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Morphological evaluation and regeneration of informal settlements: An experience-based urban design approach

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ABSTRACT

Informal urbanism has been generally studied within social, econmic and political frameworks, yet little is known of how it performs in terms of urban vitality. The aim of this article is to better understand the urban vitality of informal settlements and how they can be improved by using a combined morphological approach that encompasses street-network accessibility, building density, land use diversity and transformability index. This study focuses on the city of Cairo, which has experienced rapid urban growth over the last seven decades. Much of this growth has concentrated in informal settlements on the outskirts of the metropolis. Taking Manshiet Nasser district as a case, we measured the degree of urban vitality of the area through a combination of Space Syntax, Spacematrix, and the Mixed Use Index (MXI). Informed by a transformability index (TI), the results can be used as part of the design process to (re)develop unattractive areas. The findings show that this combined approach works as a diagnostic tool for detecting development potential and, therefore, underpins the identification of cost-effective ways of intervention, for enhancing vibrant urban environments.

1. Introduction

With the ongoing rapid urbanization in developing countries, more than two-thirds of the world's population is estimated to be living in urban areas by 2050 (Talukder et al., 2015; United Nations, 2014). Informal settlements (often referred to as 'slums')[1] occupy a significant part of such urban landscape across Asia and Africa. Driven by socio-economic forces (e.g. rural-to-urban migration, economic stagnation, poverty, unemployment, and globalization (UN-Habitat, 2007)), the urban poor construct their shelters cheaply and quickly either in buffer zones cleared for major infrastructure such as railways, metro lines and freeways, or in any other marginal, leftover and sometimes unsafe locations, which are often subject to hazards such as landslides or flooding (Dovey & King, 2011). As signifiers of disorder, lawlessness and often very poor living conditions, slums are typically demolished and redeveloped in many developing countries (Khalifa, 2015). As this radical clearance has proven to require great resources and disrupt local communities and businesses, an alternative approach – promoting upgrading – was initiated by Turner (1972) and others in the late 1960s as a mechanism to improve the living conditions of the urban poor (Abbott, 2002). It was widely adopted by both national governments and the World Bank until research revealed the failures of such upgrading programs (Khalifa, 2015). The emphasis was on tenure legalization and/or the provision of infrastructure and services with no attention to the fundamental reasons of slum formation. The physical and spatial characteristics of the settlements, which stimulate or impede socio-economic performance, have been largely overlooked until recently (Karimi & Parham, 2012).

The relationship between urban vitality/urbanity and socio-economic performance has been confirmed in several urban studies since the 1960s (Gehl, 1987; Jacobs, 1961; Montgomery, 1998). While the literature on urban vitality has burgeoned in the West, it has rarely

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[1] There is little consensus on the distinction between the terms slum, informal, squatter, or unplanned areas (Dovey & King, 2011). Informality is an umbrella term under which various shapes and forms fall, for example, "*Ashwa'iat*" (unplanned), "*Favelas*" (shantytowns), and "*Campamentos*" (camp or tent cities) (Khalifa, 2011). However, these descriptions are seen as contextual, qualitative, and are rarely based on complete morphological investigations (van Oostrum, 2018).

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focused on informal neighborhoods in cities of the Global South. The question of how such neighborhoods perform in terms of urban vitality is geared to the implications of dynamism and vitality in policy making. In this paper, a combination of street-network accessibility, land use diversity, and building density will be used to investigate the urban vitality of informal settlements. The results will subsequently contribute to identifying morphological priorities for intervention, i.e. the results will suggest spatial strategies for improving socio-economic performance of areas suffering from a lack of street lives in informal settlements of Cairo. However, it is important to stress that such an analysis alone cannot prioritize interventions. It has to be integrated with the analysis of other dimensions, such as those related to hazards, living conditions, infrastructure, public service provision, etc. Also, suggested development decisions should be shared with local communities, and participatory techniques should be used to capture the needs of residents, and to give them a say in the decision making process. However, this goes beyond the scope of this paper which focusses on the quantitative analysis.

A central question in this paper is to what extent the composite method can be utilized for understanding the degree of socio-economic performance of informal settlements? Using the approach by Ye et al. (2017), this study measures the degree of urban vitality of Manshiet Nasser in Cairo followed by a spatial profiling index, the so-called transformability index, which records the existing conditions of the buildings to determine what part of the urban tissue is easier to transform (demolish, consolidate, rebuild) physically. Manshiet Nasser settlement is built on state-owned desert land and represents one of the largest "mega-slums" in the world.

This research extends the literature in three ways: 1) this is the first study to test the transferability of the methodology provided by Ye et al. (2017) in the context of self-organized informal areas; 2) this study develops an integrated intervention framework based on the combination of space syntax, spacematrix and mixed use index (MXI) tools complemented with a transformability index to minimize disruption. The results of this research can be used to (re)develop unattractive areas; 3) finally, this study classifies unplanned areas based on their socio-economic performance. This new classification can support decisions over where and how informal settlements might be regenerated or eradicated.

2. Theoretical framework

Several authors argue that vibrant[2] urban places foster socio-economic performance (Gehl, 1987; Montgomery, 1998), and promote the adoption of healthy lifestyles (Rebecchi et al., 2019). Jane Jacobs postulated that neighborhoods should have the following set of features in order to create and maintain a lively atmosphere: a mix of land-uses, small city blocks, a sufficient density of built area, and aged buildings (Delclòs-Alió et al., 2019; Jacobs, 1961, 1970). Typically, areas with multi-functional land use, accessible spaces and high density developments are more likely to have a high degree of socio-economic performance (Gehl, 1987; Jacobs, 1961), and support a pedestrian-friendly environment. In other words, urbanity encompasses several distinctive qualities of urban design which steer vitality and diversity. It thus is a complex and multi-dimensional term and is often associated with dynamism, vibrancy and livability (Bertolini & Salet, 2003).

Hillier and Hanson (1984) introduced *Space Syntax* theory and tools to understand the link between urban space and social and economic behaviour. They argued that the configuration of the street-network, which is related to movement flows, has an impact on attracting investment and economic activity, and thus affects the social context of the city (Hillier, 1996a; Hillier & Hanson, 1984). This approach seeded the foundation for many later studies to identify the spatial characteristics of informal settlements (e.g., Hillier et al., 2000; Karimi & Parham, 2012). These studies showed that informal settlements function locally well due to their strong internal structure, but relate poorly to their wider urban context and, therefore, inefficiently interact socio-economically with the rest of the city. The suggested effective intervention, therefore, is to physically integrate the local structure of such areas with the surrounding context and the city as a whole, thus ensuring the consolidation of the city in the long run.

Street-network accessibility was the starting point to identify where there were issues, and how to target interventions. Karimi and Parham (2012) argued that if the street-network is left unchanged and only improvements to public spaces and utilities are made, the areas will improve in a material sense but will not put in place conditions for longer term regeneration. Although this approach has proved to be powerful in understanding spatial relations and the dynamics of urban economics, it has been criticized for focusing solely on the spatial structure in the design process assuming that other dimensions of urban form are a mere consequence of grid configuration (Ratti, 2004).

In parallel, researchers have developed more tools and methods to objectively describe other basic morphological elements of the built environment. For instance, Pont and Haupt (2009) developed *Spacematrix* to measure building types and building density, and thus provide information on the intensity and compactness of a settlement. Moreover, Hoek (2009) suggested the *Mixed Use Index* (MXI) to quantify the level of land use diversity based on the shares of floor surfaces devoted to housing, working, and amenities. Based on Conzen's model of urban morphology (Conzen, 1960, 2010), the combination of Space Syntax, Spacematrix, and Mixed Use Index (MXI) allows researchers to measure urban vibrancy (e.g., Ye et al., 2017). Yet although the validity of this composite method has been verified in various cities, little is known about the factors contributing to street life vibrancy over irregular and informal settlements, which often have intensive construction and poor accessibility.

3. Study area

3.1. Informality profile in Egypt: a brief overview

Rural-to-urban migration was a major factor in Egypt's rapid urbanization since the 1960s. This migration has impacted most cities of the country producing an extensive peri-urban fringe (El-Batran & Arandel, 1998). The Greater Cairo Region (GCR) experienced rapid informal urban expansion occurring largely on 'privately-owned ex-agricultural land' (about 80 %), and on 'state-owned desert land' (about 15 %) (MHUUD, 2008). The population of the region increased from 6.77 million in 1976 to 20.58 million in 2016 (Mohamad Mosilhi, 2017). Today, more than 60 % of the Greater Cairo Region's population live in informal settlements (Sims, 2010), and Cairo houses four of the thirty largest "mega-slums" in the world; these are Manshiet Nasser, City of the Dead, Ezbet El-Haggana, and Imbaba (Khalifa, 2011).

The Egyptian government first attempted to address informality in 1992, when they launched a national fund for slum upgrading (El-Batran & Arandel, 1998; Ibrahim et al., 2020), and has since then worked with several international agencies such as the World Bank (WB), the German Development Bank (KFW), the German Corporation for International Cooperation (GIZ),[3] and UN-Habitat to improve living conditions in the

[2] Vibrant urban place means vital and lively urban environment (Fu et al., 2021). Some authors associate the concept of urban vibrancy with the number of people in and around urban spaces over different times of the day and night. Urban vibrancy can also be described in terms of street-network accessibility, land use diversity, and activity intensity (Barreca et al., 2020). In this paper, we use the terms vibrancy, urbanity and urban vitality interchangeably.

[3] The earliest cooperative projects with the German government were done through the German Technical Cooperation Agency (GTZ), which eventually became part of the GIZ.

Fig. 1. Urban evolution of the study area (source: authors based on ISDF, 2016; Photos: Al-khalafawy (2018) (This photo is used with permission under Egypt's "fair use" clauses 171 (4) and 172 (3) (https://en.wikisource.org/wiki/Egyptian_Copyright_Law).) (upper right); authors (2020) (bottom right); Tadamun (2015) (These materials were developed by TADAMUN: The Cairo Urban Solidarity Initiative. TADAMUN has given us permission to use the materials for a non-commercial purpose, and distribute any modifications under a similar license.) (the rest)).

worst areas. Most of these efforts were focused on in-situ upgrading or tenure normalization, to improve the structural integrity of buildings and infrastructure, improve basic service provision, or provide residents with additional sources of capital for business investment. While important, these parcel-specific solutions overlooked fundamental issues with the structure of the city and, therefore, were often ineffective (El-Batran & Arandel, 1998; Ibrahim et al., 2020; Khalifa, 2011; Piffero, 2009). The physical and economic integration of informal areas with their surroundings has received relatively little attention.

In 2009, the ISDF divided informal settlements to two distinct categories: unsafe areas (about 1 % of total urban area) and unplanned areas (about 60 %) (Khalifa, 2011). Unsafe areas are territories which threaten life, have inappropriate housing conditions, are exposed to health risks or insecurity of tenure. Unplanned areas are primarily characterized by their independence of official planning, buildings laws and state regulations. While this classification prioritizes areas in need for urgent intervention, it remains problematic as it overlooks significant differences between unplanned areas which constitute the majority of informal housing. In other words, it merges all unplanned areas in one category neglecting differences in their socio-economic performance. If so, being able to classify informal areas based on their socio-economic performance could lead to better (re)development policies.

3.2. *Manshiet Nasser as a case in point*

Manshiet Nasser district in Greater Cairo was selected to exemplify informal urbanism. The area has 370,091 inhabitants squeezed in 4.53 km^2 (ISDF, 2016). This informal settlement is situated on a public desert land covering the hilltops of the Muqattam Mountain (Tekce et al., 1997). Manshiet Nasser radiates southward from the historic core of the city. The locational pattern of the settlement isolates its community from the mainstream of urban life. The area is bounded by the great cemetery, namely '*the city of the dead*', to the north and the sharp cliffs rising above the district to the south. Al-Nasr highway —built next to the old British track railway— demarcates where the slum ends, and the city of the dead quarters begin (Fig. 1).

Manshiet Nasser is an outcome of a long process of uncontrolled migration. The first generation, consisting of poor families displaced by urban building projects, settled there in the early 1960s (Tadamun, 2015). A few years later, Manshiet Nasser experienced a significant expansion, aided by the relocation of garbage collectors (ISDF, 2016; Joos & Conrad, 2010; Sims, 2010). As the area grew, many households started to run their own businesses at home to earn a living. The cheap land and the proximity to the city center encouraged skilled workers to open their own workshops in the settlement. Over the recent decades the settlement was expanding, and its population was growing. Besides the informal growth, many public housing projects emerged. The pace of investment was so fast in Manshiet Nasser that it has been transformed into a bustling community of homes, stores, and workshops (Tekce et al., 1997). However, the problems of density, the rugged cliffs, the inadequate sewage, and the lack of organized infrastructure make the area a byword for exclusion and deprivation.

Access to Manshiet Nasser settlement is limited from the main highway connecting the settlement with the rest of Cairo. The area is characterized by an organic urban pattern of mostly unpaved narrow streets arranged parallel to the slopes to best fit the topographic structure of the land. Numerous staircases and ramps are frequently used to connect various topographical levels in the area. The urban blocks are extremely irregular, most buildings are unfinished, and the dead ends are typical for the outdoor spaces. About half of the buildings are less than three floors, and the rest is a mixture of higher and lower buildings.

4. Methods and data

The aim of this article is to better understand the urban vitality of informal settlements by using a combined morphological approach that encompasses street-network accessibility, building density, land use diversity and transformability index. Fig. 2 shows the research framework. In stage 1, *accessibility* index is based on street-network configuration, building *density* is based on the floor space score, the ground space score, and the average number of floors, and the land use *diversity* index is based on the shares of residential and non-residential building uses. The sDNA software has been used to measure street-network accessibility, while spacematrix and mixed use index (MXI) have been employed to quantify density and land use diversity respectively. In stage 2, we combine these three parameters to reveal the settlement's socio-economic performance. In stage 3, we have concurrently developed a transformability index using the Analytical Hierarchy Process (AHP) to be used as a guideline for any decision related to physical intervention. The accuracy of this index has been supplemented by field study visits. The selection of fieldwork sites was based on criteria of safe access for field research and to cover a range of different morphological conditions; there is no claim to random sample. Unfortunately, taking representative photos for visual comparisons was not possible due to safety issues; also, Google Streetview was unavailable for the study area. Finally, in stage 4, the results from stages 2 and 3 have been complementally overlaid to suggest regeneration strategies.

4.1. Measurement tools

4.1.1. Space syntax

Space syntax is a set of theories and tools developed in the 1970s at University College London for analyzing spatial configurations of buildings and urban spaces (Al-Sayed et al., 2014; Hillier, 1996a; Hillier & Hanson, 1984). Space syntax analysis has proven a strong association between human activity patterns and street accessibility. Typically, more accessible spaces would generate higher movement flows and, in turn, mediate movement-seeking activities (Hillier, 1996b).

Syntactic analysis can provide a large variety of measurable variables. A key centrality measure is 'betweenness', which counts the number of times a node lies on the simplest, shortest possible path between pairs of nodes within the network. This feature gives a basic knowledge of connections analysis and generally corresponds with the level of liveliness and urbanity. Interestingly though, the betweenness model overestimates by-passing traffic flows in more dense areas. This makes it unrealistic and, thus, undesirable in informal areas where link count is often higher than elsewhere. Accordingly, we used the 'Two Phase Angular Betweenness' (TPBtA) model which assumes that each link has a fixed amount of journeys that the agents will actually make (Cooper et al., 2016a). The analysis can be calculated at multiple scales, from global to local. Empirically, a radius of 4000 m (R4000) has shown to fit actual vehicle flow data well, while a powerful indicator of pedestrian flow might be radius 500 m (R500). In this research, we employed spatial design network analysis (sDNA) developed by Cooper

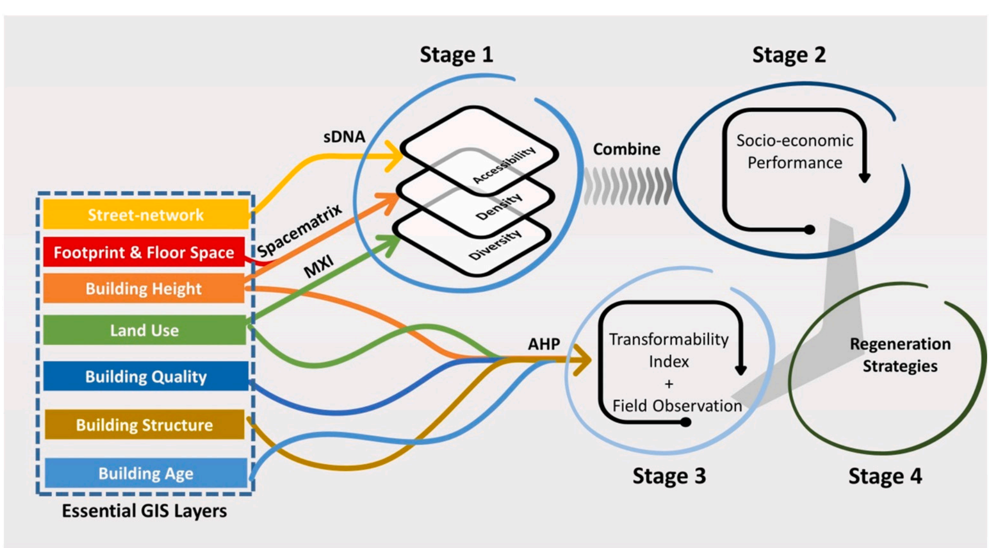

Fig. 2. Research framework (source: authors).

et al. (2016b) to calculate betweenness for street centerlines.

Transferring the configuration results to street blocks is sensitive to the aggregation method and the number of street centerlines we merge. Generally speaking, the average value of the surrounding links flattens the distribution and gives similar values everywhere. Betweenness centrality suffers most as it gets low values everywhere, because of its distribution. The maximum value of the axis surrounding a block would, therefore, be more appropriable for compensating distance decay. The outcomes are then classified into high, medium, and low ranges based on the GIS natural break (Jenks) scheme to put features of similar values in one group and separate classes by distinct breakpoints. The highly accessible blocks should have high values for both local and global measures. Conversely, most isolated areas contain two low values. A medium street block contains either medium values in both global and local scales or one measurement with a high value and one with a low value (Table 1).

Although the space syntax approach has proven to be powerful in predicting the socio-economic impact of urban design schemes, it neglects some key morphological aspects, such as land use and built-mass density arguing that both are a mere outcome of the urban grid configuration (Joosten & van Nes, 2005; Ratti, 2004). In other words, space syntax alone cannot provide a complete picture of the physical settings of the built environment in relation to the degree of socio-economic performance (Ye et al., 2017; Ye & van Nes, 2014).

4.1.2. Spacematrix

The Spacematrix defines building density as a multivariable phenomenon of three basic indicators: the floor space index (FSI), the ground space index (GSI), and the average number of floors (L) (Pont & Haupt, 2007, 2009). The FSI reflects the intensity of a settlement and the GSI provides information on the compactness of the development. Additional variables such as spaciousness (OSR) can be derived using FSI and GSI to indicate pressure on the non-built space at ground level (Fig. 3).

The variables of building density are calculated at the street block level as follows:

$FSI_x = F_x / A_x$ where F is gross floor area in m^2, and A is the gross area of the street block in m^2; $GSI_x = B_x / A_x$ where B is gross building footprint in m^2; $L_{average} = FSI_x / GSI_x$; $OSR_x = (A_x - B_x) / FSI_x$.

Urban blocks are divided into low-rise, mid-rise, and high-rise based on their L average values. They are further classified into point-type, stripe-type, or block-type depending on their GSI values. This produces a total of nine classes ranked from low-rise point to high-rise block. As illustrated in Fig. 3, low-rise points represent street blocks with up to three floors and GSI less than or equal to 0.2. Blocks with average number of floors (L) greater than seven and GSI values over 0.3 are classified as high-rise blocks. Based on Berghauser Pont and Haupt (2009), all low-rise types are attributed to the low value and mostly labeled as less rural or suburban; mid-rise point, as well as high-rise point and high-rise stripe, fall into the medium value category; and mid-rise stripe, mid-rise block, and high-rise block belong to the high value.

4.1.3. Mixed use index

The mixed use index (MXI) is introduced by Joost van de Hoek (2009) to quantify the degree of multi-functionality based on the proportions of floor surfaces devoted to housing, working, and amenities. 'Housing' implies places for living such as apartments, condominiums, row houses, and villas. 'Working' encompasses offices, workshops, factories, and laboratories. 'Amenities' includes urban services such as schools, universities, hospitals, hotels, cinemas, theaters, supermarkets, shopping centers, mosques, churches, and museums; typically they receive the largest number of visitors (Hoek, 2009). Fig. 4 shows a ternary plot on how these three major components can be represented graphically. An urban block consisting of only one function is considered monofunctional. Likewise, a bifunctional block consists of two clusters, whereas a multifunctional or mixed one encompasses all three urban functions. Mixed uses are considered as the most vibrant urban spaces.

Following Ye et al. (2017), we find the threshold of land use in each block that falls into the high, medium, and low category to classify street blocks into eight groups: mono-working, mono-housing, mono-amenities, bifunctional (working + amenities), bifunctional (working + housing), bifunctional (housing + amenities), mixed (housing + working + amenities) and highly-mixed. As can be seen in Fig. 4, monofunctional areas have at least 95 % for one cluster and up to 5 % for each of the other two, Bifunctional blocks have up to 5 % for one cluster and more than 5 % for each of the other two, mixed areas have more than 5 % for each of the three components. Finally, highly mixed observations are located in the middle of the plot and have at least 20 % for each variable.

4.1.4. Combining street-network accessibility, building density, and land use diversity

Based on their accessibility values, density types, and land use diversity degrees, street blocks are divided into seven classes ranging from low to high values: from rural to suburban, various semi-urban or in-between areas, urban and highly urban areas (Fig. 5). The distinctions outlined here are not equivalent in meaning to those used in urban geography. Instead, they express categories associated with the spatial properties of urban form as part of a cityscape gradient and indicate the quarter's degree of socioeconomic performance. For instance, rural and suburban categories are 'balanced with low values', urban and highly urban groups are 'balanced with high values', whereas semi-urban ones are 'unbalanced' and have big differences between the values of the three morphological measures. Such a typology is mainly a way of visualizing the degree of street life vibrancy rather than simply classifying areas (Ye et al., 2017; Ye & van Nes, 2014).

4.1.5. Transformability index

Any recommended physical intervention, such as street widening, needs to be very carefully managed; demolishing buildings without considering the existing conditions of the buildings will disrupt people and businesses (Karimi et al., 2007). Then, the question is how to balance the intervention that could generate the greatest social, economic, and cultural benefits and the least disruption. The choice of the intervention strategy may be judged on several criteria. Intervention should be limited in areas with relatively good physical conditions, high land

Table 1
The classification of high, medium and low values in the space syntax analysis (adapted from Ye & van Nes, 2014; van Nes, 2021).

		Two phase angular betweenness radius 500 m		
Two phase angular betweenness radius 4000 m		Low	Medium	High
	Low	LL	LM	LH
	Medium	ML	MM	MH
	High	HL	HM	HH

Low values: LL, LM, ML; Medium values: LH, HL, MM; High values: HM, MH, HH

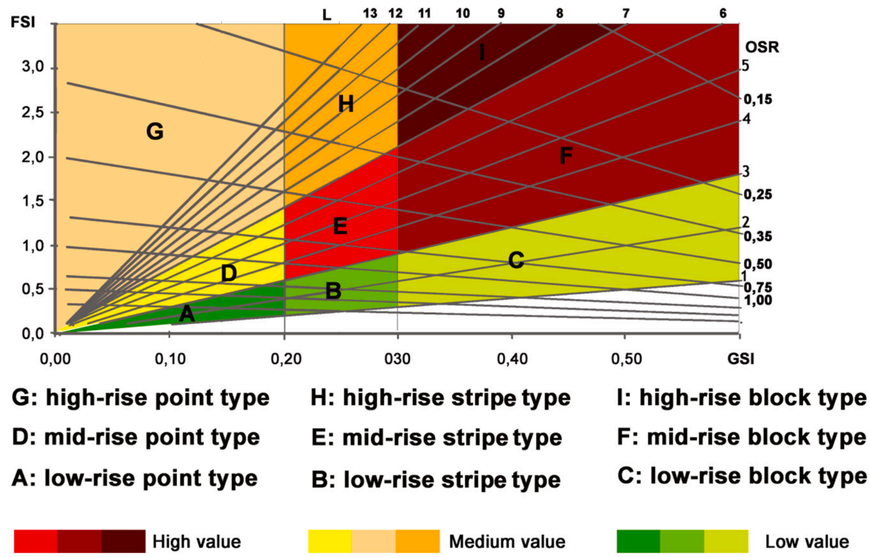

Fig. 3. The FSI-GSI plane of the Spacematrix analysis (adapted from Pont & Haupt, 2009; and Ye & van Nes, 2014).

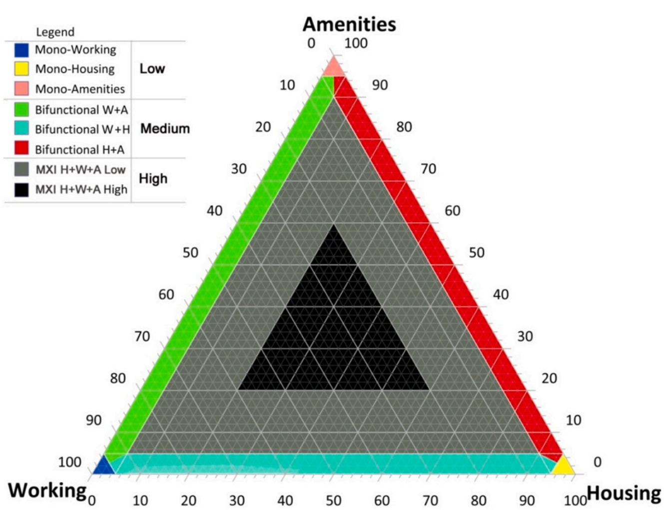

Fig. 4. Ternary plot of functional composition analysis (adapted from Hoek, 2009; and Ye & van Nes, 2014).

values, high density, greater public use, and adequate infrastructure and public services. In other words, interventions should mainly focus on areas at risk of hazards, and where shelter/living conditions are sub-standard, and with insecure land tenure, and inadequate infrastructure (Rismanchian & Bell, 2014). This also depends on funding availability on city side.

Karimi et al. (2007) developed a transformability index – an experimental ranking system to support intervention decisions. To produce this index, several criteria and sub-criteria, depending on the data availability and the nature of the project, need to be selected to reveal existing conditions of each building. Then, the pairwise judgments of all criteria and sub-criteria to weight their priorities have to be done. The importance given to each criteria and sub-criteria can change due to the context and the needs of the specific project.

Fig. 6 illustrates the criteria chosen for this study. We used the Analytical Hierarchy process (AHP) (Saaty, 1980) to assess these weightings (Goepel, 2018) to quantify the present marketable cost of a building. The use of a building, its structure, durability, quality, materials, height, size, location, age, and infrastructure provision affect the valuation of the building. A suitable depreciation value should be allowed based on age of the building, maintenance, etc.; generally, the building depreciates over time, whereas the value of land keeps

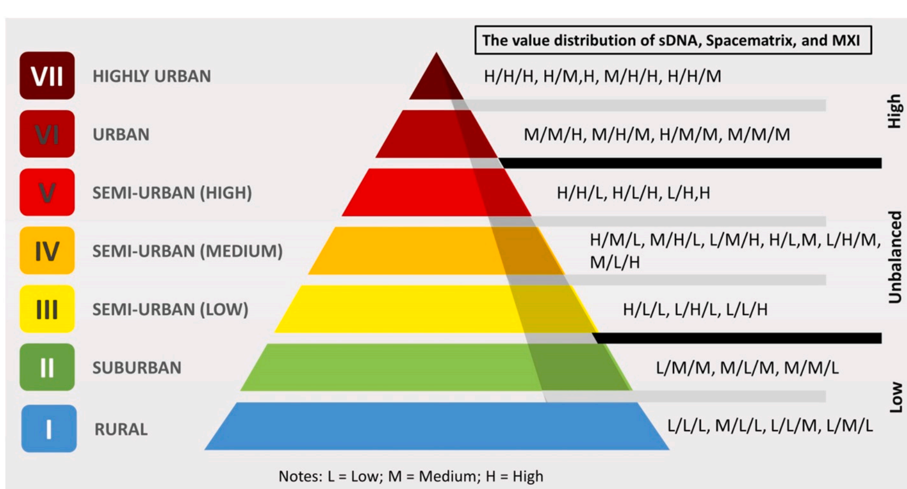

Fig. 5. The definition of urbanity based on the aggregation of accessibility, density, and diversity measurements (adapted from Ye et al., 2017; Ye & van Nes, 2014).

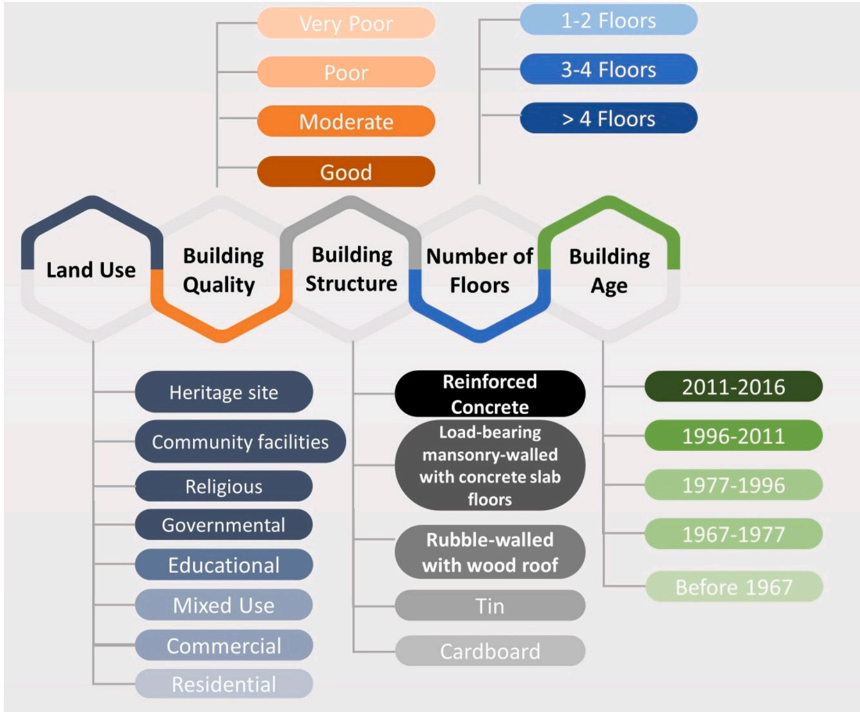

Fig. 6. The transformability index criteria and sub-criteria (source; authors).
Note: adapted to the context and different design criteria. The darker the color, the more important the sub-criteria is; in addition, similar shades are equally important.

appreciating.

After examining different models, it was found that the weighting presented in Table 2 best reveals the conditions in Manshiet Nasser. The resulting weights are based on pairwise comparisons to reflect the importance of each criterion in relation to the other criteria (on a scale 1 to 9 or from equal importance to extreme importance). As the principle is to provide services and to minimize disruption, then land use and building quality should be more important than other criteria. In other words, if the quality of a building is good, then it should be preserved where possible and vice versa (Karimi et al., 2007).

When the selected criteria and sub-criteria are weighted, we know how difficult or easy it would be to transform a specific area. For instance, residential uses could be provided more easily than some other uses and so residential uses have a higher (more transformable) score. On the contrary, heritage buildings and uses or buildings with cultural value are given a low score, or even zero. This is applied to mosques, community facilities and other important buildings (Karimi et al., 2007). The index presented here could be further improved by additional criteria, such as availability of infrastructure, degree of risk to life and health, etc.

4.2. Data

To test our methodology, we have used official GIS database from the ISDF for Manshiet Nasser (ISDF, 2016). The data are available at the building level and are separated into six layers (residential buildings, non-residential buildings, mixed use buildings, infrastructure plants, boundaries of districts and neighborhoods/*Shiyakhas* 2015, and urban evolution). We used the ArcMap 10.3 Dissolve tool to create the urban blocks map from the building coverage; all areas defined by streets and occupied by a group of buildings were considered. Lastly, we corrected the produced layer using aerial imagery, satellites.

The buildings layers include information about number of floors, building quality, building structure, and family size. The non-residential buildings layer contains additional field about the building function and the mixed use buildings layer encompasses detailed information on the use of each story (Table 3).

Finally, the road network map was acquired from General Organization for Physical Planning (GOPP) for Cairo (2015). To explore the accuracy of this map, we overlapped it with the urban block map. The final map consisted of 4945 street nodes with a total length of 144 km.

5. Results

The urban vitality looks at three indicators: street-network accessibility, building density and land use diversity, also indicated in the research framework (Fig. 2). These indicators will be calculated solely and combined. Then, results of the combined index will be overlapped with the transformability index in order to identify priorities and possible ways of interventions.

Table 2
The AHP priorities for the main criteria in Manshiet Nasser based on the principal eigenvector of the decision matrix (source: authors).

Rank	Criteria AHP	Land use	Quality	Structure	Age	No. of floors	Consistency ratio (CR)	Priority
1	Land use	1	2	3	4	6	2.2 %	42.0 %
2	Quality	0.50	1	2	3	5		26.5 %
3	Structure	0.33	0.50	1	2	4		16.4 %
4	Age	0.25	0.33	0.50	1	3		10.3 %
5	Height	0.17	0.20	0.25	0.33	1		4.8 %

Table 3
Summary statistics for Manshiet Nasser (2016) (Source: ISDF, 2016).

Total number of buildings	13,203 (100 %)
Residential buildings	8541 (64.7 %)
Non-residential buildings	698 (5.3 %)
Mixed use buildings	3964 (30 %)
Number of housing units	94,351
Average unit size (meters)	55.50
Average family size	3.94
Number of street blocks	1367
Number of street nodes	4945
Total length of street-networks (km)	144
Vacant lands (%)	15.06
Households connected to the electricity network (%)	100
Households connected to the water network (%)	61
Households connected to adequate sewage network (%)	42.3

5.1. Street-network accessibility

The results of the street-network accessibility analysis (sDNA) in Manshiet Nasser are shown in Fig. 7 where the street-network accessibility values are already converted from street centerlines to street blocks, and the two scales of measures (local and global) are already combined. The results of the analysis highlight the main pathways running throughout and between various quarters. Specifically, Al-Nasr road along with the fewer longer streets are highly accessible, both locally and globally. These longer street centerlines are more evenly distributed throughout the whole structure. They start from the main entry points and elongate organically through residential areas. Many wholesale and retail establishments dominate these lines to get benefit from the passers-by movement. Similarly, the main street in Zabbaleen, the quarter of Coptic Christian minority in Manshiet Nasser, has medium global and local betweenness values, marked in orange. This is the 'spine road' that many of the residents use to transport the garbage from the city into the settlement. In contrast, all of the other parts of Manshiet Nasser, particularly the very recently built neighborhoods, are highly spatially isolated, appearing vividly in light and dark green patches. Although the settlement is substantially linked with the city through the definable edge of Al-Nasr highway, its connection with adjoining neighborhoods is considerably poor, the isolation being reinforced by the fact that the cemeteries and the desert often encircle the area. In other words, the transitional zones between the old and newly developed parts of Cairo reduce its overall interconnectivity. Also, Manshiet Nasser's masterplan does not encourage vehicular movement due to the difficult topography. In a nutshell, the settlement is poorly embedded in the global structure of the city.

Similar results can be revealed by exploring the correlation between local and global values (Fig. 8). The shape of the scattergram helps in understanding part-whole relations. In other words, the strength of the correlation between local and global structures indicates the overall performance of an area (Hillier, 1996a; Karimi & Parham, 2012). If the points of the plot form a tighter line sloping at around 45 degrees, then a perfect association between local and global measures can be indicated and vice versa. The orientation and width of the probability ellipse can also give information about the correlation between the two variables. If the ellipse is more circular, then the two variables are weakly correlated or uncorrelated. In Manshiet Nasser, the scatter is diffused, the probability ellipse is more circular, and the R-squared value is significantly low. This occurs when street segments have either high local values and low global values, or low local values and various global scores like our case study. This confirms that Manshiet Nasser is poorly connected to the rest of the city.

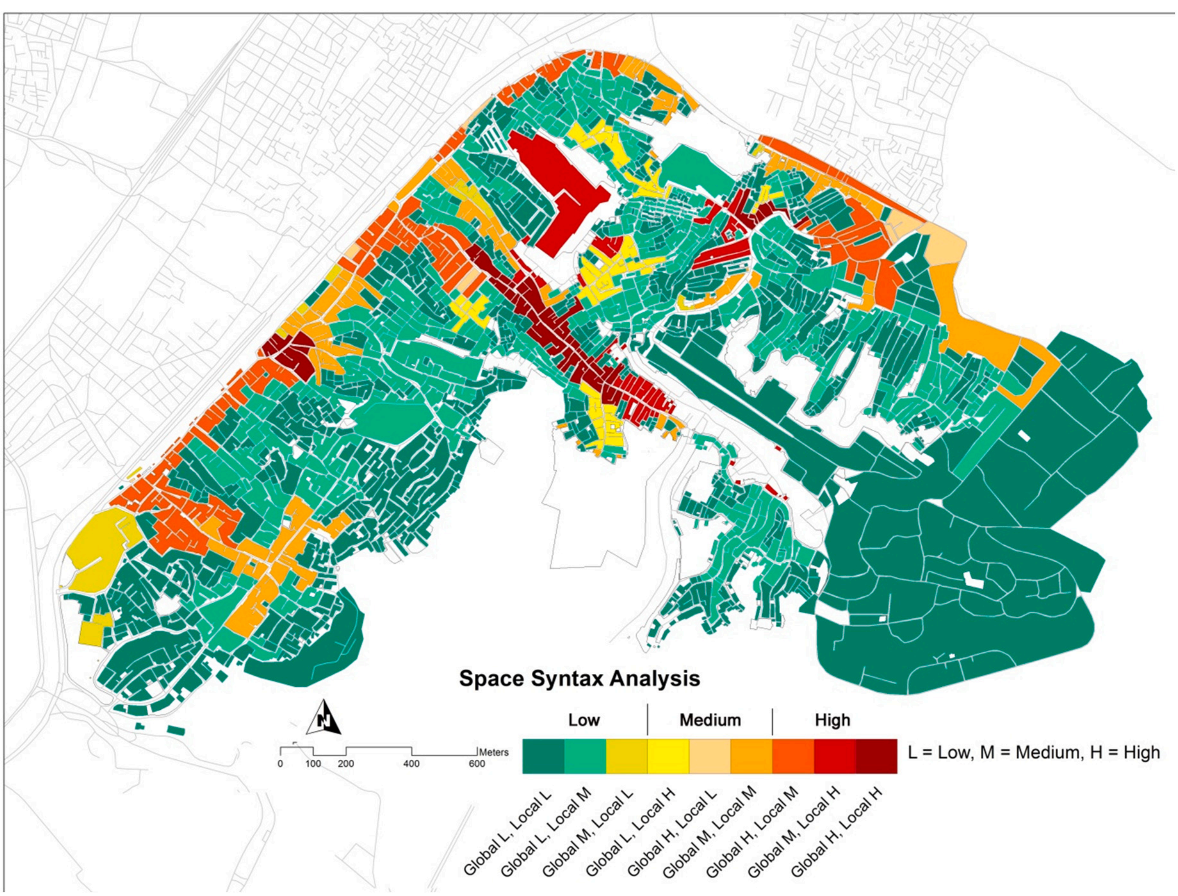

Fig. 7. Results of the sDNA analysis in Manshiet Nasser (source: authors).

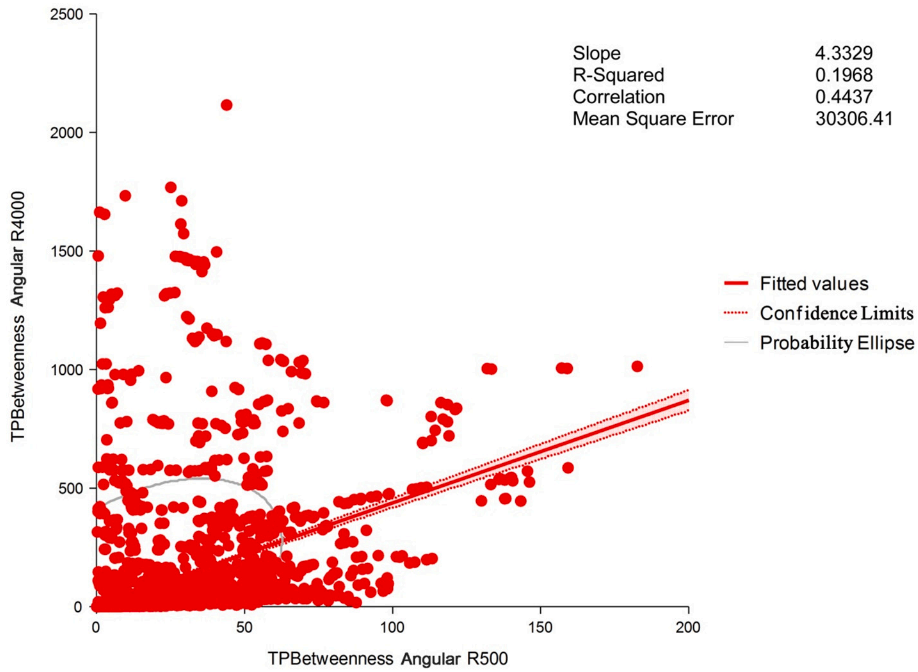

Fig. 8. Defining spatial structure problems through scattergram analysis (source: authors).

5.2. Building density

Spacematrix results are graphically summarized in Fig. 9. The green color spectrum represents urban blocks dominated by low-rise developments, light and dark shades of red represent high-rise developments, and the yellow scale shows what is in the middle. As can be seen, the mid-rise block type, mostly found in older quarters and public housing zone, accounts for almost half of the total built mass. Moreover, low-rise blocks represent nearly one-third while low-rise point category comprises less than one-sixth, marked in dark green. In contrast, high-rise categories represent the smallest proportion. These figures indicate that Manshiet Nasser is a compact mid-rise development. It is also more oriented towards block categories. Similarly, the graph below shows that the majority of street blocks have an FSI greater than 1.0, a GSI over 0.3, an OSR less than 0.25, and building height (L) lower than 5 floors.

5.3. Land use diversity

Fig. 10 shows the distribution of urban functions in the settlement. The blue areas are used to represent workplaces (workshops, offices, factories, and storages), the yellow areas are dwellings, and the pink blocks represent amenities (retail outlets and services). The turquoise areas represent a mixture of working and housing, while the red ones have a mixture of housing and amenities. The grey areas have a mixture of all three functions. Approximately one-fifth of blocks are dominated by mono-housing areas, and more than two-thirds of blocks are bi-functional. In other words, informal home-based businesses are prominent, even in poorly accessible locations, to meet the daily needs of less affluent households. Mixed areas occupy only 6.2 %. These blocks are where accessibility is better. Further, highly mixed blocks are least common in the settlement (0.02 %). The same pattern can be observed in the ternary diagram below; all features are highly concentrated in the lower right corner indicating that mono-housing and bi-functional (H + A, H + W) are generally the dominant modes in the settlement.

5.4. Urbanity

The combination of spatial accessibility, density, and land use diversity values reveals the degree of urbanity in Manshiet Nasser. The results in Fig. 11 indicate that the settlement has a mixture of rural and urban features. In other words, the study area is considerably heterogeneous. The category ‘unbalanced with mixed-values’ has by far the greatest proportion of street blocks—57.8 %, compared with 32.5 % in the ‘balanced with low values’, and 9.7 % in the ‘balanced with high values’. Most rural and suburban blocks are badly-deteriorated and predominantly located in recently self-developed quarters, whereas highly urban areas are found in the older parts, particularly along the major pathways.

5.5. Transformability

Transformability index is an experimental tool to support design. It aims at reducing the socio-economic cost of physical changes in regeneration plan through considering the existing condition of the buildings. The results of our analysis in Fig. 12 show that the red buildings are the easiest to be manipulated, whereas the blue ones should be retained. High transformability index means that the buildings are highly redevelopable in terms of the actual demolition. Such buildings resemble rural Egypt in terms of poor accessibility, lack of land use diversity, low building density, and makeshift building material. The majority of buildings in the quarters of public housing projects have low transformability. These buildings tend to be taller, newer and durable with social value and, thus, to be preserved where possible. However, design decisions should meet inhabitants' immediate needs and other factors, when the data is available, such as hazards, infrastructure and public service provision should also be taken into account.

As street block is our unit of analysis, we took the average of the AHP scores of the buildings comprising each block in the study area. The outcomes are then categorized into high, medium, and low classes (Fig. 13).

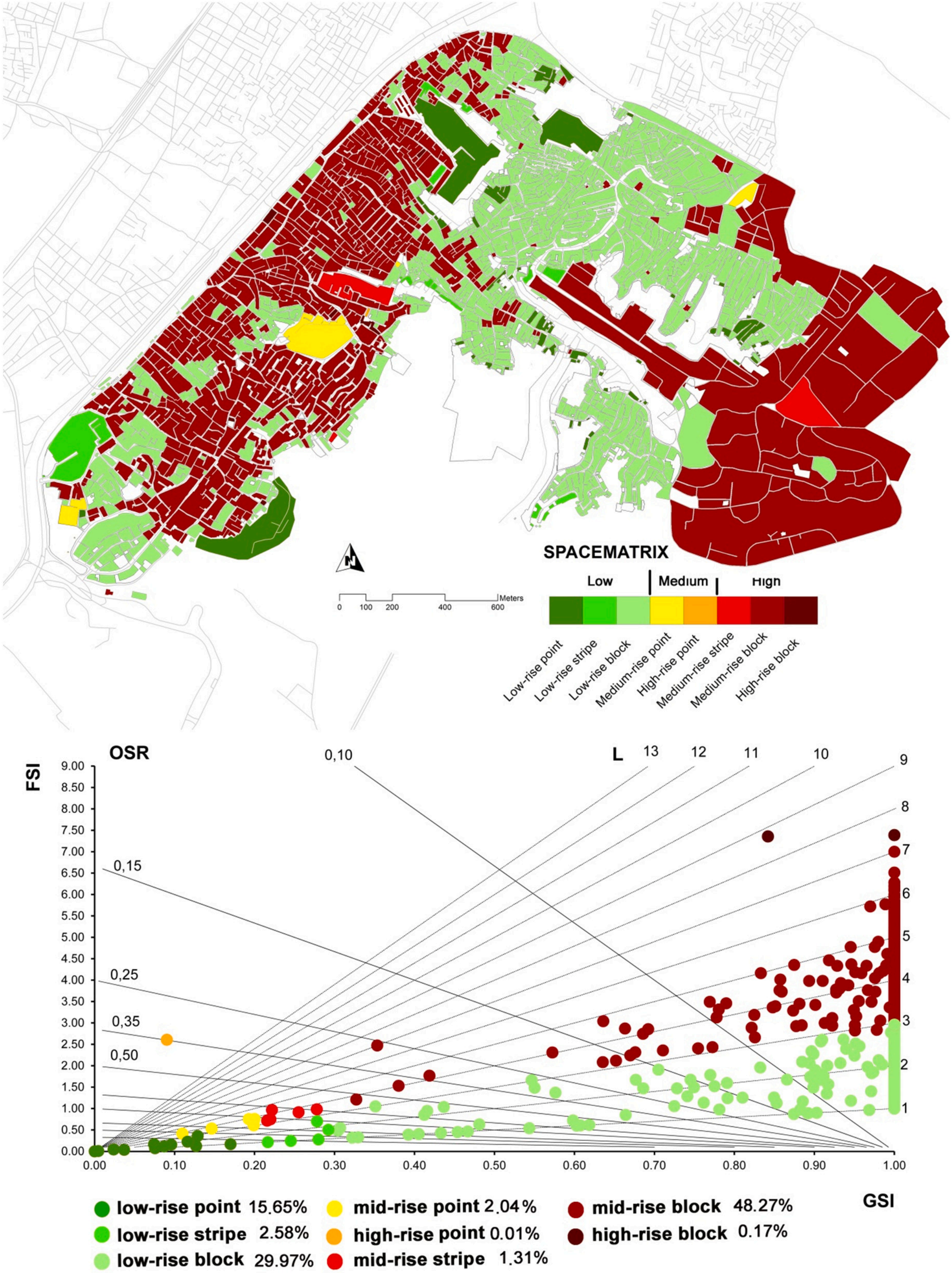

Fig. 9. Results of the spacematrix analysis in Manshiet Nasser (source: authors).

5.6. The identification of intervention strategies

In the previous sections, we have discussed how the degree of urban vitality could be used to better map spatial differences and, therefore, reveal the socio-economic performance of informal settlements on Cairo's public desert land. We have utilized and developed further some existing tools to objectively quantify urban vitality. A combination of street-network accessibility, building density, and land use diversity variables has been the objective criterion for defining what is vital/ livable and vibrant and what is not. We also have developed a transformability index to show how easy it is to transform street blocks.

The analysis of Manshiet Nasser showed that taller buildings tend to

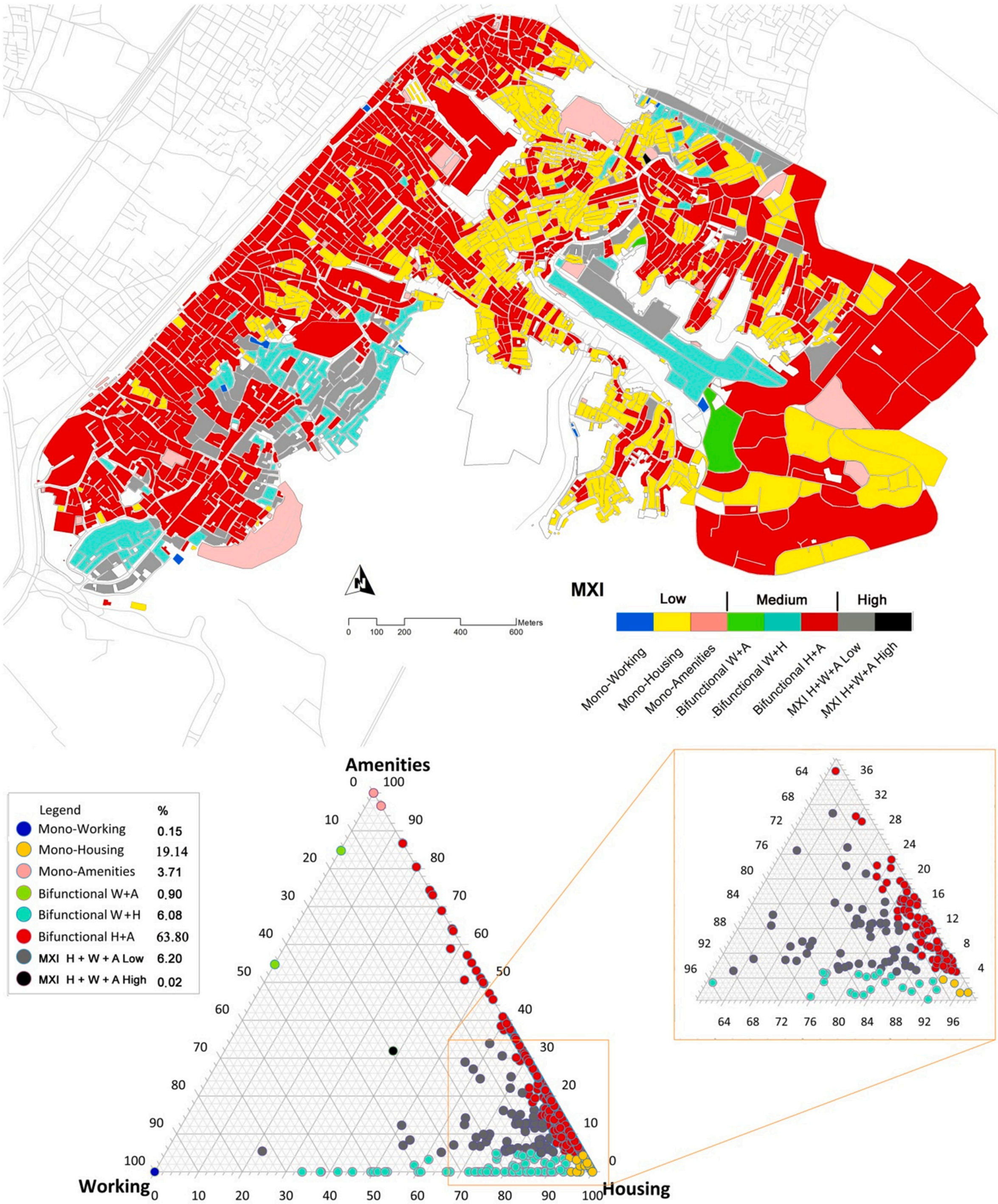

Fig. 10. Results of the MXI analysis in Manshiet Nasser (source: authors).

appear in the most accessible parts of the settlement, and high degrees of land use diversity are generally related to areas with high building densities. Based on this interrelationship over-laid on transformability index, improvement strategies targeting the causes of imbalances between the three spatial indexes can be proposed.

As mentioned earlier, the wholesale demolition of the densely populated informal settlements is socioeconomically and environmentally unworkable. Yet the long-term significant challenge is to suggest strategies to minimize the disruption to existing inhabitants (Dovey, 2013). This limited physical intervention approach prioritizes street blocks with a high or medium transformability value to reduce socio-economic cost. Table 4 shows improvement strategies for street blocks in Manshiet Nasser based on accessibility values, density types, and the degree of functional mix. For instance, policies encouraging high building densities are required in category A locations, which score high in the space syntax analysis, but low in the spacematrix analysis. In contrast, the building density is high in areas belonging to category B where space syntax values are low. For the street blocks belonging to category C, both the space syntax and spacematrix values are high, but the MXI value is low.

Fig. 14 shows the final results of our empirical analysis. As can be seen, there are four ways of intervention for improving urban vitality and, in turn, socio-economic performance in Manshiet Nasser. Street blocks with the potential for increasing density are mostly along highly

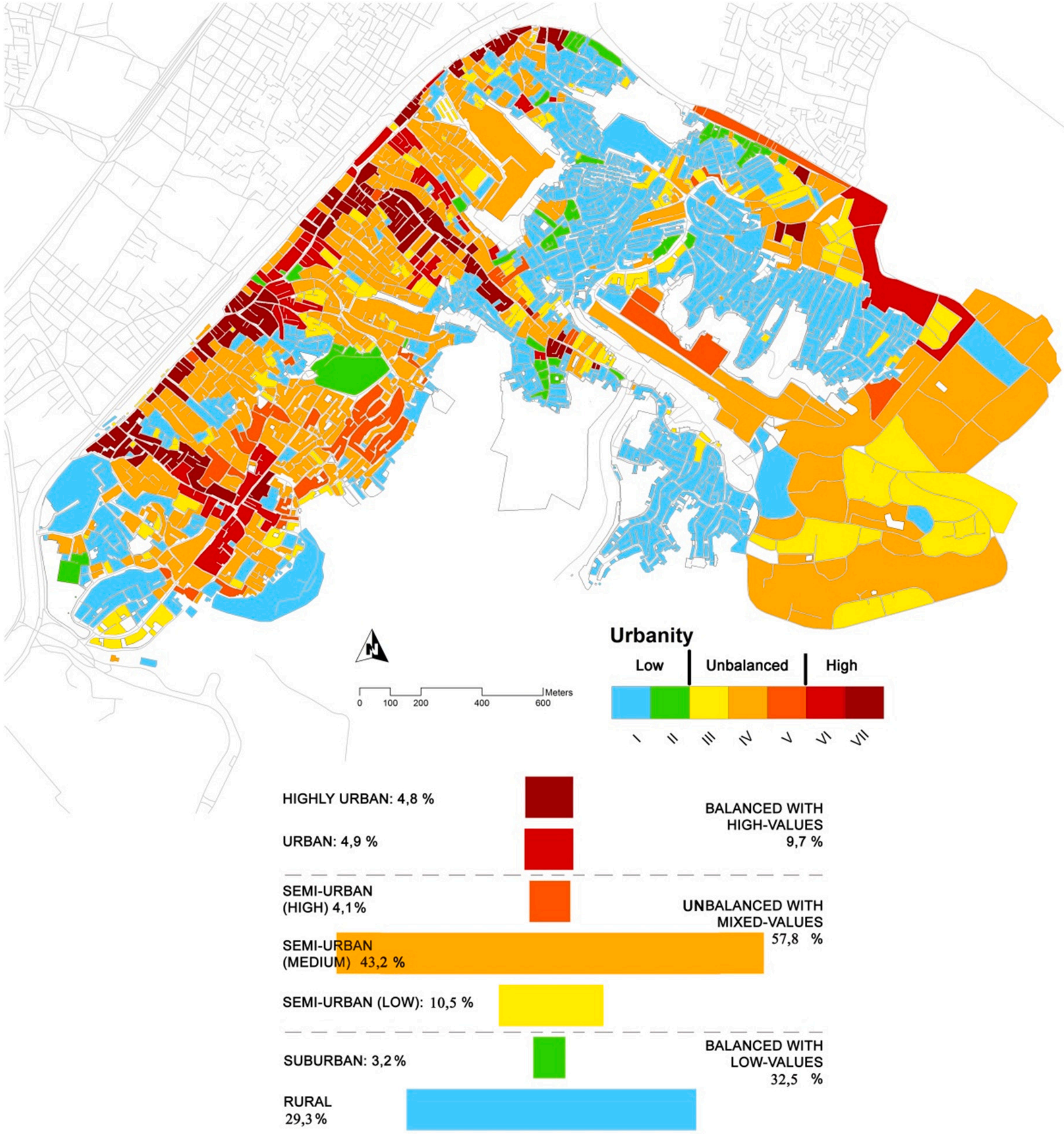

Fig. 11. Results of the aggregation of sDNA, spacematrix and MXI analysis in Manshiet Nasser (source: authors).

accessible streets (category A). Likewise, spatially isolated areas with greater density and land use diversity have the potential for improving their street network (category B). Strategies suggesting an increase in land use diversity are needed in category C areas, which already have higher accessibility and density. Finally, policies encouraging both densification and street-network configuration developments are required in category D areas where both the space syntax spacematrix and values are low, but the MXI score is high.

Importantly, the proposed regeneration plans will inevitably result in partial demolition of some buildings. Nevertheless, based on our experience-based approach, designers can precisely identify the street blocks that, if well-developed, they can foster the urbanity of the area with minimum cost. Decisions on what to manipulate also will be always supported by the transformability index. In this sense, joining and integrating spatially isolated areas with the wider urban fabric will follow careful and subtle changes in the spatial configuration of the settlement. Accordingly, demolition could be avoided where possible to minimize urban disruption.

6. Discussion

6.1. Informality and spatial segregation

Our results showed that the study area inefficiently interacts spatially with the rest of the city. In fact, this local feature has manifested in many other contexts (Hillier et al., 2000; Karimi et al., 2007; Karimi & Parham, 2012; Rismanchian & Bell, 2014). Typically, informal settlements contrast sharply with the urban life.

As signifiers of failure and poverty, informal settlements are commonly deeply spatially isolated and invisible even to those who reside nearby (Dovey et al., 2020; Dovey & King, 2011). Invisibility and disconnection of informal settlements enable governments to abrogate accountability through allocating an insufficient budget or even turning a blind eye (Dovey & King, 2011). Invisibility also results in the unavailability of consistent and accurate data (Sabry, 2009) leading policy makers to take generalized solutions for geographically amorphous spaces (Ibrahim et al., 2020). Eventually, if such places are left isolated,

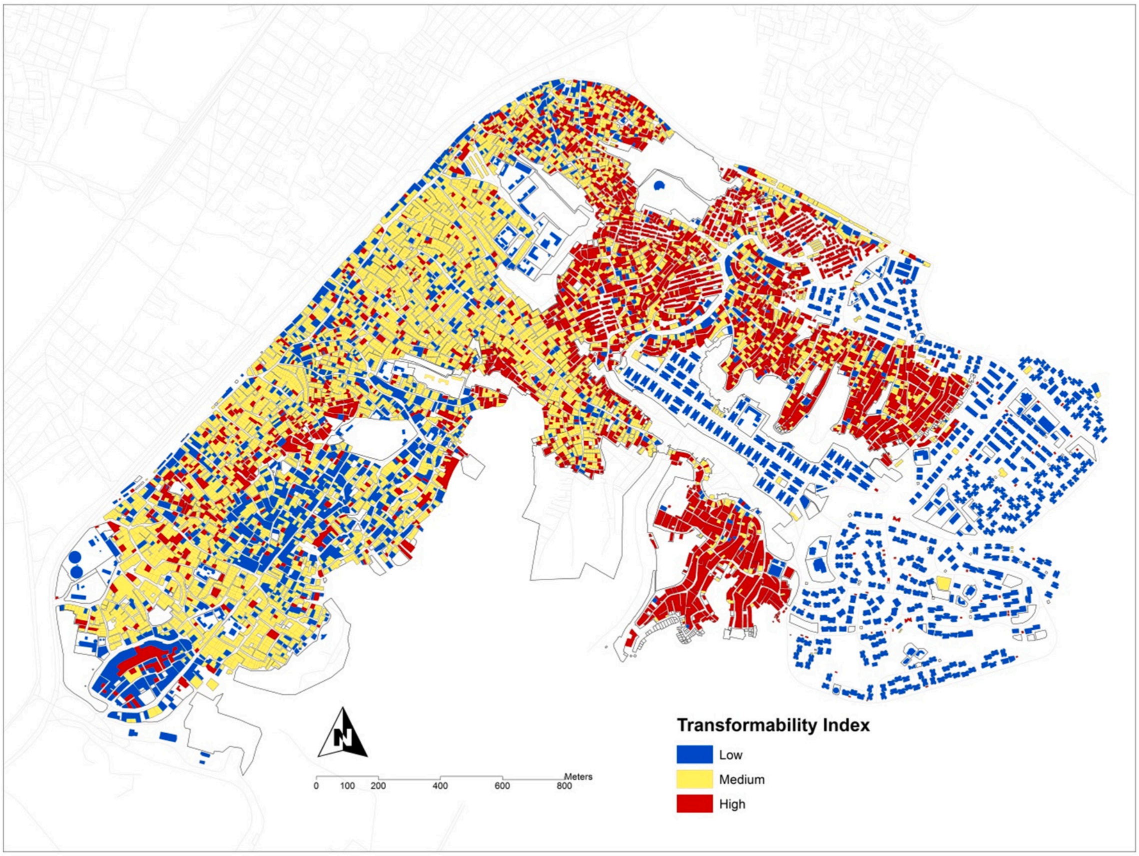

Fig. 12. The transformability index at the building scale (source: authors).

they often will be an increasing cost to the metropolis, will contribute to socio-economic segregation, and will have no opportunities for local or international attention and investments. Any strategy that suggests under-developed solutions will fail because it aggravates isolation and poverty. Policy solutions for building inclusive cities necessitate reducing physical barriers and ensuring that no communities are being marginalized. This is one of the biggest challenges that decision makers should place on the top of the urban agenda.

6.2. Informality and urbanity making

Our study helped understanding the influences of basic morphological elements on urbanity. Areas with good street-network accessibility, high density and land use diversity were more likely to be vibrant urban places. In the words of Boer (2015), the highly urbanized structures in Cairo "have matured over time and have densified, expanded vertically, and developed a vibrant commercial life and strong social cohesion". These structures are a product of an evolutionary process of formation running over a long span of time, while rural and suburban areas are shaped very quickly to meet the escalating housing demand (Hillier et al., 2000; Karimi & Parham, 2012). On the one hand, areas with a minimal amount of urbanity are likely to turn into slums. On the other hand, areas in the midway of urbanity have the potential to turn into highly urban areas. However, ways of intervention are largely determined by the value of each spatial parameter in these types of areas. Also, the interrelations between street accessibility, density/compactness, and degree of mixed-functional development should be taken into consideration.

Then, which variable is most important in achieving urbanity? In Fig. 15, the results of Spearman test show significant positive interrelations between all three variables: street-network accessibility, building density, and land use diversity. Street-network has longer life than buildings and the rapidly changing uses within buildings (Dovey et al., 2020; Hillier, 2012), therefore, the street network layout may influence both buildings and land uses, but the latter two cannot change the street pattern. In other words, building density and the degree of functional mix are a mere consequence of the grid configuration (Ye & van Nes, 2014). Typically, accessible spaces would generate natural movement and, thus, encourage movement-seeking activities, such as retail and entertainment services (Hillier et al., 1993). A similar effect is produced by taller buildings, and by other urban attractors such as bus stops and underground stations (Ratti, 2004). In the study area, however, some very poorly connected areas have greater density and bi-functional developments to better meet the housing demand and daily needs of the low-income populations. This is in line with 'smart growth' goals (Kalinosky, 2001; Smart Growth Network, 2001). Previous studies of low-income households also indicate that settlements with a minimal percentage of non-residential uses are preferable to potential visitors (Song & Knaap, 2004; Stull, 1975). This means that a greater mixture of uses may decrease the demand and prices of housing, possibly resulting in multiple benefits for affordable housing properties (Aurand, 2010). In other words, informal areas with high land use diversity are affordable for low-income residents due to lower housing demand and lower housing prices.

6.3. Limitations and future work

While the analytical tools used and developed in this study could significantly contribute to both geodesign and urbanity making, there are still several limitations that should be addressed in future work. First, the analytical approach confines socio-economic performance to the integration of street-network accessibility, land use diversity, and building density. Although these indicators are considered as crucial properties of city life, they are not enough. Certainly, there are other

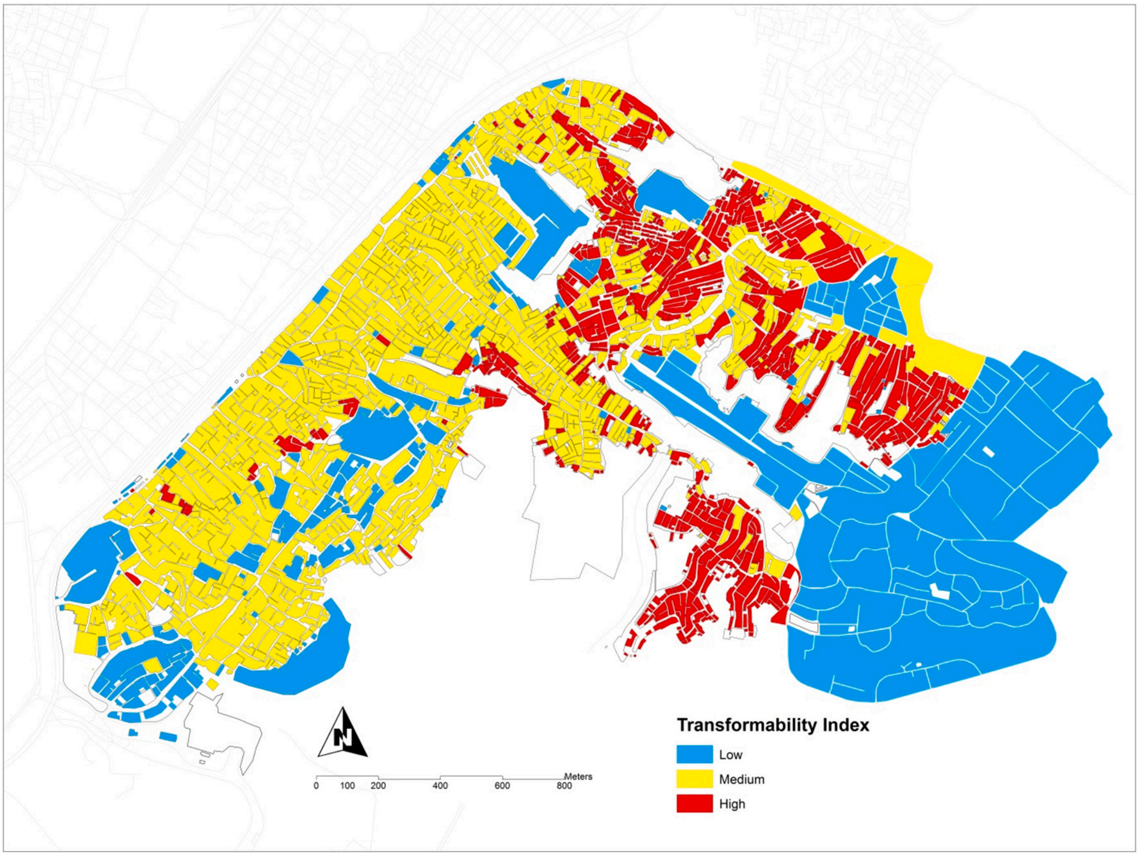

Fig. 13. The transformability index at the street block scale (source: authors).

Table 4
The classification system of improvement potentials in rural, suburban and semi-urban areas (adapted from Ye et al., 2017).

Potentials	A						B						C		D = A + B			E= A + C	
MXI	L	M	L	M	H	H	L	M	L	H	M	H	L	L	L	M	H	L	L
Spacematrix	L	L	L	L	L	L	M	M	H	M	H	H	H	H	L	L	L	M	M
Space Syntax	M	M	H	H	M	H	L	L	L	L	L	L	M	H	L	L	L	M	H
Transformability	H or M																		

Notes: L = Low, M = Medium, H = High; A = potential for densification/morphological development; B = potential for street-network configuration developments; C = potential for functional mixture development; D contains both potentials as identified under point A and B; E contains both potentials as identified under point A and C.

physical parameters that could steer, or impede urbanity and, therefore, could be investigated in future research. Second, due to data limitations, the developed transformability index excludes important variables, such as hazards and access to infrastructure like household-level water, electricity, and sewerage connection. Last, the model has been computed for only one Egyptian settlement. Future research should investigate cases from other contexts in the world to validate and fine-tune the concluding remarks that can be drawn from this work.

As for future work, several areas seem to be significant for the extension of this study besides addressing the approach limitations:

1) Enhancing the model by the addition of more morphological parameters, such as percentage of blind spaces (Holanda, 2002), the degree of inter-visibility of entrances (van Nes & López, 2010), perimeter and type of façade (Canuto & Amorim, 2012), and other urban design qualities (Hamidi, Bonakdar, Keshavarzi, & Ewing, 2020) could have the potential to influence the pattern of urbanity.
2) Exploring other cases and contexts. For example, the comparison between informal settlements established on privately owned ex-agricultural land and areas built on public desert land could answer the question of why the former perform socioeconomically better than the latter.
3) Considering the influence that urban vitality principles, particularly urban density, could have on the spread of Covid-19 pandemic which becomes a serious international health concern (Khavarian-Garmsir et al., 2021; Lai et al., 2020; Teller, 2021).

Self-organized, namely called organic, settlements, and the way people conform to city life can teach us more about the strategies of bringing the built environment to life than official practices. Planners, urban designers, and policymakers should consider the integral role of street-network configuration, density, and land use mixture in promoting city life. Identifying the degree of urbanity in settlements is the first step in informing practitioners and government officials on where and how liveable and vibrant environments could be achieved. Finally, this study is a positive response to the growing scholarly interest in using new analytical techniques and employing scientific thinking to better understand different urban issues.

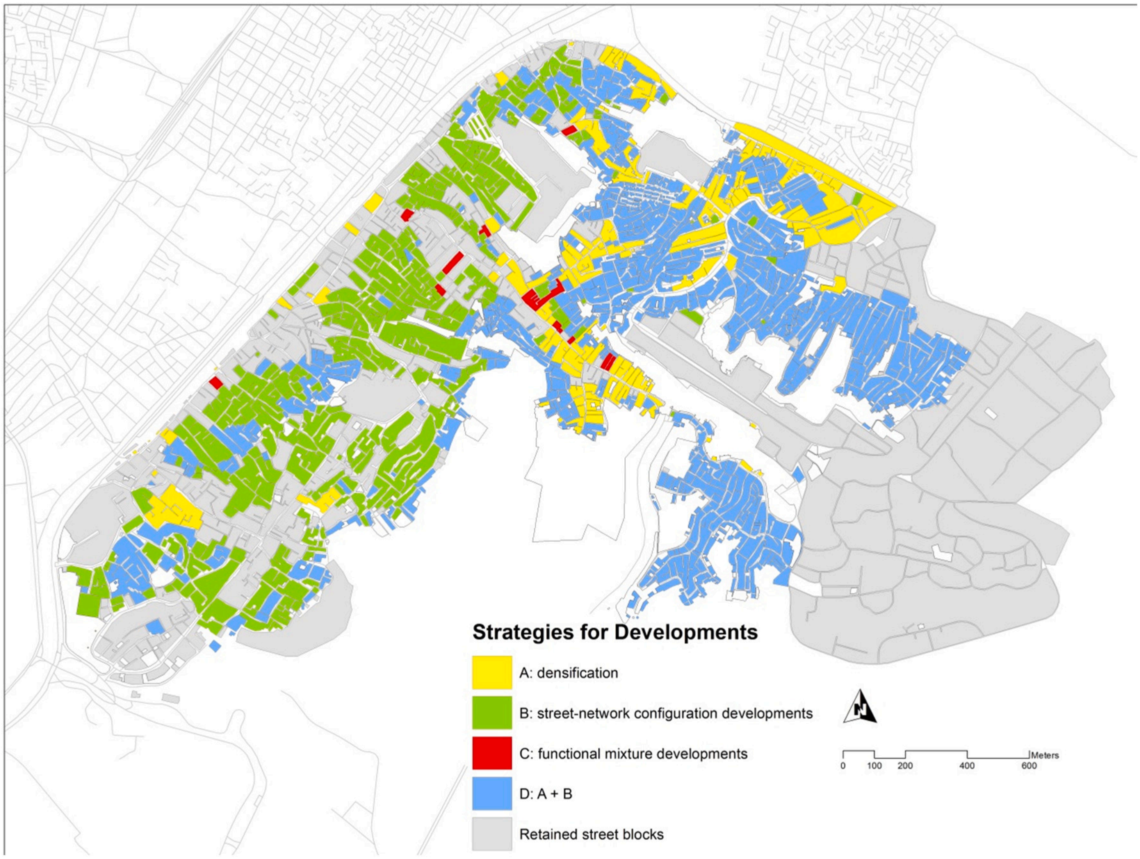

Fig. 14. Various strategies for interventions in Manshiet Nasser (source: authors).
Notes: street blocks with low transformability index, which are more costly to change or demolish, are not included. We also have excluded those with medium transformability index if they are balanced with high-values of urbanity.

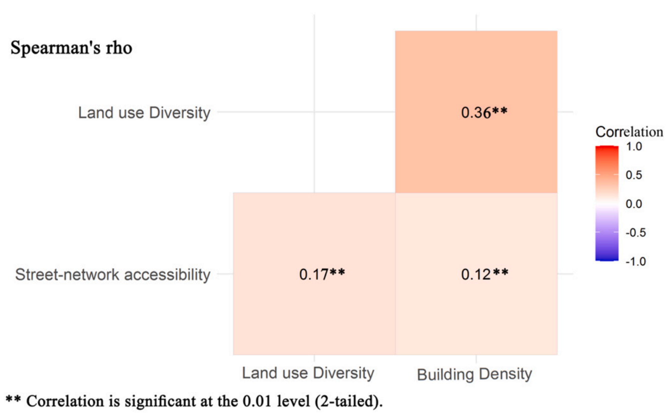

Fig. 15. Results of the correlations between street-network accessibility, building density, and land use mixture in Manshiet Nasser (source: authors).

7. Conclusion

The continued growth of informal urbanism demands decision-makers to better understand the nature of informality and its impact on residents. This paper aims to contribute to understanding informal areas by quantifying urban vitality – a feature that indicates the socio-economic performance, which is relevant for designing policy interventions in informal areas. We focused on answering a key research question; whether it is possible to identify the socio-economic performance of informality in a city by understanding urban vitality.

In this research, we utilize and develop further a research framework to identify 'where' and 'how' to improve socio-economic performance of a certain area. The framework is based on four indexes: street-network accessibility, building density, land use diversity, and transformability (i.e. how socio-economically easy it is to demolish or consolidate an area).

The framework has been examined using Manshiet Nasser in Greater Cairo, Egypt. The findings of this study explain why certain quarters flourish while others retain slum features and fail to reverse their negative trends. Generally speaking, informal settlements, if they have good connectivity, high built-mass density and, a sufficient diversity, will have a potential to evolve and steer urban vitality; in contrast, poorly performing areas most often are bound to disadvantageous and cheapest locations, such as steep slopes and rail yards. A very basic principle of urban development is that investing a limited budget in areas in midway of urbanity such as those dense quarters and those adjacent to the urban core would have greater impact on the quality of life in the city as a whole than investing the same amount of money in underdeveloped locations or in settlements enjoying high levels of urbanity. This more realistic view is evidently an approach that is replicable. Nevertheless, any suggested urban policies should be shared and co-produced with residents to meet their urgent needs.

CRediT authorship contribution statement

Abdelbaseer A. Mohamed: Conceptualization, Writing – original draft, Methodology, Formal analysis, Investigation, Data curation, Writing – review & editing, Funding acquisition. **Rūta Ubarevičienė:** Conceptualization, Writing – review & editing. **Maarten van Ham:** Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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