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Street network and home-based business patterns in Cairo’s informal areas

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ABSTRACT

Identifying the economic potential of informal urban areas is a topic of increasing interest for policymakers and practitioners in less developed countries, yet little is known of how informal street design influences the type and count of business opportunities. By adapting a space syntax framework, this study aims to quantitatively verify the association between the street design of informal areas in Cairo and patterns of home-based businesses in areas where small business prevalence is high. This paper contributes to the literature by developing a methodology which is fit for testing hypotheses, allows to control for the influence of unobserved factors, and which extracts the spatial rules, trends or logics of business patterns. The results show that street accessibility is an important factor in encouraging (or discouraging) the settlement of home-based businesses. Home-based businesses are spatially distributed along the local primary streets, which provide flows of potential customers. Our findings contribute to a better knowledge base for understanding how different types of economic activities and the spatial properties of the built environment relate to each other, how street design may impact on the emergence of small and micro-enterprises, what kind of business may suit isolated laneways, how informal business activities can be anticipated and managed, and how land use regulations can be improved.

1. Introduction

In Egypt, the informal economy, including agriculture, contributes to up to 60% of the total GDP, according to official estimates (El-Sharnoubi, 2019). A major part of this informal sector is organized around ‘home-based businesses” (HBBs) in which low-income households rent out, or use part of their residential property for retailing, light manufacturing, food preparation, and/or repair services with less than five workers (Dwelly et al., 2005; El Mahdi, 2010; Singerman, 1996; Smit and Donaldson, 2011; Thai et al., 2019; Tipple, 1993). HBBs tend to be an important feature of the urban landscape in developing countries (Breen, 2010; Tipple, 1993) as they were in Europe, prior to industrialization (Strassmann, 1987).

There is a voluminous body of literature on the relationship between the spatial structure of built environments and economic land use patterns at the street level (e.g. Akiyode, 2017; AL-Ghatam, 2009; Chiaradia et al., 2012; Greene, 2003; Han et al., 2019; Hillier et al., 2000). Many of these studies are based on the use of Space Syntax theories and tools, underpinned by two ideas. The first is that movement patterns are related to the interaccessibility of street spaces (natural movement, see Hillier et al., 1993). And the second is that the distribution of land uses is largely determined by the structuring of natural movement (Hillier, 1996a). Generally speaking, more (less) connected spaces, for which volumes of population movement will be largest (smallest), are expected to have more (less) retail and service activities (Porta et al., 2012). However, more research on how such activities are distributed within less connected, accessible neighborhoods is needed (Thai et al., 2019). Furthermore, most prior studies have mainly focused on patterns of movement-driven activities, largely neglecting the patterns of other types of businesses, such as manufacturing and food preparation, where clients rarely visit. These types of businesses are understudied within the context of informal urbanism.

Perhaps more importantly, many previous studies (e.g., Mohamed and van Nes, 2017; Shafiei, 2007) do not take into account the absence of business in many streets. Also, the impact of unobserved variables, such as spatial autocorrelation, remains unexplored. Overall, existing studies are limited in terms of the sophistication of the methods, often using a very small sample size (Thai et al., 2019), considering solely one index of accessibility (Han et al., 2019), or employing only descriptive statistics or correlation analysis (Shafiei, 2007), which generally

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restricts statistical validity.

This study contributes to developing a framework for examining the relationships between street design and patterns of home-based businesses in informal areas. Particularly, we attempt to identify more detailed spatial distribution and competitiveness rules of different types of small home-based enterprises. We investigate their interrelated features with different spatial street-network metrics in the city of Cairo, the capital and largest city of Egypt and the world's 18th largest metropolitan area, with more than 60% of the region's population living in informal settlements (Khalifa, 2015). While many such settlements may have strong variations of building type and density, they also have significant morphological similarities that have largely been used to identify informal urbanism in cities of the global South – often a small-grain, dense, narrow and irregular street/laneway networks (Dovey et al., 2020).

The paper will answer three key questions: (1) what is the relationship between street-network accessibility and the occurrence of HBBs? (2) to what extent can the physical layout of streets explain different spatial patterns of businesses? And (3) whether and how are the spatial patterns of business activities in movement-poor areas (i.e. irregular and isolated street segments) different from traditional businesses in movement-rich areas, i.e. integrated street segments where there are high movement flows of pedestrians and vehicles?

Using space syntax tools as well as zero inflated negative binomial regression models, this study will examine the spatial impacts of irregular fine-scale street patterns on the spatial distribution of home-based economic activities in Abu Qatada, Ezbet Al-Nasr and Ezbet Bekhit in Cairo. Abu Qatada is established on privately-owned ex-agricultural land, whilst the other two cases are built on state-owned desert lands. The three settlements are predominantly spontaneous or unplanned and represent the two main typologies of informal housing in Egypt. The results of this research will contribute to a broader understanding of how economic opportunities for various types of businesses are related to the configuration of the street-network in informal areas. The street-networks of these areas matter because they are the infrastructure that define the ways cities mix different populations and practices (Dovey et al., 2020).

The rest of the paper is organized as follows. The next section briefly presents profile of HBBs in Egypt. The third section reviews relevant literature. The study area is described in Section 4. Section 5 presents the proposed analytical framework. The final two sections show results, discusses the main findings, concludes the implications for design practices, considers the limitations, and suggests directions for future research.

2. Informal labor and home based businesses in Egypt

The process of rural-urban migration is identified as a key factor underlying overurbanization in developing countries (Jenks et al., 2013; Pacione, 2001). In Egypt, as in most developing countries of the global South, a lack of affordable housing and escalating housing demand push new immigrants to cluster in overcrowded enclaves, turning large parts of cities into densely built informal housing settlements. However, dwellings in these areas are not only for shelter but also for earning a living through HBBs (Smit and Donaldson, 2011; Strassmann, 1987; Tipple, 1993). Such businesses contribute largely to the household economy as it takes little capital to set up one's own business (Singerman, 1996; Smit and Donaldson, 2011; Tipple, 1993). HBBs are commonly set up in ground floor blocks (Crosbie and Moore, 2004). While HBBs have some negative consequences (e.g. noise and privacy violations) and are primarily constrained in official housing projects, especially in the global North, they are still the largest bulk of private economic activities in many developing-world cities.

The informal economy is made up of all production units, economic activities by informal workers and the output from that employment that is partially or fully uncovered by formal arrangements (UN-Habitat, 2015). Similar to informal housing, the informal economy arises for a variety of reasons, including rapid urbanization and a lack of job opportunities in the formal sector. Although it may occur in formal/planned areas, the informal economy is largely associated with the unplanned settlements. In other words, it is the main option for work for informal settlers, who constitute the greatest proportion of urban population in developing countries. In Egypt, World Bank estimates show that informal workers between the ages of 15 and 64 comprise 55% of the country's overall labor force (Benjamin et al., 2014). Moreover, small and micro-enterprises (SMEs), which are employing no more than four workers, constitute more than 90% of the country's economic activity (Central Agency for Public Mobilization and Statistics CAPMAS, 2017; El-Sharnoubi, 2019), accounting roughly for 58% of employment and contributing around 75% to the national income by some estimates (AfDB, 2016). In Greater Cairo, at least 25–40% of all workers are informally employed, and in 2006 the SME sector generated more than 1.05 million jobs in the metropolis as a whole. While there is a lack of accurate statistics on informal household businesses, these figures show that SMEs are by far the prevalent mode in Greater Cairo (Sims, 2010) and demonstrate the importance of family-related businesses operating from a dwelling (Singerman, 1996).

While many studies acknowledge the large size of familial enterprises in developing-world cities, most of the existing literature focuses on estimating the size of the informal enterprise sector in general and trying to grasp working conditions (e.g., El, 2002; Elshamy, 2014). Even those few studies which have qualitatively examined the streetscape of economic behavior represented by activities (e.g., Nagati and Stryker, 2013; Shehayeb, 2011) were unsuccessful in identifying the spatial features of urban spaces where such businesses occur. Overall, the ways in which the spatial arrangement of pathways supports or stymies community-oriented businesses are seldom considered.

3. Theoretical framework and hypotheses

Understanding the relationship between business activities and the urban structure has received a lot of attention in recent years. Since the 1960 s, a growing number of studies (e.g., Gehl, 1989; Jacobs, 1961; Montgomery, 1998) have been undertaken to understand how the built form of cities influences social life. For instance, Jacobs (1961) argued that small blocks promote walking and provide permeable public realm for interactions and activities (Jacobs, 1961).

Space syntax provides a set of techniques that can empirically verify Jacobs' ideas on viable and safe environments through quantifying the interrelationship between city's spatial structure and aspects of social life (Hillier, 1996b). Unlike traditional street life studies, space syntax tools examine social life indirectly by simulating patterns of urban mobility through analyzing the relational properties of the urban layout. According to Hillier and Hanson (Hillier and Hanson, 1984), the street network of any city is the infrastructure that establishes urban movement patterns and practices. Once this infrastructure is built it gets hard to change and usually exists in place for centuries. Hillier (1996b) argued that the spatial configuration or organization of the street network would naturally draw different patterns of urban movement and the face-to-face interactions of pedestrians. According to the theory of natural movement, street spaces connected to many other streets will enable pedestrian access between buildings, allow the transportation of goods and, therefore, generate more movement flows, which then facilitate economic activities and other movement-seeking land uses. Also, emerging activities are likely to generate "multiplier effects" on movement and further influence on land uses through attracting more customers and activities. Referring to this sort of circular causality, Hillier (1996a) argued that the association between spatial connectivity and land use patterns is mediated by patterns of movement.

Space syntax has shown to be empirically powerful in interpreting economic opportunities. For instance, the abovementioned thoughts were pursued further in studies of socioeconomic class (Omer and

Goldblatt, 2012; Vaughan, 2007), office buildings (Desyllas, 2000), retail activities (Narvaez et al., 2014; Ortiz-Chao and Hillier, 2007; Porta et al., 2009; Scoppa and Peponis, 2015; Sevtsuk, 2010), and various types of businesses (Thai et al., 2020, 2019).

The main findings from previous studies that have investigated the relationship between spatial patterns of retail activity and street-network configuration are as follows: first, more accessible streets are more likely to be associated with higher numbers of businesses (Omer and Goldblatt, 2016; Porta et al., 2012, 2009; Scoppa and Peponis, 2015). Second, the degree to which a settlement is able to develop economic activity through its street-network determines the pathway of development (i.e. its degree of social and physical consolidation) (Greene, 2003; Hillier et al., 2000; Shafiei, 2007).

However, many of the abovementioned studies are not without limitations and, therefore, we should be careful when generalizing their conclusions to other places. For instance, In their studies on a sample of 17 informal settlements in Santiago de Chile, Hillier et al. (2000) and Greene (2003) examined the association between the ratio of 'edge oriented commercial activities' (EOCA) of an area and its degree of social and physical consolidation. They found that well-integrated streets, especially the edges, are more likely to have significant levels of car traffic flows and therefore can develop commercial activity, which contributes to the wider local economy. However, the average size of the 17 settlements did not exceed five hectares where internal commercial streets are unlikely to be existent (Shafiei, 2007). More importantly, informal areas vary mostly across and within countries in form, shape, and urban design, so broad conclusions about them tend to be wrong (Dovey et al., 2020).

Another relevant study (Han et al., 2019) used a variety of methods including spatial network metrics to identify the spatial patterns of retail stores in Zhengzhou city in China. However, the paper only considered one index of accessibility, disregarding more powerful space syntax metrics that are able to predict the potential flows of passers-by, potential customers. In this work, we will consider various spatial measures at different scales of analysis to capture different modes of urban mobility.

Except for Han et al. (2019) and Thai et al. (2019), the majority of studies put spatial patterns of various types of activities, such as people-oriented services (e.g., hair salons, restaurants, coffee shops) and goods-oriented services (e.g., light industrial work, repairing, and storage), in the same category. Though ideally expected to be spatially distributed and sorted, the question of whether all various types of small enterprises need similar levels of street accessibility has to be addressed.

Altogether, this study extends the previous studies in two ways. First, it empirically attempts to identify the spatial conditions of different economic functions by examining various spatial patterns of HBBs in public spaces of informal settlements where the grid system is irregular and unclear. Second, unlike many existing studies, we develop an integrated analytical framework including both descriptive statistics and zero inflated negative binomial regression models to test the association between the spatial layout of a city and its socioeconomic functionality. We estimate not only how many businesses are captured, but also the likelihood that informal street design captures any business at all. The proposed method also accounts for the effect of some unobserved factors (e.g., spatial autocorrelation). The hypotheses for our inquiry are formulated as follows:

H_1: Home-based businesses are not chaotic; rather, they epitomize a set of social logics that are largely understudied. They are located on spatially accessible street segments (as estimated by space syntax syntactic measures), as flows of potential customers are expected to be higher on such segments.

Although this hypothesis has been confirmed by many scholars since the 1960 s, including Jacobs (1961), Hillier (1996a) and Hillier et al. (2000), more research is needed to better understand how irregular, less accessible informal streets influence business activities.

H_2: The proximity to a local main street influences the type of business opportunities. The present study also asks what type of economic activity can suit alleyways and isolated locations.

The results of this research may contribute to our overall knowledge of optimal economic land use distribution, and to a better understanding of how urban morphology structures business opportunities. Also, the outcomes of this study can act as a reference that can help urban planners and urban designers better understand the current mechanisms of survival in informal areas where financial resources are limited. Hence, appropriate planning regulations and development strategies for declining settlements may be formulated to enhance the living conditions of such areas.

4. Study areas

For the present study, we selected three informal areas in Cairo: Abu Qatada in *Boulaq Al-Dakrour* district, Ezbet Bekhit in *Mansheit Nasser* district, and Ezbet Al-Nasr, previously known by *Turab Al-Yahud* (Jewish cemeteries), in *Al-Basateen* district (Fig. 1).

Abu Qatada is built on privately-owned ex-agricultural land. It is a home for nearly 27,016 persons occupying 28 ha (almost 1000 persons/ ha) (Central Agency for Public Mobilization and Statistics CAPMAS, 2017). Land parceling in the area is linear following the former agricultural basin lines. Despite its proximity to the campus of Cairo University, Abu Qatada is bounded by strong physical barriers that isolate the quarter from its surroundings. To the south, the area is demarcated by Abdel-Al Canal, whereas Al-Sudan street, Cairo railway Metro line, and El-Zumour Canal border the area from the east. Besides, all interior streets and alleyways are unpaved, broken, and potholed.

Unlike Abu Qatata, the other two settlements are established on state-owned desert land. Ezbet Bekhit is a hilly area of sharp mountain cliffs accommodating 34,116 inhabitants covering an area of 21.02 ha (about 1600 persons/ ha) (Informal Settlement Development Facility (ISDF), 2016) whereas Ezbet Al-Nasr is built on flat land with 72,190 people living on over 30 ha (nearly 2400 persons/ ha) (Integrated Urbanism and Sustainable Design IUSD, 2013); these highly unusual high population densities imply potentially high local foot traffic upon which many types of businesses depend, The two areas have relatively similar labyrinthine systems of mostly short or crooked narrow streets, mostly unpaved, without sidewalks, going in all directions, with varying widths and irregular subdivisions. These tortuous structures are not just for walking and cycling, but also for commerce and social interaction. The few larger streets are occupied with motorized vehicles, such as tuk-tuks, motorbikes, and cars. Like Abu Qatada, the two areas are in many ways socially and physically separated from their surroundings. The majority of inhabitants are shop salespersons, construction laborers, and machinery mechanics, while others work for the government or in the private sector.

5. Analytical framework

The proposed framework for identifying the influence of spatial accessibility on the opportunities for income-generating activities is composed of four main steps.

First, we conduct space syntax analysis to measure both local accessibility (R400 m) and global accessibility (Rn). Then, following Thai et al. (2019), we combine these two measures into a single map to capture street segments that function as a potential destination for foot traffics and a pathway for vehicular movements. Afterwards, we chose a threshold value for combined 'local and global accessibility' to capture well-used street segments which serve as primary/local main streets. This threshold value was chosen to highlight at least one street block in each case study area as a primary street.

Second, we map out distribution patterns of HBBs in relation to primary streets to extract the overall spatial attitudes and trends of these patterns, i.e. whether they are developed along busy borders and/or internal local streets.

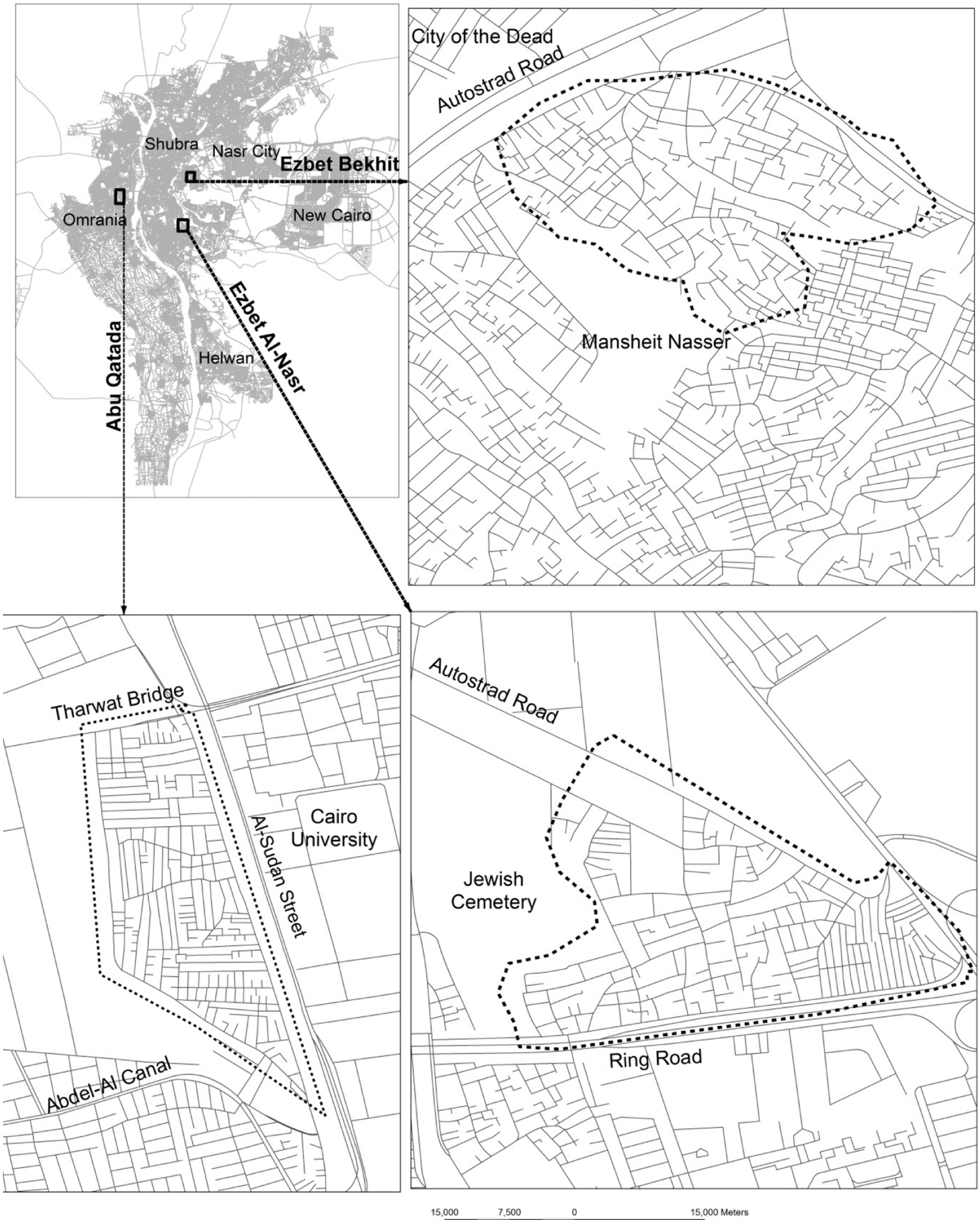

Fig. 1. Case study areas.

Third, we test various regression models to explore the statistical connection between street accessibility and HBBs count per street segment. In order to get trusted regression results, HBBs data must be independent of each other (i.e., randomly distributed). We employ spatial statistics tools in ArcGIS to indicate whether this problem of spatial dependence (usually referred to as spatial autocorrelation) exists. Objects exhibit a clustered pattern (positive spatial autocorrelation) when businesses exist in close proximity to one another, while dispersed pattern (negative autocorrelation) takes place when businesses are spread out from one another. A random pattern (no autocorrelation) exists when objects are neither clustered nor dispersed. If the incidents are clustered or dispersed, then a weighted average of the values at nearby locations must be calculated and controlled to properly measure the relationship between space syntax indexes (independent variables) and HBB observations (an independent variable).

Fourth, we calculate the topological (number of turns) and network metric distances of each HBB from the nearest primary street, or the highest syntactic values, as an indicator of the spatial affordances that the spatial arrangement of pathways provides to different types of HBBs.

5.1. Variables and materials

The density of home-based businesses per street segment is the dependent variable selected for this study whereas a series of space syntax attributes are considered as independent variables. The material sources and calculation methods of the variables are illustrated below.

5.1.1. Dependent variable

Incident data for home-based businesses were collected at a building scale level in 2018 and updated in 2019. Collected HBBs were analyzed at the level of street segments, by aggregating the number of business activities per street segment. As noted, there is a diverse spectrum of business activities in the study areas. Guided by Thai et al. (2019), the different HBB types were categorized into five main groups (Table 1): trade (wholesale and retail establishments); manufacturing (food products, clothing, leather products, metal products, pottery, carpentry, marble workshop); people-oriented services (hairdresser, cafe, food and drink outlets, clinic, consultancy office); goods-oriented services (mobile or car maintenance and or repair, parking lots, storage); and others (mobile stands). As shown below, trade businesses, followed by service categories, are the most prevailing HBB types in the study areas.

5.1.2. Independent variables

5.1.2.1. Street pattern descriptors. The unit of our analysis is the street segments generated from the 'least line axial map' of the City of Cairo. This map consists of a set of the fewest *axial lines* (the longest straight sight-lines that maximally extends until striking a building or other material object) that cover roads, streets, squares, or other spaces of movement. The axial model was created using an official GIS street map which includes all urban blocks and a network of movement spaces. While the axial map represents the longest straight lines that can be drawn through urban pathway systems, street segments are the sections of streets situated between each pair of intersections. Each street segment can be described quantitatively in terms of the degree of connectedness it has with all others in an urban system (Seamon, 2020). The evaluation of street-network configuration be defined by three different types of distance: the metric (shortest path), the topological (the fewest turns), and the geometric/angular (the least angle rotation distance). Segment angular analysis has empirically proven to be the best predictor of different modes of movement, followed closely by topological analysis (Hillier and Iida, 2005).

Table 1
Home-based business types in the study areas.

Business type	Ezbet Bekhit		Ezbet Al-Nasr		Abu Qatada	
	Count	%	Count	%	Count	%
Trade	292	75.06	420	68.40	573	74.42
People-oriented services	66	16.97	52	8.47	61	7.91
Goods-oriented services	21	5.40	119	19.38	114	14.81
Manufacturing	2	0.52	16	2.61	12	1.56
Others	8	2.05	7	1.14	10	1.30
Total	389	100	614	100	770	100

Segment angular syntactic measures can be executed at multiple scales: *global* measures of a place consider the whole pathway system without restriction, while *local* measures restrict the analysis to a defined catchment area (Baran et al., 2008). In terms of space syntax, this is called the radii, which could be angular, topological or metric. For instance, segment angular syntactic analysis at radius *n* meters (the entire street-network system, Rn) can capture global motorized traffic potential and, therefore, corresponds to a large-scale accessibility. On the other hand, the radius 400 m (R400) (also referred to as the '*pedestrian shed*') has shown to be empirically effective in capturing foot traffic within a 5-minute-walking distance and, therefore, would be a more local scale (Al-Sayed et al., 2014; Garau et al., 2020; Mohareb, 2009; Thai et al., 2019; Tran et al., 2015). Following most existing space syntax studies, five explanatory variables are investigated in the current research, and all of them are briefly described next.

Normalized angular integration (NAIN) (Hillier et al., 2012) shows the to-movement potentials/closeness of each street segment from all others, based on the sum of angle deviation distances. In this sense, the most integrated street segments would have the minimal absolute angular turns that are made on each route and vice versa. We executed the analysis at both radius *n* (global integration, NAIN Rn) and radius 400 m (local integration, NAIN R400.

Normalized angular choice (NACH) (Hillier et al., 2012), also known as betweenness, shows how many times each street segment would be part of the straightest/shortest path between all pairs of potential origins and destinations within a predefined distance (radius). The shortest path would have the least angular deviation. In other words, choice refers to the through movement potentials of various scale levels. Global angular choice (NACH Rn) highlights the main route network of cities because these main routes have the least angular deviations to all other street segments in the system. On the other hand, local angular choice at radius 400 m (NACH R400) can contribute to identifying the most vital street segments at a local neighborhood level.

Combined NAIN R400 and NACH Rn (Thai et al., 2019): this index simultaneously highlights the importance a street segment in the settlement and in the entire urban system; while local integration shows how street segments work as a substantial local destination for pedestrians, global choice captures the main route network or global connectors linking potential destinations and various settlements with one another (van Nes, 2021). In other words, the combined measure captures multi-modal and multi-scale movements and, therefore, is essential for wayfinding tasks and other types of functionality such as land use choices (Al-Sayed et al., 2014). This is similar to what Hillier (1996b) called "Intelligibility", the degree to which the local properties of a line indicate the importance of that line in the entire urban system. For brevity, the combined index is hereinafter referred to as INCH.

The above index was also utilized to identify primary/local main streets through dividing the INCH values in the study areas into high, middle, and low value levels using the natural (Jenks) method. Street segments with high INCH values were classified as local main streets, while those attributed to low or middle value classes were identified as alleyways, secondary streets (Thai et al., 2019).

5.1.2.2. Topological and metric step depth. The topological (number of directional changes) and network metric (walking distances) catchment steps from primary streets to HBB activities can be measured to determine if varying travel distances from primary streets have any effects on the types of businesses. Although angular step depth analysis has proven being useful for measuring permeability (van Nes, 2021), it might not be appropriate for visibility analysis at a fine scale level (Thai et al., 2019). For example, in angular analysis we can unify curving streets as one element, even if we cannot see the other end; but in topological such streets would be in several elements/steps of visibility, as opposed to long quasi straight streets. For one, the notion of discreet steps is possible with topological/visual distance, while in angular deviation we would need to define some sort of threshold of what is a step. And with a threshold, angular distance becomes virtually identical to axial step.

5.1.3. Control variables

5.1.3.1. Street segment length. It is a fundamental element of the street-network structure of towns and cities. It might be expected that the properties of different lengths of blocks would affect the number of dwellings and, thus, HBBs found on a street segment. Longer street blocks are likely to have higher number of homes and businesses than shorter ones (Hillier and Sahbaz, 2005; Shafiei, 2007). In other words, street segments with zero observations are expected to be significantly shorter than those with nonzero observations. In order to operationalize the higher observations often found on longer street segments, our statistical models will control for the urban block length. The term used for modeling the length of street segment in regression analysis is exposure (Summers and Johnson, 2017). The exposure variable changes each observation from a count into a rate per length.

5.1.3.2. Spatial lag. A potential problem with incident data is that they may exhibit some locational similarity. Specifically, if neighboring observations have similar values, they would be spatially autocorrelated thus violating the assumption about the independence of residuals (i.e. the difference between an observed and a predicted value) and questioning the validity of standard significance tests. Put another way, p-values and coefficients of the regression models cannot be trusted when spatial correlation exists. Then a weighted variable (spatial lag) must be calculated and controlled to properly examine the relationship between dependent and independent variables.

In this study, we used the Global Moran's I tools in ArcGIS to check whether there is a spatial autocorrelation problem. This tool measures spatial autocorrelation based on feature locations and values (Mitchell, 2005). As an incident data aggregation method, Moran's I mandates providing both points input features and an analysis field. Justifying a specific distance to reflect the scale of analysis was not possible. Consequently, we employed the ArcGIS Optimized Hot Spot Analysis tool which is based on the Getis-Ord Gi* statistics (Ord and Getis, 1995) to automatically compute an optimum polygon cell size, 17 m in our study, to create a fishnet polygon joined with the point dataset. Then each cell polygon was given a numeric attribute based on the sum of the points that fall inside it, and a count field showing how many points in each polygon was specified as an analysis field. Then, the Global Moran's I was given as:

$$I = \frac{n}{\sum_{i=1}^{n} \sum_{j=1}^{n} Wij} \quad \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} Wij \quad (xi - \overline{X})(xj - \overline{X})}{\sum_{i=1}^{n} (xi - \overline{X})^2}$$

Where n is the entire number of features, (x_i - $\overline{X}$) is the deviation of a feature i from its mean, w_{ij} is the spatial weight between feature i and feature j. Positive Moran's I index (maximum=1) means that values cluster together (positive spatial autocorrelation) whereas a negative value (minimum = −1) typically indicates dispersion (negative autocorrelation). Additionally, random dispersion (no autocorrelation) takes place when Moran's I is zero. Overall, the results of the analysis are explained in the context of the null hypothesis which states that the pattern expressed is randomly distributed (spatially uncorrelated). If the returned p-value is statistically significant, then the null hypothesis that the analyzed data is independent or randomly distributed will be rejected (Moran, 1950).

One explanation for data clustering is 'multiplier effect' which describes that businesses will attract more businesses and people to gain the biggest share of the market (Hillier, 1996a). This is also referred to as the 'Hotelling's Law' where similar businesses appear close to other similar businesses as possible in space (Hotelling, 1929).

The present study controls for this issue of spatial dependence in regression models through spatial lag operators. Spatial lag comprises a weighted average of the values at nearby sites (Anselin and Bera, 1998). The spatial lag for a given segment is calculated as follows:

$$SLagi = \sum_{j=1}^{N} \frac{Ci}{dij}$$

where i is the root segment; N is the total count of segments; C_i *is* the number of HBBs on segment j; and d_{ij} is the Euclidean (straight-line) metric distance between the centroids of segments i and j (Summers and Johnson, 2017).

5.2. Statistical analysis

5.2.1. Analysis of Variance (ANOVA)

Statistical testes are conducted to determine whether the differences among various spatial attributes for the study areas are statistically significant. The one-way ANOVA test (Fisher, 1992; Howell, 2002) or Kruskal-Wallis H test (nonparametric ANOVA) (Kruskal, 1952) can be used to make comparisons between more than two groups; the former is often used when the data are not normally distributed, while the latter is generally applied if the assumption of normality distribution is violated. While the Kruskal-Wallis H test compares mean ranks, the one-way ANOVA test assesses the differences among the means. The results of these tests can indicate whether the differences among groups are statistically significant overall, but do not identify where those differences lie. Consequently, if, and only if, there are significant results, then a post-hoc multiple comparison test, namely the Tukey's HSD test (Tukey, 1949), is conducted in order to determine which specific groups are different.

5.2.2. The negative binomial regression models

As noted before, a number of space syntax studies have determined the effect of the street-network structure on the spatial distribution of retail activities. However, these studies have varied significantly in terms of their methodological and analytical approaches. For instance, Omer and Goldblatt (2016) performed traditional linear regression analysis which assumes that the dependent variable is normally distributed. Yet, the dependent variable, the number of retail stores per street segment, is count data that might have an excess of zero counts (i.e. the absence of HBB on many streets); thus it does not necessarily follow a normal distribution. In contrast, in his study, Shafiei (2007) aggregated commercial street segments into 13 "bands" of the similar count of buildings and calculated the actual commercial rate for each band by aggregating all commercial buildings comprising the band and dividing by the gross number of buildings. Grouping segments based on the number of buildings, however, does not control for any logarithmic function that the segment length may exert and, therefore, may significantly smooth the sample thereby normally producing misleading correlation results with fine-resolution datasets (See Summers and Johnson, 2017).

Differently, Shafiei (2013) and Mohamed and van Nes (2017) borrowed the "Lorenz curve", which is widely used to describe the inequality distribution of income and wealth (Lorenz, 1905), in a planar that plots percentiles of commercial buildings according to spatial accessibility. In a typical application of the "Gini coefficient" (Gini, 1912), a mathematical summary of the difference between the hypothetical line presenting maximal equality and the actual line of income distributions(Lorenz curve)', people might have a clear definition of the group they will focus on. In contrast, the aforesaid studies plotted percentiles of accessibility to find the 'lowest accessibility' groups, which might define the group in a fuzzy way, and reduce the reliability of the results especially in small size neighborhoods.

In the present research, the data being analyzed are count data which might not be normally distributed. Count data sometimes have excess zeros where the observed frequency of zero values is uncommonly large. Also, the variance of the count data is usually greater than its mean. In other words, count data tend to exhibit greater variability (statistical dispersion). A zero-inflated negative binomial regression (ZINB) model can be used for over-dispersed count data (Hilbe, 2014).

ZINB models combine two distributions: (1) the negative binomial distribution to model the effects of independent variables on non-zero counts and (2) the logistic (logit) distribution, the inflation model, to model the probability of excess zeros (zero observations vs. nonzero observations) to determine whether or not a space syntax variable indulged in a successful investing activity (Cameron and Trivedi, 1998); put another way, the logit model predicts the probability of being the 'certain-zeros'/structural zeros (likelihood for being a non-commercial street) (He et al., 2014). Vuong test statistics (Vuong, 1989), a likelihood-ratio-based test, is estimated in regression analysis to test whether the zero-inflated model better predicts our dependent variable than the non-zero inflated (standard) model. Significantly positive Vuong statistics favor the ZINB models, whereas significantly negative results favor the standard models.

6. Results

6.1. Spatial characteristics of the study areas

Comparisons between the study areas reveal substantial differences in their spatial properties. As shown in Fig. 2, global choice and integration analyses indicate that the three neighborhoods are located along at least one definable edge which tends to be a freeway, marked in red. The outer active edges offer high vehicular traffic which has been reflected in the development of home-based businesses. While the bordering highways can act as integrators that support residents to keep socio-economic connections with adjoining settlements, some can act as barriers that physically disconnect the wider metropolis by segregating or splitting settlements (Abozied and Vialard, 2020). As expected, the study areas are generally globally isolated (marked in green and blue patches) from the surrounding context by strong physical barriers, such as railways, metro lines, canals and flyovers. For instance, Aub Qatada is largely divorced from its wider urban context by the major barriers of Cairo railway Metro line, El-Zumour Canal and Tharwat flyover. Visual comparisons generally show that Ezbet Bekhit is the most isolated quarter due to steep landform which creates a labyrinth-like street structure with frequent dead-ends. Similar results can be also found for local choice and integration values.

In order to make statistical comparisons between the study areas, we need first to check for the normality assumption to decide which statistical test is more appropriate to use. We found that Syntactic data for our groups violate the assumption of normality that is required for ANOVA, and therefore, we chose Kruskal-Wallis H test instead. The outputs of Kruskal-Wallis statistics point to significant differences among the study areas in all space syntax spatial attributes ($p < 0.05$). Thus, it is meaningful to apply post hoc Tukey's test to identify which specific groups differed (Table 2).

As can be seen from the results of post hoc test in Table 2, there is a statistically significant difference in both global (NAIN Rn) and local integration (NAIN R400) between Abu Qatada and Ezbet Al-Nasr, as well as between Ezbet Al-Nasr and Ezbet Bekhit ($p = 0.000$). Put it simply, Abu Qatada is the most spatially integrated at the city-wide scale, whereas Ezbet Bekhit is the most spatially segregated at both settlement and city levels. Moreover, the mean ranks of NACH Rn for both Abu Qatada and Ezbet Al-Nasr are significantly higher than that for Ezbet Bekhit. These spatial factors affect pedestrian and vehicular movement patterns and, therefore, are prime determinants of the development of HBB, especially at the edges of the settlements (Hillier, 1996a; Hillier et al., 2000). This may explain why Ezbet Bekhit has the lowest number of street segments with HBB as compared to the other two areas. On the other hand, street segment length in Ezbet Bekhit is significantly shorter than that in the other two areas to best fit the difficult topography of the land.

6.2. Distribution patterns of HBBs

As mentioned in Section 5, INCH index was employed to capture primary streets through combining both NAIN R400mNACH Rn measures into a single map (Thai et al., 2019). Then, we divided the output index into high, middle, and low value levels using the natural (Jenks) method. The threshold for the minimum value of INCH for local main streets was at 1.30. This threshold value can highlight at least one main street in each study area. This was in line with the onsite visits of the study areas where many well-used street segments are highlighted in the map. Seemingly, the INCH index is more powerful than the traditional integration core analysis (i.e. a pattern made up of 5%, 10% or 25% most integrating streets, or a given number of street blocks based on the size of the system), because the former can show how street blocks act as both a potential destination for pedestrians and a route for large-scale vehicular traffic flows.

As observed, Fig. 3 shows that Ezbet Bekhit has a lower number of primary streets as compared to the other two settlements. Such streets capture 51.41% of HBBs in Ezbet Bekhit, as compared to 60.71% and 64.38% in Ezbet Al-Nasr and Abu Qatada respectively. Notably, business developments are not confined to the study areas' borders/edges, but dominantly cluster along the internal routes as well. As spatially accessible locations, primary streets host various types of businesses, especially retail trading businesses (e.g., supermarkets) and people-oriented services (e.g. food stalls and cafes). Meanwhile, goods-oriented services, especially car repair workshops, and larger-scale trade establishments, such as building material businesses, are usually found on the busy borders rather than the internal routes. Indeed, these businesses target non-local residents, thus require a stronger direct link to the outside to find clients. It is also easier to transport goods through external routes. In contrast, local groceries and food outlets mostly serve the inner residential blocks and, therefore, show clusters within the internal routes (see Venerandi et al., 2017).

In contrast to trade and various service categories, small-scale manufacturing businesses (e.g., iron-work and carpentry workshops are less observed in the study areas as compared to other types of businesses. Finally, in line with Thai et al. (2019), other uses such as mobile stalls offering fresh foods or drinks are usually found in empty corners where main routes intersect.

6.3. Statistical analysis

6.3.1. Checking for spatial autocorrelation

A potential problem with HBB data is that they might be spatially autocorrelated. A common GIS tool of measuring the level of spatial autocorrelation is the Global Moran's I tool which tests this problem based on both attribute locations and values simultaneously. Calculations for Moran's I and its associated p-value indicates whether or not to reject the null hypothesis which states that the data are spatially uncorrelated. Given the results in Table 3, we reject the null hypothesis at the level 0.1% of confidence. Furthermore, the positive Moran's values indicate that the pattern expressed is clustered. One possible explanation for this clustered pattern is multiplier effects produced by similar businesses on urban movement, which then attract more movement-driven land uses (Hillier, 1996a). As mentioned above, this autocorrelation violates most statistical tests, so it is essential to weight it by including a spatial lag variable in the statistical analysis.

6.3.2. Regression models

To reveal the link between HBB count and street-network accessibility, several ZINB regression models were employed: the baseline one with only one variable, spatial lag, for controlling for problems caused by spatial autocorrelation in our data; the five separate models to

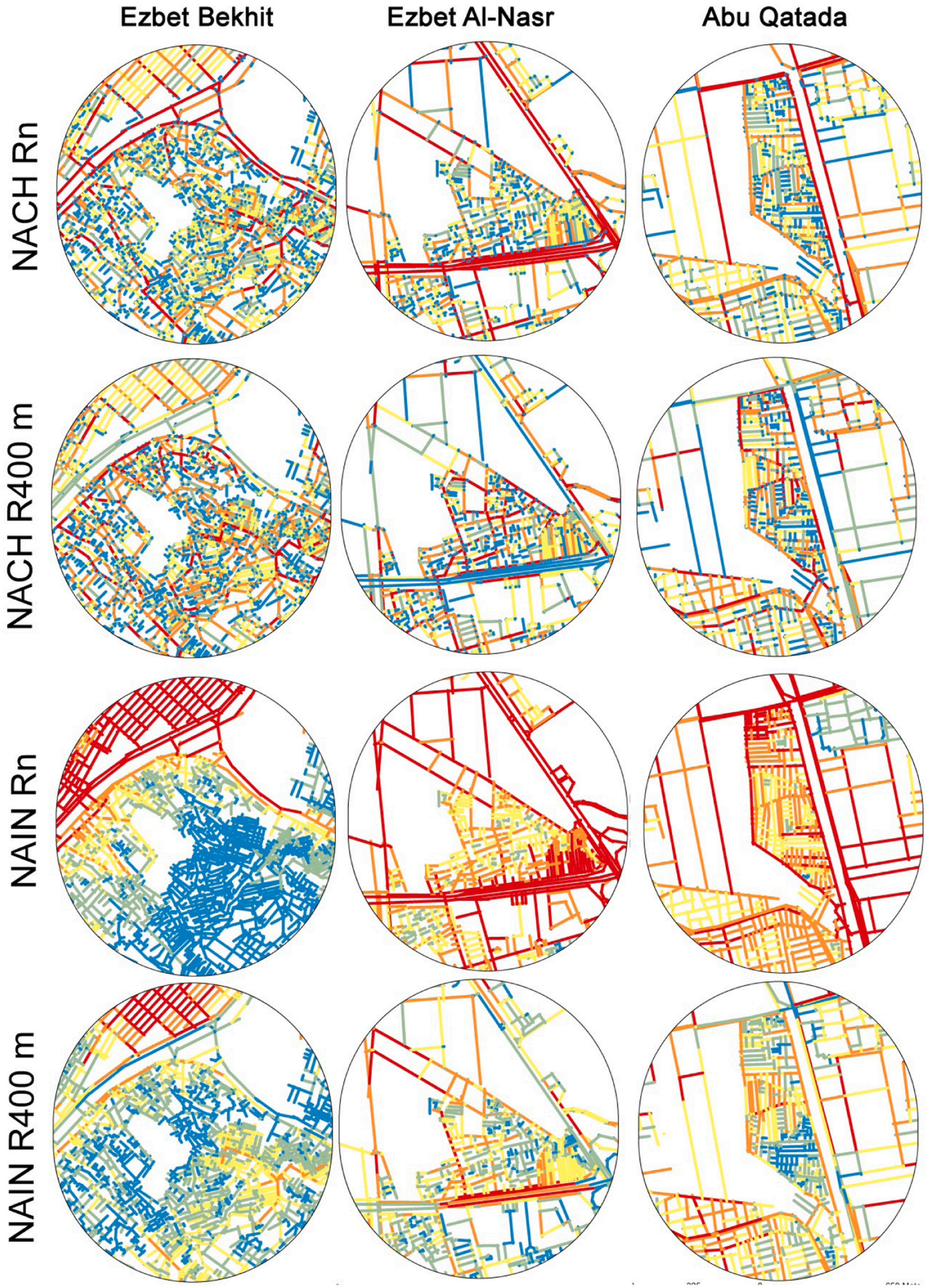

Fig. 2. Space syntax analysis in the study areas, considering that red colors represent higher values while blue ones indicate lower values; NACH = normalized angular choice, NAIN = normalized angular integration.

Table 2
Descriptive statistics for various space syntax spatial attributes in the study areas.

		EB	EN	AQ	Kruskal-Wallis (Sig.)	Tukey's test (Sig.)	
Total number of segments		659	551	516			
Non-residential segments		128	277	244			
NAIN Rn	Mean	.7466	.9161	.9449			
	Mean rank	407.34	1073.68	1221.65	.000*	EB: AQ	0.000*
	Std. Dev.	.1055	.0635	.0740		EB: EN	0.000*
	Min	.5347	.7306	.7099		AQ: EN	0.000*
	Max	.9593	1.1876	1.1822			
NAIN R400m	Mean	.9155	1.1210	1.0631			
	Mean rank	656.36	1043.90	935.41	.000*	EB: AQ	0.000*
	Std. Dev.	.2118	.2473	.2598		EB: EN	0.000*
	Min	.3453	.5342	.4735		AQ: EN	0.000*
	Max	1.4713	1.7788	1.7353			
NACH Rn	Mean	.8214	.8535	.8355			
	Mean Rank	822.97	888.78	888.27	0.029*	EB: AQ	0.025*
	Std. Dev.	.4118	.4040	.4137		EB: EN	0.022*
	Min	.2605	.4090	.1530		AQ: EN	0.987
	Max	1.380	1.4949	1.4950			
NACH R400m	Mean	.9662	1.0143	.9857			
	Mean rank	819.82	905.96	873.94	.009*	EB: AQ	0.064
	Std. Dev.	.4786	.4716	.4822		EB: EN	0.003*
	Min	.5421	.8232	.3487		AQ: EN	0.293
	Max	1.4529	1.4954	1.5579			
Street segment length (meters)	Mean	20.704	29.1813	32.7168			
	Mean rank	731.43	946.52	943.51	.000*	EB: AQ	.000*
	Std. Dev.	14.274	22.0246	35.4922		EB: EN	.000*
	Min	5.0165	6.0063	5.0112		AQ: EN	0.921
	Max	131.8917	154.7302	305.3445			

Notes: EB = Ezbet Bekhit, EN = Ezbet Al-Nasr, AQ = Abu Qatada; NACH = normalized angular choice; NAIN = normalized angular integration; * represents significance at the 0.05 level of confidence.

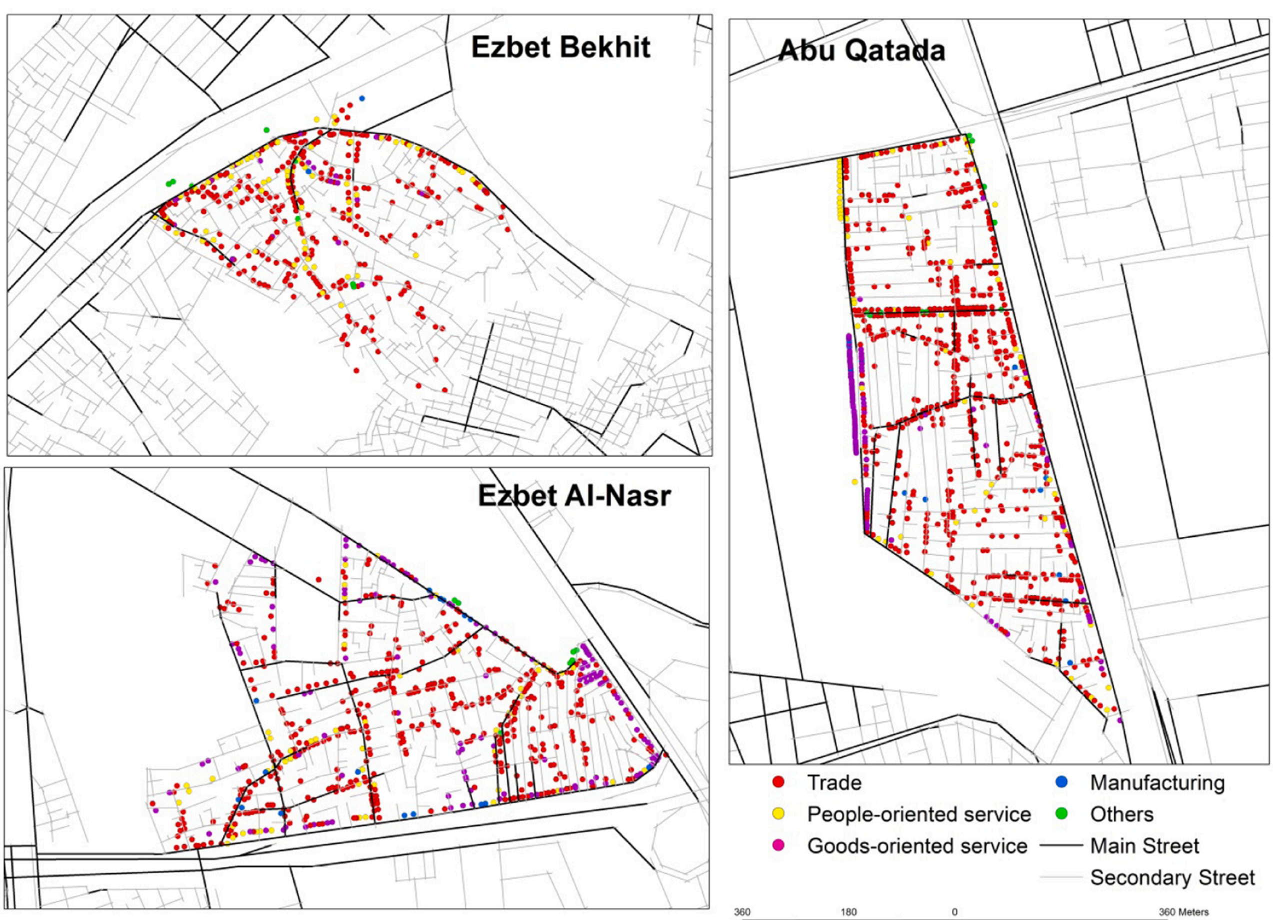

Fig. 3. Locations of home-based businesses and main/secondary streets in the study areas.

Table 3
Results of Moran's I analysis.

	Moran's I index	Expected index	z-score	p-value
Ezbet Bekhit	0.1382***	-0.0049	4.5433	0.000006
Ezbet Al-Nasr	0.1397***	-0.0028	4.1138	0.000039
Abu Qatada	0.1403***	-0.0051	2.5882	0.0096

Notes: * represents significance at the 1% level of confidence.

investigate the influence of each of the space syntax indicators independently after controlling for the effects of the spatial lag variable; and the full model with all the independent variables to simultaneously determine their relative effects on HHBs occurrence.

In the regression analysis, we aggregated the five types of home-based business under one variable because some separate types of business in the study areas were relatively small for a meaningful analysis (e.g. manufacturing type had 18 and 23 parcels in Ezbet Bekhit and Ezbet Al-Nasr respectively).

For all statistical models reported here, the dependent variable is the number of businesses on the street segment; the control variable is the spatial lag; and the exposure variable is segment length. We also used standardized regression coefficients (sCoef.) (Menard, 2004) to determine which of the space syntax attributes (the dependent variables) has a greater effect on HBB count (the dependent variable). In other words, Standardization of the coefficient quantifies the magnitude of the effect. A higher coefficient reveals a stronger influence, and vice versa. Prior to testing the influence of space syntax spatial attributes on HBB count, a baseline model that considered only one predictor, the spatial lag, was assessed (see Table 4). ZINB models were found to be statistically superior to other count models (i.e. standard negative binomial models and Poisson models) in interpreting the spatial distribution of HBBs.

The baseline model (Table 4) shows that neither the standardized coefficient (sCoef.) for the count model, or the log odds in the inflate part were statistically significant in the case of Ezbet Bekhit. This means that street segments adjacent to those segments with (more) HBB count do not necessarily have business activities. In contrast, for Ezbet Al-Nasr and Abu Qatada, the spatial lag variable had a positive and significant effect on HBB count. For instance, in Ezbet Al-Nasr, if spatial lag increased by one unit, the HBB count would be expected to increase by 0.173 per unit of street length, and the log odds of being an excessive zero would decrease by 1.073. In other words, the closer the street segments are to those segments with a higher HBB count, the less likely there would be zero economic activities. This could be a result of the multiplier effects generated on land use choices (Hillier, 1996a).

Table 5 shows the outputs of the five separate models (NACH Rn, NACH R400, NAIN Rn, NAIN R400 and INCH) after weighting the influence of the spatial lag variable. For the variable of NAIN R400, statistically significant coefficients were found in both of Ezbet Bekhit and Abu Qatada. As expected, for the remaining models, significant associations were found either for the predicted count of HBB, or for the log odds of being an excessive zero. Generally speaking, NACH Rn was the best predictor of HBB count followed by NACH R400. For Example, in Ezbet Bekhit NACH Rn (1.21) enjoyed considerably higher standardized coefficient than that for NAIN Rn (0.626), NAIN R400 (0.517), and INCH (0.616). This simply means that a unit increase in the local choice variable would be accompanied by a 1.21 increase in the HBB count per unit of street length, while holding the other variables in the model constant. On the other hand, the results from the logit component of the ZINB model showed that INCH was the most useful for estimating the likelihood of whether or not a street segment has no business. In Ezbet Bekhit and Abu Qatada, the standardized coefficients of INCH are significantly negative which means that as the INCH value increases, probability of no business being captured by that variable decreases. This is in line with our expectations. In contrast (in Ezbet Al-Nasr), the higher the INCH score, the more likely the street segment is a structural zero (i.e., a residential segment).

These findings are fully supported by previous studies in that commercial uses are more probably to take place on street segments with higher local and, or global-scale street accessibility (Omer and Goldblatt, 2016; Porta et al., 2012; Scoppa and Peponis, 2015).

The full model with all independent variables can simultaneously estimate their relative effects on HBB count. Due to multicollinearity problems, all space syntax variables were initially not significant neither in the count part, nor in the inflate part of this model. We eliminated this problem through omitting two highly correlated variables (i.e. NACH Rn and NACH R400). All remaining variables in the final model passed both correlation analysis and variance inflation factor (VIF) examinations.

The results from the final model demonstrated that predicted HBB count was significantly positively associated with INCH in both Ezbet Bekhit, and Ezbet Al-Nasr (Table 6). In other words, economic activities were largely agglomerated along street segments with higher INCH values, which tend to be local main streets (i.e. key local destinations with high rates of large scale passing movement). Additionally, NAIN Rn was only significantly positively associated with predicted HBB count in Abu Qatada. One possible explanation of this is that major nodes such as the metro station of Cairo University on the area's outward facing edges function as major global destinations for people and therefore encourage developing business activity. On the other hand, NAIN R400 was neutral in predicting HBB count in the full model. Finally, the logit part of the ZINB model showed that those segments affected positively by NAIN R400 had a significant higher probability of being in the 'certain-zero' group.

In other words, street blocks adjacent to these main streets are expected to have more economic opportunities than those located further away from.

Although regression analysis commonly confirms the relationships between street design and economic activities, further analysis is needed to examine more closely the proximity of different types of businesses to key routes, which supply potential customers. In other words, the next section attempts to examine the influence of both topological and network metric proximity to local main streets on the choice of business type.

Table 4
Standardized coefficients of the baseline zero-inflated negative binomial.

	Ezbet Bekhit			Ezbet Al-Nasr			Abu Qatada		
	sCoef.	St Err.	P>|z|	sCoef.	St Err.	P>|z|	sCoef.	St Err.	P>|z|
Count									
Spatial lag	.2776	.1638	0.090	0.1725*	0.0669	0.010	.1859*	.0814	0.022
Inflate									
Spatial lag	-1.8227	.9986	0.068	-1.073*	0.4179	0.010	-1.775**	.6727	0.008
	Likelihood-ratio test of alpha = 0: chibar2(01) = 19.62 Pr> = chibar2 = 0.0000Vuong test of zinb vs. standard negative binomial: z = 2.60 Pr>z = 0.0046			Likelihood-ratio test of alpha = 0: chibar2(01) = 16.57 Pr> = chibar2 = 0.000Vuong test of zinb vs. standard negative binomial: z = 2.12 Pr>z = 0.0171			Likelihood-ratio test of alpha = 0: chibar2(01) = 23.92 Pr> = chibar2 = 0.000Vuong test of zinb vs. standard negative binomial: z = 1.85 Pr>z = 0.0321		
	The Vuong tests (Vuong, 1989) in all study areas are significantly positive suggesting that the ZINB models are better than standard negative binomial models.								

Notes: * and ** represents significance at the 5% and 1% levels of confidence respectively.

Table 5
Standardized coefficients of the negative binomial model with spatial lag as control variable and segment length as exposure variable, with five separate models for each syntactic measure.

Model	A			B			C			D			E		
	NACH Rn			NACH R400m			NAIN Rn			NAIN R400m			INCH		
	sCoef.														
	EB	EN	AQ	EB	EN	AQ	EB	EN	AQ	EB	EN	AQ	EB	EN	AQ
Count															
Space syntax measure	1.2068***	.4771***	1.017***	1.5599***	.5296***	.7831***	.6260***	.1700*	.793***	.5170***	.2066	1.5983***	.6163***	.4860***	.8205***
Spatial lag	.4593***	.1894**	.2174**	.2929**	.1686**	.1722*	.2230*	.2292**	.5016***	.2691*	.2453***	.0723	.3887***	.2839***	.1567*
Inflate															
Space syntax measure	-.8617*	.3335	-.3811	-.3630	.2331	-1.2491	-.5014*	-.8246	.1870	-.3802*	-.6286	-9.918*	-.774***	1.5213*	-1.317*
Spatial lag	-.8862***	-1.233**	-2.004**	-1.145***	-1.295**	-1.841**	-.5604**	-.9707**	-.4470	-.949***	-.9671**	-3.741*	-.856***	-1.6801**	-2.052**

Notes: EB = Ezbet Bekhit, EN = Ezbet Al-Nasr, AQ = Abu Qatada; NACH = normalized angular choice; NAIN = normalized angular integration; *$p < .05$, **$p < .01$, ***$p < .001$. The Vuong tests also suggested that the zero-inflated negative binomial models were a significant improvement over standard negative binomial models.

Table 6
Standardized coefficients (sCoef.) of the full negative binomial model.

	Ezbet Bekhit		Ezbet Al-Nasr		Abu Qatada	
	sCoef.	P>|z|	sCoef.	P>|z|	sCoef.	P>|z|
Count						
INCH	.7141*	0.021	.3899***	0.000	.1522	0.505
NAIN Rn	-.3414	0.179	.1279	0.076	6.141***	0.000
NAIN R400	.14325	0.626	.0284	0.765	.5422	0.202
Spatial lag	.4281***	0.000	.3040***	0.000	.3440***	0.000
Inflate						
INCH	-1.5522**	0.003	2.6662	0.228	-2.1587	0.281
NAIN Rn	-.6676	0.081	-.6125	0.482	6.933	0.064
NAIN R400	1.1795*	0.011	-.3132	0.817	-2.080	0.103
Spatial lag	-.6989*	0.010	-1.7769**	0.001	-3.6603	0.106

Notes: NACH = normalized angular choice; NAIN = normalized angular integration; *$p < .05$, **$p < .01$, ***$p < .001$. Likelihood-ratio tests of alpha = 0 verified that the negative binomial was more appropriate than the Poisson model. The Vuong tests also demonstrated that the zero-inflated negative binomial models were a significant improvement over standard negative binomial models.

6.4. Distribution patterns of HBBs using topological and metric step depth

This section uses both topological and metric step distances to examine whether varying distances from HBBs to the nearest primary streets have any effects on the types of businesses.

The scatterplots shown in Fig. 4 demonstrate how business types are topologically and metrically distributed in relation to the nearest local main streets. HBBs operated entirely on-ground floor spaces of the study areas. In Ezbet Bekhit, nearly two-fifths of economic activities opened directly onto main streets and almost one-third were within one directional change and less than 75 network meters away from local main streets. The most syntactically segregated activity was located 7 turns and 324 network meters from the nearest main street. In Ezbet Al-Nasr, nonetheless, 67.4% of HBBs were located less than two turns from their nearest main street while the deepest business was no more than three turns and 175 m away. Finally, about 99% of businesses in Abu Qatada were within two turns and less than 165 m from their closest main street.

As can be seen in Table 7, Abu Qatada commonly had the smallest mean topological and metric distances for various HBBs from the nearest local main streets as compared to Ezbet Al-Nasr and Ezbet Bekhit. A Kruskal-Wallis H test yielded significant variation among the study areas, $p < 0.05$. Pairwise comparisons using post hoc Tukey test showed that various HBBs types in Ezbet Bekhit and Abu Qatada settlements differed significantly ($p < 0.05$) in terms of both topological and metric proximity to primary streets. In contrast, Ezbet Al-Nasr was not significantly different from Ezbet Bekhit in terms of goods-oriented activities. Moreover, Abu Qatada was not significantly different from Ezbet Al-Nasr with regard to people-oriented activities. Overall, HBBs in Abu Qatada were topologically and metrically closer to the local main streets, as compared to the other two areas. In other words, these businesses were more spatially distributed and sorted in Abu Qatada. These results extend and confirm the findings of the previous studies of an association of homed-based economic opportunities and urban morphologies (Hillier, 1996a; Thai et al., 2019). Finally, topological distance was commonly better than network metric distance in revealing HBBs differences among the study areas.

The evidence from the three settlements confirms that various types of business opportunities in the study areas are shaped by the possible volume of pedestrian and vehicular traffic (Hillier, 1996a). In contrast, business activities tend to be scarce and selective in less accessible locations, such as laneways. As an example, storage spaces are usually found in very isolated locations with less exposure to foot traffic. Those living on these locations depend on lower rates of local traffic to run their businesses. While these businesses do not necessarily follow the theory of natural movement, they might be driven by other potential

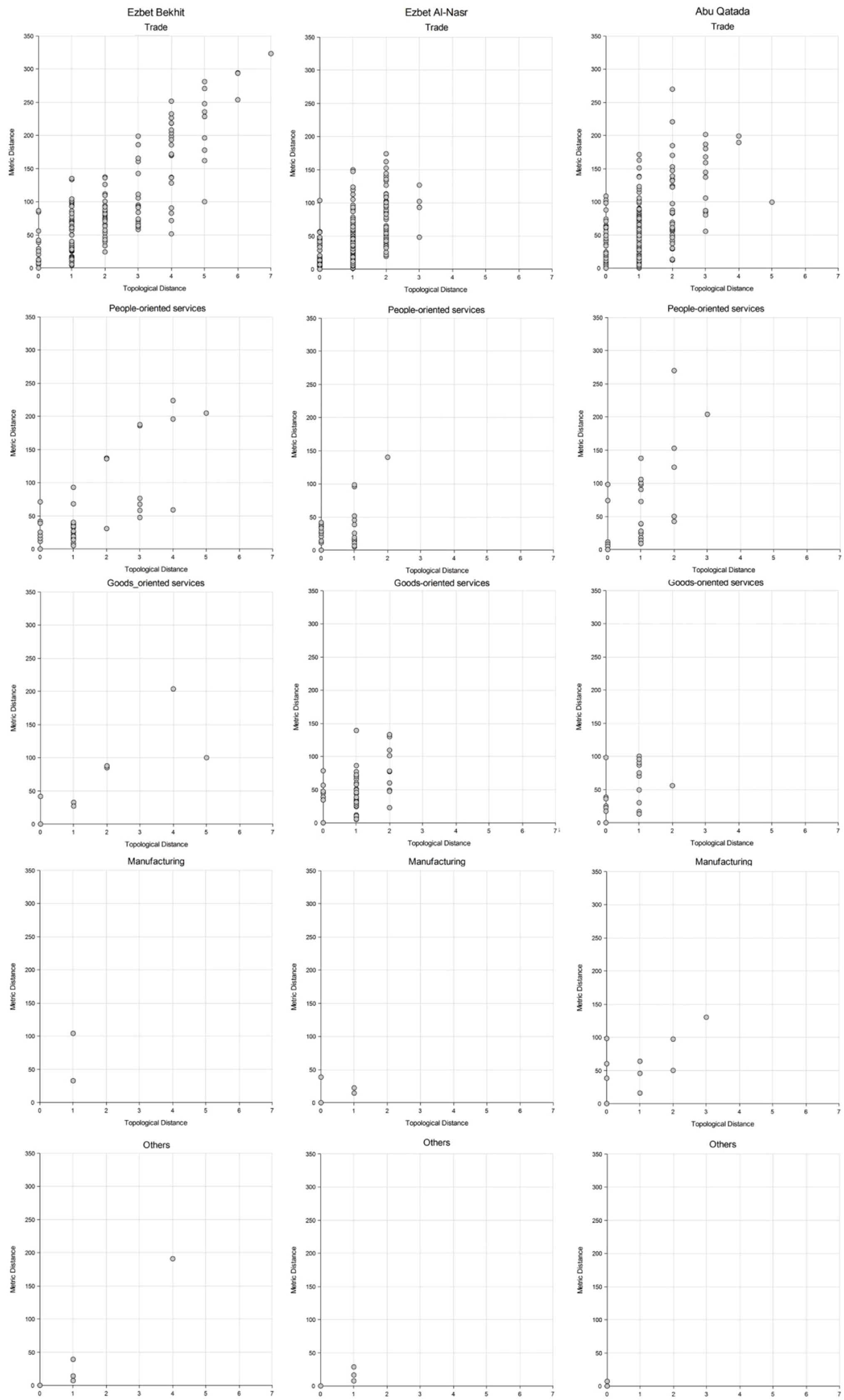

Fig. 4. The topological and network metric proximity of various types of HBBs from the dwelling to the local main street for the three study areas.

Table 7
Descriptive statistics and multiple comparisons for topological and metric distances for various types of businesses in the study areas.

		Topological Distance						Metric Distance					
		EB	EN	AQ	Kruskal- Wallis (Sig.)	Pairwise Comparisons (Adj. Sig.)		EB	EN	AQ	Kruskal- Wallis (Sig.)	Pairwise Comparisons (Adj. Sig.)	
Goods-oriented services	Mean	0.9047	0.7563	0.1667		EB: EN	0.613	33.7004	41.9616	49.9421			
	Mean rank	143.36	153.92	97	0.000	EB: AQ	0.006	103.33	123.69	135.93	0.118		
	Std. Dev.	1.3749	0.7245	0.3973		EN: AQ	0.000	5.0164	3.8861	4.4757			
People-oriented services	Mean	0.9848	0.3846	0.4754		EB: EN	0.020	41.8508	20.7115	30.2319		EB: EN	0.089
	Mean rank	103.41	80.42	83.66	0.011	EB: AQ	0.046	103.91	83.88	80.16	0.0154	EB: AQ	0.021
	Std. Dev.	1.2464	0.5654	0.7212		EN: AQ	1.000	56.3379	32.7142	55.6635		EN: AQ	1.000
Trade	Mean	1.43	0.81	0.70		EB: EN	0.001	66.4879	38.9123	43.5731		EB: EN	0.001
	Mean rank	746.98	649.25	585.43	0.000	EB: AQ	0.000	725.46	621.93	616.42	0.000	EB: AQ	0.000
	Std. Dev.	1.570	0.781	0.875		EN: AQ	0.012	72.2434	38.4064	51.9645		EN: AQ	1.000

Notes: EB = Ezbet Bekhit, EN = Ezbet Al-Nasr, AQ = Abu Qatada.

attractors such as high building density and the like.

7. Conclusions

This article has examined the association between street layouts and HBB, using a zero-inflated negative binomial regression analysis of Cairo's informal areas blocks and employing both spatial statistics approaches and space syntax measures of street accessibility. When each space syntax variable was investigated independently in a separate model, all measures, including NACH Rn, NACH R400, NAIN Rn, NAIN R400an INCH, were found to be positively related to HBB count. In other words, more accessible streets were more likely to have higher numbers of economic activities. Furthermore, it was also found that the INCH index could add significantly to explaining economic functional capabilities of paths and alleyways. While multicollinearity undermined the statistical power of the analysis, and made it difficult to investigate the unique effect of each syntactical variable simultaneously, the full model confirmed that the HBB count was best explained by the INCH index, which captures local and global scale movement flows.

The results demonstrated that Ezbet Bekhit was less successful than both Ezbet Al-Nasr and Abu Qatada in attracting more business activities. Ezbet Bekhit had significantly shorter and denser street segments and was more globally and locally spatially segregated than the other two cases. In addition, Ezbet Bekhit had the fewest number of local main streets, which were largely found on the settlement's borders; nonetheless, home-based economic opportunities penetrated the internal spatial structure of the area to meet the daily needs of local inhabitants. In contrast, local main streets in the other two cases were distributed on both the edge and the internal structure. These findings substantiate the significance of street-network configuration to economic potentials. In a nutshell, local central streets attract capital and foster the flourishing of investment opportunities due to the good volumes of both people and vehicles; in contrast, alleyways are usually visually and spatially poorly accessible, and therefore, suit a certain type business opportunities which become scarce and selective. This diverges from traditional businesses in more connected, accessible locations.

Confirming the second hypothesis of this article, movement-seeking activities (e.g. retail establishments) were encouraged along the main street and segments nearby, whereas very isolated locations (e.g. laneways and dead ends) were used for workshops and other uses that do not require direct customer contact. These findings would serve to support informed planning decisions on developers' and cities' economic investments. For instance, amenities, major retail establishments, goods-oriented businesses, and offices can be developed through the settlement's outward facing edges, global thoroughfares, to participate in wider local economy. At the other extreme of the spectrum are local retail buildings and the like that can be located through the more local routes to achieve a smooth hierarchy in transaction from public to private spheres. In addition, homestay businesses and working places receiving fewer numbers of customers such as factories, headquarters and laboratories can be placed at less accessible streets.

Our findings, however, are partial and limited to the distinctive urban character of the case study areas. Nevertheless, the three settlements' organic urban morphologies and high density are similar to many slum areas in the global South and therefore statistical results could parallel a close trend in developing-world cities. Future empirical investigations should examine the degree to which these findings exist elsewhere. Another limitation is that the current research did not test the impact of other causal factors of economic activities such as building typologies (Narvaez et al., 2014; Thai et al., 2019), building heights (Ratti, 2004), and other urban design qualities (Hamidi et al., 2020) due to data unavailability. Also, the spatial lag variable was computed in this study based on Euclidean distance rather than network metric distance. While these limitations might question the applicability of the analysis results and conclusions, they call for additional empirical studies where there are data available for other variables.

There are numerous future research avenues. First, this article mainly considered space syntax metrics to test the effects of street network pattern on the distribution of economic activities. Utilizing tools that can combine space syntax measurements with conventional measurements of attraction can be considered for future research (Marcus et al., 2019). Also, there are undoubtedly other morphological properties of the built environment that could have a wide range of socio-economic implications and, therefore, could be explicitly included in future work. For instance, urban design qualities such as building density, "transparency" of building facades, length of frontage, number of entrances, openness, imageability, proximity of bus stops and underground stations, and numerous others could have the potential to impact various business activities. Second, further qualitative research about the typology of commercial-residential households may direct research as well. Finally, conducting complementary qualitative methods such as in-depth interviews and focus groups could properly explain the social logic behind the typological pattern of businesses and their spatial distribution.

In summary, experiences of people can often teach us more about optimal land use planning than official practices. Overall, business-owners/home buyers, planners, urban designers, and policymakers should consider the knowledge of visual and spatial accessibility characteristics of different types of economic activities. Our results could inform urban development practices not only in informal areas and the like, but also in planned places. The lesson learned from the study areas in this article is that different open spaces relate to different economic potentials that should be taken into consideration. Choosing the appropriate land use regulations can pave the way to a more sustainable economy that fits individuals' skills, financial abilities and available spaces.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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References

Abozied, E., Vialard, A., 2020. Reintegrating informal settlements into the Greater Cairo Region of Egypt through the regional highway network. Null 7, 333–345. https://doi.org/10.1080/21681376.2020.1804443.

AfDB, 2016. North Africa-Working paper-Addressing informality in Egypt. AfDB.

Akiyode, A., 2017. Spaces of the Informal Economy: Reimagining Street Trading Through Accessibility Distribution Analyses in Lagos (Ph.D. Thesis). Cardiff University, Cardiff.

AL-Ghatam, W., 2009. The village and the city: a diagnostic study of the spatial embedding patterns in villages absorbed by cities in Bahrain. In: Presented at the 7th International Space Syntax Symposium, Royal Institute of Technology (KTH), Stockholm.

Al-Sayed, K., Turner, A., Hillier, B., Iida, S., Penn, A., 2014. Space syntax methodology. Bartlett School of Architecture, UCL, London.

Anselin, L., Bera, A., 1998. Spatial dependence in linear regression models with an application to spatial econometrics. In: Ullah, A., Giles, D.E.A. (Eds.), Handbook of Applied Economics Statistics. CRC Press, New York.

Baran, P.K., Rodríguez, D.A., Khattak, A.J., 2008. Space syntax and walking in a new urbanist and suburban neighbourhoods. J. Urban Des. 13, 5–28. https://doi.org/10.1080/13574800701803498.

Benjamin, N., Beegle, K., Recanatini, F., Santini, M., 2014. Informal Economy and the World Bank (Policy research working paper No. 6888). The World Bank. ⟨https://doi.org/10.1596/1813–9450-6888⟩.

Breen, J., 2010. Gender differences in home-based business ownership. Small Enterp. Res. 17, 124–136. https://doi.org/10.5172/ser.17.2.124.

Cameron, A.C., Trivedi, P.K., 1998. Regression Analysis of Count Data. Cambridge University Press, Cambridge.

Central Agency for Public Mobilization and Statistics (CAPMAS), 2017. Census of Egypt 2017. Nata'ij al-ta'dad al-'am li-l-sukkan wa-al-munsh'at [headcounts for Census enumerations districts (shiyakhat and qura) of Egypt's governorates]. Cairo, Egypt.

Chiaradia, A., Hillier, B., Schwander, C., Wedderburn, M., 2012. Compositional and urban form effects on centres in Greater London. Proc. Inst. Civ. Eng. Urban Des. Plan. 165, 21–42. https://doi.org/10.1680/udap.2012.165.1.21.

Crosbie, T., Moore, J., 2004. Work–life balance and working from home. Soc. Policy Soc. 3, 223–233. https://doi.org/10.1017/S1474746404001733.

Desyllas, J., 2000. The Relationship Between Urban Street, Configuration and Office Rent Patterns in Berlin (Ph.D. thesis). The Bartlett, University College London, London, UK.

Dovey, K., van Oostrum, M., Chatterjee, I., Shafique, T., 2020. Towards a morphogenesis of informal settlements. Habitat Int. 104, 102240 https://doi.org/10.1016/j.habitatint.2020.102240.

Dwelly, T., Maguire, K., Truscott, F., Thompson, L., 2005. Under The Radar: Tracking and supporting rural home-based business. Live Network Report to the Commission for Rural Communities, London, UK.

El Mahdi, A., 2010. Poverty and informality: a restraining or constructive relationship?, J. Labor Demogr. Econ. Economic Research Forum (ERF), Cairo, Egypt.

El, Mahdi, A., 2002. The labor absorption capacity of the informal sector in Egypt. In: Assaad, R. (Ed.), The Egyptian Labor Market in an Era of Reform. The American University in Cairo Press, Cairo.

Elshamy, H.M., 2014. Measuring the informal economy in Egypt. In: International Research Conference on Business, Economics and Social Sciences. Presented at the IRC-2014, International Organization for Research and Development – IORD, Dubai, pp. 167–179.

El-Sharnoubi, O., 2019. Some people prefer working in the shadows. Mada Masr.

Fisher, R.A., 1992. Statistical methods for research workers. In: Kotz, S., Johnson, N.L. (Eds.), Breakthroughs in Statistics: Methodology and Distribution, Springer Series in Statistics. Springer, New York, NY, pp. 66–70. https://doi.org/10.1007/978-1-4612-4380-9_6.

Garau, C., Annunziata, A., Yamu, C., 2020. A walkability assessment tool coupling multi-criteria analysis and space syntax: the case study of Iglesias, Italy. Eur. Plan. Stud. 0, 1–23. https://doi.org/10.1080/09654313.2020.1761947.

Gehl, J., 1989. A changing street life in a changing society. Places 6, 8–17.

Gini, C., 1912. Variabilità e mutabilità contributo allo studio delle distribuzioni e delle relazioni statistiche. Tipogr. di P. Cuppini, Bologna.

Greene, M., 2003. Housing and community consolidation in informal settlements: a case of movement economy. In: Hanson, J. (Ed.), Presented at the 4th International Space Syntax Symposium. University College London, London, 38-24.

Hamidi, S., Bonakdar, A., Keshavarzi, G., Ewing, R., 2020. Do Urban Design qualities add to property values? An empirical analysis of the relationship between Urban Design qualities and property values. Cities 98, 102564. https://doi.org/10.1016/j.cities.2019.102564.

Han, Z., Cui, C., Miao, C., Wang, H., Chen, X., 2019. Identifying spatial patterns of retail stores in road network structure. Sustainability 11, 1–20, 4539(1–20).

He, H., Tang, W., Wang, W., Crits-Christoph, P., 2014. Structural zeroes and zero-inflated models. Shanghai Arch. Psychiatry 26, 236–242. https://doi.org/10.3969/j.issn.1002-0829.2014.04.008.

Hilbe, J.M., 2014. Modeling Count Data. Cambridge University Press, New York.

Hillier, B., 1996a. Cities as movement economies. Urban Des. Int. 1, 41–60. https://doi.org/10.1057/udi.1996.5.

Hillier, B., 1996b. Space is the machine: a configurational theory of architecture. Space Syntax, London, UK.

Hillier, B., Greene, M., Desyllas, J., 2000. Self-generated Neighbourhoods: the role of urban form in the consolidation of informal settlements. Urban Des. Int. 5, 61–96. https://doi.org/10.1057/palgrave.udi.9000018.

Hillier, B., Iida, S., 2005. Network effects and psychological effects: a theory of urban movement. In: Proceedings of the 5th International Symposium on Space Syntax. TU Delft Delft, pp. 553–564.

Hillier, Bill, Hanson, Julienne, 1984. The Social Logic of Space. Cambridge University Press, Cambridge.

Hillier, B., Penn, A., Hanson, J., Grajewski, T., Xu, J., 1993. Natural movement: or, configuration and attraction in urban pedestrian movement. Environ. Plan. B Plan. Des. 20, 29–66 https://doi.org/10.1068%2Fb200029.

Hillier, B., Sahbaz, O., 2005. High resolution analysis of crime patterns in urban street networks: an initial statistical sketch from an ongoing study of a London borough. In: Presented at the 5th International Space Syntax Symposium, Delft University of Technology, Delft. ⟨https://pdfs.semanticscholar.org/cb08/00eabb296574ac9266bb10ef3310e96d9c0c.pdf⟩.

Hillier, B., Yang, T., Turner, A., 2012. Normalising least angle choice in Depthmap - and how it opens up new perspectives on the global and local analysis of city space. J. Space Syntax 3, 155–193. ⟨http://joss.bartlett.ucl.ac.uk/journal/index.php/joss/article/view/141/pdf⟩.

Hotelling, H., 1929. Stability in competition. Econ. J. 39, 41–57. https://doi.org/10.2307/2224214.

Howell, D.C., 2002. Statistical methods for psychology. Pacific Grove, CA: Duxbury/Thomson Learning.

Informal Settlement Development Facility (ISDF), 2016. The strategic master plan for upgrading Mansheit Nasser area (No. 1). Ministry of Housing, Utilities and Urban Communities (MOHUUC), Cairo.

Integrated Urbanism & Sustainable Design (IUSD), 2013. Integrated site analysis: the case of Ezzbet Al-Nasr. IUSD- Ain Shams University, Cairo.

Jacobs, J., 1961. The death and life of great American cities. Random House, New York.

Jenks, M., Kozak, D., Takkanon, P. (Eds.), 2013. World Cities and Urban Form: Fragmented, Polycentric, Sustainable. Routledge, Abingdon.

Khalifa, M.A., 2015. Evolution of informal settlements upgrading strategies in Egypt: from negligence to participatory development. Ain Shams Eng. J. 6, 1151–1159. https://doi.org/10.1016/j.asej.2015.04.008.

Kruskal, W.H., 1952. A nonparametric test for the several sample problem. Ann. Math. Stat. 23, 525–540. https://doi.org/10.1214/aoms/1177729332.

Lorenz, M.O., 1905. Methods of measuring the concentration of wealth. Publ. Am. Stat. Assoc. 9, 209–219.

Marcus, L., Berghauser Pont, M., Danial, K., Stavroulaki, G., Bobkova, E., 2019. Place Syntax Tool.

Menard, S., 2004. Standardized regression coefficients. In: Lewis-Beck, M., Bryman, A., Futing Liao, T. (Eds.), The SAGE Encyclopedia of Social Science Research Methods. Sage Publications, Inc, Thousand Oaks, CA. https://doi.org/10.4135/9781412950589.n959.

Mitchell, A., 2005. Esri Press | The ESRI Guide to GIS Analysis, Volume 2 | Spatial Measurements and Statistics. ESRI Press, Redlands, CA.

Mohamed, A.A., van Nes, A., 2017. Spatial accessibility and commercial land use patterns planned versus unplanned areas in Cairo. Presented at the 11th International Space Syntax Symposium. Instituto Superior Técnico, Lisbon, pp. 94.1–94.18.

Mohareb, N.I., 2009. Street morphology and its effect on pedestrian movement in historical Cairo. Cogn. Process. 10, 253–256.
Montgomery, J., 1998. Making a city: urbanity, vitality and urban design. J. Urban Des. 3, 93–116. https://doi.org/10.1080/13574809808724418.
Moran, P.A.P., 1950. Notes on continuous stochastic phenomena. Biometrika 37, 17–23. https://doi.org/10.2307/2332142.
Nagati, O., Stryker, B., 2013. Archiving the City in Flux: Cairo's Shifting Landscape Since the January 25th Revolution. Cluster, Cairo.
Narvaez, L., Penn, A., Griffiths, S., 2014. The social and economic significance of urban form: a configurative thinking using bid rent theory. In: Cavallo, R., Komossa, S., Marzot, N., Pont, M.B., Kuijper, J. (Eds.), New Urban Configurations. Delft University Press, Delft.
Omer, I., Goldblatt, R., 2016. Spatial patterns of retail activity and street network structure in new and traditional Israeli cities. Urban Geogr. 37, 629–649. https://doi.org/10.1080/02723638.2015.1101258.
Omer, I., Goldblatt, R., 2012. Urban spatial configuration and socio-economic residential differentiation: the case of Tel Aviv. Comput. Environ. Urban Syst. 36, 177–185. https://doi.org/10.1016/j.compenvurbsys.2011.09.003.
Ord, J.K., Getis, A., 1995. Local spatial autocorrelation statistics: distributional issues and an application. Geogr. Anal. 27, 286–306. https://doi.org/10.1111/j.1538-4632.1995.tb00912.x.
Ortiz-Chao, C., Hillier, B., 2007. In search of patterns of land-use in Mexico City using logistic regression at the plot level. In: Presented at the 6th International Space Syntax Symposium, ITU Faculty of Architecture, Istanbul. ⟨http://www.spacesyntaxistanbul.itu.edu.tr/papers.htm⟩.
Pacione, M., 2001. Urban Geography. A global perspective. Routledge, Abingdon.
Porta, S., Latora, V., Wang, F., Rueda, S., Strano, E., Scellato, S., Cardillo, A., Belli, E., Càrdenas, F., Cormenzana, B., Latora, L., 2012. Street centrality and the location of economic activities in Barcelona. Urban Stud. 49, 1471–1488. ⟨https://journals.sagepub.com/doi/10.1068/b34098⟩.
Porta, S., Strano, E., Iacoviello, V., Meassora, R., Latora, V., Cardillo, A., Wang, F., Scellato, S., 2009. Street centrality and densities of retail and services in Bologna, Italy - Sergio Porta, Emanuele Strano, Valentino Iacoviello, Roberto Messora, Vito Latora, Alessio Cardillo, Fahui Wang, Salvatore Scellato, 2009. Environ. Plan. B Plan. Des. 36, 450–465 https://doi.org/10.1068%2Fb34098.
Ratti, C., 2004. Space syntax: some inconsistencies. Environ. Plan. B Plan. Des. 31, 487–499 https://doi.org/10.1068%2Fb3019.
Scoppa, M.D., Peponis, J., 2015. Distributed attraction: the effects of street network connectivity upon the distribution of retail frontage in the City of Buenos Aires. Environ. Plan. B Plan. Des. 42, 354–378. https://doi.org/10.1068/b130051p.
Seamon, D., 2020. In Memoriam: Bill Hillier (1937–2019). Rev. Morfol. Urbana 31, 6–9.
Sevtsuk, A., 2010. Path and Place: A Study of Urban Geometry and Retail Activity in Cambridge and Somerville, MA (Ph.D. Thesis). Massachusetts Institute of Technology.
Shafiei, K., 2013. The Fragmented Morphology of Spontaneous Settlements: The Case Study Cities of Jeddah (Saudi Arabia) and Zahedan (Iran) (Ph.D. Thesis). University College London, London.
Shafiei, K., 2007. Internal Commercial Streets and The Consolidation of large Informal Neighbourhoods: the case of Zahedan, Iran. In: Presented at the 6th International Space Syntax Symposium, ITU Faculty of Architecture, Istanbul.
Shehayeb, D.K., 2011. Community-oriented activity patterns. Shehayeb CONSULT & Urban Regeneration Project for Historic Cairo (URHC), Cairo.
Sims, D., 2010. Cairo: The Logic of a City Out of Control. American University Press. Find this resource, Cairo.
Singerman, D., 1996. Avenues of Participation: Family, Politics, and Networks in Urban Quarters of Cairo. Princeton University Press, New Jersey.
Smit, E., Donaldson, R., 2011. The home as informal business location: home-based business (HBB) dynamics in the medium-sized city of George. Town Reg. Plan. 59, 24–33.
Strassmann, W.P., 1987. Home-based enterprises in cities of developing countries. Econ. Dev. Cult. Change 36, 121–144. https://doi.org/10.1086/451639.
Summers, L., Johnson, S.D., 2017. Does the configuration of the street network influence where outdoor serious violence takes place? Using space syntax to test crime pattern theory. J. Quant. Criminol. 33, 397–420. https://doi.org/10.1007/s10940-016-9306-9.
Thai, H.M.H., Stevens, Q., Rogers, J., 2020. The evolution of pathways linking main streets and marketplaces to home-based business locations in Hanoi, Vietnam. J. Urban. Int. Res. Place. Urban Sustain. 1–27. https://doi.org/10.1080/17549175.2020.1858444.
Thai, H.M.H., Stevens, Q., Rogers, J., 2019. The influence of organic urban morphologies on opportunities for home-based businesses within inner-city districts in Hanoi, Vietnam. J. Urban Des. 24, 926–946.
Tipple, A.G., 1993. Shelter as workplace: a review of home-based enterprise in developing countries. Int. Labour Rev. 132, 521–539.
Tran, M.T., Chikaraishi, M., Pham, Q.H., Zhang, J., Fujiwara, A., 2015. Effects of perceived neighborhood walkability on mode choice of short-distance trips in Hanoi city. J. East. Asia Soc. Transp. Stud. 11, 1328–1345.
Tukey, J.W., 1949. Comparing individual means in the analysis of variance. Biometrics 5, 99–114. https://doi.org/10.2307/3001913.
UN-Habitat, 2015. Informal sector, Habitat III Issue Paper 14. Nairobi: UN-Habitat.
van Nes, A., 2021. Measuring the degree of permeability of the main route network with angular step depth analyses. In: Gervasi, O., Murgante, B., Misra, S., Garau, C., Blečić, I., Taniar, D., Apduhan, B.O., Rocha, A.M.A.C., Tarantino, E., Torre, C.M. (Eds.), Computational Science and Its Applications – ICCSA 2021, Lecture Notes in Computer Science. Springer International Publishing, Cham, pp. 323–336. https://doi.org/10.1007/978-3-030-87016-4_24.
Vaughan, L., 2007. The spatial form of poverty in Charles Booth\'s London. In: Vaughan, L. (Ed.), The Spatial Syntax of Urban Segregation. Elsevier, pp. 231–250.
Venerandi, A., Zanella, M., Romice, O., Dibble, J., Porta, S., 2017. Form and urban change–an urban morphometric study of five gentrified neighbourhoods in London. Environ. Plan. B Urban Anal. City Sci. 44, 1056–1076 https://doi.org/10.1177%2F0265813516658031.
Vuong, Q.H., 1989. Likelihood ratio tests for model selection and non-nested hypotheses. Econometrica 57, 307–333. https://doi.org/10.2307/1912557.