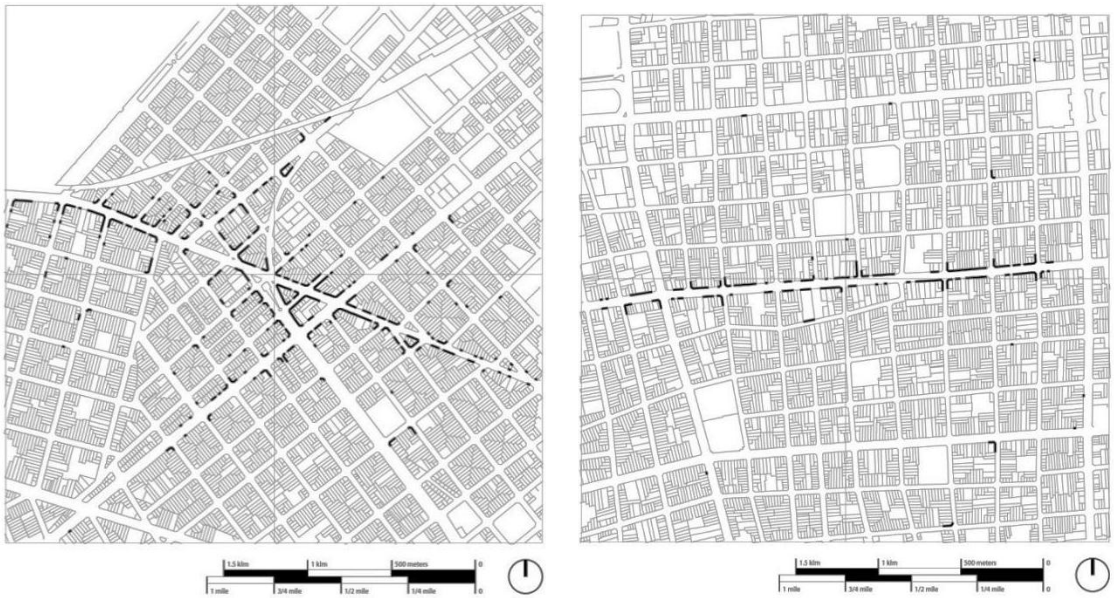


Figure 2.8 *– Clusters of competing activities in the B. Aires. Auto parts (left.) Furniture (Right)*

Still, empirical evidence also suggests that in urban centers, we not only find agglomerations of complementary stores, but also concentrations of competing activities. This was indicated by Berry when including specialized areas in his proposed urban retail structure classification (Section 2.1.1). Examples of shop types that tend to co-locate can be found in Berry's diagram, but direct observation suggests that these are also found among many others types of retail. In the particular case of the City of Buenos Aires, clear examples include the auto-parts, textiles, and furniture sellers segments. Figures 2.8

above shows the location of the auto-parts district (Warnes district), and a furniture sellers alignment (San Juan Avenue).

The earliest study addressing the clustering of competing retail premises, was presented by Harold Hotelling in a widely cited paper titled Stability in Competition (Hotelling, 1929). In this paper, Hotelling discusses a model whose main assumptions are: the presence of strictly two competing stores selling "minimally differentiated products", which will locate on an ideal linear market (i.e., a Main Street). Furthermore, customers would be evenly distributed along this line and would face uniformly priced travel. Hotelling indicated that while the optimal arrangement would be found with stores at ¼ and ¾ of the length of the linear market, thus evenly dividing the market areas and optimizing the consumers' transportation costs, uncertainty about the pricing policy of these competing stores would lead to a back to back arrangement of the stores at the center of this assumed one-dimensional market. In Hotelling's view, clustering was a wasteful phenomenon. However, later work which took into account multipurpose shopping behavior, demonstrated that if consumers were assumed to visit (sample, in the authors' words) at least two shops before making a purchase, clustering would be beneficial for both consumers and store owners (Eaton, Lipsey, 1979). It was argued that this was the case, for the co-location of competing retail stores would allow consumers to compare prices and merchandise, while also allowing for savings in transport costs. For retail store owners, co-location increases the number of potential customers to whom they are accessible, as well as access to an increased number of suppliers for the goods they sell. Still, Eaton and Lipsey's model operated under several simplifying assumptions which in terms of spatiality resorted, once again, to a linear one-dimensional market.

As we have presented in this section, the consideration of consumer behavior, and the consequent study of multipurpose shopping trips, have significantly enhanced the normative and limited behavioral approach that characterized classical theories. In addressing the subjective elements that supplement consumers' decision making, as well as the mechanisms by which firms cluster, this latter work has enlarged and enhanced our understanding of the dynamics guiding the urban retailing system. Savings in consumers' transportation costs, customer spillovers between retailers, and the profit maximizing behavior of store owners, further clarified the causes behind the concentration of competing and complementary retail in centers. Still, a key element brought up by these studies, is that related to the interdependences between the structure of centers and consumer behavior, and how they complement each other in defining the pattern of centrality. Potter, clarifying the timeframe of this relationship, indicates that retail location is likely to affect consumer behavior in the short term, while in the long term, consumer behavior would affect the location of retail (Potter, 1980).

The interrelatedness between behavior and land use is not a minor issue. As we will see, in distributed gravitation models, this interaction between travel behavior and the structure of retail is central in its approach to the study of urban land use patterns. By studying street connectivity and configuration, and its impact on the distribution of movement patterns, these models address this interaction, first, by studying it as the seed for the emergence of retail centers and ribbons, and second, as a multiplier for the growth of established commercial zones. This proposition will be further discussed from section 2.4 onward.

2.3 City and Transportation Planning. Accessibility and street connectivity.

An overarching notion addressing the interaction between supply and demand in space, is that of accessibility. While we have not directly addressed this variable yet, it is clear that accessibility is a functional requirement in all the theories discussed so far. This is the case, for the ability to reach, or access, a supply point, is a fundamental condition for the development of retail location models. The schematic transportation network of Central Place Theory for example, is useful in evaluating the consumers' transportation costs in reaching the supply points, thus helping define ranges, thresholds, and the hierarchy of centers. Later work by Berry, who applied the principles of CPT to the urban case, explicitly discussed the emergence of centers, based on the notion of points of general accessibility. In the monocentric model, accessibility to the city center (CBD), is key in explaining the rent paying mechanisms that give rise to the concentric rings pattern of urban land use. In Spatial Interaction Theory, accessibility takes a combined form, where impedance measures such as Euclidean and network distance, dampen the attraction of supply points. Finally, in the refined models addressed in the previous section, accessibility is considered along several other relevant variables which, together, shed light on the processes by which travel and shopping decisions are made, and retail clusters form.

While accessibility is a pervasive notion across urban retailing analyses, and one that is closely related to the study street connectivity, we have not yet provided a general definition, or discussed how it is studied and applied to the study of urban land use. Given that accessibility is central to city and transportation planners, we reserved the discussion of accessibility to these sections.

2.3.1 Accessibility

One of the earliest and most widely cited studies on this matter, defined accessibility as the "*measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people to overcome spatial separation"* (Hansen, 1959*).* The basic premise in this study, was that the greater the accessibility of an area to opportunities –in this case, employment opportunities–, the greater its growth potential would be. Accessibility then, was considered as a main determinant in the shaping of urban land use patterns, and was key in the development of Hansen's seminal land use model. In a more general sense, however, accessibility can be thought of as a quantification of the spatial arrangement of elements of interest in the surroundings of a given location. In the case of retail, both store owners and consumers value accessibility. While the former would value higher levels of accessibility to consumers, consumers would value higher accessibility to opportunities, including retail. A closer look at Hansen's definition, reveals that his understanding of accessibility was directly connected to the Spatial Interaction Theory models presented in earlier sections. However, in city and transportation planning, accessibility is measured using several indices, not just gravity based ones. At least five types are identified in a recent review of the literature on accessibility (Bhat, Handy, Kockelman, et al, 2000). These are: graph theory indices, cumulative opportunities indices, gravity measures, utility measures, and time space measures of accessibility.

Graph theory measures of accessibility, use node-link –technically, primal graph–, representations of the transportation network for the calculation of accessibility. In these networks, each node represents a street intersection, and each link represents a street segment. Connectivity relationships between nodes in the system are stored in an adjacency matrix, which is used in the computation of indices describing the graph's properties. These indices generally rely on the length of the links to quantify accessibility between a node, and all other nodes in the system (for a discussion and description of several indices calculated on primal graph networks, please see Ducruet, Rodigue, 2006). However, even when accurately representing the geometry of the street network, these measures have an invalidating weakness in the eyes of city and transportation planners: they do not address land use at all. From these latter disciplines perspective, land uses are fundamental in understanding accessibility for, as Britton Harris notes, in order to measure accessibility, it is necessary to indicate accessibility to what (Harris, 2001). While we will come back to the issue of graph theoretic measures later in this chapter, let us note for now that these metrics constitute the main object of study in distributed gravitation models research.

The second type of accessibility measures reviewed, are those known as cumulative opportunities. These measures, take into account both the distance to be traveled, and the purpose of the trip. By setting a distance or travel time threshold, these indices evaluate accessibility in terms of the number of opportunities –e.g. employment, shopping, education, healthcare– that can be reached within this distance threshold.

Clearly, in order to evaluate accessibility, it is necessary to establish trip origins and destinations, or have clear knowledge of the land use structure. The application of these measures has been mainly related to clarifying changes in accessibility due to land use shifts, changes in the transportation system, or urban growth in general. Their main disadvantage is related to the lack of consideration of behavioral aspects, as near locations are treated as equal to more distant ones, and that the travel time or distance thresholds are arbitrarily defined. Equation 2.5 below, defines the general form of the cumulative opportunities index.

$A_{t=\sum_t O_t}$ equation 2.4

In the generic equation above, t is the threshold within which opportunities are counted, and O indicates an opportunity found.

The third type of accessibility measure identified by Bhat and colleagues, are gravity type indices. These are, as expected, directly related to the principles of Spatial Interaction Theory earlier reviewed in this chapter (please see section 2.1.3). As previously noted, gravity type measures use an attraction factor, as well as a separation factor, in order to quantify accessibility. Thus, they differ from cumulative opportunities indices, in that they are able to differentiate characteristics of the destinations, particularly in terms of their attraction. Equation 2.5 shows how general form used to calculate gravity type accessibility measures.

$$A_i = \sum_j \frac{O_j}{t_{ij}^{\alpha}} \qquad \text{equation 2.5}$$

Where O is an attractor, weighted by travel time or distance t, raised to some exponent α, indexing the particular constraints affecting a given trip.

In order to apply gravity type indices it is necessary to identify the destinations, just as in the previously discussed measure, with the difference that these are now further characterized according to metrics quantifying their attractiveness. Measures of impedance, as earlier discussed, generally include Euclidean distance, network distance, travel time, and perceived distance or cost. The impedance factor, raised to an exponent alpha, indexes the friction of distance –or other alternative measure of impedance– and regulates the form of the spatial interactions. An alpha exponent of 0 would mean that distance does not have any effect, so that the interactions will remain the same regardless of the distance involved. A high value of alpha will result in a steep decline in spatial interaction with increasing distance.

The fourth type identified, corresponds to utility measures of accessibility. These measures, are based on the evaluation of an individual's perceived utility for different travel choices, and are closely related to the type of analysis discussed in the previous section, when addressing multipurpose shopping trips and the evaluation of center patronage using econometric models. Utility measures of accessibility, are based on random utility theory, which indicates that the probability of individual selecting a particular choice depends on the utility provided by all accessible choices (Ben-Akiva, Lerman, 1979).

Assuming that an individual evaluates the utility provided by each destination within a set of destination choices C, and assuming a multinomial logit form of destination choice, accessibility can be defined as the logsum of all location choices, as seen from an individual at a particular location. Equation 2.7 below, shows how this accessibility measure is calculated.

$A_i^{activity} = \sum_c exp^{V_{ic}^{activity}}$ equation 2.6

Where $A_i^{activity}$ is the accessibility index for different instances of a certain type of activity from location *i*, *c* is the set of alternative locations where the activity is found and $V_{ic}^{activity}$ denotes the utility of each activity location in c as seen from *i*.

The advantage of this latter measure of accessibility lies in its solid behavioral foundation, which is based on microeconomic utility theory, and the approaches discussed in the previous section. In other words, its focus is in modeling the choices of an individual, given the attractiveness of the available destinations. In doing so, the study of accessibility from this point of view, relates to an individual's perception of accessibility, and not to accessibility properties of a given location.

Finally, time-space measures of accessibility, known also as individual measures of accessibility, are calculated using the space-time framework developed by Swedish geographer Torsten Hägerstrand (Hägerstrand, 1970). This framework is based on the construction of space-time prisms representing the area within which an individual can move throughout the day, given the amount of time they must spend on various activities at various locations, and the individual's time constraints. Main activities, such as being at home at night to sleep, or showing up for work in the morning, constitute anchors in the space-time framework, which determine the ability to engage on other activities throughout the day. As participation in a wanted or necessary activity involves travel, maximum travel times and distances determine the boundary of the space-time prism. Overlaying the space-time prism onto a two-dimensional geographical space helps determine the Potential Path Area (PPA) of an individual. This is the area containing all the activities an individual can participate in, or all the locations an individual can be at, given his space-time prism boundaries. Thus, space-times prisms can be regarded as accessibility measures, since they delimit the number of opportunities available to an individual within a bounded space-time region.

As we have discussed in this section, accessibility measures are key elements in city and transportation planning studies. However, despite the consideration of graph type accessibility measures, the indices of accessibility that have gained the favor of planning scholars and practitioners, are those that evaluate accessibility once the origins and destinations have spatially located. In every type of accessibility measure described in this section, with the exception of graph theoretic measures, accessibility is defined as the summation of potential destinations about a point, given metric, time, or utility constrains, and, when applicable, attraction factors. In doing so, the street network is only studied as a means by which to link opportunities, and then evaluate accessibility differentials to them.

2.3.2 Street connectivity in city planning. Aggregate measures.

The study of accessibility has been complemented in recent years by the work of city planning scholars, whose research focused on measures of street connectivity. These studies, an emerging method supporting transportation planning and urban development policy, have helped in setting targets for land subdivision which encourage non-motorized travel and support mixed use. Given the relative ease by which these measures are able to be calculated, and the relatively straightforward manner by which they can be implemented –in zoning regulations, subdivision ordinances, and other related planning instruments–, measures of street connectivity have been progressively incorporated into mainstream city planning practice (for an analysis of the implementation of these measures in 13 US cities, please see Handy, Paterson, Butler, 2003).

The American Planning Association's *Planning and Design Standards* (2006) thus, defines street connectivity as "the quantity and quality of connections in the street network". The rationale for including street connectivity, is based on its impact on travel choices, emergency access (APA, 2006, p.230), and walkability (APA, 2006, pp.230, 479). Researchers also indicates that higher street connectivity can as well, decrease traffic congestion on arterial streets by offering greater route choice (Handy, Paterson, Butler, 2003). The APA's standards propose two ways to measure connectivity: block length, which indirectly measures the density of street intersections in an area, and the ratio of the number of street segments to street intersections (links/nodes ratio) which measures how many street segments meet at an intersection. These, and similar measures, such as the density of street intersections per area, are also useful in research on travel choices and walking (Hess, Moudon et al., 1999; Frank, Schmid, Sallis et al, 2005; Kerr, Frank, Sallis and Chapman, 2007; Lee and Moudon, 2006). However, these measures have the disadvantage of being calculated at an aggregated level –e.g., square mile, census tract, neighborhood–, which, while providing a basis for the study of differences *between* areas, they do not address connectivity variations *within* areas. Furthermore, aggregate measures fail to address connectivity as a measure dependent on the continuity of the street network outside of the bounded area. Further discussion of these measures is presented in section 3.4.1, when introducing the street connectivity measures used in this thesis.

2.4 Discussion. The concept of distributed gravitation.

As we advanced through the literature review we presented, first, the most notable theories and models addressing retail location. These studies covered the regional scale, the urban scale, and, over time, increasingly incorporated the role of detailed aspects of consumer behavior in understanding the mechanism driving the distribution of retail. In following sections, we presented accessibility measures, which provided further insights regarding the interaction between urban land use and the transportation system. Based on the presented literature review, it is possible to more clearly define the approach taken by distributed gravitation models.

In economic and geographical studies of retail location, overcoming distance –which translates into transportation costs–, and the functional composition of centers –as a means by which to evaluate the utility they provide to consumers–, are the main demand-side object of their research. How far a consumer is willing to travel, and how they make decisions about which center to visit, are central to classical and later models addressing multi-stop, multipurpose trips. On the other hand, the co-location of complementary and competing activities –given the demand externalities generated–, constitutes the main supply-side object of study in the presented research. These studies have taken the shape of economic models addressing the mechanisms leading to the clustering of competing and complementary activities. In both cases, street networks, if at all present, are only considered in their role of connecting supply and demand points, and a means by which to evaluate transportation costs or the willingness to overcome spatial separation. How the street network, by virtue of the structure of connectivity, provides alternative paths between supply and demand points, and whether these paths tend to converge towards certain streets in the network, is not the main focus of their research.

In the case of accessibility studies, street networks are evaluated once again as mediators, although this time, between spatially distributed land use types. The focus of accessibility measures, is on the evaluation of the locational advantages of an area, household, or individual, given the placement of land uses of interest about them, and the ease by which destinations can be reached, given time, cost, or utility constraints. Clearly, in order to characterize the accessibility of a location, it is necessary to know, beforehand, the distribution of land uses –or as we noted, it is necessary to specify accessibility to *what*–. We can conclude then, that locational advantages which might emerge from the structure of connectivity of the street network, and which might be important in guiding the locational decision of store owners, are not the central concern of the accessibility measures reviewed.

These conclusions, allow us to more clearly define the approach taken by distributed gravitation models. These models suggest that the structure of connectivity of urban street networks, is a main determinant in the distribution movement patterns and a key factor in understanding the emergence and location of retail centers and alignments. In contrast to the role assigned to the street network in the studies presented so far –i.e., they are used to evaluate interactions or accessibility between known origins and destinations, which can be further characterized by their attractiveness–, distributed gravitation models assume: first, that every location in the street network can be an origin, as well as a destination for trips; and second, that no particular location within the street network exerts any particular level of attraction. By doing so, it is possible to measure accessibility at every location in the network, and identify those spaces –streets or street segments– that are more easily accessible –by being metrically or topologically closer– from every other space. In other words, accessibility is studied as a descriptor of the ease by which each destination can be reached from each origin in turn, describing variations in accessibility across the city. However, we should note that by parametrically defining a metric or directional search radius, it is possible to address not just global or citywide variations in spatial accessibility, but variations at the local or areal scale. This latter scale provides for a more meaningful characterization of the surroundings of a given space, given that its accessibility values will depend on the characteristics of the mediate or immediate context, and not on its relationship to more distant spaces that are unlikely to have local impact.

The implications of this approach to accessibility, and the characterization of each space they make, are twofold. On the one hand, highly accessible spaces, or spaces which are metrically or topologically closer to other spaces, provide a locational advantage with respect to less accessible spaces. On the other hand, highly accessible spaces, are likely to be more frequently used when traveling through the network, thus being likely to concentrate higher volumes of movement. In this case, the consideration of through movement, or movement between trip ends, acquires a relevance that is not present when linking to-from pairs. Both these conditions, emerging from the structure of connectivity, are likely to play an important role in understanding *where* within the network there might be favorable conditions for the location of retail. The foundations on which these studies have been developed, and how they relate to the study of retail location, will be presented in the following sections.

2.4.1 Space Syntax. Urban movement patterns and retail location.

The proposition that street network connectivity is an important variable in understanding the distribution of retail was pioneered by Space Syntax (Hillier, 1976; Hillier and Hanson, 1984; Hillier 1996; Peponis and Wineman, 2002). A theory developed at the Unit for Architectural Studies at the University College London, Space Syntax has been applied to the study of building layouts –the architectural scale-, as well as in the study of urban street networks –the urban scale-. However, common to both scales, is the understanding that human societies use space as a key and necessary resource to organize themselves, and that in doing so, they *configure* the space of inhabitation. Configuration, as is understood by space syntax, refers to the act of turning continuous space into a connected set of discrete units (Bafna, 2003). This means, that the theoretical foundations of space syntax, lie in the understanding of spatial configuration as social construction –thus understanding the city as a social artifact–, reflecting the culture of the city and its dwellers, and how they build the urban space to satisfy their needs. In the urban case, the city streets constitute the discrete parts that together compose the whole of the street network.

In order to study the configuration of urban street networks, space syntax has based its analytical framework on the study of connectivity relationships between spaces –in this case, streets–, in order to identify spaces that are more easily accessible from their surroundings, and those that are, indeed, spatially segregated. Assuming that in relatively dense cities every destination is as important as every other one, and assuming that no destination exerts higher levels of attraction than any other one, it is possible for space syntax to focus on the study accessibility as it is distributed throughout the street network. Thus, the focus shifts from the study of street networks as the means by which to link origins and destinations, to the study of the street network as the spatial system that allows movement throughout and across the city.

Space syntax suggests that streets which are more directly accessible from their surroundings concentrate higher volumes of pedestrian movement. Syntactic accessibility, we should note, has traditionally been measured in terms of topological properties, namely, direction changes. Each linear element of a street network is characterized by the mean number of direction changes needed to go to all the other linear elements. The measure of direction changes is relativized so that systems of different sizes can be directly compared, taking into account the general tendency of systems to become proportionately more directly connected as they grow larger. The relativized measure is called "integration", and further details of the method by which it is calculated will be presented in following paragraphs. However, let us for now note that integration has been consistently reported to be positively correlated with pedestrian footfall (Hillier, Burdett, Peponis et al, 1987; Hillier and Iida, 2005; Hillier, Penn, Hanson et al., 1993).

As the correlation between integration and pedestrian movement became confirmed through additional studies in a variety of urban contexts (see for example Peponis, Hadjinikolaou, Livieratos et al., 1989, Özbil, Peponis, Stone, 2011,) the term *natural movement* (Hillier et al., 1993) was coined, in order to describe the manner in which the spatial layout of urban areas governs the distribution of movement patterns. As a consequence, it was argued that highly accessible, and thus highly traveled, spaces, were especially well suited for the location of land uses that benefit from increased accessibility and higher movement, like commercial activities. It can be argued of course, that the distribution of land uses also impacts the distribution of movement, particularly in the case of land uses like retail, that are assumed to act as attractors. It has been argued however (Hillier et al, 1993), that as the spatial structure of street systems remains relatively invariant over time while land uses evolve, the logical direction of influence in the traditional city is from spatial structure directly to the distribution of movement as well as from spatial structure to the distribution of land uses and, through land use, to the distribution of movement. In other words, spatial structure affects movement both directly and indirectly. Where integrated spaces attract retail oriented land uses which in turn attract more movement, a *spatial multiplier* effect is said to arise. This becomes the foundation of the *spatial economy* of retail. Hillier (Hillier, 1996, Ch. 6) argued that an otherwise linear correlation between spatial integration and pedestrian densities thereby becomes logarithmic. Peponis (Peponis et al, 1989) argued that the effects of space are relatively stable, regardless of the effects of land use, by comparing the distribution of movement during times of the day when businesses are open and times of the day when they are closed.

Thus, the direct and land-use-mediated effects of spatial structure upon movement have become the foundation of the syntactic theory of retail location. Additional work has essentially added two kinds of extensions. First, it has been argued that the “attraction” of a road segment on a “main street” depends on the number of other segments which are accessible within a local radius (usually a two direction changes catchment area) (Hillier, 1999a). This proposition has been developed in order to account for the variation of retail densities along the extension of main streets that traverse large urban areas. Second, it has been argued that the relationship between movement and space is subject to laws of spatial cognition (Hillier and Iida, 2005). Put simply, the spatial structure of cities influences movement according to the way in which it is cognitively understood. This argument has been made by comparing alternative descriptions of the same street system (based on syntactic integration, metric accessibility or the manner in which spaces control access to other spaces).

The fact that integration, measuring syntactic accessibility, is more strongly correlated to the distribution of movement than to other descriptors of street network connectivity, has been taken to indicate the cognitive primacy of direction changes, as is documented in several studies on spatial cognition (Baileson et al, 2000; Baileson et al, 1998; Crowe et al, 2000; Jansen-Osman and Widenbauer, 2004; Moeser, 1988; Montello, 1991; O'Neil, 1991; Sadalla and Magel, 1980; Sadalla and Montello, 1989, compatible findings can be found in Hillier and Iida, 2005; Peponis et al, 2008; Penn, 2003). Further support to the cognitive implications of direction turns, is provided by findings noting people traversing an area, tend to use the path involving fewer directional changes (Conroy-Dalton, 2003).

Space syntax's theory of retail location, therefore, can be summarized as follows: The spatial structure of cities entails a differentiation between few, linearly extended and powerfully integrated streets and a greater number of shorter and less well integrated streets. Retail distributes itself along the highly integrated streets in order to take advantage of their cognitive prominence, and also, of the fact that they act as attractors of higher densities of movement. The key to the development of the syntactic theory of retail location is the description of a street network, such that how each element (linear street extension in the case of space syntax) is related to all others, is to taken into account.

Space syntax relies on "axial maps" for the analysis of urban configuration. These maps, are built by digitizing straight lines over city maps, in order to reconstruct the street network. Axial lines, we should note, comprise the fewest and longest lines necessary to connect every space (street), to every other space, until all possible circulation paths have been covered (Hillier and Hanson, 1984; Peponis et.al. 1998; Batty, Rana, 2004). In constructing these maps, the geometry of the street network determines the length of the axial lines, so that long, straight streets, would be covered with one axial line, and curvilinear streets, would require the tracing of several interconnected axial lines. Axial maps thus, could be thought of as an alternative to traditional node-link representations of street networks (please see section 2.3.1, graph measures of accessibility). More accurately, an alternative which aggregates several consecutive links into a single line, and address each street in the city as a spatial unit. A further difference between axial maps and typical node-link maps of street networks, is that the calculations of connectivity and adjacency are based on the use of dual, not primal graphs. This means, that axial lines are studied as the nodes of the graph, and their intersections as the links, a decision based on space syntax's interest on streets as the space for movement.

Using the dual graphs' adjacency matrices, several measures describing the configuration of street networks are calculated. The main of these is a measure called "integration", and is, essentially, a measure of topological distance. This measure thus, is not calculated in terms of metric distance, but in terms of topological steps, which can be interpreted as direction turns. For example, from the point of view of a pedestrian walking down a street (represented by an axial line), the axial lines directly intersecting this street will be one step (or direction turn) away, and axial lines intersecting these latter streets, will be two steps away from the original one. However, Space Syntax's axial lines method and its topological distance basis have been called into question for its inability to deal with the metric component of movement (Ratti, 2004a; Hillier and Penn, 2004; Ratti, 2004b, Steadman, 2004). The axial maps method has been since then revised, and several new measures were introduced. In particular, newly developed measures have relied on primal graph representations of street networks, thus studying them as node-link systems with metric dimensions, which are more in tune with the long tradition within the fields of transportation planning and related disciplines.

We should note that within space syntax research, the question of accessibility within ranges of topological *and* metric distance, has been the studied by researchers of the Swedish Royal Institute of Technology (KTH) (Ståhle, Marcus, Karlström, 2005; Kalrström, Mattson, 2009; Marcus 2009). Their research, which included the development of the network analysis software Place Syntax Tool, focused on the measurement of metric and topological accessibility from individual parcels, to urban form variables like population and built area,. The analysis of accessibility to these latter variables from parcels in two Stockholm areas, indicated that accessibility with axial lines, performed better as an explanatory variable of observed movement patterns than did metric distance.

Among the latest methodological refinements, we find angular segment analysis (Turner, 2007), and the introduction of continuity lines (Figueiredo, Amorim, 2005). The former, allowing for the breakup of axial lines into segments at the points where axial lines intersect, and the study of shortest paths based on least angular deviations. The latter, addressing discontinuities in axial maps which result from curved and sinuous street spaces, and consequent inefficiencies in the calculation of configurational measures. In both these cases, the axial line method was enhanced, although they did not directly change their approach with respect to the use of dual graph representations of street networks. However, later developments based on primal graphs, which directly address accessibility in metric terms were developed, and are presented in the following section. In particular two alternative street network connectivity measures will be discussed. The first, is based on the notion of Reach, is the one used in this thesis. The second one, is based on the evaluation of street network centrality according to several indices and was named Multiple Centrality Assessment.

2.4.2 Recent developments in the metric analysis of urban street networks.

As we have noted, Space Syntax's method of analysis of urban layouts, based on the axial map and its corresponding dual graph, relies entirely on topological distance (steps). However, metric distance, has been argued to be the key measure by which travel decisions are made, and a measure that is particularly well suited for the quantification of transportation costs in terms of time, effort, or expense (Steadman, 2004). Recent research thus, has turned to primal graphs analyses, and the use of metric distance, in the study of urban street networks connectivity and configuration. These latter research in presented in this section.

The introduction of metric properties in the analysis of urban networks which more closely follows the theoretical principles and research questions posed by Space Syntax, was recently published by Peponis and colleagues (Peponis et al. 2008). The measures they proposed, have several advantages over the axial map method. The first of these, is related to their ability to address the geometry of the street network in terms of metric distance. In order to do this, these measures are calculated on standard GIS street centerline maps, now widely available and continuously maintained by official agencies. A further advantage brought by the use of GIS street maps, is that it is now possible to study street networks at the detailed scale of the segment –or link if we adopt the primal graph definition–. Also, by operating within a GIS platform, it is now possible to join, and spatially relate, geospatial data describing additional variables of urban form, such as population, employment, transportation infrastructure, a factor that was taken advantage of in this thesis. Two types of measures were proposed under the common notion of Reach.

The first measure, Metric Reach, characterizes each road segment in the network by the amount of street length available within a given metric radius. As such, it is a measure of density, and could be interpreted as a measure describing the "tightness", or "openness", of the urban fabric, as is defined by the dimensions of the urban blocks. The analysis of a large sample of 2x2 miles urban areas, confirms that Metric Reach is highly correlated to block sizes, as well as to street intersections and street length per square mile (Peponis et al., 2007). However, besides characterizing the density of the street network, metric reach can also be interpreted as a measure of potential. This is the case, for the denser the street network, the greater the likely number of parcels associated with it, and the greater the likely number of premises to which the streets provide an interface for interaction and encounter. Metric Reach, thus, describes the distribution of metric accessibility, and serves as a measure of the potential of the urban fabric.

Figure 2.9, shows how Metric Reach behaves in a controlled environment such as perfect grid, illustrating its basic definition. In Chapter 3, when describing our independent variables, the behavior of metric reach is introduced through an example of its calculation in the fabric of the City of Buenos Aires.

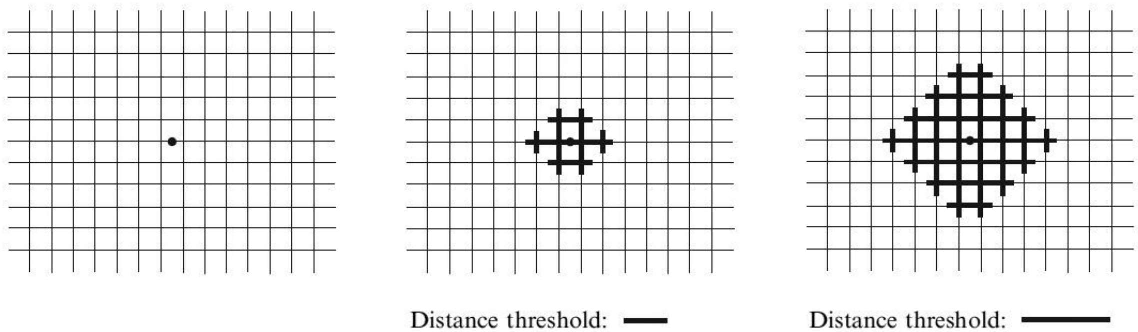


Figure 2.9 *– Metric reach in a perfect grid. From Peponis et al. 2008*

Directional Reach on the other hand, also provides a measure of density, but in this case, the analysis is more in tune with the cognitive implications that derive from the alignment of the city streets. Directional Reach measures the amount of street accessible from the midpoint of every road segment in the street centerline map, given a number of direction changes. Two parameters need to be input at the time of calculating Directional Reach, These are, the number of direction changes permitted, and the angular deviation threshold, which when surpassed will count as a direction change. Studies conducted so far, have used 0, and 2 direction changes, and 10 degrees as the threshold angle for computing direction change.

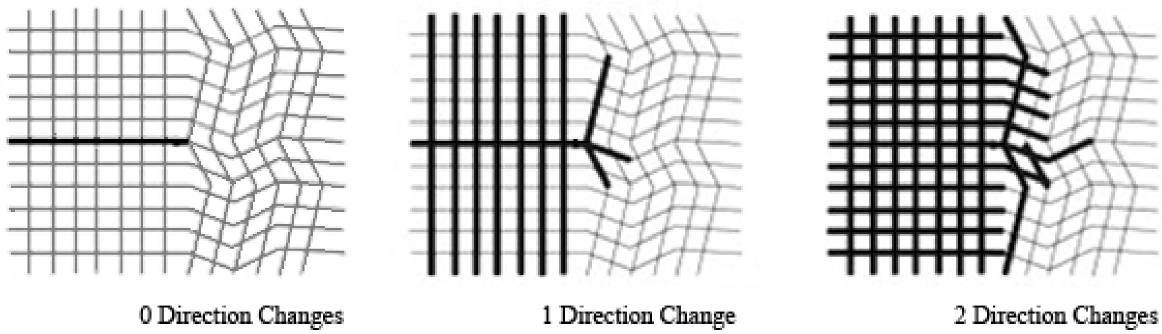


Figure 2.10 *– Directional Reach. Reproduced from Peponis et al. 2008*

Both Metric and Directional Reach, have been recently applied in a variety of studies, such as the characterization of the urban structure of US cities and the distribution of their population densities (Peponis et al., 2007), the study of vehicular and pedestrian movement (Özbil, Peponis, 2007, Özbil, Peponis, Stone 2010, Scoppa, French, Peponis 2009), and retail land use distributions (Scoppa, 2009). When discussing our independent variables in Chapter 3 (please see section 3.4), further details and examples addressing the performance of this measure will be introduced.

Multiple Centrality Assessment -MCA- (Porta et al. 2006, Porta et al. 2008, Crucitti et al. 2006) on the other hand, studies street network connectivity based on centrality indices, which again, are designed to capture properties of the street network, without predetermining origins and destinations. In MCA properties of centrality in urban street networks are measured according to three main indices. These are, closeness centrality, betweenness centrality, and straightness centrality. The first of these, closeness centrality, measures how metrically close a node is to every other node in the network. In doing so, it addresses proximity between spaces in terms of metric distance. Its calculation follows the definition of closeness centrality advanced by Freeman (Freeman, 1979). Closeness centrality thus, is the inverse of the average distance from a node, to every other node in a network, and is aimed at capturing the accessibility of a place, in light of the cost of overcoming spatial separation. Closeness centrality is calculated using equation 2.7 below.

$$C_i^C = \frac{N-1}{\sum_{j=1, j\neq 1}^{N} d_{ij}} \qquad \text{equation 2.7}$$

Where *N* is the total number of nodes in the network, and *dij*, is the shortest geodesic distance between nodes *i* and *j*.

Betweenness centrality on the other hand, measures the degree to which a node lies on shortest paths between all other nodes in the network (equation 2.8). A node is classified according to its position within the network, particularly measuring to what extent it facilitates communication between every other pair of nodes. As such, nodes are not studied as origins or destinations, but as pass through node. Its computation thus, requires the analysis of the whole network, and the evaluation of all possible paths. Betweenness centrality as is calculated in MCA is presented in equation 2.8.

$$C_i^B = \frac{1}{(N-1)(N-2)} \sum_{j=1;k=1, j\neq k\neq i}^{N} \frac{n_{jk}(i)}{n_{jk}} \qquad \text{equation 2.8}$$

Where n_{jk} is the number of shortest paths between nodes j and k, and $n_{jk}(i)$ is the number of these shortest paths that contain node i. This index varies between 0 and 1, and reaches unity when a node lies in every single path from every other location in the network.

Finally, straightness centrality measures how much a shortest path between a given pair of nodes deviates from a straight line distance (equation 2.9). This measure is related to the legibility of the environment studied, and to the level of difficulty involved when performing cognitive mapping. This measure is particularly tuned to address findings in path choice and way-finding, particularly the tendency of individuals to follow the straighter possible paths between origins and destinations, and reported by Conroy-Dalton (Conroy-Dalton, 2003).

$$C_i^S = \frac{1}{(N-1)} \sum_{j=1;,j\neq i}^{N} \frac{d_{ij}^{Euclidean}}{d_{ij}} \qquad \text{equation 2.9}$$

Where $d_{ij}^{Euclidean}$ is the Euclidean distance between nodes i and j, or the length of the crow-fly distance.

Metric and Directional Reach, and MCA, have tackled street connectivity addressing metric, not just topological distance. However, even when these two methods are close in their aims, their foundations lie in different theoretical fields. While Porta and colleagues concentrate on the study of graph theoretic measures of centrality, and how they can be applied to the study of urban phenomena, Peponis and colleagues, base their measures on the theoretical formulations described in the previous section. At this point, it is necessary to note that the theoretical foundations of Space Syntax, and its approach to the question of spatial configuration, are based on the understanding of the city as a social artifact, and an expression of culture, not merely as an interconnected graph system subject to mathematical laws. Thus, there exists a difference in the understanding of the laws that govern the configuration of cities as they evolve over time, and the post-facto measurement of its topo-geometric characteristics. As within the Space Syntax research community, several authors have addressed the distribution of commercial premises in urban environments, we will review these studies in the following section.

2.4.3 Distributed gravitation models in the study of retail location.

Distributed gravitation analyses, using either axial maps or node-link based measures, such as those presented in the previous section, have investigated the effect of measures of street connectivity on the distribution of retail. In the last decade, a relatively large body of literature has been produced, highlighting the interest in this subject from researchers in this field. This section, which concludes the review of the literature, focuses on this body of work, noting its purpose, methods, and findings.

Among the recently developed methods of street network analysis, Multiple Centrality Assessment (section 2.4.2) has been used to study the relationship between measures of centrality, and the distribution of retail in the city of Bologna, Italy (Porta et al., 2009). The authors investigated whether network centrality measures captured locational advantages, by studying bivariate correlations between these measures, and the observed intensity of retail land use. We should note that centrality measures were computed globally (taking all nodes in the network into account) and, in the case of closeness and straightness centrality, also locally (using only nodes within an 800 meters radius). In order to transfer information recorded in the nodes to the street segments, the authors took the average values of the two nodes that define the endpoints of the segments. Data on retail location, on the other hand, was available in GIS format, and its spatial resolution was the parcel level.

As street centrality values were recorded in the city's street centerline map, and land use data was recorded at the parcel level, the authors converted these GIS vector data, to raster format, creating a grid whose cells had 10 meters sides. The transformation from vector to raster, was based on Kernel Density Estimators (KDE), distributing street centrality, and retail location data, as densities over the continuous surface of the raster grid. KDE is a spatial smoothing technique, which can be used for distributing the values of localized data –as the centroid of a parcel or street segment- across a raster grid, taking a user defined 'bandwidth' to compute the density values. For example, using a bandwidth of 100 meters, the density within a 100 meter range (window) of each observation –retail shop–, is used to represent the value at the center of the window, and values will taper off according to the kernel function which weighs the presence of other observations –retail shops– within the window.

The authors used 100, 200 and 300 meter bandwidths in order to distribute street centrality and commercial premises location data, as densities over a grid of 2,771,956 cells. Initial statistical summaries indicate that the both density of retail, and global betweenness, follow a log-log relationship. This means, that very few places have high values of retail density, and very few places have high centrality values. However, no statistical models are specified, given that spatial autocorrelation between spatial variables is likely to occur. Instead pair-wise correlations between spatial and land use variables are computed. There are positive associations between spatial and land use variables, the clearest being associated with betweenness centrality at a bandwidth of 300. It looks as if the effect of global closeness and straightness become sharper after a certain threshold value. Unfortunately, the discussion of these correlations is not systematic.

We should also note, that by using KDE, the highly detailed representation of parcel data and street segments defining block faces was ‘smoothed’ across the bandwidths areas, a fact that the authors interpret as an advantage. Their reasoning is that by understanding the surroundings of a location, its “essence” is more accurately captured. While this might be the debated, the results we will present in Chapter 4, indicate that by using smoothed, or context-derived data, there exists a risk of overstating the relationship between measures of street connectivity and retail, and might miss the sharp contrasts between, e.g., a high density retail corridor traversing a medium density residential area. Within the paper, we also find evidence of this tendency, as the authors report consistently higher correlations when using data calculated using a 300 meter bandwidth for the KDE. We also find this study lacking with respect to the use of control variables. Besides the use of smoothed data, the effect of street widths, population and employment density, transportation infrastructure, and importantly, zoning, are not taken into consideration. Results are presented inconclusively (no significance levels for correlations, no complete table of correlations, no model). Treating betweenness and closeness centrality as metric variables opens up the way to discuss straightness as a separate variable.

A relatively recent study investigated the role of street connectivity and configuration measures to the distribution of retail in Cambridge and Somerville, in the Boston MSA (Sevtsuk, 2010). In this work the computation of accessibility was measured from each parcel in turn (as KTH's Place Syntax does, Ch. 2, s. 2.4.1), and evaluated the effect of two families of measures –reach and remoteness–, on the probabilities of shop location in each parcel. Reach, as defined by Sevtsuk, describes accessibility to objects of interest much in the way cumulative opportunities indices work (section 2.3.1); although in this case, it summarizes the amount of population, employment, as well as built volume within a given distance threshold. Remoteness on the other hand, measures the difficulty involved in reaching destinations, using direction turns, distance, and intersections crossed, as indicators of navigational difficulty. The analysis focuses on elucidating the role of endogenous and exogenous factors as determinants of the distribution of commercial land use. By addressing this distinction, demand externalities, which might influence the location of a shop, and are endogenous elements guiding retail location patterns, are controlled for in a statistical model that addresses these, and exogenous factors like reach and remoteness, conjointly. The author concludes that that after controlling for these factors, street connectivity and configuration measures have statistically significant effects in the location of retail.

These two studies contributed primal graph measures of street connectivity and statistical methods to the study of urban patterns of retail, and indicate the ongoing interest in the investigation of the relationship between urban spatial structure and the distribution of land use. Still, the study of accessibility and its impact on the distribution of retail, has been for long a subject of study within the Space Syntax research community, the field that as we noted, pioneered the study of configurational properties of the built environment. Several of the papers published are discussed in the following paragraphs.

One of the first published studies linking configurational measures of street layouts, to advanced analyses of retail location, proposed a multi-stop model, where configurational maps were used to measure the spatial relationships between demand and supply in urban systems (Krafta, 1996). As multi-stop models relate the relative position of supply points to the success of multipurpose trips, Krafta notes that configurational models, like syntactical analyses, measure the effectiveness of the circulation system, and its impact on the location of attractants as per the movement economy process proposed by Hillier. In this paper, two type of models, one addressing users' choice of supply locations, and the other addressing the route which will be followed, are paired. The model built, processes adjacency relationships between blocks, termed Built Form Units, or BFUs, and the public space, represented by axial maps, or point axial maps. The key element in Krafta's model however, is that BFU's are distinguished according to their function as providers of demand, or supply. In the case of supply, BFUs are further categorized according to the variety, and kind of shops they house. This latter categorization, is used to evaluate the probability of satisfying demand in multi-stop shopping trips. In Krafta's model then, the street network's configuration is considered as an additional factor by which consumers plan and decide how to more effectively conduct a multipurpose trip.

While Krafta introduced a multi-stop general model using configurational variables for the calculation of accessibility, several studies have empirically studied the relationships between street network connectivity and patterns of land use. Among them, we find the work of Ortiz-Chao and Hillier, who studied the distribution of commercial premises in centers and subcenters of Mexico City (Ortiz Chao and Hillier, 2007). The study used a land use database of approximately 160.000 records at the parcel level. Each parcel in the database received the respective values of local and global integration of the axial line they faced. Integration, we should remind the reader, quantifies how direct is the relation of each axial line with respect every other axial line in the system (global integration), and with respect to those up to a given number of topological steps, usually three (local integration). Continuity lines, i.e., the aggregation of axial lines into larger units, accounting for the sinuosity of roads that would otherwise be two or more axial lines (Figueiredo, 2005), were also tested.

Initial findings point to higher concentrations of retail on more integrated streets, and the opposite in the case of residential land uses. Further studies, were conducted through a multivariate logistic regression model on a binary "retail-no retail" per parcel response variable. Results, based on odds-ratios, indicate that larger shops in main centers are tuned to street integration at the global scale, while small shops in the same centers tend to locate more in tune with local integration values. Block sizes, on the other hand, were found to have little or no influence on the distribution of retail premises. Findings from this study highlight the role of streets connectivity in the location of centers, and the fine-tuned response of retail premises to local and global measure of spatial structure. As such this study sheds light on the fine scale at which configurational measures work within urban areas, and how they might contribute to the composition of these centers. However, by working with axial and continuity lines, it was impossible for this study to address variations that might occur along the axial spaces, or at detailed local scales, such as those that take place at the level of the block face. Also, while controlling for some variables, neither population densities, nor employment, are considered. Street widths, inter-store externalities, and zoning regulations are also not controlled for in this study.

The work of Ortiz Chao and Hillier, followed Mora's (Mora, 2003) study of the highly regular plan of Barcelona's Ensanche. In Mora's study, spatial configuration variables and their impact on the distribution of retail, were tested for the first time in a highly planned environment. Retail was classified as convenience, comparison, and specialized, following an extensive survey of commercial land use in an area of 220 blocks. An index of commercial land use intensity was calculated, by dividing the total number of shops by the length of the axial line they faced. The study concentrated on a sector of the L'Example area of Ensanche, whose axial map was analyzed embedded in the street network of Barcelona, but also in isolation. The results reported, are based on

Pearson correlations between the land use intensity variable, and syntactic integration at the local and global scale. The reported level of association (r-squared) between these variables varies between 0.31, and 0.41. However, as is generally the case, this study falls short of controlling for any alternative variables. Also, as in the previous study, the use of axial lines tends to diffuse store concentrations and clusters, evenly distributing retail premises along axial lines. Finally, the methods available at the time, particularly the lack of detailed GIS land use data, required an intense surveying effort, which covered a relatively small area, thus failing to account for the impact of connectivity variables across the whole city.

Studying the characteristically dense pattern of commercial activity generally found around railway stations, Mulders-Kusumo (Mulders-Kusumo, 2005) argued that while the station might act as an attractor for firms, it is the street network configuration that seems to determine the observed patterns of retail location. The study focused on the surroundings of central train stations in Delft and Leiden, in The Netherlands. Results indicate that the streets that connect the rail service users to the stations, particularly the more connected ones, present the higher concentrations of retail. The local structure of streets (three axial steps) analyses were aimed to reveal the compactness of the area (size of the blocks and overall grid intensifications). Shops are assigned to the axial lines as unit counts on each of the axial lines in the system. Analyses are done by visual inspection, so there is a lack of statistical rigor in the discussion of the subject. Observation of Delft indicates that integration is ‘more of a magnet’ than the Station itself. In Leiden, the pattern is similar, the station does not have shops surrounding it, but only on the street that connects it to the main streets at the global level. While in this study there is, as we noted, an overall lack of rigor in the presentation of the analyses, the results obtained seem to support the idea that measures of spatial structure provide valuable insights for the planning and design of livelier streets. The author concludes that what matters is not the station's regional importance, but how the station connects to the local urban structure.

In a recent study, Chiaradia, Hillier, and colleagues (Chiaradia et. al., 2009), explored centrality in urban agglomerations focusing on the configurational properties of main streets. This study was part of a larger research program aimed at estimating revenue derived from strategic urban design projects, and attempted to capture the "spatial signature" of centers -as opposed to non-centers-, and how these centers relate to their context. Ten centers of varied size were selected for this study. The selection was based on observed similarities in the types of goods sold in each of them. According to Greater London Authority's classification, the sample included 1 metropolitan, 4 major, and 5 district centers. Most of the retail premises in these centers, were at ground level facing the street –a situation similar to the one found in our case study–. Counting with an abundance of data, the study indicates that variables considered included: population, employment, income and spending power, mix and number of shops, floor space and competition, prices, retail rents, and pedestrian footfall. Spatial structure was measured using space syntax measures, including angular segment integration, and choice at different radii. While the authors report a clear link between spatial structure and the concentration of retail activity, the study falls short of performing multivariate analyses that would have provided controlled coefficients.

Finally, and not directly concerned with the location of retail but addressing the impact of street networks as the necessary pathway for city dwellers to access opportunities, Marcus and colleagues developed the notion of Spatial Capital (Marcus, 2009). The argument developed in this paper, hinges on the relationship between accessibility, density, and diversity, and how these variables can help provide more elaborate definitions of urbanity. For example, on density, the author notes that this variable can be a confounding measure, as similar figures can describe, for example, inner city conditions as well as a high density developments in peripheral areas. It is argued thus, that what matters is the accessibility to that density, which is provided by the street network. It is also noted that density alone may fall short of describing urbanity, as institutional buildings (hospitals, cemeteries) can also complicate the idea of urbanity for these buildings are only urban in a derived sense. Urbanity thus, is addressed as a condition best described by the quantification of accessible density and diversity. Using Place Syntax analysis (section 2.4.1), urban areas are studied through the measurement of accessible content. From this analyses the authors report a –actually expected– very high correlation between accessible building density and accessible population density. However, the originality of this finding lies in that this correlation is based on an alternative way of measuring and understanding density, by focusing on the experiential –i.e., by relating it to the city streets and their role in distributing movement–, and overriding the more abstract areal definitions of density. Following this finding, the scale of analysis shifts to the plot level, in order to study accessibility to diverse content. As these analyses are based on the use of axial lines, which have varying lengths, the measurement of accessible diversity based on a directional threshold, required the normalization of values. The normalization procedure used, was based on the ratio of plots accessible, by the total area of the plots, a measure they call capacity. Correlation analyses that follow, show that capacity correlates well with diversity, which is measured by lines of businesses, and age groups accessible. Following classification schemes indicate how spatial capital, measured in this way, can describe different urban conditions.

As we have covered in this last section, several studies have sought to shed light on the relationship between spatial configuration and street connectivity on the distribution of retail land use, and the location of central, lively districts. Still, for the most part, these studies have not fully controlled for the effect of alternative variables that are likely to influence the emergence of central districts and retail land use alignments.

2.5 Summary

The review of the literature allowed us to more clearly differentiate distributed gravitation models, from models of retail location developed by geographers, urban economists, and city and transportation planners. In particular, we have seen that in many of the classical and revised studies, street networks are usually replaced by abstract representations of urban and regional space, which take the form of featureless plains or one-dimensional linear markets. However, we have seen that Berry's seminal study, which incorporated street networks to the study of patterns of retail location, highlights the cardinal importance of addressing the retail environment in its actual, not ideal, form. However, we have noted that Berry did not provide objective measures of connectivity able to describe the higher accessibility characterizing the locational advantages sought by retail store owners. In later studies addressing the impact of consumer behavior in the location of retail, the interdependencies between consumer behavior and the structure of the retail environment, and the process of mutual implications between these variables was brought to the foreground. It was noted that while consumer behavior is influenced by the structure of the retail environment in the short term, behavioral aspects have long term impacts on the distribution of retail. This situation is in tune with the proposition of distributed gravitation models, and the movement economy process described in this chapter.

While accessibility is a notion that pervades much of the studies on retail location, its measurement has been more thoroughly addressed in city and transportation planning research. Accessibility in this case, is defined using several indices, aimed at capturing the situation of an area, household, or individual, given the opportunities that lie within their reach. Thus, in order to evaluate accessibility it is necessary to know, beforehand, the distribution of the opportunities, or land uses of interest. In this aspect, accessibility measures do not directly address centrality as relates to the structure of connectivity the street network.

For the presented reasons, street connectivity studies are seen as a necessary step forward in gaining a more complete understanding of the mechanisms leading to the emergence of centrality and patterns of retail concentration. This interest, stems from previous research findings indicating that the spatial structure of the street network, is a valuable variable in understanding the distribution of movement patterns, and through these, to patterns of retail location. Space syntax in particular, has built, through much empirical research, a strong case regarding the effect of the configuration of urban street networks, and the distribution of urban movement. This effect of street configuration on movement was the foundation for the development of a *theory natural movement*. What followed, was the proposition that, given the increased volumes of movement concentrated on these highly accessible streets, a positive feedback loop would be initiated, where movement dependent land uses, like retail, would seek to locate on these locations given the higher levels of movement encountered. Only then, would land uses begin to *attract* more movement, turning a linear relationship between accessibility and pedestrian footfall, into a logarithmic one. The effect of street configuration on movement, its impact on land use, and the further reinforcing of movement patters, was therefore termed the *movement economy*.

Chapter 3

Buenos Aires and the methods used for its study

This chapter introduces the information used in this thesis, and the geographical data processing methods used to calculate the dependent and independent variables. However, we will first introduce a brief description of the City of Buenos Aires, addressing its historical evolution, and its most notable physical characteristics. The aim is to provide the reader with necessary information about the City's built form; particularly block sizes, street widths, and parcel structure, while also describing the distribution of land use and population. Following this introduction, we will address the geographical information layers describing all the data used in this thesis. These data layers allowed us to calculate the independent variable, the distribution of retail frontage, and several independent and control variables used for the purpose of modeling the distribution of retail.

3.1 Case study: The City of Buenos Aires, Argentina.

The City of Buenos Aires is located on the estuary of the Rio de la Plata, approximately at 34°36′S and 58°22′W. It is the capital of Argentina, has a population of approximately 3 million, and a land area of 200 square kilometers (78 sq. mi.). The City constitutes the core of the Buenos Aires Metropolitan Area, one of the twenty largest urban agglomerations in the world, with a total population of about 13.5 million (Instituto Nacional de Estadística y Censos [INDEC], 2010). The total urbanized area of Metro Buenos Aires, including the City, amounts to roughly 3100 square kilometers (1200 sq. mi.). In the national context, Metro Buenos Aires is the largest urban agglomeration in Argentina, with a population almost tenfold that of the next following metropolitan area in the country.

Buenos Aires has the particular condition of having been founded twice. The first foundation, in 1536, failed to evolve into a self-sustainable colony and was abandoned in 1541. The second, and definitive, foundation took place in 1580, and can be credited with the initiation of a systematic land subdivision strategy which, besides being common to many Spanish America settlements, would have an indelible and profound impact on the City's urban form. Following the recommendations for the settlement of new towns in America complied in the Laws of the Indies of 1573, the founders adopted a gridiron pattern whose blocks, parcels, and streets dimensions were to be measured in *Castilian varas*, an archaic measure of length which translates to approximately 0.866 meters (2.84 feet).

Over the vast plain on which Buenos Aires lies, the founders traced a grid oriented to the cardinal points, whose vertical and horizontal lines crossed at right angles every 150 *varas* (130 meters/ 426.2 feet). Each resulting portion of land enclosed by the intersecting gridiron lines, would be called *quadra*, a term that still remains in use today when referring to urban blocks. Rights of way, would be 10 *varas* wide (8.66 meters/ 28.4 feet), astraddle of the gridiron lines. The parceling of the blocks would also be based on this measurement system, setting the standard lot width at 10 *varas* multiples. Today a large majority of Buenos Aires' parcels have frontages of exactly 10 varas (8.66 meters, 28.4 feet), while the City rights of way, would be eventually enlarged from the original 10 *varas*, to 20 *varas* (17.32 meters/56.82 feet). The impact of this land subdivision system on Buenos Aires' urban form and architecture, was described in remarkable detail by Sir Charles Darwin when he visited Buenos Aires in 1833. At the time of his visit the subdivision regulations have been enforced for over two centuries.

> *"September 20th, 1833.— The city of Buenos Ayres is large, and I should think one of the most regular in the world. Every street is at right angles to the one it crosses, and the parallel ones being equidistant, the houses are collected into solid squares of equal dimensions, which are called quadras. On the other hand, the houses themselves are hollow squares; all the rooms opening into a neat little courtyard. They are generally only one story high, with flat roofs, which are fitted with seats, and are much frequented by the inhabitants in summer. In the centre of the town is the Plaza, where the public offices, fortress, cathedral, etc., stand. Here also, the old viceroys, before the revolution, had their palaces. The general assemblage of buildings possesses considerable architectural beauty, although none individually can boast of any." (*Darwin, C., 1890, pp. 109-110)

As the City grew, and new blocks were added, the regularity of the original plan was altered. Topography, the roads and trails converging towards the City from the interior, the progressive subdivision of once rural land, and the encroaching of peripheral towns, are among the main factors that caused the pattern of colliding grids that characterizes Buenos Aires today. Also, railway lines would influence the development of Buenos Aires, whose form in the 1940's would show the characteristic "string and beads" pattern formed by railway lines, and higher density hubs surrounding the railway stations.

The selection of this city as a case study was based on several considerations. Buenos Aires presents, in the first place, a strong monocentric structure, where the importance of the CBD, overshadows smaller subcenters and other radial and transversal commercial lineups. This characteristic indicates strong agreement with classical location theories and economic models, as the CBD leads the hierarchy of centers, while constituting the most powerful attractor and accessible location. Still, the overall distribution of commercial premises, suggests that other factors need to be considered when accounting for the distribution of retail and service businesses in its jurisdiction. In particular, the distribution of commercial premises along corridors seems to require the consideration of the configurational properties of the street network, while the study of subcenters, seems to require the consideration of both configurational properties and classical theories.

Figure 3.1, presents a map of the City, highlighting road segments where commercial frontage on both sides of the street covers more than 60% of the total available frontage. As such, it provides a clear image of the pattern of its center, subcenters, and commercial lineups.

Figure 3.1 *- Shop frontage distribution. Segments with more than 60% of their length dedicated to retail.*

In second place, the City's gridiron pattern presents an interesting configurational property. While the radial thoroughfares that provide access to the CBD operate at a global scale, connecting the periphery to the center, local conditions of accessibility could be considered equally distributed; a product of the non-hierarchical gridiron plan. Blocks are, for the most part, of regular size and shape, and choice nodes are found at regular intervals of slightly over 100 meters (328 ft.). A good measure of this condition, is given by the percentage number of nodes that are not dead ends; a variable derived from the one referred in the literature as 'connected-link ratio' (Handy, Butler, 2003). Nodes located at dead ends, typical in cul-de-sac suburban developments, would have a value of one, while four way intersections (crossroads) would acquire a value of four. In Buenos Aires, dead ends amount to an almost trivial 3.3%, out of more than fourteen thousand nodes. The remaining 95% of the nodes have either a value of three –T intersections-, or more. The full range of measures describing this situation is presented in Table 3.1.

Table 3.1 *- Percentage distribution of dead ends and choice nodes.*

	Dead Ends (value 1)	**T Intersections (value 3)**	**4-way intersections (value 4)**	**5+ way intersection (value > 4)**	**Total Nodes**
Number of nodes	490	4991	9097	213	14,791
Percentage	3.31%	33.74%	61.51%	1.44%	100%

We should also note, that in terms of the distribution of commercial premises, street edge retail can reasonably be considered the predominant form of commercial activity in Buenos Aires. A numerical summary of the map presented in Figure 3.1, indicates that 425 km. (264 mi.) of streets have more than 60% of the total frontage dedicated to commercial activities, representing an approximate 15% of the total 2812 km. (1747 mi.) of streets available in the city. Moreover, within the city limits only eight shopping malls were found in 2001, the year of the data used in this thesis. These malls were located on large existing, but obsolete, buildings which were adapted to this new function, fully occupying standard size city blocks, and directly facing the city streets.

Finally, the social and cultural qualities of this metropolis are in agreement with the need to analyze a pedestrian intense environment. In Buenos Aires shopping on street edge stores is still customary, reinforcing our study of the link between commercial frontage, passing trade, and configuration.

We should finally add that gridirons are a common subdivision pattern, and that in this respect the City of Buenos Aires represents a case of a large family of cities. Many of them found in Latin America, but are not uncommon in the US, Australia, and Canada. Results from this study could provide valuable insights regarding the impact of these type of subdivision patterns on the distribution of land uses. In summary, the noted characteristics point to the important role played by streets edge retail in everyday commercial activities, thus highlighting the importance of analyzing the city's streets network configurational properties, and their potential impact on commercial land use location.

3.2 Hypotheses and research questions

Distributed gravitation models (Ch. 2, p. 43) study the impact of street connectivity on patterns of movement, bridging urban spatial configuration with the distribution of movement-dependent land uses. In the previous chapter, we also noted that several studies report correlations between measures of street connectivity and patterns of retail location. However, the majority of these studies do not control for variables, overlooking the importance of interstore externalities, population density, or transit infrastructure, in explaining retail clusters. In other words, the possibility that the effect of street connectivity measures on patterns of retail location is annulled once other non-configurational variables are considered, has been rarely addressed. For this reason, and in order to better understand the relationship between street layouts and land use patterns, this dissertation will address the following hypotheses:

Our first hypothesis is that, even after controlling for variables likely to influence retail location, measures of street network connectivity and configuration will contribute to explain observed patterns of retail location in the City of Buenos Aires. We expect this to be the case, based on preliminary work (Scoppa, 2009) indicating that even in the highly regular, and highly connected street network of Buenos Aires, measures of street connectivity contribute to explain variations in retail frontage density. This hypothesis, is further supported by visual inspection of maps depicting retail frontage density, and the distribution of street connectivity values, particulary directional accessibility.

Our second hypothesis is that, given the highly regular layout of the City of Buenos Aires, measures of street connectivity capturing grid intensifications will not contribute to explain patterns of retail location in the City Buenos Aires. In particular, we anticipate that Metric Reach, a measure designed to capture grid intensification associated with centrality (Siksna, 1997, Hillier 1999a), will not contribute to explain retail location patterns in the City of Buenos Aires. We expect this to be the case, for in its highly regular grid –a result of the enduring land subdivision regulations described in the previous section–, blocks deviating from the standard shape and size prescribed are infrequent, and are typically found in planned low density residential neighborhoods, and few other cases, such as at the “seams” formed by the patchwork of colliding grids that characterizes this city’s fabric.

Our third hypothesis is that variations in the scale at which data is aggregated, particularly the aggregation of detailed segment scale data into larger units, will result in increases in the explanatory power of our models. We expect this to be the case, also based on preliminary research which used aggregated data (using concentric rings at one mile intervals and centered at the CBD), and data calculated at the segment level (Scoppa, 2009). By introducing several scale of analyses, this thesis aims to test this hypothesis, and clarify the impact of measuring urban phenomena at different scales of aggregation. As we have seen, researchers have used, among other, shops per axial line and data smoothed through kernel density estimation in studying the link between spatial structure and commercial land use (Ch.2, pp. 39-44). Results of these analyses will provide a further insight into the results obtained by the use of aggregated data, which has been also generally studied in the absence of control variables.

Finally, we investigate the impact of zoning regulations in explaining retail frontage density in the City of Buenos Aires. Zoning ordinances determine *what, where and how much* can be built in the City, constituting a cardinal factor to consider when studying land use patterns. To our knowledge, zoning regulations have not yet been addressed in distributed gravitation research. We expect however, to see a positive association between zoning, and the distribution of retail frontage density. Still, our analyses, are aimed at clarifying the impact of regulatory instruments upon the distribution of retail, while testing as well, its potential association to measures of street connectivity.

3.3 Information layers and the role of GIS

Geographic Information Systems (GIS) played a key role in addressing the complex relationships between the many variables that, according to theory and empirical research, affect the distribution of commercial premises. The spatial analysis tools available in GIS allowed us to link these variables, which in vector data format are represented using three standard geometrical types: points, lines, and polygons.

The GIS data used for this research included features of all three types. For example, point features mark the location metro and railway stations, line features make the City's street network, and polygon features delineate parcels and zoning districts. For this thesis, all point and polygon data were transferred to the street centerlines map, using various spatial join operations which will be described appropriately in each case. As a result, each segment in the street network of the City of Buenos Aires map, is linked to a database row, whose various columns compile all the necessary data for the specification of the statistical models.

These variables will be presented in detail in the following sections. First, we will introduce the dependent variable, that is, the variable that we seek to explain: the distribution of retail frontage. Then we will present the independent variables, these are, the variables used in statistical models in order to interpret and explain the distribution of retail.

3.4 Dependent variable: Retail frontage density.

In 1996, the City of Buenos Aires built, and began to maintain and update, a digital land records and cadastral information system in GIS. The status of this geo-database in 2001 is the source of the land use and parcel geometry data used in this thesis. In terms of retail land uses in the City, the year 2001 GIS data indicates that 49,061 parcels out of a total of 318,740, housed a commercial activity. These activities, classified by the prefix “C” in the land use geo-database, include retail stores, as well as varied service sector activities such as banks and restaurants. A complete list of the activities officially classified as Commercial is included in Appendix 1. In summary, about of 15% of the total parcels in the City housed a commercial activity, either exclusively, or mixed with other land uses.

Unfortunately, among the many variables recorded by the land records system, we find no reliable information about the built area per parcel dedicated to retail. This is particularly the case in multiuse parcels, given that the only distinction recorded in the official data, is that between each parcel's built ground floor area, and total built area. None of these variables provide an accurate measure of the area occupied by commercial premises in each parcel. This limited information on built area per land use and parcel, called for the adoption of a different method by which to address the distribution of retail. The variable selected was retail frontage density, and was calculated by taking the ratio of the sum of parcel frontage dedicated to retail facing each road segment, and the length of the road segment.

$FD_i = \frac{\Sigma f_i}{L_i}$ equation 3.1

Where FD_i is the frontage density of segment i, f_i, is the frontage length of commercial parcels facing segment i, and L_i, is the length of segment i in meters.

Several factors were considered in the selection of frontage density as the dependent variable. First, it accurately portrays the continuity of retail land uses on any given street segment. By using frontage density, the metric extent of the commercial lineups is precisely gauged, providing a more refined measure than number of shops by axial line length (Mora, 2005, Ortiz Chao, 2007), or shop density per unit area (Porta et. al., 2010). Also, by considering the actual length of the commercial lineups, characteristics of public space, its quality, and its role as the place where social interaction and encounter take place are more finely addressed. We should note however, that this measure assumes that the whole of a commercial parcel's frontage is dedicated to retail. In reality, and particularly in the case of multiuse parcels (e.g., retail/housing), a portion of the parcel's frontage must be used to provide access to the non-retail use. However, while undoubtedly overestimated, commercial frontage density can be consistently calculated across the study area.

We should also add, that the parcel subdivision structure and the setback regulations of Buenos Aires, contribute to validate the study of retail frontage density as an appropriate measure of commercial intensity. Throughout the city, and particularly in commercial zones, setbacks are rare, and most buildings are built abutting the property line. Parcels' frontages on the other hand, tend to be of relatively constant widths, given the longstanding regulations that set their width to 8.66 meters. These characteristics support the adoption of frontage density at the City scale, given that most commercial premises are located on standard size parcels, directly facing the street.

Besides the noted justifications for the adoption of this metric, we should note that lately, retail frontage begun to take an increasingly important role in urban design and planning discussions. In particular, discussions on the importance of regaining the street as a key element in building more livable and enjoyable environments. A recent publication compiling best practices in New Urbanism, indicates that the amount of continuous retail frontage is a key variable to consider when developing compact and pedestrian friendly retail areas (Steuteville, Langdon, 2009, p.76). Lately, changes in urban policy also focused on retail frontage. The City of Oakland, contained in San Francisco's Metropolitan Statistical Area, has passed zoning regulations (S-9 zones), aimed to protect and enhance the attractiveness of continuous retail frontage, and its role in creating more lively urban environments. The characteristics of S-9 zones described in Oakland's Planning Code are as follows:

> *"The provisions of this chapter shall be known as the S-9 retail frontage combining zone regulations. The S-9 zone is intended to create, preserve, and enhance compact, attractive, and clearly defined street frontage, to assure continuity of retail and consumer service uses at ground level along principal shopping streets, and to encourage retail establishments serving both short and long term needs to locate in compact locations oriented toward pedestrian comparison shopping, and is typically appropriate to district shopping areas and along important shopping streets. These regulations shall apply in the S-9 zone, and are supplementary to the regulations applying in the zones with which the S-9 zone is combined."* (Oakland, CA. Planning Code, 2010).

The use of parcel frontage as a valuable metric can also be found in research and practice. Rent, measured in dollars per foot of frontage, is commonly used in commercial real estate for land valuation and appraisal (see for example Michael, Boyle, Bouchard, 1996). This measure was also used by Hurd in one of the first studies of the economics of land use, and by Berry when studying retail location in Chicago, as changes in price per foot of frontage were observed to be correlated to the intensity of pedestrian movement (Hurd, 1903; Berry, 1963, Chapter 2, pp.47-52). Potter on the other hand (Potter 1980, Ch. 4, pp. 96-101), developed a fabric-gap index, aimed at characterizing the morphology of urban centers. This measure indexed the amount of continuous commercial frontage, by calculating the ratio of parcels dedicated to retail, to total number of parcels on a given street. Figure 3.2 shows a detail of the city fabric where the commercial parcels frontage can be clearly seen.

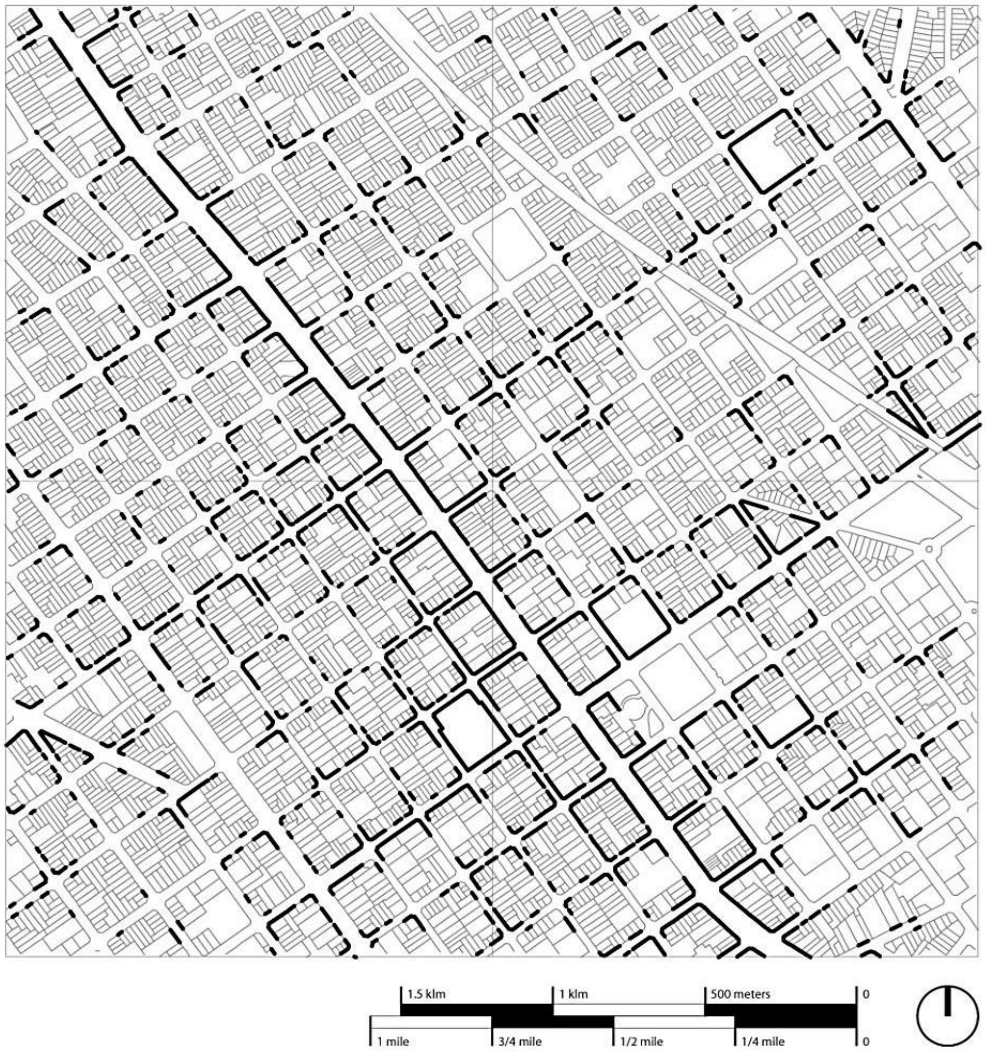


Figure 3.2 *–Retail frontage in Belgrano sub-center. Darker lines indicate front of commercial parcels*

The procedure used to transfer commercial frontage data to the road segments that make the street network of the City of Buenos Aires, was based on a series of spatial joins using GIS. In the first place, the parcels identified as having a commercial land use, were extracted from the complete set of about 320.000 parcels of the City of Buenos Aires. These parcels were further processed, by ‘exploding’ the parcels polygons, in order to extract the segment that makes the front of the parcel. An operation to calculate the length of the frontage segments ensued, resulting in a final GIS layer of measured frontage segments. We should note that in the case of corner, parcels, i.e., parcels that faced two road segments, these were further processed, dividing the frontage line at its midpoint, and recalculating their corresponding lengths. In order to transfer the retail frontage parcels' lengths to the corresponding street segment they faced, we used a buffering method, so that the street centerline segment, received the total retail frontage length facing it.

In sum, the presented antecedents in the application of retail frontage in academic research, practice, and urban planning policy, paired to the characteristics of the GIS information available for this research, seem to appropriately justify the decision of using retail frontage density as our dependent variable.

3.5 Independent and control variables:

In order to gain well-founded insights about the distribution of retail frontage in the City of Buenos Aires, several independent variables were calculated. These variables were selected based on the review of the literature, and account for aspects of urban form and street connectivity which we expect, will allow us to explain the location patterns of retail and service land use. First, we introduce these variables in a list for general reference. Then we provide a brief description of these variables, and a summary justification for their selection. Following subsections will describe these variables in detail, along with the corresponding descriptive statistics and methods used for their calculation. We should note however, that given the focus of this thesis, a distinction will be made between the independent variables. In particular, independent variables not related to the study of street connectivity properties, will be referred to as Control Variables for, as we have noted, a large majority of distributed gravitation models, have failed to control for the effect of alternative variables which are likely to influence retail location. The aim of this distinction, is the foregrounding of the impact of street connectivity variables and their relationship to the distribution of retail, while accounting for the effect of alternative measures describing the built environment.

The independent and control variables calculated were:

- *Independent Variable*: Metric Reach, 1 mile, 10˚.
- *Independent Variable*: Directional Reach, 0 and 2 direction changes, 10˚.
- *Control Variable*: Distance from each street segment to the city center (CBD).
- *Control Variable*: Street width of each street segment
- *Control Variable*: Population and Employment Density on each segment.
- *Control Variable*: Zoning regulations at the street segment level.
- *Control Variable*: Distance from each street segment to nearest transit station.

Starting by the variables describing properties of street connectivity, the measures used in this thesis are those developed by John Peponis and colleagues at Georgia Tech (Chapter 2, section 2.4.2). The street network of Buenos Aires was analyzed as a system of interconnected spaces, where all segments in the GIS maps were considered as origins and destinations for trips. The measures calculated were Metric and Directional Reach.

The calculation of distance from each street segment to the City's CBD was included, in order to account for the pattern of commercial land use in Buenos Aires. This pattern seems to agree with the monocentric city model, and the hierarchical structure proposed by Central Place Theory. Street segments located at further distance from the city center, are likely to exhibit lower values of commercial frontage density.

Street widths, on the other hand, are fundamental descriptors of the spatial characteristics of the public space, and the hierarchical structure of the City's transportation network. Given that street widths have been absent in many studies within the emerging field of distributed gravitation, we consider that the inclusion of this variable as one of the major contributions made by this thesis to this field.

Population and employment density were calculated at the level of the street segment, in order to account for the spatial distribution of consumers across the City. By studying their distribution, it will be possible to estimate the extent, and strength, of the relationship between the location of consumers, and the location of retail.

The inclusion of zoning regulations represents a significant enhancement over previous distributed gravitation studies of commercial land use distribution. To our knowledge, zoning regulations have not been considered in any of the studies conducted so far. Each segment in the street network of Buenos Aires was associated to the zoning category to which it belongs, either by falling completely within its boundaries, or by making the edge of a zoning district.

Finally, distances from each segment to the nearest metro and railway stations, were calculated. The role of these nodal points in the transit network, and the higher concentrations of potential consumers entering or leaving these facilities, were considered for they are likely to have measurable impact on the location of retail. Details on the methods used for the calculation of these variables, as well as the detailed rationale for their inclusion, will be presented in the following sections.

3.5.1 Measures of street network design. Metric and Directional Reach.

Two measures describing metric and configurational properties of street networks were used in this thesis. These measures are: Metric Reach, and Directional Reach. The former, was designed to measure the amount of accessible street length within a parametrically defined movement radius. The latter, addresses the alignment and arrangement of streets, and the cognitive effort required to navigate the urban grid. Three key properties distinguish these variables from previously developed ones, particularly axial maps. First, their ability to address the scale of the street segment. Second, they were conceived the address the metric, not just topological, component of movement. Finally, they capitalize from the wide availability of GIS software and data, allowing for the completion of highly detailed studies of street networks, and the study of a large number of descriptors of urban form.

Metric and Directional Reach were calculated using Spatialist Lines (Georgia Institute of Technology), a standalone Java program which takes descriptions of GIS street centerline maps in text format as inputs. These text descriptions of the street network maps are based on the unique identification number (ID) of each segment, and their corresponding start, intermediate, and endpoint coordinates (X, Y coordinates). The output text file produced by the Metric and Directional Reach algorithms, is linked back to the GIS street network map using the unique ID numbers, allowing for the coloring of street segments according to the calculated values. These choropleth maps help in the visualization of the structure and density of the street network.

We should finally note, that while our research is focused on the distribution of retail within the jurisdiction of the City of Buenos Aires, connectivity analyses were performed on a street centerline map of the whole Buenos Aires Metropolitan Area. By using this 'complete' street network map, we account for "edge effects" that would have occurred, had we studied the City area in isolation. Edge effects, we should note, refers to the misestimating of connectivity values in segments at the edge of a street network map which has been extracted form a larger street system.

3.5.1.1 Independent Variable: Metric reach.

Metric reach is essentially a measure of density. Directly, it measures how much street network is available within a range of movement. Indirectly it measures urban potential: the denser the street network, the greater the likely number of parcels associated with it, and the greater the likely number of premises to which the streets provide an interface. Metric Reach can be interpreted as a measure of urban potential in the sense that it allows us to understand characteristics of the urban fabric in the surroundings of any given location in the street network.

Once the Metric Reach algorithm is run, each road segment in the street network will have information regarding the amount of street that is accessible within a given metric radius. The concept, we should note, is not fundamentally different from walking distance contours (Hess, 1997), or a GIS network buffer, such as those available within GIS and their network analysis extensions (e.g., Esri's ArcMap 9.3, Network Analyst). However, unlike these two methods, Metric Reach is calculated from each road segment in turn, thus not necessarily dealing with accessibility from a previously defined location. In that it takes all available streets into account, metric reach differs from street network analyses that compute the distance from each parcel to a set of specific destinations such as the nearest shop, school, transit stop or open space (Aultman-Hall, Roorda & Baetz 1997).

Metric Reach relates to other measures of spatial density commonly used in the literature, such as block size (Moudon 1986; Southworth & Owens 1993; Jacobs 1961; Jacobs 1993; Siksna 1997; Hess 1997), distance between intersections, street length per unit area (Southworth & Owens 1993; Jacobs 1996), and number of intersections per unit area (Southworth & Owens 1993; Jacobs 1996). In particular, it is very strongly correlated with block size, street length per square mile, average distance between choice intersections, and number of choice intersections per square mile (Peponis et al. 2007).

However, there are several reasons why Metric Reach is a valuable addition to the set of spatial density measures available to city planners and urban designers. First, Metric Reach describes the individual road segment, while street length or intersections per square mile describe areas as a whole. Second, unlike distance between intersections, metric reach describes a road segment in relation to its surroundings, not in isolation. Third, unlike block size, metric reach describes the properties of individual road segments, which can vary around the same block. Reach, therefore, is a highly discriminating measure. It can capture the finest grain of the urban fabric while at the same time describing coarser properties when we take averages over areas.

The values of Metric Reach used in this thesis were obtained using 1 mile radius (1609.34 meters). The choice of this radius was based on several criteria. The main of these, is that 1 mile radii were used in previous analyses of urban street networks both in the US and major cities around the world (Peponis et. al. 2007). Using a 1 mile radius, allows us to compare Buenos Aires' street network to the street network of these other cities. Additionally, this radius is not foreign to studies addressing the distance a person is willing to walk for shopping, and characteristics of the City of Buenos Aires. If we consider how Metric Reach is calculated in a regular grid like Buenos Aires', we can see that the effective coverage at this radius, is approximately 1 mile in opposite directions. Half a mile, is the standard walkable distance used in most studies, and one that corresponds to approximately 10 blocks in Buenos Aires' grid. It is usual for Buenos Aires' dwellers to consider a 10 blocks walking distance as 'acceptable'.

The following figures illustrate how Metric Reach behaves in a controlled environment, such as a half perfect-half warped grid, and in an area of the street network of Buenos Aires. The red dot in in the center of both figures indicates the midpoint of the road segment that serves as the starting point.

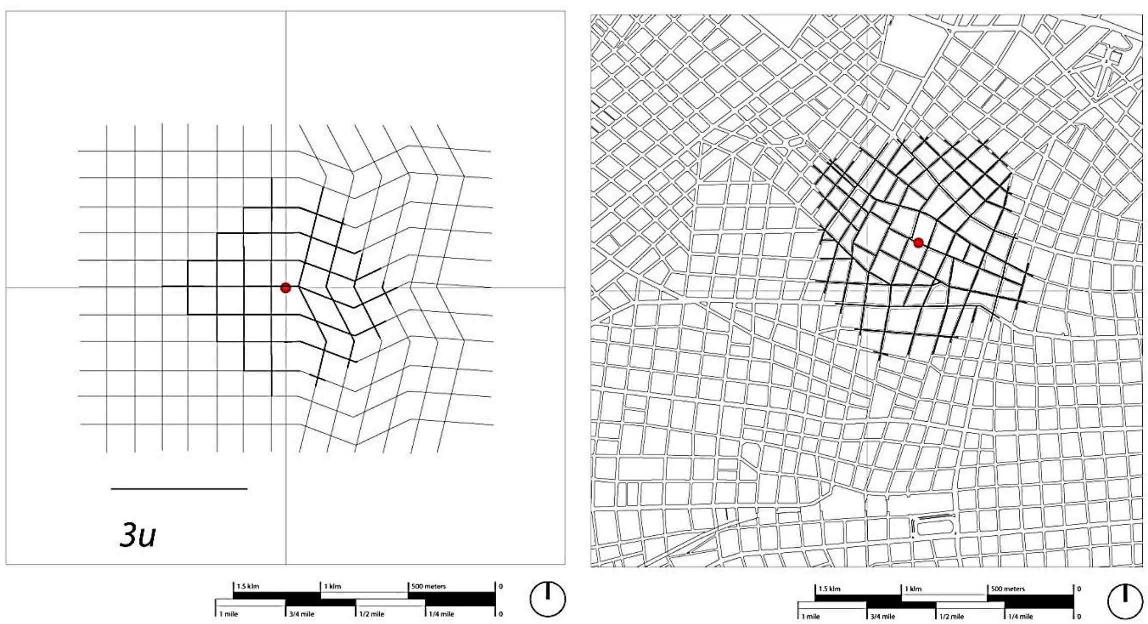


Figure 3.3 *– Metric Reach in theoretical grid, radius is 3 length units(left) and in Buenos Aires (right), radius is 0.5 miles.*

The average Metric Reach for all street segments in Buenos Aires is 54.96 miles within a mile radius, with a standard deviation of 10.31 miles. This figure is comparable to values found in the Chicago Loop (51.83 mi.), Downtown Manhattan (57.71 mi.), and Downtown Atlanta (52.48 mi.). However, we should note that the presented values for US cities, correspond to 2x2 mile sample areas, which characterize their downtowns. Alpharetta and Peachtree City, two suburbs in the Atlanta MSA, characterized by large blocks and low density residential land use, have much lower Metric Reach values; respectively, 11.33 miles, and 12.44 miles (Peponis, Allen, Haynie et al, 2007).

3.5.1.2 Independent Variable: Directional reach.

As presented in Chapter 2 (pp. 46-53), the effect of direction changes on the distribution of urban movement has been extensively studied in space syntax research. We have also noted that research in environmental psychology and cognitive neuroscience, provided important insights and results, supporting the importance of direction changes in wayfinding ease, estimation of route metric lengths, and preferred paths choice. Following the results of these previous research findings, and having its roots in Space Syntax theory and methods, Directional Reach computes metric accessibility subject to directional changes constraints. While it could also be interpreted as a measure of density, Directional Reach is more directly linked to the shape, alignment, and configuration of the street network, and not just the tightness or looseness of the urban fabric. As a result, the correlation between Directional Reach and previously introduced measures of street connectivity, like block sizes and intersections per square mile, is much less pronounced (Peponis et al., 2007).

For the calculation of Directional Reach, two parameters need to be input. The first one, is the total number of direction changes allowed; the second, is the angle threshold that defines what constitutes a direction change. For example, if the number of direction changes is set to 0, and the angle threshold is set to 10 degrees, the total extension of a linear alignment of road segments, which does not deviate more than 10 degrees at the point where two consecutive segments meet, will be retrieved.

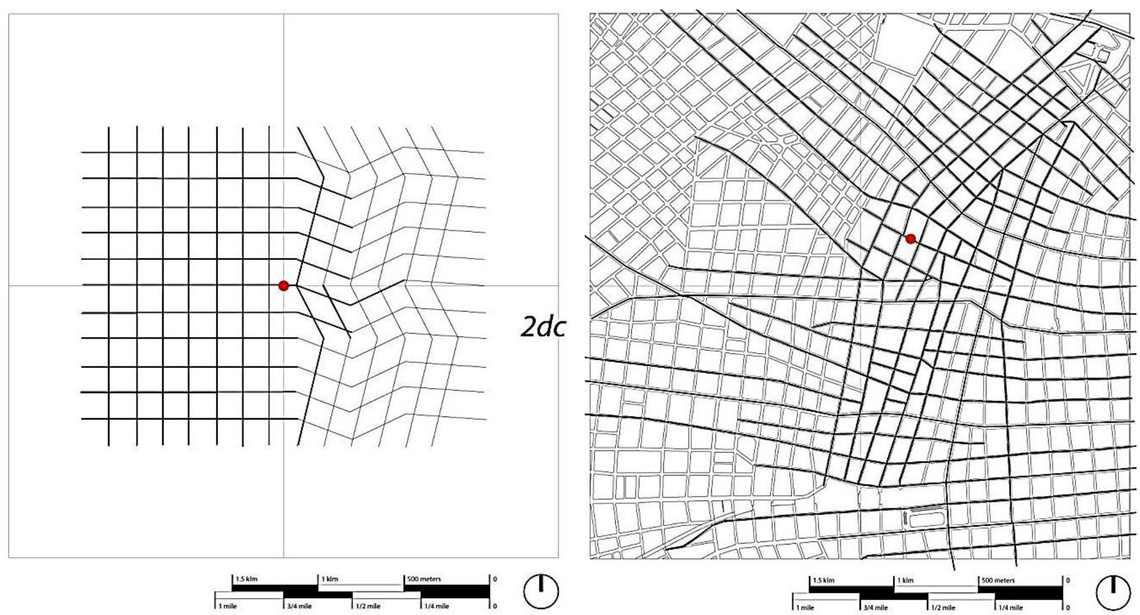


Figure 3.4 *– Directional Reach in theoretical grid (left) and in a 1x1 mi. sector of the City of Buenos Aires.*

Two Directional Reach measures were calculated for this study. The first was Directional Reach with 0 direction changes, considering that a direction change occurred when two consecutive segments met at an angle larger than 10˚. This measure is tuned to capture the extension of city streets, and could be considered as a metric analogous to axial lines in space syntax. The second, was Directional Reach, with 2 direction changes, using the same threshold angle of 10˚ for counting a direction change. Two directional changes computes the total street length accessible with zero direction changes, when turning into adjacent street, and those adjacent to these latter ones. Directional Reach within 2 direction could be interpreted as a measure that informs us about the regularity of the grid in the surroundings of each street segment.

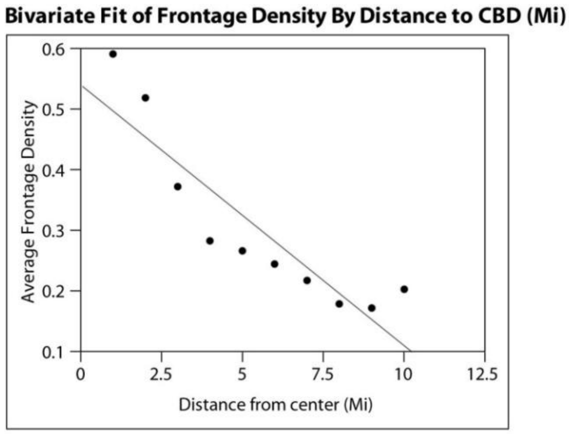
Directional Reach with 2 direction changes, and a 10˚ threshold angle, averages 102.75 miles in the City of Buenos Aires. Unlike Metric Reach, its distribution is positively skewed, indicating that a large number of Buenos Aires' street segments have lower values of Directional Reach while few are highly connected to the surrounding street network. Directional Reach with 0 direction changes, is also positively skewed, with a mean of 1.18 miles.

3.5.2 Control Variable: Distance from the City's CBD

The intense concentration of retail activities in the City of Buenos Aires CBD, seems to correlate with the monocentric structure proposed in the classic economic model of land use. In addition, the hierarchy of the CBD, and the existence of lower order subcenters, indicates that Buenos Aires' centers appear to be in accord with the structure proposed by Central Place Theory.

Quantitatively, the prominence of Buenos Aires' CBD can be verified through a summary of the retail premises and employment found in its surroundings. Within 5 kilometers (3 mi.) of the City center, taken to be the historical foundation square Plaza de Mayo, we find approximately 35% of the total number of commercial parcels in the City. In terms of employment, 60.5% of the total jobs in the City are found within this same radius. Both figures, but particularly the employment data, support the consideration of Buenos Aires as a monocentric city, and place the CBD's as the top of the hierarchy of centers. Given that such a large proportion of commercial premises satisfying the demand of the City of Buenos Aires' population is centrally located, it would be expected that the amount of retail frontage density found in peripheral areas will be negatively correlated to distance to the CBD.

In order to verify the effect of distance on the distribution of retail premises, we conducted a study on the distribution of retail density at increasing distance from the center. Using concentric rings centered at the CBD and spaced at 1 mile intervals, we calculated total retail frontage density, and plotted it against distance. The results of the analysis are presented in Figure 3.5 below.



Linear Fit

DENSITY = 0.5405801 - 0.0429705 Distance from center (Mi)

Summary of Fit

RSquare	0.808421
RSquare Adj	0.784474
Root Mean Square Error	0.067175
Mean of Response	0.304243
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.15233295	0.152333	33.7583
Error	8	0.03609965	0.004512	Prob > F
C. Total	9	0.18843260		0.0004

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.5405801	0.045889	11.78	<.0001
Distance from center (Mi)	-0.04297	0.007396	-5.81	0.0004

Figure 3.5 *– City of Buenos Aires. Mean retail frontage density at increasing distance to the CBD.*

The results of this analysis indicate that, at the scale of concentric rings, the distribution of commercial premises in the City of Buenos Aires, evidences a sharp fall-off from CBD to periphery. These results supported the selection of distance to the CBD as an important control variable, and we proceeded to calculate the distance from each road segment to this center.

For each road segment, we calculated two distances to the City's CBD. First, we calculated the simple Euclidean distance from the midpoint of every road segment to the CBD. This straight line, as the crow flies distance was, however, ill- suited for the purpose of this thesis, given that it fails to account for the geometry, and potential discontinuities of the street network. As such, it did not provide a directly equivalent treatment of the street network as Metric and Directional Reach. For this reason, distance from each segment to the center were recalculated, using ArcMap 9.3 Network Analyst (ESRI, 2009), allowing us to use calculate the network distance from every road segment to the City's CBD. Network distance to the CBD will be the variable used in the statistical analyses that will be presented and discussed in Chapter 4.

3.5.3 Control Variable: Street widths

Street widths, a variable likely to have a significant impact on movement and land use patterns, has been noticeably absent in configurational studies. By not addressing this variable, distributed gravitation models have ignored the hierarchical structure of the urban circulation system, and the role of width on the carrying capacity of streets. Wider streets, designed to carry higher volumes of movement, and at higher speeds than their narrower counterparts, can play an important part in the location patterns of commercial premises. First, by concentrating higher volumes of movement, both pedestrian and vehicular (private and public), shops on highly traveled streets capitalize from increased flows of potential customers, while also commanding higher visibility. Second, by acting as important connectors, as wider streets build in the City of Buenos Aires a circulation supergrid, wide streets are likely to figure predominantly in cognitive maps, as was noted by Lynch's findings regarding the importance of Cambridge Ave, Commonwealth Ave, and Atlantic Ave (Lynch, 1960).

Following the foundational subdivision system described in section 3.1, we find three characteristic street widths within the City. In the historic urban core, today's CBD, rights of way range between 10 and 16 *varas* wide (respectively, 8.66 meters/28.4 feet, and 13.85 meters/45.4 feet). About 25% of the total road segments of the City have these widths. The following category of streets widths is composed of those that are 20 *varas* wide, or 17.32 m. (56.8 ft.). Streets of this width add to about 54% of the total, making it the most commonly found street width in Buenos Aires. Finally, wider streets, usually avenues, account for the remaining 21%. Rights of way in this category make the circulation supergrid of radial and transversal avenues, clearly distinguishable in Figure 3.6 below.

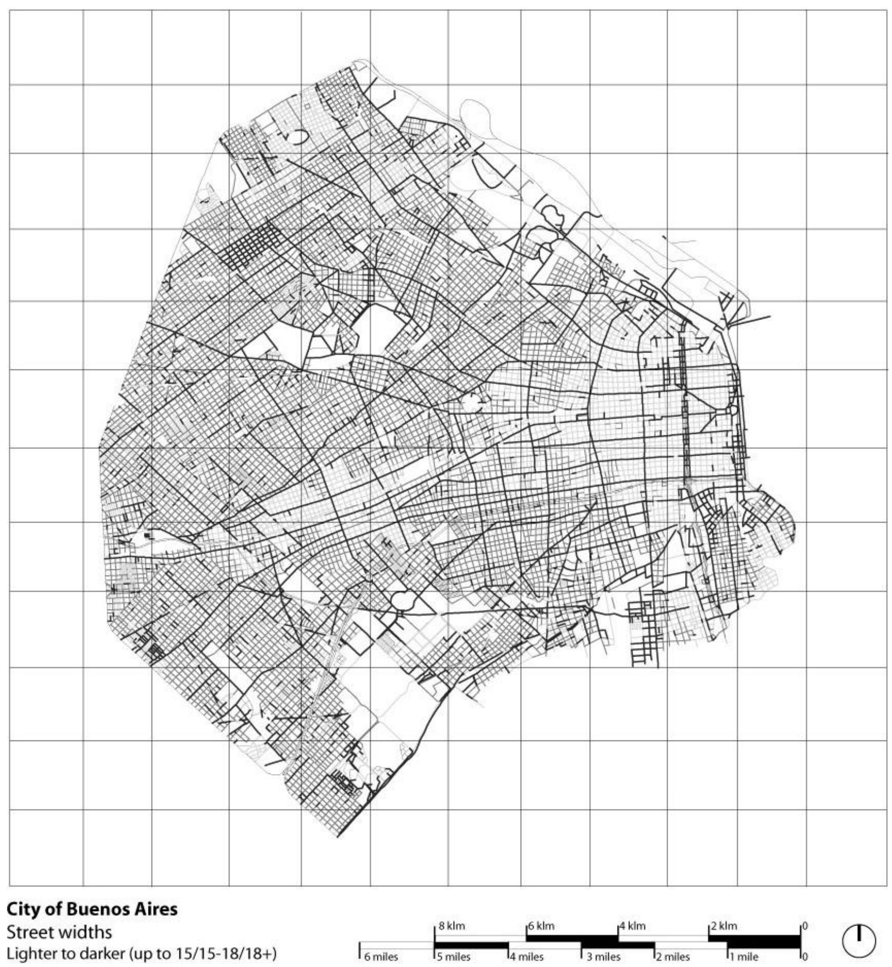


Figure 3.6 *– City of Buenos Aires. Street widths.*

Information about street widths was obtained from the City of Buenos Aires Cadastral Office, and was recorded in a GIS street centerlines map identical to the one used in the computation of Metric and Directional Reach. We should note that while the available information in this GIS data layer also included street and sidewalk widths, this information was visibly incomplete, and not as accurate as the recorded Rights of Way. Thus, the variable considered in this study will address the Right of Way, combining sidewalks and roadways, and characterizing the whole of the public space.

A side by side comparison of Figure 3.1, and Figure 3.5, attests to the potential contribution of street widths to the distribution of retail. High retail density values are found in continuous linear patterns on the radial and transversal arteries that connect the city center with its peripheral areas, indicating a likely correlation between the location of retail and the circulation *supergrid*.

3.5.4 Control Variable: Population and employment

The spatial location of potential consumers can have a significant impact on the distribution of retail. Being close to a large pool of potential consumers is a key variable guiding the locational decision of retail firms, which in other words, translates into commercial distribution patterns likely to be concentrated on the points of maximal demand. In order to address the relationship between consumers and retail location, the distribution of the urban population, both daytime (employment) and nighttime (residence), was calculated at the level of the road segment.

A notable characteristic of the City of Buenos Aires, is related to the fact that its population has remained fairly stable for the past 60 years. In 1947, the National Census counted close to 3 million inhabitants within the City while in 2010, the year of the last Census, the total population was within 5% of the numbers registered in the mid-twentieth century (INDEC, 2010). This population is distributed in the manner one would expect for a “mature” city. That is, a CBD that has fairly low values of permanent residents, a densely populated arc surrounding the City center, and a gradual decay of population densities as we move towards the peripheral areas (Clark, 1951, Haggett, 1977, pp.222-224; Ishikawa, 1980; Millward, Bunting 2008). To this structuring concentric ring pattern, we must add the presence of high density corridors connecting the CBD with the peripheral areas and subcenters. Also, characteristic of the City of Buenos Aires is the low population in the southern areas, which is also less affluent than that in the northern neighborhoods.

In order to map the City’s distribution of day and nighttime population, we relied on census data. Population was obtained at the level of the census block, and corresponds to the 2000 National Census of Population and Housing (INDEC, 2000). In terms of employment, this was obtained also at the level of the census block, and corresponds to the Economic Census of 1994 (INDEC, 1994). We should note that in the case of employment, data for blocks that house a single employer are removed from the databases by the official agency in charge of the census, in order to preserve confidentiality. It is also important to note, that both the population and employment data, as well as the land use information and parcel geometry obtained from the City of Buenos Aires Cadastral Office, are temporally congruent.

In order to compute segment level population figures, we first transferred population data from the block level to the parcels within the block, and from the parcels to the street segments. The transfer to the parcels was done by using population per block, divided by the total square meters built for residential purposes in each block. This operation provided a population per built square meter in each block, which was later multiplied by each residential parcel built area (in square meters) to compute a figure of population per parcel. Considering the scope and scale of this study, we tried to be as accurate as possible in calculating the amount of people living on each block face.

The final figure of population on a block face was linked to the street segment it faced. In the case of corner parcels, we divided the total population of these parcels by the number of street segments it faced, while also assigning the total population of a parcel to each segment the parcel faced. By dividing the population of a parcel by the number of segments it faced, we made sure that the total population, now recorded in the street segments database, added up to the total population of the City. This final figure was used in the statistical models which will be presented in Chapter 4.

Figure 3.7 *– City of Buenos Aires. Population by road segment.*

In terms of employment, the procedure followed paralleled the one used for the assignment of population to the parcels, and subsequent transfer from the parcels to the street segments. Employment per block was divided by the total square meters in each block dedicated to non-residential use, in order to obtain an employees/sq. meter index. The product of each parcel's built area and this index, results in the employees per parcel figure that was then transferred to the street segment. In Figures 3.7 and 3.8, below, we show the results of these operations. Each segment in the street centerline map of the City of Buenos Aires is colored from darkest to lightest, representing respectively, higher and lower values of population and employment. We present these data using three intervals in each case. For the spatial distribution of population the intervals from lightest to darkest indicate 0-100, 100-500, and more than 500 people per street segment. In the case of employment, the intervals are 0-20, 20-100, and more than 100 employees per street segment.

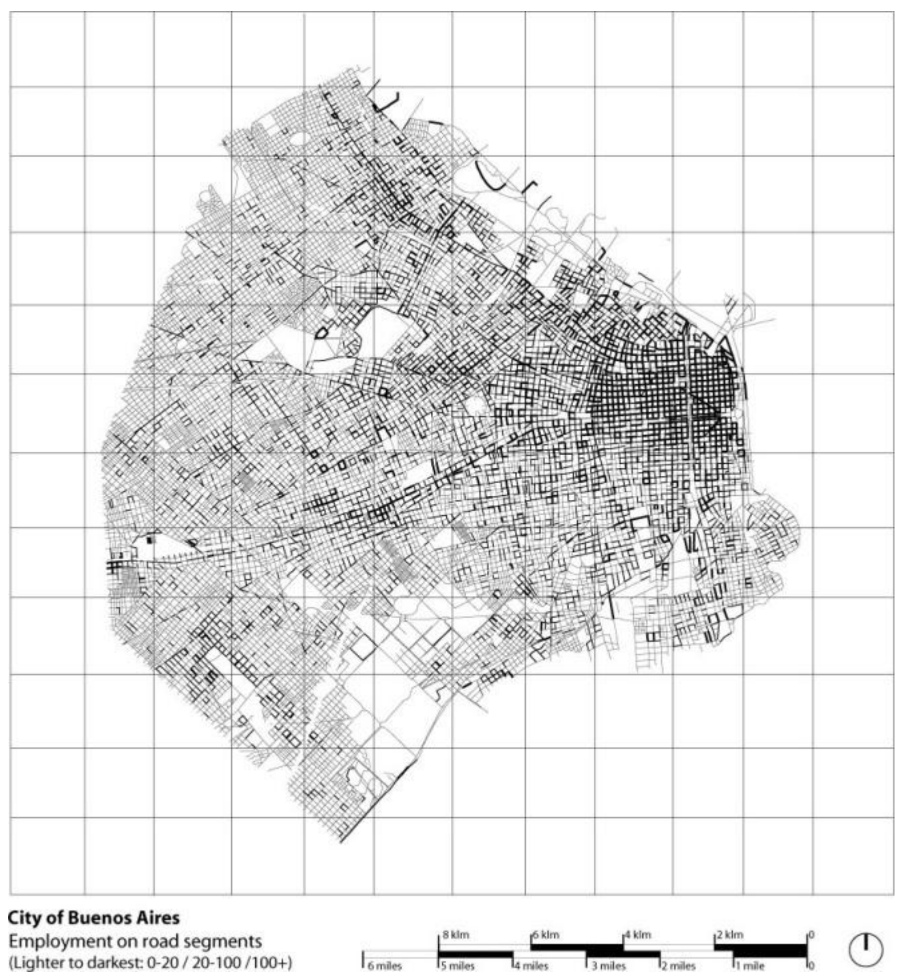


Figure 3.8 *– City of Buenos Aires. Employment by road segment.*

3.5.5 Control Variable: Zoning

Zoning regulations are a key instrument by which city planners organize land uses and guide urban development. One of the main functions of zoning is the segregation of incompatible land uses with the purpose of limiting negative externalities. A classic example of this restrictive function of zoning, is that addressing the incompatibilities between industrial and residential land uses, as it was precisely this situation one of the main forces behind the development of land use regulations (Jackson, 1985, pp.241-242). Other functions of zoning include the regulation of residential use densities, the preservation of the character of particular areas, the distribution of green spaces, and the provision of area for urban infrastructure, such as rail stations, ports, and airports.

Clearly, given the scope of this thesis, the main concern is on the effect of zoning regulations which restrict, or encourage, the location of commercial land uses. The consideration of zoning is key to understanding true location options available to store owners, and a factor that has been consistently omitted in distributed gravitation studies. In order to address the impact of zoning on the distribution of retail frontage density we studied the zoning regulations of the City of Buenos Aires, and we present in this section their main characteristics, along with the methods used for adding this information to our list of street segment independent variables.

The latest City of Buenos Aires zoning regulations are compiled in the Urban Planning Code, also known as Law 449. This law, passed in 1997, is the latest version of the set of land subdivision and development control regulations for the City. In it, we find the zone breakup of the City in districts, and all pertinent and relevant information regarding these districts' properties. We should note however, that Buenos Aires has had previous zoning ordinances, which regulated the distribution and intensity of land uses. These were instituted in the early 1940's, with revisions introduced in 1959 and 1977. The main factors addressed by these original zoning regulations were: the land uses allowed in each district, and the maximum building heights and maximum buildable areas allowed. As is the case with zoning ordinances, these constitute a complex and extensive body of regulations. Buenos Aires' are no exception. The total number of zoning districts in Law 449 is 42. However, a careful study of the zoning characteristics, allowed us to reclassify these zones into a smaller set, while still retaining their most salient characteristics. After this reclassification was completed, the original 42 zones were summarized into 16. The compressed classification includes commercial zones in a single category, residential in three density intervals, industrial, use-specific zones, and special mixed-categories for segments that make the boundaries between zones. The complete zones reclassifications is presented in Table 3.2 below.

Consistent with the scope of this thesis, zoning districts information was transferred to the road segments, so that the this variable could be analyzed in conjunction with the previously presented ones. Segments were easily assigned in the cases where they fell within the boundaries of a zoning category, but required special attention in cases where they constituted the boundary line between different zones. Of the total number of segments in Buenos Aires, about 15% fell in this latter category. Of this 15%, the large majority corresponded to segments defining the boundary between Central A (Commercial Districts) and Residential A (High Density Residential), and those defining boundaries between Central A, and Residential B (Medium Density Residential).

Table 3.2 *– Reclassification of zoning categories. (* Streets bound zoning districts together).*

Zone Reclassification	Original Zones	Description
Central A	C1, C2, C3 I, C3 I 2, C3 II, C3 II 2	Commercial Districts
Central B	Streets that make the boundary between Central A and C	Central Districts adjoining Historic Preservation Districts
Central C	APH, 1, 3, 4, 5, 6, 13 14, 15, 16,17	Historic preservation districts.
Central D*	Streets that make the boundary between Central A and H	Central Districts adjoining E Districts
Central E*	Streets that make the boundary between Central A and Residential A	Central Districts adjoining High Density Residential Districts
Central F*	Streets that make the boundary between Central A and Residential B	Central Districts adjoining Med. Density Residential Districts
Central G*	Streets that make the boundary between Central A and Residential C	Central Districts adjoining Low Density Residential Districts
Central H	E1, E3	Mixed used districts
Residential A	R2a I, R2a I 2, R2a II, R2a II 2	High Density Residential (FAR > 2)
Residential B	R1a, R2b I, R2b I 1, R2b II, R2b III	Medium Density Residential (2 > FAR > 1)
Residential C*	Streets that make the boundary between Residential A and Residential B	High Density Residential adjoining Medium Density Residential Districts
Residential D*	Streets that make the boundary between Residential B and Residential F	Medium Density Residential adjoining Low Density Residential Districts
Residential E	APH, U2, U3	Housing projects
Residential F	R1b I, R1b I 3, R1b I 4, R1b II,	Low Density Residential (FAR < 1)
Industrial	I1, I2, E2	Industrial and mechanical shops
Special	E4	Hospitals, Government buildings
Other	RUA, UP, P, AEP, U1 to U16	Parks, Port, Airport, Railway infrastructure

We noted in subsection 3.4.4 (Population and Employment), that the City of Buenos Aires had about the same population in the mid 1940's as it has today. While the City would have certainly looked very different from what it looks like today, this population was distributed across a city that had not yet instituted zoning. It would be possible to assume then, that today's pattern of commercial land use, started to develop based on economic opportunities offered by location, to be later reinforced by zoning regulations which grandfathered-in existing commercial land uses. The postulates of the monocentric model, or the principles of Central Place Theory, could have operated without the mediation of zoning.

We acknowledge however, that there might be well founded objections to this assumption. In the first place, we lack *precise* information about the distribution of retail at any time before the 2001 GIS data we are using, making impossible at this time, the verification of the existence of any parcel-based patterns sustaining this assumption. Second, the institution of zoning in 1944, might have had a significant impact on the distribution of commercial premises between this year and 2001, the year of the data we are using. Still, the purpose of adding zoning regulations to the list of independent variables, is not primarily aimed at the unveiling the impact of zoning regulations over time, or the causes behind the demarcation of the zones' boundaries, but to explore possible correlations between commercial zones and location advantages described by variations of Metric and Directional Reach values. Furthermore, including zoning to our list of control variables, it is possible to more accurately evaluate the relationship between land use regulations and actual patterns of land use, a relationship which has been consistently omitted in distributed gravitation studies conducted so far.

3.5.6 Control Variable: Transit

We have noted that accessibility and the cost of transportation are fundamental factors in understanding the distribution of urban land use. In order to account for public transportation infrastructure, we calculated the distance from each segment to the nearest metro and railway stations. On the other hand, stations of the metro and rail system constitute points where potential customers concentrate when entering or leaving the system, so their consideration as independent variables aims at covering their contribution to the location of retail premises.

Particularly in the case of railway stations, these have, historically, influenced the development of the City, much in the way that Transit Oriented Development the practice of developing or intensifying residential land use near rail stations– attempts to do today. Local/neighborhood centers developed in their proximity, benefiting from the increased movement, and offering convenient multi-stop shopping for commuters that use the transit system.

Using network analyst we calculated, for each rod segment, the shortest network distance to railway and metro stations. Unfortunately, bus stops location data was unavailable at this point. However, in the City of Buenos Aires, bus lines form a network that evenly crisscrosses the jurisdiction of the City. Thus, distance to bus stops, we estimate, would have not provide additional, or particularly valuable insights. Moreover, buffering bus lines shows that all street segments in the City lie within 400 meters of a bus line.

3.6 Extending the analysis to address context: Network Buffers.

The dependent and independent variables discussed in the previous sections were, in all cases, calculated for each road segment in the City of Buenos Aires street network. In the case of Metric and Directional Reach, the values assigned to each road segment, describe characteristics of the street network in their surroundings. In other words, Metric and Directional Reach, are recorded at the segment level, while their values quantify the conditions of the urban fabric within a parametrically defined context (please see Figures 3.3 and 3.4). The dependent, and control variables however, describe local properties at the scale of the street segment. We have noted however, that the co-location of similar and complementary retail activities can have a positive effect in the attractiveness of a center or shopping destination, offering opportunities for comparison and multi-stop shopping. On the other hand, the presence of higher densities of potential customers in an area, exceeding the scale of the road segment, might also contribute to the decision of a store owner to locate in a particular area and not in other. In order to characterize the surroundings of a street segment in terms of the density of retail it exhibits, and potential customers location, we studied the distribution of these variables using network buffers.

This method constitutes a type of proximity analysis available within GIS network analysis extensions, in this case, ArcMap 9.3 (Esri, 2009). Centered at each road segment mid-point, network buffers are polygons that enclose road segments, and parts of road segments, that lie within a given distance radius. As opposed to circular buffers, which use straight line distances, network buffers use the network segments to calculate distances, thus being more in tune with the scope of this thesis. These buffers were constructed using an 800 meters (½ mi) radius, a commonly used distance in accessibility and pedestrian movement studies.

Using network buffers, it was possible to summarize the total street length, and the total retail frontage accessible within 800 meters (½ mile) of each road segment's midpoint. As in the case of individual segments, the ratio of retail frontage, to accessible street, was used to calculate retail frontage density within half mile network buffer areas. This information was recorded for each road segment in the database. Following the same procedure as described for the calculation of retail frontage density, we measured the total residential population and employment within each network buffer. Dividing the total population and employment, by the total street length accessible within this radius, we calculated the population and employment density in the neighborhood of each road segment. This measure of density could be considered analogous to the accessible density proposed by Marcus (Marcus, 2009).

Figure 3.9 *– Network Buffer in Belgrano sub-center. Black line shows the perimeter of the netwk. buffer The red dot indicates the street segment centroid for which this buffer was constructed.*

Using network buffers we also calculated the average distance of the segments in the surroundings of each segment, to the CBD and Metro and Rail stations. This average characterizes the distance of a network buffer to these locations, and could be interpreted as a smoothed distance measure for each segment. The calculation of average street widths within each segment's network buffer, also provided a smoothed version of the segment's own width, which would be based on the widths found in its surroundings. As expected, the histogram of average street widths, approximates a normal distribution whose central value lies very close to 17.32 meters (xx ft.), the most commonly found width in the City. Average values of metric and directional reach values were also calculated using network buffers, and once again, we can interpret their values as characterizing the general values found within this ½ mile context. Finally, zoning regulations, were not redefined using network buffers, given that their influence does not transcend the boundaries established by the ordinances.

3.6.1 Edge effects in the calculation of Network Buffer Control Variables.

We noted that Metric and Directional Reach were calculated using a street centerline map of the Buenos Aires Metropolitan Area. Once connectivity values at the scale of the Metro Area were calculated, we extracted the segments that make the City of Buenos Aires street network. Through this procedure, segments at the edge of the City were treated as fairly as segments at the center. Thus, in the case of street connectivity measures, edge effects were avoided, and the context of each street segment was appropriately evaluated.

Unfortunately, edge effects in the calculation of contextual variables using network buffers, could not be accounted for. While the continuity of the street network was guaranteed by using the Metropolitan Buenos Aires street network for the connectivity analyses, data relative to commercial frontage, population and employment, and other control variables, outside the limits of the City of Buenos Aires, were unavailable at the time of this study. For this reason, the network buffers used in the calculation of contextual variables, are not as accurate as would be desired at edges of the City. In order to reduce errors, and the miscalculation of population, employment, and retail frontage density in these locations, these segments were removed from the final street segments database used for the statistical analyses. The original segments database containing more than 25,000 records, was reduced to slightly over 23,000.

3.7 Extending the analysis to address linear contexts: Named streets.

The analysis of urban space and retail location at the level of the street segment has significant advantages. The main of these, is the ability to address the smallest, but still meaningful, scale at which the street, as public space, is defined (see for example Suttles, 1972; Galster 2001). The aggregation of buildings that characterize a street between intersections can, however, be addressed in relation to its immediate and mediate context. Streets can be understood by their parts, but also as the aggregations of segments that make the corridors and paths that we use and experience every time we engage in travel. In view of this, we proceeded to address this larger scale, amalgamating the street segments into longer linear elements, using street names as the criteria for aggregation. As a method, we find antecedents in studies dealing with street networks connectivity and configuration, where street names were used for the aggregation of segments in node-link maps, as well as axial lines, into larger linear units (Jiang, Claramunt, 2004; Rosvall et al., 2005; Figueiredo, 2009).

The aggregation of segments into named streets allowed us to calculate the average value of the dependent variable, and corresponding averages of the independent and control variables. These averages were: average retail frontage density, average metric and directional reach for each named street, average street width, average population and employment density, and average distance from the segments that make the named street to the CBD, as well as their average distance to rail and metro stations.

The calculation of these averages took into consideration the length of each segment as a weighting factor. For example, in the case of named street retail frontage densities, we summed the results of the multiplication of total retail frontage length facing each segment by the length of the segment, and divided this summary figure by the total length of the named street. The formula by which named street averages of the dependent and independent variables were calculated is presented in equation 3.2 below.

$$SF_i = \frac{\sum_i^n f_{i} \, L_i}{\sum L_i} \qquad \text{equation 3.2}$$

Where SF_i is the frontage density of the named street i, f_i, is the frontage length of commercial parcels facing segment i, and L_i, is the length of segment i in meters.

When discussing the results in the following chapter two named street samples will be used. In the first case, all named streets in the City (n=1923) were used. In the second case, a reduced sample (n=1201) was analyzed. The reduced sample results from the removal of named streets that are made of 1, or 2, segments, which generally correspond to passageways and alleys found in the City of Buenos Aires. Removing these short named streets was done for exploration of the data, and for the assessment of the impact of these short street spaces on the overall explanatory power of the models. While relevant because of their occurrence, passageways and alleys could be taken to be alterations of an otherwise highly regular and continuous gridiron pattern.

Besides the calculation of variables using network buffers at the segment level, we repeated the procedure at the level of the named street. The total frontage within 800 meters (½ mi.) of each of the segments that make a named streets, was added, and divided by total length of the named street in order to obtain a figure describing the average frontage density within 800 meters (½ mi.) of a named street. In this case, this procedure was aimed at capturing the context within which each named street is embedded.

We should note that named streets were not assigned to zoning districts. The reasons for this are both technical and conceptual. As named streets are likely to traverse different districts, in many cases it would have been impossible to assign a named street to a single zoning district. Also, named streets can constitute the boundary between zoning districts, so that the assignment of zoning in these cases would have resulted in a double classification for each of these streets.

3.8 Limitations

Models are selective and highly simplified representations of reality aimed at the identification of general principles influencing a given outcome; in this case, the location of retail frontage. While the independent and control variables presented in this chapter are numerous, many qualities of the City of Buenos Aires were still omitted from consideration. For example, building heights and other architectural properties, sidewalk widths, or qualitative characteristics of centers, were not included in our list of independent variables. Also, outside the sphere of the built environment, socioeconomic variables like purchasing power and income levels, were not addressed. While these and other variables, are likely influence store location decisions, or the desire of a consumer to visit a particular center, they were not included in our study. However, the inclusion of the control variables covering socio-demographic, built environment, and regulatory framework aspects, even when possible to be perfected, constitutes a necessary step forward in studying the effect of street network connectivity and configuration on the distribution of commercial land use.

We should finally note that developments in spatial statistics have progressively advanced methods and tools by which to address spatial autocorrelation. Spatial autocorrelation, defined as the coincidence of value similarity, with locational similarity (Anselin, Bera, 1998), or the presence of spatial patterns in a mapped variable due to geographical proximity (Hepple, 2000, p. 775), is likely to be present in spatially distributed phenomena like the one studied in this thesis. In our case, this would mean that variables values in a particular location would not be independent from values in the proximal areas. The application of spatial statistics holds much promise for researchers interested in configurational analysis of urban street networks, and we expect to apply these developments in spatial statistics in future research. Nonetheless, the calculation of contextual variables through the use of network buffers, even when likely to be perfected through the application of these more sophisticated methods, is aimed at understanding the impact of value similarities in the surroundings of a given location.

3.9 Summary

In this chapter we introduced the data that will be used in this thesis to evaluate the likely impact of measures of street connectivity on the distribution of retail in the City of Buenos Aires. Characteristics of this city, and the reasons that make it a valuable case study were introduced in the first sections. Following sections introduced the dependent variable, and the independent and control variables. These variables addressed several dimensions of the built environment, as well as the regulatory framework and transportation infrastructure. In the last sections, we introduced the units of analysis, and the processes and computations that allowed us to construct the databases compiling the relevant information for our study. The resulting databases at the level of the street segment, and the named street, will be used for the statistical analysis we present in the following chapter. The statistical modeling of the distribution of retail, using recently developed measures of street connectivity, and the use of control variables constitutes one of the main contributions of this thesis to the field of configurational analysis.

Chapter 4

Results

In this chapter, the results of statistical analyses and models are presented and discussed. The first series of analyses, involves studies at the scale of individual road segments that make the City of Buenos Aires street network. Studies at the segment level include bivariate correlations and regression models, analyzing the extent and strength of the relationship between independent and control variables, and the distribution of retail frontage density. Following analyses, incorporate zoning categories into these previously specified regression models. By including zoning into our models, we control for the effect of the regulatory framework on the distribution of urban land use. Further studies of zoning districts, will focus on the relationship between the regulatory framework, measures of street connectivity, and control variables. Lastly, we present the results of correlations and models using segment aggregations into named streets, and the analysis of retail frontage density using data calculated using half-mile network buffers.

4.1 Segment scale analyses.

The street segments database, compiling the dependent, independent, and control variables presented in the previous chapter has 23,767 records. For each record we compiled data describing: a) the density of retail frontage on the block faces that define street segments, b) how connected to the surrounding areas these street segments are, c) how many people live and work on them, d) how wide the rights of way are, e) how far these segments are from the CBD and transit stations, and f) to which zoning district they belong. As we noted in the previous chapter, we also calculated contextual measures at the segment level. These were obtained using network buffers and correspond to: retail frontage density, and population and employment density, within 800 meters (½ mile) of each segment.

While the presented variables provide a comprehensive description of the situation found on, and around, each street segment, we noted that the selection of these variables was based on the theoretical and methodological aspects discussed in the literature review, and that it does not attempt to be an exhaustive and definitive set of variables. The focus of this thesis is on the evaluation of the impact of measures of spatial structure –as is described by Metric and Directional Reach– on the distribution of retail frontage, while controlling for alternative variables characterizing the built environment. The overriding aim, is to understand the effect of connectivity measures in fostering concentrations of commercial land use, and to provide a theoretical and methodological framework by which to evaluate urban design decisions involving street networks, and the impact of urban growth and change on these networks. These include, more specifically, shifts in the degree of local or global centrality and liveliness of a certain area as a consequence of growth and transformation.

4.1.1 Segment scale bivariate correlations

The first analyses, which will be performed for each scale (i.e., street segments, named streets, network buffers), consist of bivariate correlations between retail frontage density, and the independent and control variables presented and described in the previous chapter. This first step, is aimed at gaining initial insights regarding the sign and strength of the relationship between all the variables considered. Table 4.1 below, summarizes the results of these bivariate analyses. In this table, the coefficients of determination (r^2) are presented in decreasing order to facilitate comparison.

Table 4.1 *– Street Segments: Bivariate correlations summary*

Dependent Variable	**Independent & Control Variables**	N= 23767 **r^2**	**p>|t|**
Street Segment Shop Frontage Density	Frontage density within 800 m. (½ mile)	0.2449	<0.0001
	Population and employment density	0.2383	<0.0001
	Population density within 800 m. (½ mile)	0.2028	<0.0001
	Directional Reach, 2 Dir. Changes, 10˚	0.1094	<0.0001
	Directional Reach, 0 Dir. Changes, 10˚	0.0936	<0.0001
	Distance to CBD	-0.0896	<0.0001
	Distance to nearest metro station	-0.0725	<0.0001
	Street width	0.0333	<0.0001
	Metric Reach, 1 Mile, 10˚	0.0056	<0.0001
	Distance to nearest railway station	-0.0013	<0.0001

The strongest relationship, was found between frontage density on the street segment, and the frontage density found within 800 meters (½ mile) of it. This positive, moderately strong, and statistically significant relationship, indicates that the presence of other shops in the surroundings of a given segment, is the main factor by which to understand its retail frontage density. Thus, the commercial character of an area, and the concentration of commercial premises that defines centers, are important predictors of retail intensity at the scale of the street segment in the City of Buenos Aires. This relationship however, is likely to be affected by morphological variations in the pattern of retail land use, particularly with respect to nucleations and ribbons. This is the case, for retail frontage density values in the surroundings of a segment within a nucleated center, are likely to be higher than those in the surroundings of retail ribbons. The study of street connectivity and configuration, and the inclusion of street widths, could provide additional information by which to more accurately estimate the distribution of retail frontage, by addressing precisely these morphological differences.

The second strongest relationship found, was that between shop frontage density, and the density of population living and/or working on a segment. As expected, higher concentrations of potential customers, correlate with higher concentrations of retail. The positive relationship between retail frontage density and these two variables –population and shops in the surrounding area-, highlight the connection between the concentration of retail activities, and the overall higher population and employment, characteristic of commercial districts and busy corridors. Interestingly, the contextual variable population and employment density within 800 meters (½ mile) of each segment's centroid, exhibits a lower r-squared value than population and employment density on the segment itself. While the difference between these two measures of consumer density are not large, it is an interesting finding that the segment scale is, in this case, a better explanatory variable than the contextual one. These results could be taken to reinforce two points. First, the importance of addressing detailed scales of analysis, avoiding the smoothing of spatial data, given that these detailed scales can more finely inform urban policy and design decisions (e.g., at the level of the block face). Second, the need to consider zoning regulations, so far never addressed in configurational studies on land use. This is the case, for it is likely that high residential density ridges along main arteries, as mandated by zoning ordinances, are the cause of this higher correlation between non-contextual population and employment density, and retail frontage density.

Following shop clustering and consumer density distribution variables, we find measures of street connectivity tuned to capture urban spatial configuration and structure. The results of the analyses indicate that Directional Reach, provides valuable insights regarding the role of street connectivity measures in capturing spatial aspects related to centrality and commercial lineups. The strongest relationship was found between retail frontage density, and Directional Reach, 2 direction changes. This means that in the City of Buenos Aires, higher accessibility with two direction changes from a road segment, is associated with higher presence of retail frontage density. These results, are in tune with the results of previous configurational models indicating that accessibility with two direction changes is positively correlated with higher concentrations of pedestrians, and consequently, higher concentrations of retail (Hillier 1993; Hillier, 1996, Ch. 6;Hillier 1999a).

This configurational variable is followed closely by Directional Reach, with 0 direction changes. Segments that are part of longer streets, tend to have higher concentrations of retail frontage than those which are part of shorter streets. As we have noted in Chapter 3 (section 3.5.2), the radial and transversal avenues of the City of Buenos Aires, form a transportation supergrid that provides global scale, and higher speed, connections between different areas of the city. Given the higher volumes of pedestrian and vehicular traffic that concentrates on these avenues, they are likely to be favorable locations for retailers. Directional Reach with 0 direction changes captures the linear continuity of the elements that make this supergrid, and we understand that this condition explains the correlation found between retail frontage and this metric. However, the overall continuity and regularity of the street network of Buenos Aires, with many narrower streets running parallel to the avenues that make the supergrid, might explain why the correlation between retail frontage and Direction Reach with 0 direction changes is not a stronger one.

The last of the street connectivity measures tested was Metric Reach with 1 mile radius. This measure, designed to capture grid intensifications associated with centrality (Siksna, 1997, Hillier, 1999a), has a statistically significant, but weak impact on the density of commercial land use. While this result is consistent with the characteristics of Buenos Aires' non-hierarchical gridiron plan, the positive sign of the relationship, and its significance value, support, albeit weakly, the idea that smaller blocks are more favorable for the location of commercial activities than larger blocks. We should note that Ortiz Chao's analysis of Mexico City –which like Buenos Aires shows a non-hierarchical gridiron layout– also finds no relation between grid intensification and retail location (Ortiz Chao, Hillier, 2007).

As expected, all measures concerning distance, form key locations and infrastructure, have a negative relationship with the distribution of retail frontage. The further away we move from the CBD, or points of access to the transit network, the lower the values of retail frontage density found. In the case of distance to the CBD it is interesting to note that the strength of this association is lower than the street connectivity variables. A possible reason for this, relates to the ability of street connectivity measures to capture accessibility differentials, as in higher values of connectivity found on retail ribbons and subcenters' segments. In the case of metro stations, we interpret that the strength of the relationship is affected by the convergence of metro lines in the CBD, and their location underneath important thoroughfares. Finally, in the case of rail stations, the correlation coefficient is almost negligible. As opposed to metro stations, rail stations are widely distributed across the City, locating on high, medium and low residential density areas. While the effect of train stations as anchors for retail hubs might be the cause of the negative sign of this correlation, the relationship between this variable and the distribution of retail is too weak to be conclusive.

Lastly, street widths also have a statistically significant, but weak, effect on a segment's retail frontage density. This can be attributed to several causes. The main of these, is the non-linear relationship that exists between width and retail. Regulations set standard widths for streets, and these widths tend to remain constant, regardless of the amount of retail that is allowed to locate along a street's length. For example, the City's CBD shows the highest concentration of retail frontage density, while at the same time, the streets in this area are amongst the narrowest in the City (see section 3.5.2). Conversely, retail ribbons tend to from along the City's avenues –the wider corridors that make the circulation supergrid–. While frontage densities in streets and avenues might be similar, sharp contrasts in width explain the weak relationship between these variables at the scale of the street segment.

4.1.2 Segment scale multiple regression model

The results of the bivariate correlations presented in the previous section, provided key insights for the specification of a multiple regression model. Multiple regression models, allow for the study of a dependent variable –in this case retail frontage density–, taking into account the combined effect of the independent and control variables. The main purpose of this model, is the study of the impact of measures of street connectivity on retail frontage, while controlling for alternative variables which have been so far omitted in configurational models of retail land use. While all the street network design variables were tested, Directional Reach with 2 direction changes, having the highest impact on the distribution of commercial frontage density, was selected for the statistical model presented in this section. Table 4.2, shows the dependent, independent, and control variables, and reports the result of the model. Along with the model's R^2 value, we report beta coefficients of the regression equation, significance values, standardized beta coefficients, and Variance Inflation Factors (VIF). Standardized Beta coefficients we should note, constitute a means by which to evaluate the importance of each of the independent and control variables in explaining retail frontage. These coefficients are measured in standard deviations, instead of the units of the variables, and are the coefficients that would be obtained if the outcome and predictor variables were all transformed to standard scores (z-scores) before running the regression (Schmee, Oppenlander, 2010, pp.472-475). Variance Inflation Factors on the other hand, are used to evaluate collinearity among the independent variables. As rule of thumb, VIF values above 4, or 10 in the majority of cases, are indicative of severe collinearity among the explanatory variables (O'Brien M, 2007; Schmee, Oppenlander, 2010, pp.472-475; Cohen, et. al., 2003).

Table 4.2 – *Street Segments: Ordinary least squares regression model summary*

Dependent Variable	Independent and Control Variables	R^2	b (slope)	p>|t|	Std. β	VIF
Street Segment Shop Frontage Density	Intercept	**0.351**	-0.203149	<.0001	-	-
	Frontage density within ½ mile		0.6744208	<.0001	0.314	1.18
	Population + Employment Density		0.0661096	<.0001	0.265	1.61
	Reach, 2 Direction Changes, 10˚		0.0006081	<.0001	0.153	1.18
	Street width		0.0082103	<.0001	0.141	1.05
	Distance to nearest metro station		0.0000052	< 0.0005	0.028	2.46
	Distance to nearest railway station		-0.0000097	< 0.0002	-0.02	1.04
	Distance to CBD		0.00000047	0.5613	0.005	2.89

The interaction between the independent and control variables used in this model, presented in Table 4.2 above, results in a correlation coefficient (R^2) of 0.351. In other words, about 35% of the variation in retail frontage density found on the City of Buenos Aires' segments, is explained by the independent and control variables in the model. These variables are ordered in Table 4.2 according to the Standardized Beta coefficients, allowing for the evaluation of the impact of each variable in the predicted distribution of retail frontage density.

As expected, given the results of the bivariate analysis, the presence of shops in the surroundings –800 meters, ½ mile– of a street segment, is the variable that has the strongest impact on the distribution of retail frontage density (Std. Beta 0.31). Following this variable, we find population and employment density on each segment (Std. Beta 0.265). Higher numbers of potential consumers on a segment are the second most important variable in the model. In third place, the density of retail frontage found on a street segment is linked to the accessible street length with two direction changes (Std. Beta 0.153). Higher connectivity with two direction changes is associated with higher values of commercial frontage density. So far, the effect of the variables in the model, parallels the order of the bivariate correlations introduced in the previous section[1].

However, following street connectivity with two direction changes, we now find street widths (Std. Beta 0.141). The results of the model indicate a positive association

[1] *A stepwise regression model was specified to verify, and further evaluate, the effect of street connectivity variables on the distribution of retail. When all control variables are forced into a stepwise model, Directional Reach with 2 direction changes still enters the model in the only remaining forward-step possible, raising the R^2 value from 0.331 to 0.351. When the main variables, interstore externalities, and population and employment density, were forced into this model first they produced an R^2 coefficient of 0.301. In the first forward-step after these two key variables are forced in, Directional Reach with 2 direction changes enters the model, and rises the explanatory power to 0.331.*

between commercial frontage density and the width of streets. In the City of Buenos Aires, wider street segments are associated with higher retail frontage density when controlling for other variables. This result points to the importance of considering street widths, given that it is likely that the circulation *supergrid* of radial and transversal avenues, coinciding in many cases with the City's retail ribbons, are the cause of this positive association. Street widths, when studied in conjunction with other independent variables, acquires a relevance that was not observed in the bivariate correlations presented in section 4.1.1. We estimate that this is the case for, when analyzed in conjunction with accessibility with 2 direction changes, the impact of the circulation supergrid segments' width on retail frontage is foregrounded.

Finally, when studied in conjunction with the already discussed independent and control variables, we find that distance measures, both to the City's CBD, and to transit stations, only slightly contribute to the overall explanation of retail frontage. Notably, the effect of distance to the CBD, which was negative and significant as presented in Table 4.1, is the only not statistically significant variable in this model. This is a particularly important finding, highlighting the fact that the structure of retail in the City of Buenos Aires, which clearly responds to the monocentric city model when analyzed using concentric rings (please see Section 3.5.1), shows a more complex pattern of interdependencies at the scale of the street segment. Retail frontage density in a segment is mainly explained by the location of other shops in the surroundings, the presence of potential patrons, its connectivity value, and its width, regardless of its distance to the CBD.

In sum, the results of this model highlight the importance of studying the interaction of several variables in the explanation of retail location. While all the variables studied in this thesis contribute to explain retail presence, the consideration of all these variables together contribute to more robustly address the distribution of retail at the very fine scale of the street segment. Particularly noteworthy, is the interaction between street connectivity and street widths, as these variables' contribution to the explanation of the distribution of retail, is noticeably larger than that of any of the distance measures. Finally, we should note that in the presented regression model, variable inflation factors (VIFs) remained in all cases below the value of 4 threshold, indicating that there is no prohibitive degree of collinearity between our independent and control variables. As specified, this model's independent and control variables, uniquely contribute to the explanation of retail frontage density.

4.1.3 Zoning Districts and their role in the distribution of retail.

The results of the bivariate statistical analyses presented in Section 4.1.1, allowed us to identify the role of each of the independent and control variables on the distribution of commercial land use. In order to better understand the combined effect of the independent variables on the distribution of retail, and more finely evaluate the effect of street connectivity on the dependent variable, we introduced multivariate models in 4.1.2. While we have so far analyzed several quantitative variables, we have not yet studied the impact that zoning regulations might have on the distribution of retail. In this section we discuss the impact of zoning on retail frontage by adding this variable to the multiple regression model presented in the previous section.

Including zoning in this statistical model improves its explanatory power, increasing the value of the coefficient of determination (R^2) to 0.41, from (R^2) 0.35. About 41% of the variance in the distribution of retail frontage density found in each segment of the City of Buenos Aires street network, is explained once zoning districts are incorporated into the model. Moreover, when included in the list of variables from which to select in a stepwise model, zoning categories are the first variable to enter the model. Clearly then, zoning is a key element in explaining the distribution of retail.

Being a nominal variable, the effect of zoning regulations on retail frontage density at the segment level, can be more clearly evaluated by studying the Least Squares Means (LSMeans) plot, presented in Figure 4.1 below. The LSMeans plot, shows the predicted values of retail frontage density for each zoning category, after controlling for the effect of other variables in the model. In this plot we see that Central Districts (first 8 zoning categories from the left) are responsible for higher response values of retail frontage density, than their residential and industrial counterparts. Zoning regulations are key in understand retail density variations in the City of Buenos Aires.

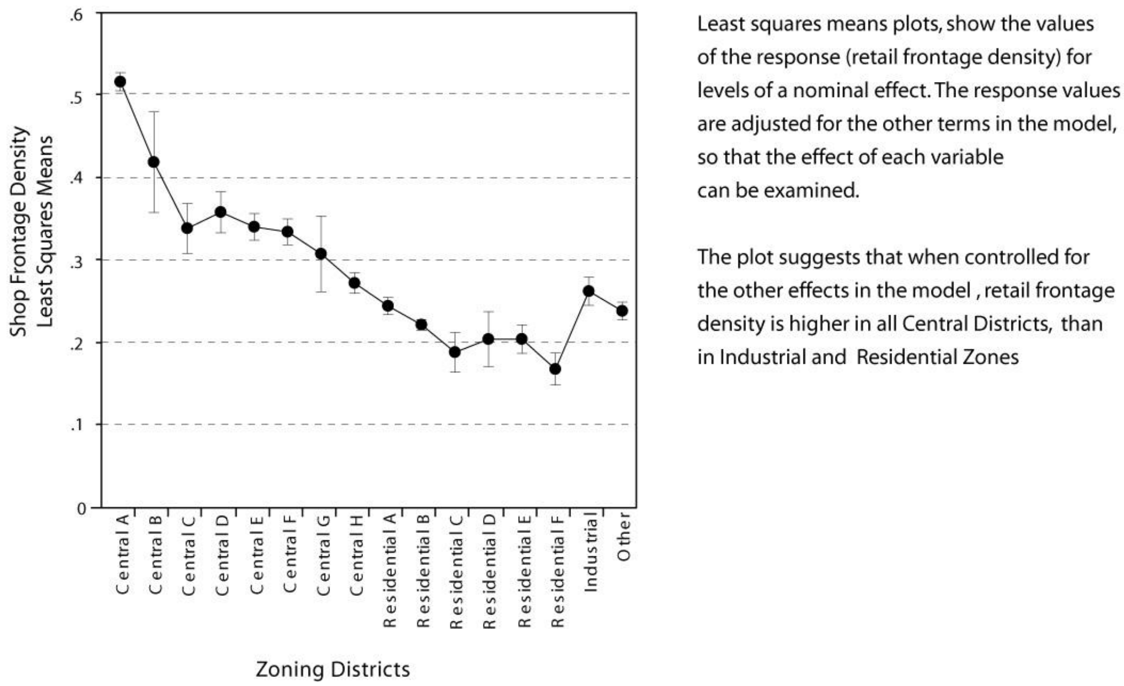


Figure 4.1 *– Least Square Means plot showing the distribution of retail frontage within Zoning Categories.*

A closer look at Figure 4.1 indicates that, when considering all variables in the model, street segments falling in Central Districts of type A, produce higher responses of retail frontage density, than segments in Central Districts of type B, C, D, E, F, G, and H, in decreasing order, and according to the specifics of zoning ordinances, or ordinances of the districts they bound together (see Table 3.1). This is the case also in terms of residential zones, as Residential A (highest density, see Table 3.1) produces higher responses of retail frontage density than residential districts reclassified as B, C, D, E, and F –in decreasing order of authorized land use intensity–. The clarity of the order of precedence in predicted values of retail frontage density in zoning districts, highlights the key role of this variable in understanding patterns of commercial land use.

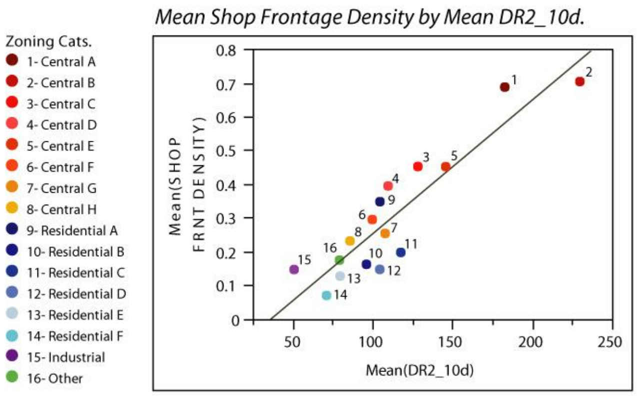
In sum, this analysis emphasizes the pitfalls of not considering land use regulations in the analysis of land use location, and the sole reliance on measures of urban spatial structure that has characterized configurational studies of commercial land use location. Zoning has, to our knowledge, never been addressed in these type of models.

4.1.4 Zoning Districts and street connectivity.

The impact of zoning in the distribution of retail frontage density was highlighted by the improvement of the explanatory power of the multiple regression model. Furthermore, the Least Squares Means plot discussed in the previous section, showed in detail how retail frontage density responds to zoning ordinances. These results confirm that all areas of the City zoned for commercial land use produce in this model, as intended and expected, higher values of retail frontage density.

As discussed earlier, land use regulations in the City of Buenos Aires were introduced in the mid 1940's, the time at which the City had achieved its population peak (Chapter 3, section 3.5.4 Zoning). It was also noted, that it was likely that patterns of retail location developed in the absence of zoning ordinances, following location advantages offered by the spatial structure of the built environment. The City's CBD, and the historical subcenters, are examples of concentrations of retail activities which undoubtedly developed in the absence of zoning ordinances. It is likely thus, that pre-zoning patterns of retail land use, responded to accessibility advantages, such as that provided by the structure of radial arteries converging to the CBD, along these arteries, and at the intersection of radial and transversal main roads. These mechanisms, linking accessibility and land use are at the core of the monocentric model of land use and Berry's analysis of urban retail location discussed in previous chapters.

Of course, measuring the impact of Buenos Aires' zoning regulations in today's pattern of land use, would require time series data and, most likely, a different methodological and theoretical approach than that of this thesis. However, the study of the connectivity characteristics of each zoning district, might provide valuable insights regarding the relationship between urban spatial structure –as measured by Metric and Directional Reach–, and the actual land use patterns which emerged from both planned (post-zoning) and unplanned (pre-zoning) processes in the City Buenos Aires. We proceeded thus, to summarize retail frontage density, and street connectivity measures in each zone, in order to study their correlation. These summaries correspond to average values of retail frontage density, and average values of street connectivity and control variables, for each of the 16 zones defined in Table 3.2. Directional Reach with 2 direction changes, has been the connectivity measure that has performed better in all the analyses presented so far. For this reason, Figure 4.2 below introduces the results of a bivariate correlation analysis between the average value of this variable in each of the 16 zoning categories, with retail frontage density in these same districts as its covariate. The results indicate that accessibility with 2 direction changes, and retail frontage density are very highly correlated, with an r^2 value of 0.82. These results, indicate that zoning districts in the City of Buenos Aires, enclose different spatial structures, with higher values of accessibility in central districts, lower values in residential areas, and the lowest values in industrial zones.



Linear Fit

Mean(SHOP FRNT DENSITY) = -0.138924 + 0.0039653*Mean(DR2_10d)

Summary of Fit

RSquare	0.828179
RSquare Adj	0.815907
Root Mean Square Error	0.082121
Mean of Response	0.302921
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.45508326	0.455083	67.4804
Error	14	0.09441510	0.006744	Prob > F
C. Total	15	0.54949837		<.0001 *

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.138924	0.057572	-2.41	0.0301 *
Mean(DR2_10d)	0.0039653	0.000483	8.21	<.0001 *

***Figure 4.2** – Correlation between mean connectivity and mean retail frontage density per zoning district.*

While we have graphically introduced the correlation between retail frontage and Directional Reach with 2 direction changes, we have also studied the distribution of retail frontage in each zone, with respect to all other independent and control variables. In terms of independent variables, we calculated for each zone, the average Directional Reach with 0 direction changes, and the average Metric Reach within 1 mile. In terms of control variables, average values of population and employment, distance to the CBD, metro and rail stations, and street width, were calculated for each zoning district. The results of bivariate correlations between average retail frontage density in each zoning district, and independent and control variables is presented in Table 4.4 below.

Following Directional Reach with 2 direction changes, the next highest correlation coefficient was found between population and employment density and retail frontage density per district. Zones that have and allow higher retail frontage, are zones that concentrate higher values of potential customers. Continuing down Table 4.4, we find that the average Directional Reach with 0 direction changes in a zone, is highly correlated with the amount of retail frontage density found on that zone. High retail frontage density zones, enclose segments that are part of longer streets. This result was expected, given that many commercial zoning districts, are constituted by the parcels facing avenues and important thoroughfares –the supergrid components–, while the remaining parcels of the block are assigned to other zones, in many cases, residential zones.

Table 4.3 *–Zoning Districts: Correlation of average values of the independent variables on retail frontage*

Dependent Variable	Independent Variables	r^2	p>|t|
Zoning Districts Mean Shop Frontage Density	Mean Directional Reach, 2 Dir. Changes, 10˚	0.828	0.0001
	Mean Pop+Emp Density	0.821	0.0001
	Mean Directional Reach, 0 Dir. Changes, 10˚	0.775	0.0001
	Mean Dist. CBD	0.625	0.0003
	Mean Distance to Metro Station	0.518	0.0017
	Mean Street width	0.316	0.0233
	Mean Distance to Rail Station	0.017	0.6222
	Mean Metric Reach, 1mile, 10˚	0.0009	0.907

We also observe, that districts concentrating higher values of retail frontage, tend to locate closer to the CBD, and metro stations. The width of streets, is also characteristic of higher retail concentration zones, although this relationship is far lower than any of the previous ones. As noted earlier, the role of street widths is not as clear when considered independently, even at this aggregated scale. Finally, distance to rail stations is not statistically significant, nor is Metric Reach. This latter measure, addressing block size variations, does not correlate to the amount of retail found in each zone. This result was expected, given the regularity of Buenos Aires' grid.

4.2 Named streets scale analyses.

The City of Buenos Aires has 1923 named streets. Their average length is 1,370.4 meters (0.85 mi.), with a standard deviation of 1,728.9 meters (1.07 mi.). The longest street in the sample is about 15,000 meters (9.3 mi.) long, and corresponds to an artery well-known among City residents for its extension (Rivadavia Ave.). Short streets and alleys, amount to 722, and represent 37.5% of the total number of named streets in the City. However, the length of these short streets, amounts to only 5% of the total length of the City's street network. These short streets are constituted by either one or two street segments, with an average length of 181.07 meters (0.11 mi.), and a standard deviation of 171.47 meters (0.10 mi.). The analyses presented in this section were conducted on two samples. First, all the named streets were included in our analyses. Then, short named streets were excluded, reducing the sample to 1201 named streets. The results of the statistical analysis of these two samples, are presented in the table 4.5 below.

First, we introduce the result of bivariate correlations between the dependent variable, retail frontage density at the scale of the named street, and independent and control variables able to be calculated at this same scale. These variables are: a) average Metric Reach with a 1 mile radius, b) average Directional Reach, with 0 direction changes, c) average Directional Reach with 2 direction changes, d) average network distance to the CBD, e) average street width, and f) average population and employment density. Also, the population and employment density within 800 meters (½ mi.) of each named street, and the shop frontage density within the same distance were used to study their relationship to shop frontage density.

***Table 4.4** – Named streets: Bivariate correlations summary.*

Dependent Variable	**Independent and Control Variables**	N= 1923 **r^2**	N= 1201 **r^2**
Named Street Shop Frontage Density	Frontage Density within 800 m. (average)	0.3882*	0.4787*
	Population + Employment w/in 800 m. (avg)	0.3495*	0.5562*
	Population + Employment. (average)	0.2746*	0.5507*
	Street DR 2dc. 10d. (average)	0.2104*	0.2473*
	Street DR 0dc. 10d. (average)	0.1802*	0.2115*
	Street Distance to CBD. (average)	- 0.1401*	-0.2019*
	Street Width. (average)	0.0544*	0.0732*
	Street MR 1mi. 10d. (average)	0.0042*	0.0047*

** Significant at the 0.0001 level*

The results of these bivariate correlations indicate that all the studied variables have a statistically significant relationship to the amount of retail density found on a street. The main of these is, again, the presence of shops in the vicinity of a named street, and is followed by the total population and employment, also within 800 meters (½ mile) of a named street. Population and employment density, distributed on the named street itself, shows a positive correlation to the distribution of retail, while its coefficient of determination is lower than the one in the previous two cases.

Following population and employment, we find the first of the street connectivity variables. As in previous analyses, Directional Reach with 2 direction changes, is the variable that is most strongly correlated to the density of retail frontage density, now at the scale of the named street. Streets from which higher metric distance with 2 direction changes is accessible, concentrate higher values of retail frontage density. This variable is followed closely by Directional Reach with 0 direction changes. Longer, and likely straighter, streets tend to concentrate higher densities of retail frontage.

At the level of the named street, distance to the CBD is significantly, and negatively, correlated to the density of retail frontage density. The coefficient of determination in this case, is higher than it was at the level of the street segment. However, this distance should be interpreted with some care, as it represents the average of the distances calculated from each segment to the CBD. As such, distances from, e.g., the end segments of a named street can vary significantly in terms of distance to the city center. Still, even when imperfect, this metric is applied consistently across the sample of named streets, and the negative relationship found, coincides with previous findings, at the scale of the segment, and at the scale of concentric rings. Street widths, show a positive, though moderate, relationship to the distribution of retail frontage density. Wider streets tend to have higher densities of retail. It is important to note, as we have before, that the narrower streets found in the CBD, and the retail alignments found on the City avenues, characterize a scenario where street widths are not likely to individually contribute to the overall explanation of retail frontage density. Lastly, Metric Reach, 1 mile, shows a very weak, but positive, correlation with retail frontage density at the level of the named street. The highly regular gridiron pattern of blocks in the City of Buenos Aires, does not vary significantly across its area, or in this case, the proximity of named streets, thus failing to contribute significantly to the explanation of retail frontage density. Finally, we should note that correlation coefficients, when analyzing the reduced sample of named streets (n=1201), are consistently higher that those obtained when analyzing the complete sample (n=1923). However, we should note that the highest differences are found in the case of population and employment density coefficients, but are not fundamentally different in the case of measures of street connectivity.

The explanation for these differences, can be traced back to a variety of causes. In the first place, several of these short streets are typically internal streets in the City's housing projects. As such, these streets are characterized by very high population densities, but very low retail frontage densities, either on them, or in their surroundings. This is the case, for these projects tend to be located in peripheral areas, as high density enclaves in low density, and poorly accessible areas, where retail is not found in abundance. The opposite case, is that of short streets found on peripheral low density neighborhoods, which are characterized by low populations and low retail frontage. Finally, single segment streets are used in Buenos Aires' GIS centerline map to ensure the connectivity of the network. In many cases, these segments are found in peripheral areas, and have zero population and employment values. In sum, the extreme difference between these three types of short or single segment streets, is the likely cause behind the improvement of the correlations of the reduced sample. We should also note, that short streets directional connectivity values are, in general, lower from those in their surroundings, thus explaining the moderate increase in the correlation coefficients presented in Table 4.5.

4.2.1 Named street multiple regression model

Following the results of the bivariate correlations presented in the previous section, we proceeded to specify a multiple regression model using, as in previous analyses, Directional Reach 2 direction changes as the connectivity variable. We decided to use this variable given that it is, as in the segments case, the one that is more strongly correlated to the density of retail frontage. We should remind the reader that at the scale of the named street, both zoning districts and distance to transit stations, were not possible to be calculated and included in the list of control variables. We should also note, that while we have studied the bivariate correlations between named street frontage density and: a) population and employment within 800 meters (½ mile) of each named street, and b) retail frontage density within 800 meters (½ mile) of each named street, these variables were not included in the regression model presented in this section. This is the case, for the VIF values in models including these variables were very close to 10, indicating severe collinearity between contextual and non-contextual variables calculated at the level of the named street.

Table 4.5 *–Named streets: Ordinary least squares regression model summary. Full & Reduced sample.*

Dependent Variable	**Independent and Control Variables**	N= 1923 **R^2**	Std. β	VIF	N= 1201 **R^2**	Std. β	VIF
Named Street Shop Frontage Density	Population + Employment	**0.43**	0.364	1.13	**0.645**	0.584	1.49
	Street DR 2dc. 10d.		0.323	1.11		0.239	1.22
	Street Distance to CBD		-0.21	1.17		-0.12	1.33
	Street Width		0.05	1.15		0.141	1.08

** All variables significant at the 0.0001 level*

The final model is presented in Table 4.6 above, both for the complete named streets sample, and the reduced sample which excludes alleys and passageways. Along with the coefficients of determination, we include, as we did previously, Standardized Beta coefficients, and Variable Inflation Factors[2].

[2] Once again, a stepwise regression model was specified to verify the effect of street connectivity variables on the distribution of retail. In this case, both the full named streets sample, and the reduced sample were tested. In the case of the full sample, forcing all the control variables produced an R^2 value of 0.3402. With all control variables in, directional reach with 2 direction changes entered the model in the only step forward allowed, and increased the R^2 value to 0.431. In the reduced sample case, with all the control variables forced into the model, the R^2 value is 0.598. Proceeding one step forward, directional reach with 2 direction changes enters the model, and rises its R^2 value to 0.645. In both cases, if no variables are forced into the model, population enters the model in the first step, and is followed by directional reach with 2 direction changes (R^2 values increase from 0.274 to 0.384 and from 0.55 to 0.61 respectively).

The results of the named street scale of analysis indicate that, when considering all named streets in the City of Buenos Aires (n=1923), the independent and control variables, are able to explain 43% of the variance in retail frontage density (R^2 = 0.4309). Average Population and Employment density of a named street, is the variable that has the most influence on the distribution of retail frontage density (Std. Beta 0.364). This control variable, is followed closely by the connectivity variable, average Directional Reach, 2 direction changes (Std. Beta 0.323). The named streets' distance to the CBD is the third most important variable in the model and shows, as expected, a negative sign (Std. Beta -0.21). Finally, street widths, trail the previous three variables, with a noticeable lower standardized beta coefficient (Std. Beta 0.05). Overall, this named street model, does not significantly improve the results obtained in the street segments model which included zoning districts.

However, when analyzing the reduced sample of named streets, the coefficient of determination of the model rises, explaining about 64% of the variance in retail frontage (R^2 = 0.645). Once again, population and employment density, is the variable that has the stronger effect on retail frontage (Std. Beta 0.584). However, in this model, consumer density differentiates itself from the remaining variables, having, by far, the highest standardized beta coefficient. As we discussed earlier, short named streets are associated with wide fluctuations in population density, and by accounting for these fluctuations, the model performs noticeably better. Population and employment density, clearly the main explanatory variable in this model, is followed by Directional Reach 2 direction changes.

Accessibility with two direction changes retains its place as the second most important variable in the named streets models (Std. Beta 0.239).

Interestingly, the importance of the third and fourth variables in this reduced sample model are reversed: street widths has now the third highest beta coefficient (Std. Beta 0.141), followed closely by distance to the CBD (Std. Beta -0.12). As in the segments model presented in 4.1.2, street widths take precedence over distance to the CBD in the reduced sample named streets model. This difference however is not particularly large, and seems to indicate an increase in the impact of widths in the model, more than a reduction in the importance of distance to the CBD. Short streets, we should note, tend to be narrower than the city average (average 12.8 meters -42ft.- vs. 16.7 meters -55ft.-), and have a noticeably smaller Directional Reach with 2 direction changes (average of 78 miles -125km.- vs. 28 miles -45km.-). While consumer density seems to be the main factor in the better performance of the reduced model, removing the narrow and less connected short named streets, contributes to highlight the role of street widths in explaining retail frontage density at this scale. When short named streets are removed, the role of the uninterrupted and continuous street grid is foregrounded, especially with regards to street widths.

We should note however, that the removal of short named streets, was done for exploration of the data, and does not constitute an attempt to develop it, at this stage, as a standard method of analysis. Through these analyses we have found that, when the continuous structure of the City of Buenos Aires is examined at the scale of the named street, consumer density, accessibility with 2 direction changes, and street widths, are major contributors to the explanation of retail frontage density**.**

4.3 Network buffers scale analyses

So far, the analyses covered the scale of the street segment, and the scale of the named street. A final series of statistical analyses, addressed the correlations between the dependent variable, and the independent and control variables, using values calculated with network buffers. Values of retail frontage density within 800 meters (½ mile) of a street segment, are now the independent variable. Values of street connectivity, population and employment density, distance to the City's CBD, and street width, all calculated using network buffers, are now our independent and control variables.

In the literature review, we noted that in studying retail in the city of Bologna, Italy, researchers used Kernel Density Estimation (KDE), as the method by which to bring street centrality measures calculated on street centerline maps, and land use data at the parcel level, to a common scale for analysis (Porta et al 2010). We also noted that KDE, is a spatial smoothing technique, in which values of individual cells in a raster surface, are determined by variable values' in their surroundings. KDE is a well-established technique in spatial analysis, and tools for the calculation of raster surfaces using this technique are included in many GIS programs' set of standard tools. However, in our studies, we opted to keep the road segment as the unit of analysis, given that by using street segments, the actual geometry of the street network is preserved, allowing us to clearly read the city's spatial layout, and permitting us to address the well-defined scale of the block face.

As presented in earlier analyses, network buffers were used in order to characterize the context within which each segment fell. In this final series of analyses, we explore the relationship between retail frontage density within network buffers, and all our independent and control variables describing the context within which they are inscribed. The results of the study of bivariate correlations between retail frontage density within 800 meters (½ mile) of each street segment, and independent and control variables calculated using these same network buffers, are presented in Table 4.8 below.

***Table 4.6** – Bivariate correlations between shop frontage density and variables w/in 800mts (1/2 mile).*

Dep. Variable	**Independent Variables**	N= 23767 r^2	Prob > F
Shop Frontage Density within 800m.(½ mi.) of each segment	Population + Employment w/in 800 m. (avg.)	0.8609	< 0.0001
	Distance to CBD w/in 800m. (average)	- 0.4165	< 0.0001
	DR 0dc. 10d. w/in 800m. (average)	0.2304	< 0.0001
	DR 2dc. 10d. w/in 800m. (average)	0.1816	< 0.0001
	MR 1mi. 10d. w/in 800m. (average)	0.0019	< 0.0001
	Street Width w/in 800m. (average)	0.000008	0.6579

The results of bivariate correlations, indicate that the density of shops in the vicinity (800 meters, ½ mile) of a street segment, is highly and positively correlated to the number of potential consumers found within this same area (r2 = 0.86). These results demonstrate a high level of spatial coincidence between supply and demand at this level of aggregation. A segment in a context of high retail frontage density is found, almost invariably, in a context of high population and employment density.

The average distance from each buffer's segments to the CBD, has the second highest correlation coefficient of those studied. At this level of aggregation, distance to the City's CBD, regains an important role, which was lost when studying the distribution of retail frontage at the level of the street segment, and the reduced sample of named streets. To some extent, this coarse scale measurement of distance to the city center, relates to the study of shop frontage density using concentric rings, although these 800 meter network buffers are more sensitive to contextual variations at detailed and smaller scales.

Following distance to the City's CBD, we find the first of the connectivity variables. This variable, we should note, has a noticeably smaller coefficient of determination than the previous two control variables. Moreover, as opposed to what has been the norm in previous analyses, the connectivity variable that has the highest correlation to the contextual distribution of retail density, is Directional Reach, with 0 direction changes. At the network buffer scale, average values of Directional Reach with 0 direction changes, are stronger predictors of retail frontage density, than the so far predominant 2 direction changes Reach. The cause for this, could be related to sharper differences between areas where streets are long and continuous, and areas where the grid is more regularly interrupted, either by the pattern of colliding grids, or by infrastructure barriers such as railway lines. In capturing these continuity differences, Directional

Reach with 0 direction changes, captures the regularity and continuity of the CBD –the more perfect and continuous grid, given that it is the foundation core–, and historical subcenters which also show more regular and uninterrupted grids. Directional Reach with 2 direction changes on the other hand, while not trailing this previous measure by far, could fail at this scale to foreground differences in accessibility likely to be related to the patchy nature of Buenos Aires' street network. By allowing two direction changes, the differences captured by the metric focused on the continuity of the street network –i.e., by Directional Reach with 0 direction changes–, are not as sharp.

At this scale, as in all previous scales of analysis, Metric Reach shows a weak, and almost negligible effect on the distribution of retail density. While statistically significant, this variable does not contribute to explain retail frontage density in the context of street segments of the City of Buenos Aires. This final data, confirms the nonexistence of grid intensifications associated with local and global centers in this city.

Finally, street widths, is the only not statistically significant variable in this model, and does not contribute to explain the distribution of retail frontage density at the scale of the network buffer. Average street width values within network buffers, as evidenced when analyzing its distribution histogram, tend to remain very close to the City's standard width for streets (17.34 meters/ 20 varas/ 56 feet), with a mean of 17.75 meters, and a standard deviation of 1.29 meters. This smoothing of street widths data, is the likely cause for the failure of this variable to contribute to the explanation of retail frontage density within network buffers.

4.3.1 Retail frontage density within network buffers. Multiple regression model.

The results presented in the previous section, showed a clear predominance of average population and employment density within network buffers, as the driver of retail frontage density at this scale of analysis. As we did with the street segment and named street scales, we used the variables examined in the previous section to specify a regression model. However, we should note that while Directional Reach with 0 direction changes is the connectivity variable that performs better at the scale of the network buffer, we proceeded to use 2 direction changes in this model, in order to be consistent with the previous models presented in this Chapter. The results of this model are presented in Table 4.9. along with Standardized Beta coefficients, and Variable Inflation Factors.

Table 4.7 *– Multiple regression model shop frontage density and independent variables. Network buffers*

Dependent Variable	Independent Variables	R^2	p>|t|	Std. β	VIF
Shop Frontage Density w/in 800m.(0.5mi.) of segment	Pop. + Employment w/in 800 m. (avg.)	**0.877**	0.0001	0.817	1.95
	DR 2dc. 10d. w/in 800m. (average)		0.0001	0.117	1.20
	Distance to CBD w/in 800m. (average)		0.0001	-0.106	1.81
	Street Width w/in 800m. (average)		0.0544	-0.004	1.09

The results clearly indicate that population and employment density (Std. Beta 0.817), is the variable with the strongest effect on the distribution of retail frontage density. Given the results of the bivariate analysis presented in the previous section, we were expecting the model to be dominated by this variable. However, the difference between the coefficient of determination of this model (R^2=0.877), and that of the bivariate correlation coefficient between population and employment density, and retail frontage density at the scale of the named street (r^2=0.86), indicates that other variables in the model are not substantially contributing to the explanation of . The distribution of population and employment is, undoubtedly, the main explanatory variable of retail frontage density at this scale[3].

However, the standardized beta coefficient of Directional Reach with 2 direction changes, is slightly higher than that of distance to the CBD. While the difference between these two variables' coefficients is minute, the importance acquired by accessibility with two direction changes in this model, contrasts with the results obtained in the previous section's bivariate correlations. While bivariate analyses showed that distance to CBD was moderately strong in explaining the distribution of retail at the network buffer level, accessibility was not nearly as important. Now, when considering the combined effect of connectivity and other control variables, connectivity surfaces as a more important variable than distance to the CBD. Finally, street widths is not a statistically significant variable in this model.

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[3] *The network buffer scale was also tested by specifying a stepwise regression model. Forcing all the control variables produced an R^2 value of 0.865. With all control variables in, directional reach with 2 direction changes entered the model in the only step forward allowed, and increased the R^2 value to 0.877. If no variables are forced into the model, population enters the model in the first step, and is followed by directional reach with 2 direction changes (R^2 values increase from 0.8609 to 0.871).*

4.4 Summary of findings

In this chapter we presented the results of statistical analysis aimed at gaining a better understanding of the relationship between retail frontage density, and several independent and control variables. These analyses encompassed three different scales. These were: the scale of the street segment, the scale of the named street, and the scale of the network buffer. In this section we review and summarize the results obtained at each scale, and those regarding zoning regulations, in order to provide a general reference for the discussion and conclusions we will present in the following chapter.

At the scale of the street segment, results of bivariate analyses indicate that the amount of retail found in the surroundings of a given segment, is the most important variable in explaining the distribution of retail frontage at this highly disaggregated scale. This variable was followed by the number of potential customers, which live and/or work on a segment. Connectivity values of a segment, measured as metric accessibility with two and zero direction changes explained, to a lesser extent, the amount of retail found on a particular street segment. Distance to the CBD, and to transit stations, follow these variables in explaining retail frontage density at the street segment level. Finally, we found that street widths and Metric Reach, while statistically significant, had a negligible relationship to retail frontage density.

While the intensity of commercial activity in the context of street segment, and the presence of potential consumers on a given segment, exhibited the highest coefficients of determination in the initial analyses, the specification of a multiple regression model allowed us to more clearly understand how the independent and control variables interact, with a consequent increment in the explanation of the variance of retail frontage at the segment level. The key finding in this model, is related to the increased importance of street widths, and diminishing importance of distance to key locations – particularly to the City's CBD– in explaining retail frontage density at the segment scale. From this results, we conclude that the spatial structure of the City of Buenos Aires, as it is defined by connectivity measures and street widths, provided important insights by which to understand retail location, which at the scale of the street segment, appears to behave independently form distance to the city center. The interplay between contextual land use variables, and local (segment scale) consumer density, connectivity, and width, override the importance of locating close to the city center.

In a following regression model, we controlled for the effect of zoning regulations on the distribution of retail frontage. The results indicate that segments located in commercial districts, are predicted to have higher values of retail. Moreover, the intensity of retail predicted in each district, followed a very clear order of precedence which parallels the prescribed retail intensity of the City's zoning regulations. We concluded thus, that zoning regulations were key in explaining the intensity of retail location at the level of the street segment. For this reason, and in order to better understand the relationship between spatial structure and the regulatory framework, we calculated average values of street connectivity, as well as control variables, at the zoning district level. Bivariate analyses indicate that the higher retail frontage values which characterize commercial zoning districts, are highly and positively correlated to connectivity values. Particularly, measures addressing street network configuration like Directional Reach with 2 direction changes. The zoning districts of the City of Buenos Aires, which as we have seen are key to understanding retail frontage density, are characteristically different in terms of their spatial configuration. Commercial districts which have, as expected and intended, higher retail frontage values exhibit as well the highest values of directional accessibility.

Following analyses addressed the scale of the named street. The analysis of named streets, were conducted using two samples. The largest sample, includes all named streets in the City of Buenos Aires. The second, includes only named streets that are constituted by more than two street segments. This smaller sample, removes short alleys and passageways amounting to only 5% of the total length of the City's street network. However, while constituting a small portion of the City's street network, these short named streets introduced 'noise' in the data, given that the show extreme variations in terms of population and other contextually computed data.

Bivariate analyses of these two samples of named streets, reveal that frontage density on a named street correlates primarily with contextual data –frontage density and population and employment density within 800 meters (½ mile)–, than with named street scale computed data. However, correlations coefficients of the non-contextual data indicate that population and employment density, with the highest r-squared, is followed by Directional Reach with 2 direction changes, then 0 direction changes, and then by distance from the named street to the CBD. Following correlations indicate that named streets widths contribute to explain the distribution of street level frontage density. Finally, Metric Reach, does not contribute significantly to understand the distribution of retail frontage at this scale, a result that coincides with previous analyses at the segment level.

Based on the results of the bivariate correlations, we specified a multiple regression model by which to test the combined influence of the independent and control variables on the distribution of retail frontage density at the scale of the named street. Once again, two samples were used. These were: the complete set of named streets, and the reduced sample which excludes short streets. The results point to the dominant influence of population and employment density distributed over named streets, as the main factor explaining the distribution of retail frontage density. In both the complete and reduced sample models, Directional Reach with 2 direction changes was the second most important variable by which to explain the distribution of retail frontage at the named street scale.

However, the complete and reduced sample models differ in the importance assigned –as per the standardized beta coefficients– to street widths in explaining retail frontage density at the level of the named streets. In the complete model, distance to the City's CBD, is the third most important variable in the model, and street widths the fourth, with a significantly lower standardized beta coefficient. Results of the reduced sample model on the other hand, indicate that street widths are more important than distance to the CBD, although by a very small margin. This results seem to confirm that when the predominantly continuous and uninterrupted street network of the City of Buenos Aires is considered, street widths regains its role as a key variable in explaining retail location.

The final series of analyses involved the scale of the network buffer. These buffers describe the context of each segment, in terms of retail frontage density, population and employment density, connectivity measures, distance to the CBD, and street widths. Bivariate analysis indicate that the amount of retail frontage density found within 800 meters (½ mile) of a street segment, correlates strongly and positively with the population and employment density in the same area. Following this variable, we find that retail density in the context of a street segment, correlates negatively and moderately with the buffer segments' average distance to the CBD. Following distance, we find the directional measures of connectivity. As opposed to the results of previous analyses, Directional Reach with 0 direction changes shows a slightly larger correlation coefficient than the 2 direction changes measure. Metric Reach, while statistically significant, shows a negligible r-square value. Finally, street widths are the only not statistically significant control variable at the scale of the network buffer.

Following the bivariate analysis at the scale of the network buffer, we proceeded to specify a multiple regression model, with Directional Reach 2 direction changes as our independent variable. Control variables included population and employment density, distance to the CBD, and street widths. The standardized beta coefficients indicate that population and employment density, is the variables that have the strongest impact in predicting retail frontage density at the network buffer scale. Notably, and as in previous regression models, the importance of distance to the CBD is reduced when analyzed in conjunction with other variables. In the regression model, Directional Reach 2 direction changes, shows a slightly higher standardized coefficient than the distance variable. Street widths are not statistically significant in the model addressing the scale of network buffers.

While the explanation and interpretation of each of the results obtained was discussed in detail in each of the previous sections in this chapter, this summary of findings provide the necessary basis for the discussion and conclusions presented in the following chapter.

Chapter 5

Discussion and Conclusions

In the past decade measures describing the spatial structure of the built environment have been increasingly incorporated in the analysis of land use distributions. In particular, much research focused on the distribution of commercial land use. The interest in addressing this particular type of land use is based on the importance of retail in creating urban nodes or urban centers, vital for the sustainability of urban economic systems and for the experiencing of a richer urban life. However, in the majority of studies conducted so far, the relationship between measures of spatial structure and the distribution of retail, was studied without taking into consideration other important physical and functional elements describing the built environment, and which are likely to influence retail location. Thus, these studies have examined the distribution of commercial premises as it relates –singularly– to street connectivity and configuration, without evaluating the potential impact of other variables in the distribution of retail.

For this reason, this dissertation focused on the study of retail location and its relationship to measures of spatial structure, while controlling for variables that are likely to affect the distribution of commercial premises. Among the control variables included was a measure that captured interstore externalities: commercial frontage density within a ½ mile (800 m.) from each street segment's centroid. This control variable was developed to test the impact of the co-location of commercial premises in retail centers, which as we noted, benefits both consumers (through transport savings in multi-stop and multipurpose shopping trips) and suppliers (through customer spillovers). Also, by studying the distribution of potential demand, as indexed by population and employment density, we have also addressed the likely increase of supply points in order to meet demand, as is proposed in classical models of retail location. Not surprisingly, these two variables proved to be the main factors explaining retail frontage density at all levels: street segments, named streets, and network buffers. However, and also at all scales of aggregation, we found positive and statistically significant bivariate correlations between measures of street connectivity and retail frontage density. In our multiple regression models, measures of street connectivity consistently contributed to increase their explanatory power.

These findings allow us to address the first hypothesis, which stated that: *even after controlling for variables likely to influence retail location, measures of street network connectivity and configuration will contribute to explain observed patterns of retail location in the City of Buenos Aires.* Results of multiple and stepwise regression models conducted at three scales of aggregation, indicate that measures used to describe the City's spatial structure contribute to explain of the distribution of commercial frontage density. In particular, directional accessibility with 2 direction changes was found to be the connectivity measure with the highest explanatory impact on retail location patterns, controlling for other variables. These findings thus, support previous research findings indicating that directional accessibility is a key factor in understanding the relationship between urban spatial structure and the distribution of commercial land use.

Notably, further analyses indicate that while long radial and ring streets –described by Directional Reach with 0 direction changes– are likely to concentrate retail activities in retail ribbons as proposed by classical literature, directional accessibility with 2 direction changes, capturing not just one dimensional accessibility but the extent of the 2 dimensional network surrounding a given segment, is a stronger predictor of retail frontage density than linear extension alone. Moreover, street width, a measure intuitively likely to have a strong impact on the distribution of commercial premises, especially in the case of retail ribbons, trails directional accessibility in all the statistical analysis performed. Thus, in the City of Buenos Aires, a better understanding of the distribution of commercial land use as it relates to its street network, is given by the measure that provides a more extensive profile of a street segment, or aggregation of segments, than street length or street width. These results, obtained using models with numerous control variables confirm the first hypothesis regarding the effect of street connectivity upon patterns of retail location in the City. At the same time, they allowed for a more precise evaluation of the impact of each measure of street connectivity upon retail frontage density.

As to the second hypothesis: *measures of street connectivity capturing grid intensifications will not contribute to explain retail location in the City Buenos Aires*, the results of the analyses performed confirm that this is the case: grid intensifications are only weakly associated with retail location in this city. In particular, Metric Reach, points to different conclusions than those obtained in previous research. Metric Reach, being a measure designed to capture variations in the tightness of the urban fabric within a parametrically defined context –in this case, a 1 mile radius-, did not provide any particular insights regarding the distribution of retail. Regression coefficients, even when positive and significant, indicate a very weak tendency towards the location of retail in areas characterized by smaller blocks. As expected given the highly regular structure of blocks and highly connected the street network of the City of Buenos Aires, intensifications of the urban grid, such as those reported by Siksna and Hillier (Siksna, 1997, Hillier 1999a), and which tend to occur as a result of pressures for increasing block frontage and reducing travel distances within centers, were not found in the City of Buenos Aires. In contrast to grid intensifications reported in organic cities, or in cities with large blocks in their downtown areas, Buenos Aires' block structure seems to have adapted well to the challenge of time and growth.

The third hypothesis, addressed the impact of aggregating data at different scales stating that: *variations in the scale at which data is aggregated, particularly the aggregation of detailed segment scale data into larger units, will result in increases in the explanatory power of the statistical models*. As we have seen, previous research addressed street connectivity and land use, using either axial lines or smoothed data through the use of kernel density estimation (Hillier, 1999a; Porta et al., 2009, Ortiz Chao, Hillier, 2007; Mora, 2005). By doing so, these studies did not focus on the relationship between highly accurate retail location data, and precise street connectivity data, but on intermediate scales representing a blurred version of the actual situation on the ground. The results of the analyses presented in this thesis indicate that aggregations at different scale can have significant impact on the explanatory power of statistical models. The specification of models using aggregate versions of variables calculated at segment level, allowed for the verification of a tendency towards higher coefficients of determination at increasing levels of aggregation. These results could help researchers and practitioners select, and better interpret the results, of more or less data-intensive models.

As to the questions regarding zoning and street connectivity, this thesis made a first step into a more complete understanding of the interdependence between urban form, the distribution of land use, and planning policy as is manifested through regulatory instruments. The study of zoning regulations indicates that commercial zoning districts, planned to accommodate higher volumes of retail, enclose segments with characteristically higher values of Directional Reach with 2 direction changes. Once again, higher accessibility to surrounding areas is the key spatial structure measure, and a measure that proved to be clearly and strongly associated with urban planning instruments encouraging the formation of commercial centers and corridors. The direction of influence, at this stage tentative given the absence of time series data, seems to indicate that patterns or retail location forming centers and corridors which predate to a large extent zoning regulations, responded to locational advantages provided by the structure of the street network. While more research on this subject is necessary, the results obtained are an original contribution to the field of distributed gravitation and fill a much-needed gap in the study of spatial structure as it relates to the distribution of land use.

Given this discussion of the thesis findings, it should finally be noted that the studies presented in this dissertation could be interpreted as a direct contribution to the set of urban planning accessibility measures discussed in Chapter 2 (pp. 24-29). This is the case, first, for the results obtained could be taken to reinforce the importance of graph theory measures of accessibility, currently considered *weaker* than those that take into account land use data. Second, because accessibility from the perspective of distributed attraction constitutes a factor influencing the location of land use. As such, the accessibility measures used in this thesis could be interpreted as being directly linked to the notion that accessibility affects the potential for urban growth (Hansen, 1959). However, in the case of distributed gravitation measures, it is argued that the potential for growth derives from the uneven distribution of metric and/or directional accessibility to other spaces –e.g., the ability to reach other street segments–, and not, e.g., employment or other land uses. Distributed gravitation, and its focus on spatial configuration as a key variable behind the emergence and organization of urban land use, thus contributes to expand the urban planning's current definition of accessibility and its impact on patterns of land use.

5.1 Limitations and future work.

As discussed in the previous section, this thesis has contributed to clarify the role of measures of street connectivity and configuration upon the distribution of retail land use. However, this work is not without limitations. These will be addressed in this section, while outlining the directions for future work.

A main issue that will be addressed in future work is that related to the limitations of the statistical models used in this thesis. In particular, it is necessary to address spatial autocorrelation –i.e., the coincidence of value similarity with location similarity–, given that its presence violates the assumption of independent observations of the non-spatial models used. As a result, the regression coefficients obtained in this thesis could be biased and inefficient. For this reason, I consciously refrained from interpreting the coefficients of the models, and only focused on the impact of street connectivity in their overall explanatory power, beta coefficients, variable inflation factors (VIFs), and significance values. While spatial econometrics models addressing spatial autocorrelation (either in the form of spatial lag, or in the form of spatial error), and software to implement these models, is currently available (Anselin, Ibnu, Youngihn, 2005), software supporting the specification of *joint* spatial lag and spatial error models is currently being developed and close to being released by researchers of the GeoDA Center at Arizona State University. Tests conducted on the City of Buenos Aires data indicate that in order to address spatial autocorrelation a joint model is needed, and future work will take advantage of latest advances in spatial econometrics modeling.

Also, in this thesis the focus was placed on the study of street connectivity, using measures that describe the urban spatial layout in metric and metric-directional terms. While metric measures of connectivity could be interpreted as indirectly addressing travel time, they do not do so explicitly. New developments in network analysis however, allow for the estimation of travel time, a factor likely to impact on the decision of engaging on a trip or not. A widely cited study indicates, for example, that the speed at which pedestrians travel can vary depending on the purpose of the trip –e.g., when commuting 1.49 meters/second, when shopping 1.16 meters/second (Weidmann,1993)–, consequently impacting a person's time budget. Further studies of street connectivity can take advantage of these research findings and new technology, and expand the range of variables considered when studying the effect of spatial structure on the location of land use. Measures of accessibility, based on metric, directional, and travel time constraints, could prove a valuable addition to the set of accessibility measures presented in this thesis.

Finally, in this thesis all the retail types found in the City of Buenos Aires are addressed as a single category. By doing so, the logic behind the location strategies of different types of retail and service establishments is not examined. Thus, this thesis provided valuable insights regarding the relationship between street connectivity, and the overall commercial structure of the City of Buenos, but did not take full advantage of the fine grained data available in the cadastral database used. More refined analyses are expected to be addressed in future work, based on the methodology developed in this thesis –particularly the transfer of data from parcels to street segments–, and the noted advances in terms of spatial econometric tools by which to specify joint lag and error models. Questions regarding whether the decision to co-locate that characterizes certain activities –like the furniture and auto parts establishments discussed in Chapter 2, pp. 21-22– responds solely to *non-spatial* business strategies, or whether it is also influenced by the spatial structure defined by the city streets, could be answered with greater rigor based on readily available data. Questions regarding the location strategies of different types of businesses –such as high end stores, or food and drink establishments– could, as well, be studied in greater detail in future work based on available data and cutting-edge statistical modeling tools.

Still, besides addressing the noted limitations of this thesis, in future work I expect to address other substantial issues based on the results obtained so far. The main of these, is the examination of connectivity and configuration properties of streets that support retail, and those which are mainly associated to other type of land use. Once again, the database and the methods used for managing data and variables presented in this thesis will be key in developing these more discriminating studies. A possible method by which to further explore the data available, could be based on randomly sampling street segments, classifying them as having or not having retail activities, and studying variations in their connectivity values. These studies could be conducted as well, using the "named street" sample, in order to better understand which factors support the formation of retail ribbons.

Finally, findings from this thesis could help frame and interpret broader theoretical questions such as the cultural significance of retail as an aspect of urban life. Retail and services can act as catalysts for increased social interaction, contributing to create livelier, safer, and more commonly shared urban spaces. However, this type of land use can also be seen as perpetuating a cycle of consumption, thus widening the gap between have and have-not urban dwellers. I expect that the results of this thesis, will provide a firmer foundation for refining planners and architects' questions regarding the role of spatial layout as a, potentially key, factor in addressing complex problems posed by increasing urbanization.

5.2 Conclusions

This thesis contributed to a more complete statement of the theory that links the distribution of retail to the structure of urban street networks. The results obtained, allow us to present conclusions from theoretical as well as practical points of view.

From a theoretical point of view, the underlying aim remained to be the understanding of the city as a material artifact, in which spatial configuration acts as the long term structuring factor and where land uses emerge as particular investments informed by the spatial layout provided by the street network. The study of retail, provided critical insights in terms of this relationship between spatial structure and land use. This is the case, for retail, more than any other urban land use, is associated with the emergence of centrality –i.e., local and global concentrations of activities acting as points of convergence of movement patterns–; with exploratory movement through the city streets –as when searching for specialized shops, variety of products, and shopping opportunities–, with a sense of interest because there is more to see –as shops displays are part of the urban scenery–; a sense of safety because there are “eyes on the street”; a sense of identity –for diverse people pursuing diverse shopping itineraries both affirm and display social identities associated with patterns of consumption– and, last but not least, a sense of intelligibility as retail oriented exploration is likely to lead to the construction of richer cognitive maps, at least of some areas, and the cognitive understanding of the city is likely to influence search patterns. Understanding the patterns of implication that link the spatial distribution of retail to the spatial structure of street networks is thus an important aspect of any larger theory of urban form as social and cultural artifact and resource.

From a practical point of view, the aim is to understand not only how the average properties of street networks influence the aggregate distribution of retail (in sparse cul-de-sac oriented urban environments retail is likely to be concentrated in a few larger nodes while in deformed grids it is more likely to be distributed across the urban fabric) but also how the precise spatial articulation of an urban area creates a hierarchy of location desirability from the point of view of retail. This, in turn, helps orient building frontages, the overall distribution of forms and uses over any large development site, and the reinforcement of the distinctive modulation of activity and the distinctive patterns of hierarchy that define the character of places. Thus, at a more practical level, the proposed work will provide a better interface between urban theory and urban design. At the simplest level it will help evaluate development proposals as for their potential to accommodate successful retail and as for the congruence between form and use as prescribed by design. At a slightly more sophisticated level it will help to design street layouts that are so structured a priori, as to create uneven and intentionally enmeshed opportunities for future development. A perfectly uniform and infinitely extended grid is homogeneous at all points. Real grids, such as the one encountered in Buenos Aires, have a specific structure which creates uneven opportunities for different kinds of land use. Understanding how this works is key to support design decisions aimed at creating cities and places which are, simultaneously, intrinsically diversified and spatially integrated and coherent.

As to the title of this thesis, *towards a theory of distributed attraction*, the more complete models introduced in this thesis support the conclusion that measures of street connectivity contribute, in the case of the City of Buenos Aires, to a better understanding of observed patterns of retail location. The fact that measures designed to capture variations in accessibility have sizeable impact in a city exhibiting a highly connected street network, a highly regular blocks structure, and a retail structure which tightly fits classical models, further supports previous research linking *form and function* at the urban scale. The results of this dissertation thus, support the thesis that "urban attraction" should not be conceptualized in terms of distances from a unique central location, or a number of central locations, but rather in terms of a model of distributed centrality governed by the structure of street networks.

Appendix 1

List of activities

The following table lists the coded Commercial Activities provided by the Government of the City of Buenos Aires Office of Cadastral Records. The categories listed correspond to the classification scheme current as of December of 2001.

Description	Key in City of Buenos Aires database	Type
Auto parts	CAA	Commercial
Drive-in Movie Theater	CAC	Commercial
Electronics	CAE	Commercial
Movers	CAF	Commercial
Commercial Agency	CAG	Commercial
Home appliances	CAH	Commercial
Printing services	CAI	Commercial
Lottery	CAJ	Commercial
Grocery stores	CAL	Commercial
Antiques	CAN	Commercial
Home alarms/ Security	CAS	Commercial
Auto dealers	CAT	Commercial
Camping, yachting	CAU	Commercial
Bars	CBE	Commercial
Bike shops	CBI	Commercial
Banks	CBN	Commercial
Bazaar	CBZ	Commercial
Arms	CCA	Commercial
Currency Exchange	CCC	Commercial
Funerary Services	CCH	Commercial
Religious paraphernalia	CCL	Commercial
Informatics	CCM	Commercial
Cinemas	CCN	Commercial

Party Supplies	CCO	Commercial
Couriers	CCP	Commercial
Butcher	CCR	Commercial
Carpenter shops	CCT	Commercial
Sport items	CDP	Commercial
Newspapers	CDR	Commercial
Record Store	CDS	Commercial
Home appliances 2	CEL	Commercial
Pharmacy	CFC	Commercial
Flower shop	CFL	Commercial
Financial Services	CFN	Commercial
Pasta shop	CFP	Commercial
Hardware shop	CFR	Commercial
Photocopy services	CFT	Commercial
Diary goods	CGA	Commercial
Commercial Galleria	CGC	Commercial
Tire repair and sales shop	CGM	Commercial
Gymnasium	CGS	Commercial
Ice Cream Parlor	CHL	Commercial
Lighting shop	CIL	Commercial
Real Estate Agency	CIN	Commercial
Music Instruments Shop	CIS	Commercial
Toys shop	CJG	Commercial
Jewelry	CJY	Commercial
Candy Store	CKS	Commercial
Car wash	CLA	Commercial
Book store	CLB	Commercial
Lottery 2	CLT	Commercial
Coin Laundry	CLV	Commercial
Furniture	CMB	Commercial
Market	CMD	Commercial
Haberdashery	CME	Commercial
Machining	CMQ	Commercial
Leather goods	CMR	Commercial
Construction Materials Yard	CMS	Commercial
Metallurgy	CMT	Commercial
Whole sale	CMY	Commercial
Other	COA	Commercial
Photography/ Optics	COP	Commercial
Orthopedics	COT	Commercial
Plastic goods	CPC	Commercial
Fur coats shop	CPL	Commercial
Bakery	CPN	Commercial
Beauty salon/ Hairdresser	CPQ	Commercial
Perfumes/Beauty products	CPR	Commercial
Fish market	CPS	Commercial
Paints store	CPT	Commercial
Chemical products	CQM	Commercial

Recreation	CRC	Commercial
Wheels and Bearnings	CRD	Commercial
Home appliances	CRE	Commercial
Locksmith	CRJ	Commercial
Clothes	CRO	Commercial
Parts and accessories	CRP	Commercial
Restaurants	CRS	Commercial
Take-out food	CRT	Commercial
No Activity	CSA	Commercial
Beauty Parlor	CSB	Commercial
Party Salon	CSF	Commercial
Bathroom and Plumbing	CSN	Commercial
Supermarket	CSP	Commercial
Tailors	CSS	Commercial
Tobacco	CTB	Commercial
Awnings	CTL	Commercial
Dry Cleaners	CTN	Commercial
Upholstery	CTP	Commercial
Theater	CTT	Commercial
Disco/ Club	CTT	Commercial
TV Station	CTV	Commercial
Textiles	CTX	Commercial
Glass shop	CVD	Commercial
VHS Rental	CVI	Commercial
Arcade	CVJ	Commercial
Green Grocers	CVR	Commercial
Veterinary	CVT	Commercial
Plants and Garden	CVV	Commercial
Shoe repair	CZP	Commercial

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VITA

Martin Scoppa was born in Gent, Belgium, but lived in Buenos Aires, Argentina, most of his life. He holds a professional degree in architecture from the University of Buenos Aires, and is a registered architect with the Professional Council of Architecture and Urbanism of the City of Buenos Aires. He has several years of research and practical experience in urban design and planning, and has worked extensively with Geographic Information Systems (GIS).

His professional experience encompasses public service, as a Planning Officer for the City of Buenos Aires, and private practice, as an urban design consultant. He collaborated in the design and assessment of urban planning and design projects in Argentina, Canada, Saudi Arabia, and the US. Of these projects, the Master Plan for the Extension of Uses of the Port of Santa Fe, Argentina, was exhibited at the 9^{th} Venice Biennale of Architecture, arguably the most important event on the contemporary architecture calendar.

His research focuses on measuring and describing the spatial structure of the built environment, which he does by studying urban street networks in GIS, and assessing its impact on accessibility, and the location and emergence of central places. He has published his work in peer-reviewed journals, and has presented his research in national and international conferences. He collaborates extensively with the Center for GIS at the Georgia Institute of Technology, and the University of Minnesota Brain Sciences Center.

Apart from his research and professional activities, he has been an instructor at Georgia Tech for the last three years, teaching design foundation studios to undergraduate students.