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Adapting a composite street connectivity index as a spatial tool for approaching informal settlements in Egypt; Applied to Giza City

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Abstract

Enhancing street connectivity has been recently adopted as one of the most significant actions to improve the quality of life of the informal settlements. Respectively, it is deployed as a key factor and a starting point in the urban transformation of the informal settlements; from the physical segregation towards their integration into the overall city system. However, measuring street connectivity in informal settlements at the city level has not been properly addressed nor yet quantified. For that, by adopting a cross-sectional study approach, and using GIS spatial analysis methods, this study aims to fill this gap of knowledge by computing and assessing the street connectivity measures of 38 quasi-randomly selected locales, representing the informal settlements of Giza City. Results show that informal settlements are poorly connected; with extremely low values compared to the required. Moreover, unlike literature, street connectivity measures are neither consistently nor strongly correlated; which strongly fits the conception of urban informality. Finally, the study proposes a Composite Street Connectivity Index for informal settlements (CSCI for IS), as a spatial analysis tool, which could contribute to understanding and approaching them at the city-level.

Keywords: Street Connectivity; Street Network; Street-Led Approach; Informal Settlements; GIS

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1. Introduction

As a result of urbanization and cities growth, informal settlements have been rapidly arising where one-sixth of the population lives, with nearly one billion inhabitants worldwide (UN-Habitat, 2016). Based on the estimates of UN-Habitat (2003), 32% of the world's population live in informal settlements, and given current rates of their formation, the number will reach 50% by 2050 (UN-Habitat, 2003). Consequently, some studies argued that the informality has become, in some cities, the norm where informal settlements have grown to be the most common type of human settlements; leading to the rise of the term "the informal city"(García-Villalba, 2014; UN-Habitat, 2009).

Informal settlements, in this context, refer to the unplanned urban districts that have been developed and operated out of the formal processes and regulations of the state. Co-existing but not synonymous with neither 'slums' nor 'squatters'; informal settlements are not seen as pockets of poverty as the latter (Dovey and King, 2011) but, instead, they are seen as settlements embracing a wide spectrum of socio-economic groups; from street vendors to professors (O'Donnell, 2010; Shehayeb, 2009). According to their own regulations and norms, those settlements are self-structured and self-organized, that have grown over a long period to become large mixed-use districts. However, Living in such settlements is inexpedient; as inhabitants suffer from the overcrowding, poor housing conditions, insufficient of public services, poor street networks, and lack of public spaces (Dovey and King, 2011; García-Villalba, 2014; UN-Habitat, 2012).

Being the only public space available, streets in informal settlements are multi-functional; that could be of more significance than those in formal districts. They are the channel of mobility, communication, social interaction, informal commerce, economic productivity, and cultural activities (UN-Habitat, 2012; 2013a; 2016). Correspondingly, they provide the identity and the liveability of such communities (García-Villalba, 2014; UN-Habitat, 2013a). However, the poor conditions of streets have led to the physical segregation of the informal settlements and, therefore, their exclusion from the overall city urban system (UN-Habitat, 2012). Moreover, evidence from practice has shown that the lack of street connectivity could increase social exclusion, generate inequalities, as well as impede access to basic utilities and services (UN-Habitat, 2013a).

Given the failure of half-a-century traditional interventions to deal with the complexity of urban informality (varying between demolition, gradual displacement, and urban upgrading) (Dovey and King, 2011), suggestions have been arisen to adopt a street-based city-wide approach; where streets are the core of the urban upgrading interventions (UN-Habitat, 2012). Contextually, increasing the street connectivity is a key factor and a starting point in the urban transformation of the informal settlements; towards their physical integration into the overall city system (Gouda, 2013). This is based on the assumption that the physical integration contributes to the socio-economic integration needed and, finally, to the enhancement of the overall quality of life in the informal settlements (García-Villalba, 2014; UN-Habitat, 2012). In other words, The greater the street connectivity, the more integrated, productive, liveable, and sustainable the informal settlements (Angle et al., 2015; Tasic et al., 2015).

Although the conception of street connectivity has been widely discussed in the urban planning and transportation discourses (Angle et al., 2015; García-Villalba, 2014; Nasreen, 2014; Tasic et al., 2015), and several individual measures have been proposed (Dill, 2004; Schlossberg et al., 2005; Tasic et al., 2015;

Tresidder, 2005) as well as a Composite Street Connectivity Index (CSCI) developed by the UN-Habitat (2013b), however, measuring street connectivity in informal settlements has not been properly addressed nor yet quantified. For that, this study aims to fill this gap of knowledge by (a) computing the street connectivity measures of the informal settlements at the city-level using GIS spatial analysis methods, (b) assessing the suitability of CSCI to address the street typologies of the informal settlements and, ultimately, (c) proposing a Composite Street Connectivity Index for informal settlements, as a spatial analysis tool, for understanding and approaching them at the city-level.

Accordingly, this study is divided into four main parts: the first part introduces the conception of street connectivity, and the various measures used to determine it, with a special highlight on the UN-Habitat index. The second part gives a brief description of Giza informal settlements, and the main street typologies recognized in their street networks, moreover, it discusses the research methods used. As the third part represents the main results, the fourth and final part formulates the discussion and conclusion.

2. Background

Street connectivity generally refers to the density of street connections and link directness (Victoria Transport Policy Institute, 2014), which is mostly influenced by the street width and continuity (Nasreen, 2014). Dill (2004) defines connectivity as the main purpose of any transportation system; by which it links desired destinations to be easily accessed with various route options and minimal travel distances. Congress for New Urbanism (2001) and UN-Habitat (2013a), consequently, have introduced street connectivity as a key factor of a good neighborhood design and, hence, the city prosperity.

In this respect, a well-connected street network is characterized by its several short links, many intersections, and least dead-ends (cul-de-sacs) (Victoria Transport Policy Institute, 2014). Accordingly, grid-like street networks could be preferable than hierarchical street networks. The former provides an overall highly connected system while the latter includes numerous dead-ends and long blocks (Dill, 2004) and, thus, increases the travel distances and impedes accessibility (Tresidder, 2005). Although this argument could be diverted according to the viewpoint of the different types of modes (motorized or non-motorized), connectivity generally increases when travel distances decrease (UN-Habitat, 2015; Victoria Transport Policy Institute, 2014). This could be governed by streets morphology and quality (degree of maintenance, type of pavement, and legibility) (UN-Habitat, 2016).

2.1. Connectivity measures

There are various measures that can be used to determine connectivity (Babatunde, 2015; Mohamad and Said, 2014; Ozbil et al., 2011; Schlossberg et al., 2005; Tasic et al., 2015; Tresidder, 2005; Trova, 2012; UN-Habitat, 2013a), which can be grouped into three main categories according to scope of interest and level of analysis.

- The first category measures street connectivity with respect to its overall accessibility for different modes. The measures include, in this category, are: streets density per area, intersections density per area, block size per area, the ratio of intersections to dead-ends, the links–nodes ratio, and the average distance between intersections.

- The second category measures street connectivity mainly according to walkability. The measures included are: the pedestrian catchment areas around a specific destination, routes directness, and the directional reach (by measuring the directness of available routes from numerous surrounding origins to particular destinations).
- The third category adopts a spatial configurational approach associated with space syntax studies. Considering each individual street element, measures within this category seek to provide a general description of spatial structure and connectivity hierarchy without making assumptions about desirable or typical trips.

Accordingly, the first category comprises objective (quantitative) measures which do not need any form of subjectivity. They could, consequently, be used at the national/ city-level; as minimal data and costs needed, in addition to their suitability to policy priority. Conversely, the other two categories depend, to extent, on subjective selections of origins and destinations. For that, they suit more the neighborhood/ block-level; as they provide a better understanding of the non-motorized (pedestrian and cycling) connectivity.

Table 1. Below shows the different street connectivity measures identified and used in different studies

Measure	Definition	Calculation	Comments
Percentage of Land Allocated to Streets	Area occupied by streets as a percentage of the total area.	Total area of streets / Total land area	30 % of land allocated to streets is considered efficient for connectivity
Street Density	Lenght of linear kilometers of street per square kilometer of land	Total street length in km/ km^2	A higher number indicates more streets, and higher connectivity.
Intersection Density	Number of intersections per unit of area	No. of real nodes / km^2	A higher number indicates more intersections, and higher connectivity
Connected Node Ratio	No. of street intersections divided by the no. of intersections plus cul-de-sacs	# Real Nodes / # Total Nodes (real + dangle)	A higher number indicates relatively fewer dead ends, and higher connectivity.
Link-Node Ratio	Number of links divided by the number of nodes within a study area	# Links per unit of area (streets) / # Nodes per unit of area	A perfect grid has a ratio of 2.5. This measure does not reflect the length of the link in any way
Pedestrian Route Directness Index	Actual travel distances divided by direct travel distances.	Actual Walking Distance / Direct Distance	An index of 1.0, which indicates that a pedestrian can walk directly to a destination.
Walking Permeability	A ratio of the no. of	lots within ¼	Values range between 0 and

Distance Index	parcels within a one-quarter mile walking distance from an origin point to the total number of parcels within a one- quarter mile radius of that origin point.	mile walking distance of origin point / lots within ¼ mile radius	1, with a higher value indicating that more parcels are within walking distance of the pre-defined point.
Gamma Index	Ratio of the no. of links in a network to the maximum potential number of links between nodes.	# Links per unit of area / 3*(# Nodes – 2)	These two measures come from geography. Values range from 0 to 1.
Alpha Index	Ratio of the no. of actual circuits to the maximum number of circuits	(# Links - # Nodes) + 1 / 2*(# Nodes) - 5	

Source: Author after Tresidder, 2005; UN-Habitat, 2013a

2.2. UN-Habitat Composite Street Connectivity Index (UN-CSCI)

It has been recommended, for a best connectivity measurement, to construct a composite index that compiles the usual quantitative measures (Schmidt and Wells, 2005 cited in UN-Habitat, 2013a); as only one measure cannot sufficiently assess the connectivity of a street: wide streets in a very limited street density and intersections do not probably promote high connectivity. Also, a high street density and dense intersections with very narrow streets do not imply high connectivity. For that, a combination of measures would be more capturing to the degree of connectivity of a street network (UN-Habitat, 2014).

Although all the above-mentioned measures are directly related to connectivity, UN-Habitat has selected only those that are relevant for policies and with available large datasets: land allocated to streets (LAS); street density (SD); intersection density (ID); which are compiled through one index; named, Composite Street Connectivity Index CSCI (UN-Habitat, 2013a), and is calculated via this formula:

$$\text{UN-CSCI} = 1/3\ [\text{LAS} + \text{SD} + \text{ID}]$$

where all the measures are standardized by making their values equivalent to 100 points each (UN-Habitat, 2016).

Contextually, CSCI is used to compute connectivity for cities around the world. Being a sub-index under the infrastructure dimension of the City Prosperity Index (CPI), CSCI was deployed to assess the spatial capital of cities as a key factor of cities prosperity; such as the Mexican cities (UN-Habitat, 2016), and the Saudi Arabian cities (UN-Habitat, 2015). Practice has revealed that there is a strong correlation between the three measures; in other words, the more a city has adequate land owed to streets, the more it has appropriate intersections obtainable to decrease travel distances, the more it has sufficient street network covering all parts of the city. Moreover, based on UN-HABITAT Global Urban Observatory estimations (2013), appropriate scores for each measure were suggested as follows[1]:

- For LAS, the percentage of streets varies between 6% (as the min. score) and 36% (as the max. score) and, hence, LAS is equivalent to *100 points* if LAS $\geq$ 36%, and to *zero points* if LAS $\leq$ 6%.
- For SD, connectivity is sufficiently achieved at 20 km of streets/km^2, whereas penalties should be applied for higher or lower values; as it has been found that in both conditions mobility is negatively affected. Consequently, SD is equivalent to *100 points* if SD =20km/km^2, and to *zero points* if SD is zero or 40 km/km^2.
- For ID, the recommended value is 100 intersections /km^2 and, hence, ID is equivalent to *100 points* if it scored $\geq$ 100 intersections /km^2. However, this recommended score is conducted from studies scanning all parts of the city, including non-residential districts, whereas the residential districts have been found to have an average score of 320 intersections/km^2 (UN-Habitat, 2013b). For that, the two scores are to be considered during computing the ID measure of the informal settlements.

3. Methods and materials

3.1. Study area

Giza, one of the cities of the greater Cairo and the capital of Giza Governorate, is situated on the west bank of the Nile river opposite to Cairo City (Giza-Governate, 2002). Accommodating more than 2 million inhabitants on 44 km^2 (GOPP, 2011), Giza informal settlements have reached 87% of Giza urban expansions (Barada, 2006). Developed mainly on the agricultural land; the area of informal settlements have been grown to occupy more than 62% of the total area of Giza City as shown in [Figure 1] (GOPP, 2011). In this respect, most of Giza locality units[2] "sheyakha" are totally informal (unplanned) to the extent that the planned ones are becoming the exception (AUC, 2014). For that, Giza City could be seen as an "informal city" more than a "planned city".

Most of the informal settlements, in Giza City, have begun by purchasing of an agricultural land, subdividing it into smaller plots which were converted into housing units (Gouda, 2013). In terms of urban morphology, the main layout of these informal settlements is mostly identified by the former agricultural land and irrigation network. Accordingly, the street morphology is characterized by its straight narrow routes (usually 2-4 meters). However, this prevailing street typology could be determined as the infill between existing core-village settlements, which have been overtaken by the informal urban expansion, such as Mit Okba, Embaba, and Kom El Gharab (GOPP, 2011; Sims, 2011). This sub-typology, on the other hand, is

[1] These values are used in standardizing the measures and, hence, compiling them in one index (UN-Habitat, 2016).
[2] The locality unit is the smallest administrative geographical unit and, hence, the smallest officially identified unit in the general and economic census in Egypt.

identified by its irregular street network with multiple dead-end routes. However, with the absence of open spaces in both street typologies, local streets have been providing the least required accessibility (GTZ, 2010). Whereas the quality of construction of housing is generally good (of reinforced concrete frame and infill red brick walls), there is an increasing densification which causes a serious overcrowding issue (Sims, 2003); as the average building height is 6-8 floors, and some buildings rise to exceed the 12 floors; forming a very compact pattern (Shehayeb, 2009).

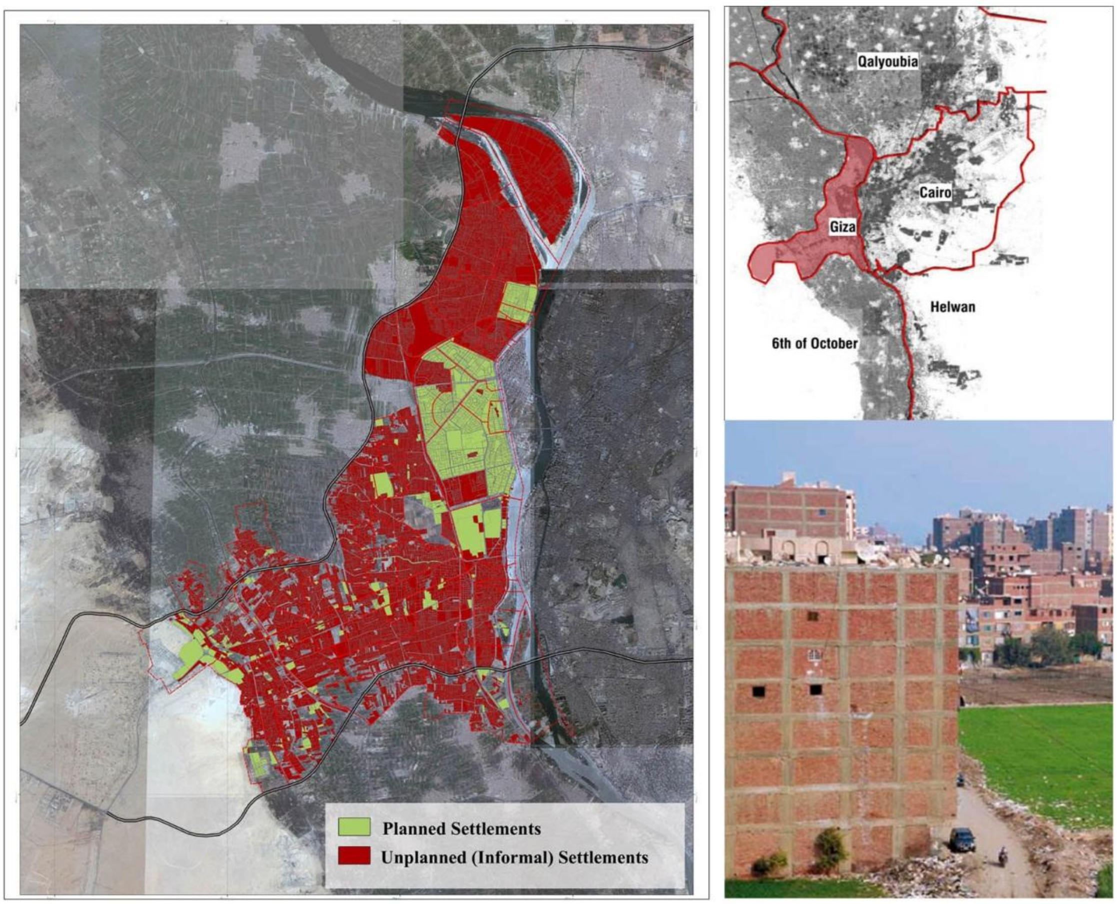

Figure 1. Informal Settlements in Giza city (Source: GOPP, 2011)

3.2. Methods

The ultimate aim of this study is to develop a street connectivity index that can properly relate to the urban morphologies of the informal settlements at the city level. Accordingly, adopting a cross-sectional approach (Neuman, 2014), and depending on the GIS spatial analysis methods, data of street networks was extracted from the geospatial data of Giza Governorate developed during the preparation of the strategic plan of Giza (GOPP, 2011). The rational beyond using GIS is two-fold: first, the shortage of the baseline information for the streets of the informal settlements in Egypt (Gouda, 2013); second, the adoption of GIS as a planning tool in Egypt and, hence, the establishment of GIS database within most of the Egyptian municipalities (GOPP, 2008). Consequently, four connectivity measures were employed in this study: the proportion of land allocated to streets (LAS), street density (SD), intersection density (ID), and connected node ratio (CNR)[3]: LAS and SD represent the streets, while ID and CNR represent the intersections within a street network. These measures were chosen as they rely on similar data and tools within GIS; they are totally objective measures which depend solely on the street network and, thus, comparisons could be legitimately created between different areas (Tresidder, 2005).

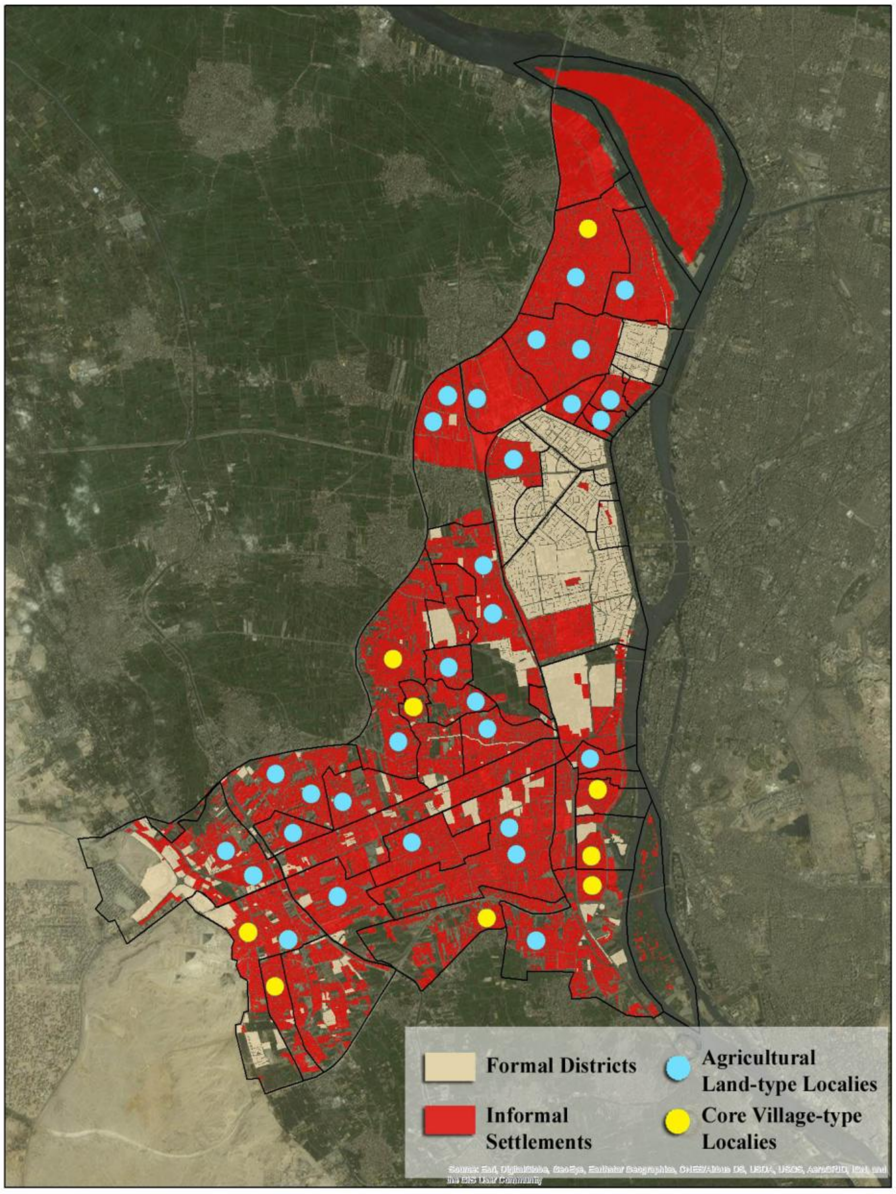

Figure 2. Quasi-random placement of 10-hectare locales representing the informal settlements of Giza City (Source: Author after GOPP, 2011)

3 Although the link-node ratio (LNR) measure relies on similar data as the chosen measure, it was excluded for two reasons: first, based on Dill's study (2004), LNR is weakly correlated with the other measure; second, it is neither related to the block size nor to the intersection density; a pattern of large blocks has the same LNR as one of small blocks.

Depending on a quasi- random spatial sampling technique, 10-hectare locales (sample points) were selected (UN-Habitat, 2016); by excluding the planned locality units in Giza city, and randomly selecting the locales in the informal (unplanned) locality units; one sample per an average-sized locality unit (400 acre), and two samples for large locality units ($\geq$ 900 acre), of total 38 locales: 9 locales representing the core-village street typology, and 29 locales representing the agricultural-land street typology [Figure 2]. The boundary of each locale was determined by including the streets along the entire perimeter of all blocks within the locale, together with those clipped by the circular 10-hectar buffer [Figure 4].

Street network, within each locale, was symbolized by a) links representing segment roads, b) real nodes representing the intersections, and c) dangled nodes representing the dead-ends (cul-de-sac) [Figure 4]. Consequently, the above-mentioned street connectivity measures, besides the UN-CSCI, were computed for each locale using ArcGis. Finally, data was statistically analyzed using Microsoft Excel and SPSS to fulfill the aim of the research.

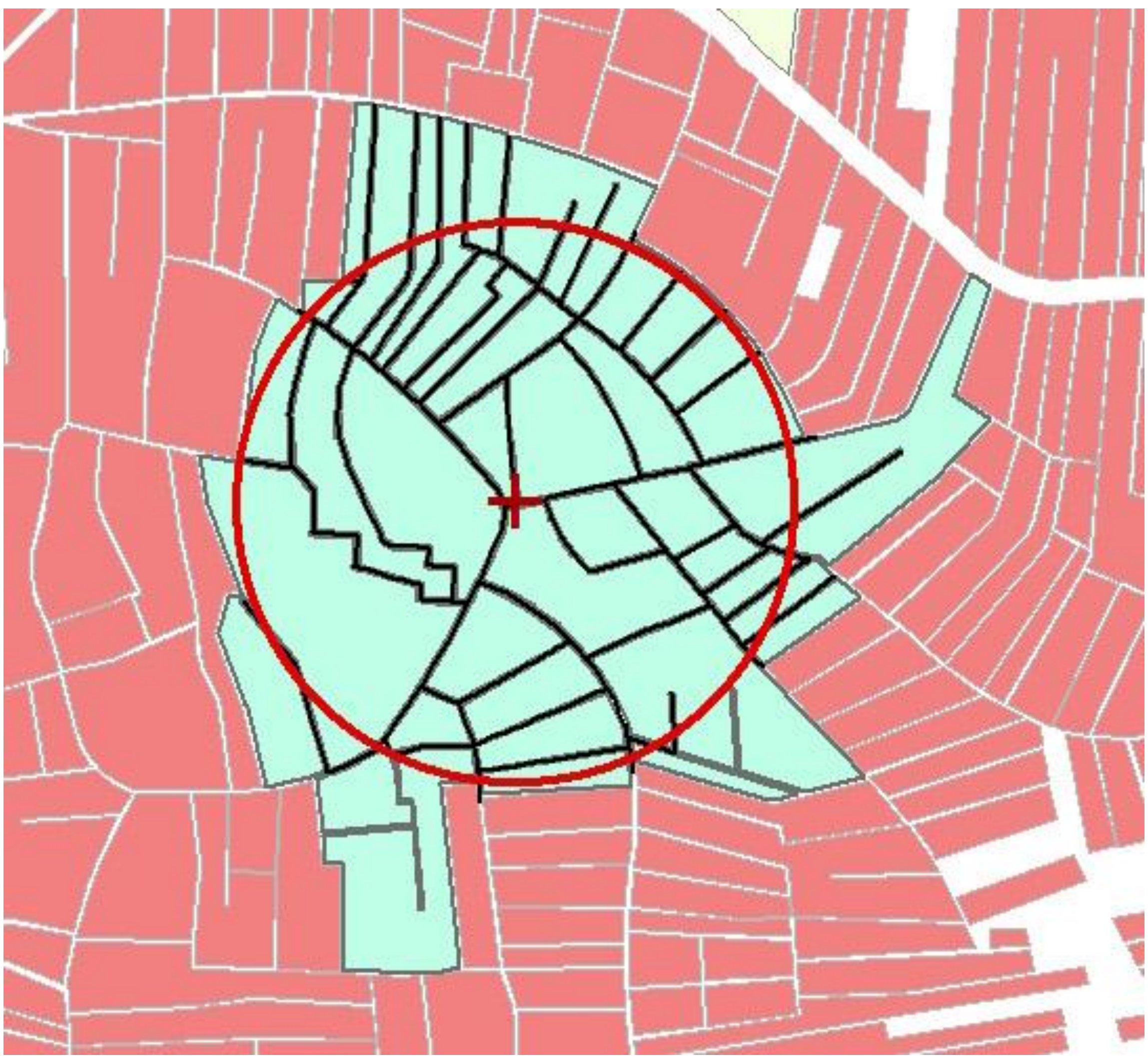

Figure 3. A typical 10-hectar locale, including blocks that are clipped by the calculated buffer

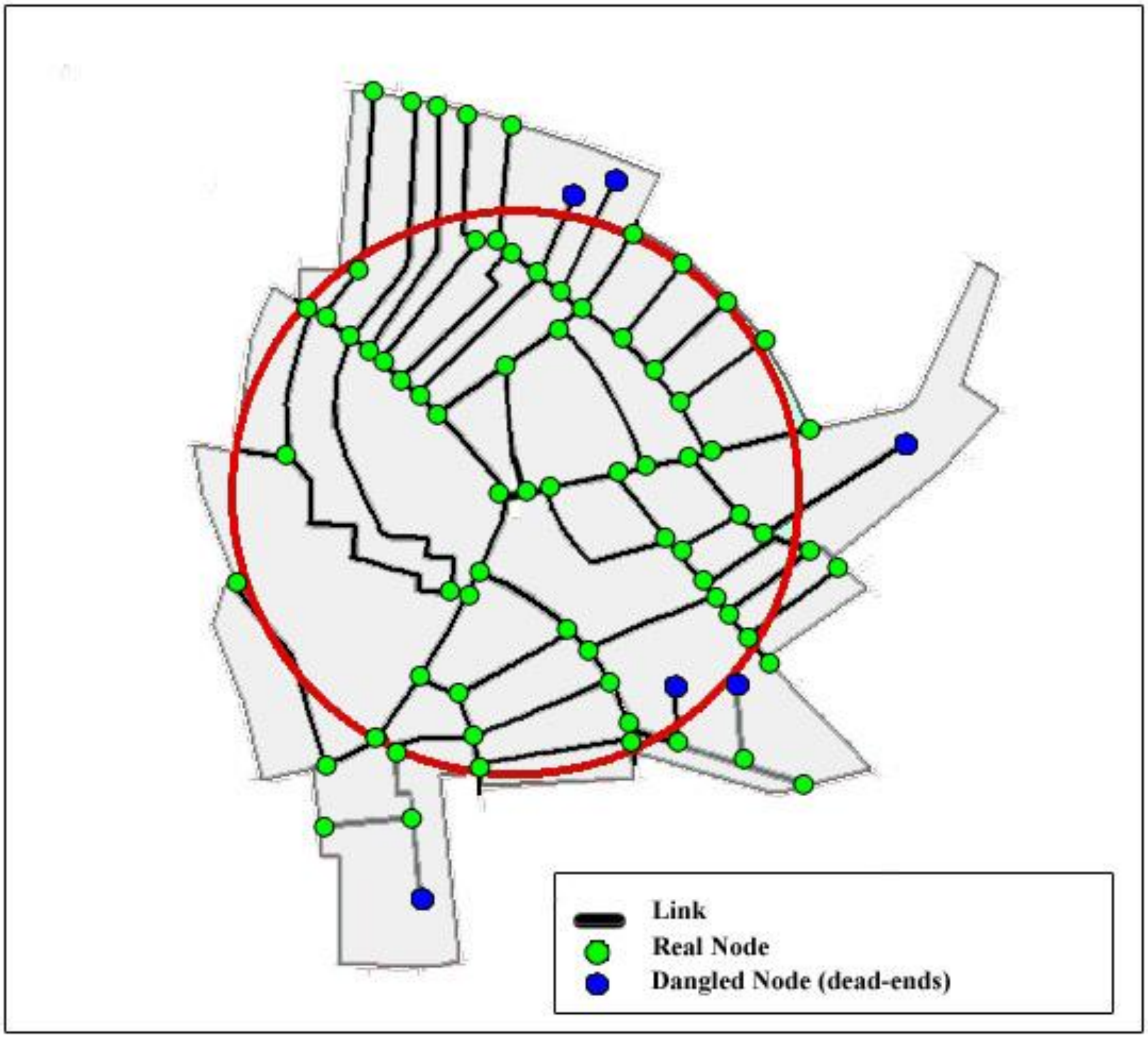

Figure 4. Symbolizing the street network within each locale

4. Results:

4.1. Main features of the Selected Street Connectivity Measures:

After computing the selected connectivity measures for each locale [Figure 5], a descriptive statistical analysis has been conducted for each measure [Table 2]:

- LAS ranged between 7% and 19%, with an average of 12%, and standard deviation 3%. These values appeared to be relatively low, and far below the recommended percentage (30%) needed for sufficient connectivity.
- SD ranged between 19 km/km^2 and 45 km/km^2, with an average of 34 km/km^2, and standard deviation 5.59. Given that values higher than the recommended (20 km/km^2) could impede connectivity, SD values appeared to be relatively unsatisfactory regarding connectivity.

- ID ranged between 228 int/ km^2 and 758 int/ km^2, with an average of 475, and standard deviation 150.48. These values appeared to be relatively problematic; as they negatively affect connectivity.
- CNR varied between 0.67 and 1.00, with an average of 0.85, and standard deviation 0.1. These values appeared to be relatively matching with the recommended value (more than 0.75) needed for sufficient connectivity.

Beside these measures, streets widths have been statistically calculated based on LAS and SD, and found to be distinctively very narrow (2.35m -5.9m) with average value 3.5m.

Table 2. Descriptive Statistics of Connectivity Measures applied to Informal Settlements in Giza city

	LAS (%)	SD (km/km^2)	ID (#int/km^2)	CNR
Minimum	7%	19	228	0.67
Maximum	19%	45	758	1.00
Mean	12%	34	475	0.85
Median	11%	34	479	0.86
Standard Deviation	3%	5.59	150.48	0.10
Coefficient of Variance	24%	16%	32%	12%

n=38

Moreover, by testing the correlation between the connectivity measures and to what extent they reflect the street typology of a locale [Table 3], some initial findings have been evolved:

- It has been found that correlation was neither significant nor consistent between the different measures: the degree of correlation was mostly weak between LAS, SD, and CNR (ranged between 0.1, 0.3). ID results, on the other hand, showed inconsistency in its relation with other measures: although it was, to some extent, positively correlated with SD (r=0.4, p = 0.00), it had a negative weak correlation with the other two measures.
- As for the correlation test between the connectivity measures and the street typologies, it has been found that CNR had a strong correlation with the street typology (r=0.7, p = 0.00), followed by ID with weak correlation (r=0.3, p = 0.01), while both LAS and SD had relatively very weak correlation. This highlights the significance of CNR measure in addressing the informal settlements.

4.2. Composite street connectivity index for informal settlements CSCI for IS

Computing CSCI for IS has gone through three main steps:

1- *Step (1): Computing the original UN-CSCI:* The first step in calculating the original UN-CSCI was to standardize the scores based on UN-Habitat recommendations. While doing so, ID (standardized by considering 100 int/km^2 as the recommended value) scored zero for the entire locales; leading to disqualifying this measure, and limiting the index to only LAS and SD (representing only the streets); with the absence of any representation of the intersections. Correspondingly, this index showed no correlation with street typologies (r= 0.006, P = 0.75).

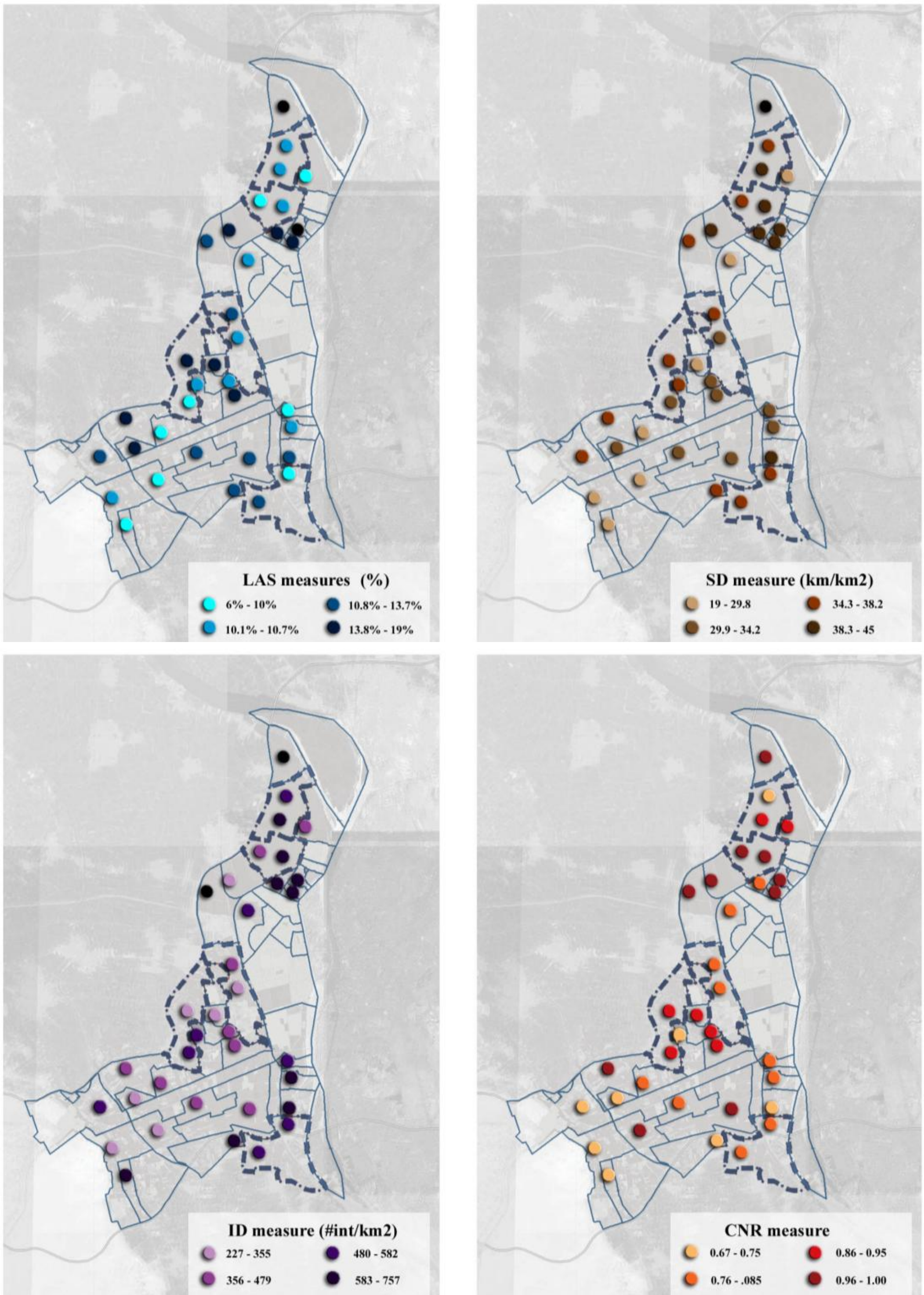

Figure 5. street connectivity measures distributed within the locales

2- *Step (2): Computing a modified* UN-*CSCI:* In order to overcome this pitfall, ID was again standardized by considering 320 int/km^2 as the recommended value (the average value for residential housing from practice). However, the modified UN-CSCI showed a weak correlation with street typologies (r= 0.33, P = 0.03).

3- *Step (3): Adding CNR to the* modified *UN-CSCI:* being the only measure of a strong correlation with the street typologies, CNR was compiled to the index[4]; consequently, the new index showed better results regarding its ability to reflect the street typologies of the informal settlements (r= 0.65, P = 0.00); leading to changes in locales ranking compared to those evolved from the modified UN-CSCI [Figure 6].

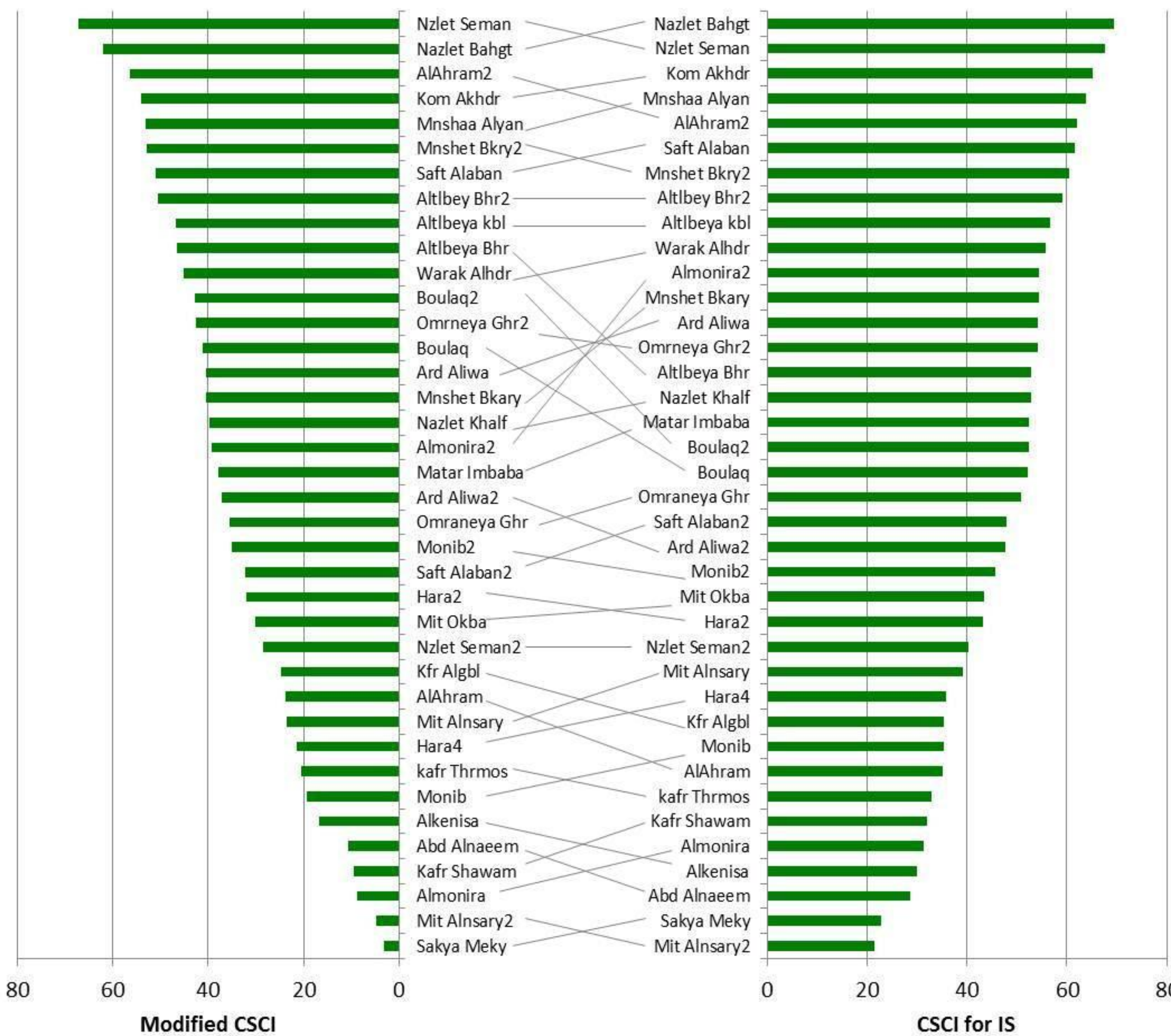

Figure 6. Locales Ranking according to the modified UN-CSCI and the newly addressed CSCI

[4] As the measure already ranges from 0 to1, it was normalized by multiplying its values by 100

Table 3. Pearson Correlation coefficients for street connectivity measures

	LAS	SD	ID	CNR
SD	0.3517 (0.05)			
ID	-0.1810 (0.05)	0.4406 (0.00)		
CNR	0.2774 (0.05)	0.1846 (0.05)	-0.3396 (0.01)	
Street Typology	0.2973 (0.05)	0.1971 (0.05)	0.3597 (0.01)	**0.7148 (0.00)**

5. Discussion and conclusion

This study is an attempt to assess and quantify the street connectivity of the informal settlements at the city-level. Contextually, four connectivity measures were deployed for this purpose: two representing streets (LAS, SD), and two representing the intersections (ID, CNR) within a street network. Being a cross-sectional, not a case study, helped in capturing the general features of these measures, where values were extremely low compared to the recommended for sufficient connectivity: 12% instead of 30% for LAS, 34km/km^2 instead of 20 km/km^2 for SD, and 475 int/km^2 instead of 320 int/km^2 for ID, whereas CNR (0.85) relatively matched the recommended value (> 0.75). This implies that dead-ends within the existing street network are not the main factor of the poor connectivity unlike the other measures; especially the extremely high no. of intersections which, in some locales, exceeded 700 int/km^2: a clear manifestation of the urban informality sub-division processes. Moreover, unlike literature, street connectivity measures were neither consistently nor strongly correlated; whereas those measures showed strong correlation in the formal planning practice, they were relatively uncorrelated in this study: ranging between 0.1 and 0.3, LAS, SD, and CNR showed very weak correlation. While as for ID, there was inconsistency in its relation with other measures; from a positive weak correlation with SD to a negative weak correlation with LAS and CNR. This highlights the fact that those measures did not regularly assign the same level of connectivity within the locales; where only 3% of the locales were in the same quartile on all four measures, and 37 % were in the same quartile for three measures, while the rest 60% were in the same quartile for only two measures. These preliminary findings, again, fit the conception of urban informality and provide an entry point for addressing the issue of the heterogeneity of street networks of the informal settlements; which needs a further research.

The second part of the study was to assess the suitability of UN-CSCI in addressing the street connectivity within the informal settlements. Given that street typologies were more related to ID and CNR than to LAS and SD highlights the limitation of this index; as a) the recommended value of ID, used for its standardization, is inadequate to the case of informal settlements and, hence, needs adaptation; b) the three measures of the index do not investigate the types of intersections of a street network and, for that, CNR is highly recommended to be included in the index; especially that it is the most suitable measure to address the dead-ends: a key element in the street network of the informal settlements. Respectively, in order to overcome these limitations, a Composite Street Connectivity Index for Informal Settlements (CSCI for IS) is proposed as a result of UN-CSCI modifications; where CNR is included, and the standardized ID is adjusted to 320 int/km^2 instead of 100 int/km^2. This index is a spatial analysis tool which could contribute to understanding and approaching informal settlements at the city-level. It is meant to facilitate and enable officials to benchmark the informal settlements and prioritize them according to their connectivity, as a proxy to the degree of their physical segregation and, hence, identify the type and degree of interventions that could take place. Given that this index has been applied and modified to reflect Giza informal settlements, the most common type prevailing worldwide, makes this index highly compatible to informal settlements in other countries; especially those of relatively safe, but informally developed districts. However, the extent of suitability of this index to address the connectivity of other types of slums; especially squatters and unsafe slums, is still untested and, hence, further research is needed. Moreover, it should be noticed that connectivity is a complicated issue; and that this new index is still limited, and focuses on specific aspects and, consequently, cannot explain everything. However, tailoring it to reflect the street typologies, the new index could be perceived as the first step towards a better understanding of the urban morphologies of informal settlements; which could be later compiled with the other related dimensions and, ultimately, develops a Composite Urban Morphology Index for informal settlements.

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