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# A Classification of Streets in the Greater Cairo Region

## A quantitative approach to classification and urban intervention

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## ABSTRACT

In Greater Cairo, the street patterns of informal settlements can be influenced by the underlying presence of agricultural subdivision or the absence of underlying urban structure. Furthermore, the presence of a well-developed highway system impacts the connectivity between neighbourhoods and their edge conditions. By classifying the streets in the urban fabric of Cairo. this study contributes to a more nuanced classification of informal settlements as a whole and can be used to develop urban interventions based on the spatial form and social needs of neighbourhoods.

The study uses a sample of 13 neighbourhoods in Cairo, Egypt, consisting of planned, informal, and mixed neighbourhoods. This study primarily uses unsupervised clustering (k-means) to classify streets (Berghauser Pont et al., 2019) based on space syntax measures such as Angular Integration (Hillier and Iida, 2005) Normalised Angular Choice (Hillier et al., 2012) and Reach (Peponis et al., 2008).

The cluster analysis results in eight clusters, which are then assimilated to three existing classes; locally important routes, intra-block access, and super-grid (Karimi et al., 2007; Soliman, 2012). Another group was added from the analysis – the socially integrated core. Moreover, two street clusters seem to be unique to informal settlements and linked to the emergence of the settlement. The classification highlights the distinctiveness of street types only found in informal settlements and general role of the highway super-grid as providing important routes both locally and globally. As such, these clusters can be used to aid in classification and be preserved in any urban intervention.

## KEYWORDS

Informal Settlements, Classification, Street Types, Urban Intervention

# 1 INTRODUCTION

Informal settlements are present worldwide, with a concentration in the Global South, and provide housing for an estimated 25% of the world's urban population (UN Habitat, 2015). However, informal settlements tend to be treated as a homogenous type of illegal urban fabric with the same set of problems regarding lack of housing and services, and existence outside legal structures (Roy and AlSayyad, 2004). In reality, it is thought that informal settlements encompass a range of different urban fabrics and social structures, each with their own benefits and problems. The urban improvement projects that are proposed for informal settlements generally do not take into account the specific issues of each informal settlement, nor the benefits that these neighbourhoods provide.

The recommended method of informal settlement urban intervention is physical in-situ upgrading, which can preserve the existing social structure of informal settlements and provide a starting point for other interventions such as economic upgrading or infrastructure provision (United Nations, 2018). The physical urban fabric of informal settlements needs to be studied to understand the different types of informality and provide suggestions for appropriate in-situ physical upgrading (Dovey, 2019).

One of the primary components of any urban fabric is the street network. In the case of informal settlements, the street network evolves alongside the rest of the neighbourhood, without being planned in any way. However, the initial state of the land where informal settlements emerge can play a role in the type of streets that emerge. Types of streets can also vary between planned, mixed, and informal settlements, due to their differing emergence processes. Street types can also form specific configurations, which can be tied to the social and spatial needs of neighbourhoods. Street classification can aid in urban intervention by helping decide which streets should be preserved, and which are less necessary for the functioning of the neighbourhood. This can form part of physical in-situ upgrading and contribute to a holistic urban upgrading program.

# 2 THEORETICAL BACKGROUND

This section outlines the studies conducted in informal settlements and the existing methods of street classifications. The aim is to highlight the importance of the street network and consolidate existing classification frameworks.

## 2.1 The Form and Structure of Informal Settlements

The earliest studies conducted on the spatial configuration of informal settlements were by Hillier et al (2000) and Greene (2003) in Santiago, Chile, which studied the role of the urban form in the consolidation of informal settlements into the main city form. Informal settlements are referred to as Self-generated Neighbourhoods which reflects their unplanned nature and the fact that they are built by residents to fulfil their needs. 17 settlements in Santiago were examined and it was found that the layout of the settlements and their relation to the rest of the city affected the development of the settlement and how consolidated the settlement became over time.

The most important spatial factor was edge movement and how the streets at the edge of the settlements were integrated into the rest of the city. The edge streets have high vehicular movement which leads to higher economic activity on the edge of and within the settlement. Higher economic activity leads to greater consolidation of houses and high levels of community development (Hillier et al., 2000). This study also highlights the importance of studying the edge (boundary) of the neighbourhoods and their interface with it.

The study conducted in 2003 uncovered three main points in informal settlement consolidation. Different informal settlements have different consolidation processes which are influenced by different variables. Finding out the influence of these variables is an important step in informal settlement consolidation. The dual road system (vehicular roads and internal alleyways) have different patterns of movement and use, and both play a role in informal settlement consolidation. Infrastructure and services provision also play a role in consolidation and should be part of any urban upgrading plan (Greene, 2003).

A final study conducted in Santiago argues that highways are a driver of spatial segregation. Informal settlements tend to not be connected to the highways, often as part of the design, so they do not have access to the main transport network and resulting social and economic opportunities (Figueroa et al., 2019).

These three studies primarily indicate that the **street network configuration** on both a vehicular and pedestrian level influences informal settlement consolidation and the **vehicular transport network (highway)** can cause spatial fragmentation. They also highlight that there exist at least two types of streets **(vehicular roads and internal alleyways),** and a specific subset of vehicular streets known as **highways.**

## 2.2 Consolidation of Existing Classifications of Streets

Karimi et al (2007) categorised streets into three types: primary boulevards, secondary boulevards, and locally important routes. Local routes should be aligned as much as possible with the larger network of primary and secondary boulevards. This study shows that interventions in informal areas can be done in an evidence-based way and this methodology could be adapted to suit other cities (Karimi et al., 2007). This study has some similarities to the case in Cairo; highways cut through the unplanned areas which have a very distinct local grid and street network, but it does not fit in with the rest of the city.

Peponis et al (2015) states that a particular type of street network exists in most cities, where there is a differentiation of scale between streets. The ‘super-grid’ is a city-wide spatial grid that is composed of primary roads, which tend to be the main transport network. Local street networks are inserted into the super-grid, which connects different local networks to the primary city-wide network (Peponis et al., 2015).

Karimi's (2007) study adds three potential street classifications - **primary boulevards, secondary boulevards, and locally important routes.** Peponis (2015) reinforces the idea that there is a primary network of vehicular roads known as the **super-grid,** which aligns with the highways highlighted in Figueroa, Greene, and Mora 2019.

One research project based on Al Matariya exformal settlement by Soliman (2012) shows that the street network can be classified into three types of streets:

- **Inter-settlement arteries** – roads running between settlements – this makes up the transport network spanning Greater Cairo
- **Narrow streets bounding residential block** – these streets define the urban block as the place where activities occur
- **Intra block access (hara, darb, alley)** – usually dead end into a block providing private access.

This classification shows that there exist different types of streets in informal areas and has the potential to be built upon to inform further classification.

From the previous studies, the street types can be consolidated into:

- Group 1 – Intra-block Access ("hara" and alley)
- Group 2 – Secondary Boulevards and Locally Important Routes (streets bounding blocks)
- Group 3 - Super-Grid (inter-settlement arteries and highways of all types)

# 3 METHODOLOGY AND CASE STUDY

## 3.1 The Greater Cairo Region as a Case Study

The case study for this research is the Greater Cairo Area in Egypt, presented in Figure 1. This provides a unique location for study since two thirds of the city is built informally and houses over half of the region's population (Sims, 2012). There also exist many different forms of informality with different urban morphologies and emergences, which allows for different urban conditions to be studied in the same sociocultural context.

These case studies provide a cross section of different urban conditions within Cairo that span the entire city and 1400 years of urbanisation processes. They cover the oldest organic urbanisation in Cairo, different types of informal urbanisation and modern developments such as planned districts and satellite cities. They are initially classified into planned, informal, and mixed settlements based on the settlements' legality.

Thirteen neighbourhoods were analysed in this study; a summary is presented in Table 1. Overall, four cases were chosen to represent informal growth on agricultural grid or desert land. Three cases represent historical areas that have become informal, three cases represent fully planned settlements, one case is a satellite city, and two cases represent mixed urbanisation within the same settlement boundary.

Table 1: Summary of Case Studies

| ID | Name | Initial Classification | Date of Emergence |
|---|---|---|---|
| 1 | Ard El Lewa | Informal - Agricultural | 1980's |
| 2 | Mit Uqba | Informal - Agricultural | 1800's |
| 3 | Bulaq El Dakrour | Informal - Agricultural | 1313 AD, informal in 1980's |
| 4 | Dar El Salam | Informal/<br>Agricultural (urban fringe infill) | 1970's |
| 5 | Medieval Cairo (Islamic Cairo) | Exformal - Historically, planned but turned informal | 969 AD, grew informally |
| 6 | City of the Dead (Cairo Necropolis) | Exformal - Historically, planned but turned informal | 642 AD, informal in 1960's |
| 7 | Manshiyet Nasser (Garbage City) | Informal/ Desert<br>(aggregate) | 1950's |
| 8 | Mohandisseen | Planned – evidence of subdivision | 1950's |
| 9 | Zamalek | Planned – evidence of subdivision | 1869 |
| 10 | Nasr City | Planned – evidence of subdivision | 1960's |
| 11 | New Cairo (Satellite City) | Planned – evidence of subdivision | 2000's |
| 12 | Heliopolis, Al Matariya and Ain Shams | Mixed/<br>Planned and informal fabric together | 1905 |
| 13 | Taqseem Omar Ibn El Khattab | Mixed/<br>Planned and informal fabric together | 2000's |

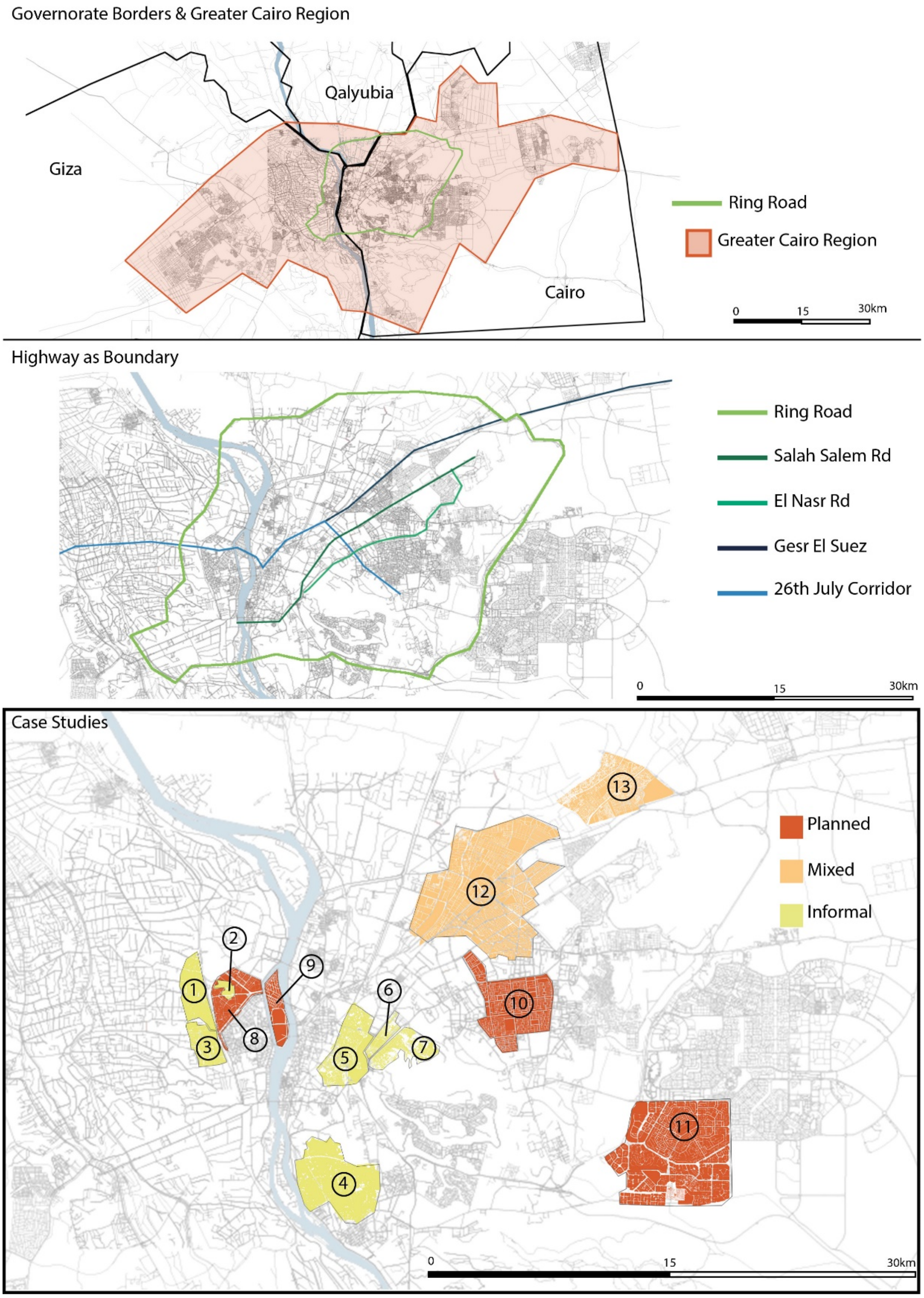



Figure 1: Diagram Showing the Extents of The Greater Cairo Region (Top), The Main Highway Network (Middle) And the Neighbourhood Case Studies (Bottom)

## 3.2 Emergence Processes of the Urban Fabric

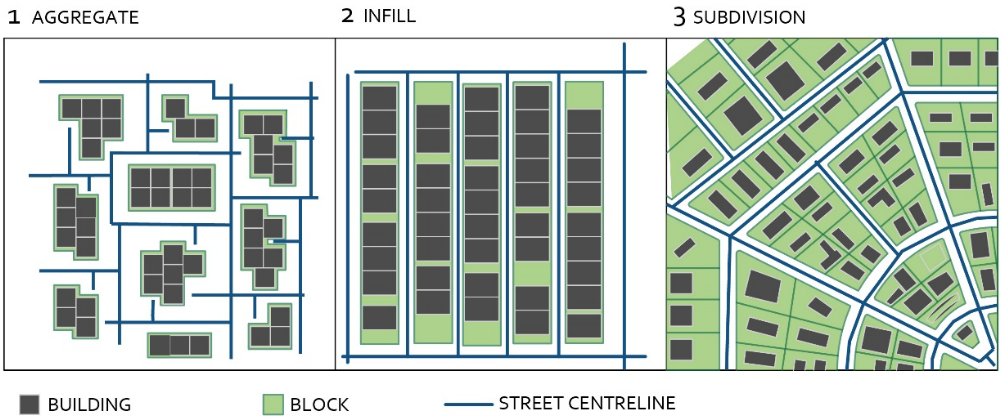



Figure 2: Emergence Types of Neighbourhoods

The emergence of neighbourhoods is also an important consideration when defining what a street is. Three morphological types, presented in Figure 2, reflect the emergence of the settlement and define the block and street in that type of settlement. Type 1 – Aggregate is when buildings aggregate into clusters and there is leftover space. These clusters are considered as urban blocks and the leftover space is considered as a street. The street centreline is taken as the midpoint of the space left between blocks. This type generally aligns with organic/historical settlements or informal settlements built on desert land.

Type 2- Infill is when there is a pre-existing grid which can be natural or manmade, and the settlement infills the grid. Existing movement pathways in the grid defines the streets, and buildings infill the leftover space to create urban blocks. An example of this is an agricultural grid initially made up of fields and irrigation canals. The canals dry up and become pathways for movement (streets) and the fields have housing built on them and become urban blocks.

This is in contrast to Type 3 – Subdivision where all elements are designed and executed at the same time, and urban blocks are not tied to the building clusters. Subdivision can take different morphologies such as grid-iron, radial, etc. and are almost always planned settlements.

## 3.3 Methods and Procedures of Analysis

This section outlines the methodology of the study, the analytical procedure, and the chosen syntactic measures. The aim was to combine a number of syntactic measures of integration, choice, and reach to find common and different characteristics of streets. K-means clustering (Berghauser Pont et al., 2019; Tan et al., 2005) is used to classify into types based on the syntactic measures. Descriptive statistics are extracted for each cluster and compared, in order to create a meaningful description of each cluster. To determine type, it is important to consider not just the numerical values of the clusters, but the distribution in the neighbourhood and any configurations the streets may make. Finally, the street types are presented and integrated into the broad categories from the literature review.

### 3.3.1 Creation of the Segment Map

In order to create models for quantitative analysis a base map of Cairo was needed. The initial CAD map was sourced from CAPMAS (Central Agency for Public Mobilization and Statistics) using their online GIS platform, Open Data for Africa, and was dated around 2006, the date of the previous census. Another CAD map was sourced from Open Street Map. These CAD maps were cross referenced with historical maps to learn more about the settlements' emergence and make sure older features are still represented in the newer maps. After this, maps were updated by tracing over satellite imagery, taking into account distortion caused by perspective and shadows.

The segment map is based on the street centreline vector map. The street centreline was split at line intersections to create individual segments. Any curves and excessive traffic detail in the street centreline were simplified enough to remain an accurate representation. Double lane roads with no access between lanes are represented as two parallel lines. In areas where streets overlap vertically, such as bridges and flyovers, segments were not split at the vertical intersection in order to accurately represent the street. Instead, 'unlink points' were added to indicate that even though the lines visually intersect, they do not intersect in reality.

After this the map was checked to make sure that all segments are split at the intersections, there are minimal extra points, and all segments correspond to roads in reality. Once this check is complete the map was imported into QGIS for analysis. The 'Create Segment Map' command in PST (Place Syntax Tool - (Stahle et al., 2005)) was used as a final step to clean the map from any geometry that may be missed visually and prepare it for analysis.

### 3.3.2 Space Syntax Analysis of Streets Using Segment Map

The objective of analysing the street network is to find out how it is potentially used by residents, its suitability for the neighbourhood (fit for purpose) and to help in classifying street types to eventually classify the neighbourhood. To this end, measures were chosen such as integration (potential for movement), choice (how likely the segment is to be passed through on shortest routes) and reach (how far one can travel from each segment by distance or number of turns) and length of street. Integration and choice also highlight the syntactic structure of a settlement that correspond to the primary street network, which can provide further insight on whether a street network is fit for purpose. Length is important to contextualise and scale the other variables and to find total length of streets per settlement.

Angular Integration (AI) is used since it can be compared across systems and takes into account the number of turns as well as total depth. The AI is normalised by Turner 2007 method which assumes that most journeys will end in the middle of a segment rather than at the ends (Turner, 2007). Normalised Angular Choice (NACH) is used as it helps address the increased choice that segregated areas add to the whole system by adjusting choice, so it is divided by the total depth. This is particularly important in neighbourhoods that have both planned and informal areas in order to reflect choice accurately. NACH also helps highlight the primary street network when it is curved/angled, which may not be picked up by AI alone.

To analyse reach, two measures are used. Metric Reach (MR) measures the total street length in the system that can be reached from a segment within a specific radius. The radii chosen are 100m and 250m (a short walk, suitable for children) 500m (a longer walk but still local) and 1000m (a longer walk or short vehicle ride). Metric reach also highlights density in settlements, as segments that are closer and more connected to each other will have a higher metric reach.

Directional Reach (DR) measures the total street length in the system that can be reached from a segment within a specific number of turns and threshold angle to define a turn. The number of turns chosen is zero turns/directional change (DR_0D) and two turns (DR_2D). Zero turns highlight the longest, straightest streets in the system which can provide insight into the primary street network and settlement type. Two turns reflect the average journey one can take without being cognitively stressed and needing to follow specific directions.

The final analysis process was completed in QGIS to preserve the IDs and make sure the data is attributed to the correct segment. For the reach analysis, shape files were extracted from QGIS to preserve the ID and converted to text files using Shape2Text program. After this, angular and metric reach were extracted using the Reach and DDL JavaScript programs. The resulting data had the ID preserved and could be joined back into QGIS shape files. Within QGIS, the updated shape files were analysed using PST to extract AI and NACH. The end result was a shape file with the length, AI, NACH and reach data attributed to each segment using a global ID. This data was then visualised using graduated colour to represent the range of each variable.

The definitions and areas of investigation are summarised below:

- Angular Integration (AI)
    - Calculated by the sum of angular changes on each route and is the inverse of depth.
    - It represents connection and potential for encounters and can highlight segregated areas.
    - The higher the angular integration value the more connected the segment is – the higher potential for encounters.
- Choice – Normalised Angular Choice (NACH)

- Calculated by how often a segment appears on all the shortest (least angular change) routes to all other segments
- This measure can highlight the spatial structure. The normalised measure picks up curved/angular main roads as well as straighter ones, also shows shortest routes that are 'deep' and allows for more insight into spatial structure than angular integration alone.

- Reach - Metric and Directional (MR and DR)
  - Calculated by setting a metric radius (MR) or number of turns (DR) and measuring the distance in m that can be travelled along segments within each radius.
  - This measure takes into account distance, not just configuration. It can be used to assess density and walkability while taking into account the size of the settlement.
  - Directional reach can also be used to highlight spatial structure (straightest streets, accessible streets within 2 turns).

### 3.3.3 Cluster Analysis to Find Street Types

The cluster analysis process involved optimising the data, performing the cluster analysis then refining the number of clusters and repeating the analysis if necessary. When the optimum number of clusters is reached, the data is extracted, reattributed to the geometry in GIS and used to create visualisations of each variable and cluster. These visualisations are used in the thematic analysis to find themes both within the cluster and within the variables.

Firstly, the data was optimised in order to reduce the errors encountered in the cluster analysis. After this, the attribute tables for all the settlements were exported from QGIS and combined in Minitab Statistical Software, making sure that all Global IDs are retained when moving from one program to another. The data was further filtered in Minitab; any urban blocks below $5m^2$ in area were removed, and street segments under 1m were combined. 98.5% of the data was retained which is an acceptable margin of error. The end result is two optimised datasets for the segment maps and urban blocks, which can be used for cluster analysis and descriptive statistic extraction.

The cluster analysis used was k-means clustering, which classifies given data into a predefined number of clusters (k) by clustering data points around a mean point in Voronoi cells (Tan et al., 2016). This type of clustering finds patterns within the data and creates a mathematical classification of the data based on the variables calculated previously. It is used as it does not need predefined cluster variables, only a predefined number of clusters, so it allows for more freedom in classification and a strict partitioning of clusters without fuzzy boundaries.

Choosing the number of clusters (k) was an important step in the analysis. Too few clusters mean that the nuance in the data may be lost, as elements that are of different types might be clustered together. Too many clusters mean that the difference between clusters is unclear and may lead to small, fragmented clusters. As the two datasets are different sizes a different number of clusters was needed for each one.

The optimum (k) was chosen by testing different numbers of clusters and comparing the results in Minitab and visually in QGIS. If clusters were small or contained very few elements the number of clusters was decreased. If the clusters were large and contained very visually different elements, then the number of clusters was increased. For each cluster trial an elbow graph was created to visualise the cluster and the cluster number reattributed to the geometry in QGIS. This process started with 4 clusters and was repeated until the optimum k was found through comparing the cluster sizes, visualisations, and placement of cluster elements in the settlement.

The results of the cluster analysis were used for statistical analysis and visualisation. Descriptive statistics were used to find which variables define the cluster and to compare between clusters. The visualisations were used to describe clusters by their settlement type and location within the settlement and what it corresponds to in the real world. The descriptive statistics and visualisations were also used in the thematic analysis to inform types.

## 4 RESULTS – MEANINGFUL DESCRIPTIONS OF STREET TYPES

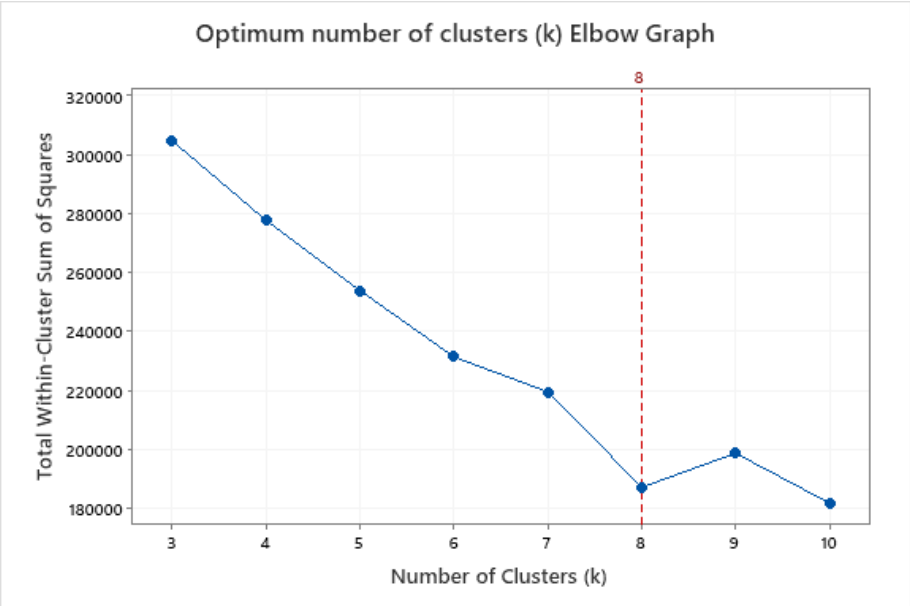



Figure 3: Elbow Graph for Street Segment Clusters

### 4.1 Determining the number of Clusters

The optimum number of clusters (k) was determined experimentally. The value of k was trialled between 3 and 10, and the total within-cluster sum of squares was calculated and plotted. As well as this, k was determined by the visual appraisal of clusters and resulting centroids, with a focus on average distance from centroid (variability within clusters) and distance between centroids (differentiation between clusters). Through this, the optimum number of clusters (k) was determined to be eight, which is backed up by the results of the elbow graph in Figure 3. This number of clusters allowed differentiation between clusters without becoming too granular.

## 4.2 Cluster Description by Variable Parameters and Ranges

This section outlines the description of the clusters using the descriptive statistics of each variable in the cluster. This can be used to determine which variable defines the cluster the most and translate the numerical description into meaningful categories of streets.

Table 2: Descriptive Statistics of Cluster 1

| **Cluster 1** | | | | | |
|---|---|---|---|---|---|
| Variable | Mean | StDev | CoefVar | Minimum | Maximum |
| Seg_AI | 0.13 | 0.05 | 40 | 0.0 | 0.62 |
| Seg_AI_NAC | 0.13 | **0.21** | **154** | 0.0 | 0.85 |
| Seg_DR_0D_m | 55 | 91 | 166 | 0.0 | 1405 |
| Seg_DR_2D_m | 2219 | 3212 | 144 | 0.0 | 39,939 |
| Seg_MR_100m | **608** | 207 | 34 | 0.0 | 1536 |
| Seg_MR_250m | **4064** | 926 | 22 | 0.0 | 7261 |
| Seg_MR_500m | 17,275 | 3333 | 19 | 7595 | 25,921 |
| Seg_MR_1000m | 62,528 | 16,611 | 26 | 23,355 | 101,243 |

**Cluster 1** has high mean metric reach at 100m (608m) and 250m (4064m) compared to the other clusters. It also has a wide range of generally high metric reach values (Table 2) which may vary due to if it branches off cluster 7 or cluster 8. There is a high variation in NACH (154% co-efficient of variation, 0.21 standard deviation), which indicates that streets may or may not be on the shortest routes in the neighbourhood. This cluster can be defined by high metric reach at low radiuses, low angular integration and lower NACH, meaning that these streets are used for access to the walkable grid (high reach) but not necessarily part of the main spatial structure (low AI, NACH).

Table 3: Descriptive Statistics of Cluster 2

| Cluster 2 | | | | | |
|---|---|---|---|---|---|
| Variable | Mean | StDev | CoefVar | Minimum | Maximum |
| Seg_AI | **0.12** | 0.04 | **33** | 0.02 | 0.52 |
| Seg_AI_NAC | **0.98** | 0.16 | **16** | 0.47 | 1.62 |
| Seg_ DR _0D_m | 175 | 211 | 120 | 0.00 | 1747 |
| Seg_ DR_2D_m | 3142 | 3666 | 116 | 0.00 | 32,457 |
| Seg_MR_100m | 345 | 116 | 33 | 0.00 | 1045 |
| Seg_MR_250m | 1516 | 547 | 36 | 0.00 | 3562 |
| Seg_MR_500m | 5591 | 2193 | 39 | 0.00 | 21,465 |
| Seg_MR_1000m | 21,822 | 9045 | 41 | 0.00 | 64,740 |

**Cluster 2** has the lowest metric reach values out of all of the clusters (Table 3), indicating that this type of street is not connected to a very walkable system. There is low variation in NACH

(16% co-efficient of variation) and fairly low variation in AI (33% co-efficient of variation). However, mean NACH values are high (0.98) which indicate that these streets are found on the shortest routes, but a low mean Angular Integration (0.12) means that some streets may be segregated. This cluster is defined by low metric reach, low angular integration, and a narrow range of NACH, meaning that these streets are not very walkable or highly integrated, but often appear on the shortest routes.

Table 4: Descriptive Statistics of Cluster 3

| Cluster 3 | | | | | |
|---|---|---|---|---|---|
| Variable | Mean | StDev | CoefVar | Minimum | Maximum |
| Seg_AI | 0.14 | 0.05 | **36** | **0.05** | **0.42** |
| Seg_AI_NAC | 1.02 | 0.18 | **18** | 0.35 | 1.62 |
| Seg_ DR _0D_m | 183 | 239 | 130 | 0.00 | 2557 |
| Seg_ DR _2D_m | 4530 | 5629 | 124 | 0.00 | 45616 |
| Seg_MR_100m | 560 | 145 | **25** | 141 | 1214 |
| Seg_MR_250m | 2945 | 635 | **21** | 0.00 | 5268 |
| Seg_MR_500m | 11,052 | 2515 | **22** | 4583 | 25,377 |
| Seg_MR_1000m | 36,905 | 11442 | **31** | 0.00 | 97,244 |

**Cluster 3** has low variation in all metric reach radii (Table 4) and low variation in NACH (18% co-efficient of variation) and AI (36% co-efficient of variation, 0.05 standard deviation). It also has a minimum metric reach at 100m and 500m. This cluster is defined by the narrow range of low integration values (0.05-0.42) and higher metric reach, meaning that these streets are not well integrated in themselves but can reach further than others, indicating that they are secondary connections.

Table 5: Descriptive Statistics of Cluster 4

| **Cluster 4** | | | | | |
|---|---|---|---|---|---|
| **Variable** | **Mean** | **StDev** | **CoefVar** | **Minimum** | **Maximum** |
| Seg_AI | **0.12** | 0.05 | 42 | 0 | 0.73 |
| Seg_AI_NAC | 0.17 | 0.21 | 125 | 0 | 0.64 |
| Seg_ DR _0D_m | 83 | 149 | 179 | 0 | 2671 |
| Seg_ DR _2D_m | 2155 | 3744 | 173 | 0 | 40,553 |
| Seg_MR_100m | **353** | 157 | 44 | 0 | 1004 |
| Seg_MR_250m | **1864** | 824 | 44 | 0 | 4534 |
| Seg_MR_500m | 7315 | 3152 | 43 | 0 | 21,883 |
| Seg_MR_1000m | 26,646 | 11,576 | 43 | 0 | 73,692 |

**Cluster 4** has the lowest mean integration (0.12), low mean Directional Reach (353m at 100m radius and 1864m at 250m radius) and low mean NACH (0.165). This cluster also has the highest variation in directional reach (Table 5). This indicates that these streets are quite deep in the system (not well integrated) and are small and generally do not appear on the most direct routes.

Table 6: Descriptive Statistics of Cluster 5

| Cluster 5 | | | | | |
|---|---|---|---|---|---|
| Variable | Mean | StDev | CoefVar | Minimum | Maximum |
| Seg_AI | **0.20** | 0.10 | 50 | 0.082 | **1.71** |
| Seg_AI_NAC | **1.10** | 0.22 | 19 | 0 | **2.05** |
| Seg_ DR _0D_m | **777** | 517 | **66** | 0 | 2873 |
| Seg_ DR _2D_m | **19,297** | 12,959 | **67** | 0 | 62,060 |
| Seg_MR_100m | **269** | 179 | 66 | 0 | **823** |
| Seg_MR_250m | 1739 | 730 | 41 | 0 | 4479 |
| Seg_MR_500m | 7221 | 3102 | 42 | 0 | 25,132 |
| Seg_MR_1000m | 27,857 | 12,043 | 43 | 0 | 92,117 |

**Cluster 5** has a high mean angular integration (0.20) and a maximum of 1.71 (Table 6). NACH is also high (1.10 mean with 2.05 maximum) with low variation (19% co-efficient of variation). Mean directional reach at both 0D and 2D is high, 777m and 19,297m respectively, and the range of values is narrow (66% and 67% co-efficient of variation respectively). Metric reach at 100m is very low, with the lowest mean (269m) and lowest maximum (823m) across all clusters. These results indicate streets that are long (greater than 100m), well integrated, appear on the shortest routes and tend to be straight (high reach at 0D). This identifies the streets as potential straight infill between the main grids.

Table 7: Descriptive Statistics of Cluster 6

| Cluster 6 | | | | | |
|---|---|---|---|---|---|
| Variable | Mean | StDev | CoefVar | Minimum | Maximum |
| Seg_AI | **0.28** | 0.34 | 122 | 0.1 | **3.40** |
| Seg_AI_NAC | **1.38** | 0.24 | **17** | 0.0 | **2.80** |
| Seg_ DR _0D_m | **3254** | 1381 | **42** | 1291 | 6966 |
| Seg_ DR _2D_m | **51,866** | 28,841 | **55** | 1865 | 113,492 |
| Seg_MR_100m | 342 | 190 | 55 | 0.0 | 1007 |
| Seg_MR_250m | 1760 | 794 | 45 | 0.0 | 4740 |
| Seg_MR_500m | 6802 | 3042 | 44 | 0.0 | 20,107 |
| Seg_MR_1000m | 26,165 | 10,994 | 42 | 1055 | 70,200 |

**Cluster 6** has the highest mean angular integration (0.28) and maximum angular integration (3.40) of all the clusters (Table 7). It also has the highest mean NACH (1.38) and highest maximum NACH (2.80), with a narrow range of values (17% coefficient of variation). This cluster also has a high directional reach compared to other clusters, with a small range of values (42% and 55% coefficient of variation). This cluster is defined as being highly integrated, often appearing as the shortest route and tends to be straight or slightly curved. This is expected as the streets this cluster highlights forms part of the highway super-grid, so they are the most integrated and shortest route streets.

Table 8: Descriptive Statistics of Cluster 7

| Cluster 7 | | | | | |
|---|---|---|---|---|---|
| Variable | Mean | StDev | CoefVar | Minimum | Maximum |
| Seg_AI | **0.13** | 0.05 | 36 | 0.00 | 0.32 |
| Seg_AI_NAC | 0.99 | 0.18 | 17 | 0.00 | 1.59 |
| Seg_ DR _0D_m | **114** | 120 | 105 | 0.00 | 934 |
| Seg_ DR _2D_m | 3332 | 3780 | 113 | 0.00 | 26,515 |
| Seg_MR_100m | **856** | 235 | 27 | 275 | **2244** |
| Seg_MR_250m | 4778 | 815 | 17 | 0.00 | 7888 |
| Seg_MR_500m | 16,946 | 2776 | 16 | 8071 | 24,607 |
| Seg_MR_1000m | 55,236 | 13,992 | 25 | 21,714 | 98,174 |

**Cluster 7** has the highest mean (856m) and maximum (2244m) metric reach at 100m radius, indicating a high walkability (Table 8). It also has low mean angular integration (0.13) and low directional reach at 0D (114m). This indicates a dense, segregated system that is composed of not straight, organic/curved) streets.

Table 9: Descriptive Statistics of Cluster 8

| Cluster 8 | | | | | |
|---|---|---|---|---|---|
| Variable | Mean | StDev | CoefVar | Minimum | Maximum |
| Seg_AI | **0.20** | 0.04 | 20 | 0.00 | 0.34 |
| Seg_AI_NAC | **1.19** | 0.2 | 17 | 0.00 | 1.64 |
| Seg_ DR _0D_m | 467 | 383 | 81 | 5.71 | 2557 |
| Seg_ DR _2D_m | 19,480 | 12,353 | 63 | 789 | 59,656 |
| Seg_MR_100m | 837 | 214 | 25 | 202 | 1501 |
| Seg_MR_250m | **5259** | 858 | **16** | 1968 | 7385 |
| Seg_MR_500m | **21,805** | 2822 | **12** | 9577 | 27,461 |
| Seg_MR_1000m | **80,106** | 14,372 | **17** | 38,677 | 104,245 |

**Cluster 8** has high mean metric reach at 100m (837m), 250m (5259m) and 500m (21805m), which have a narrow range of variation in values (Table 9). This indicates a dense, walkable network made up of high reach streets. This cluster also has the second highest mean angular integration (0.20) and NACH (1.19), after cluster 6. It can be considered to represent the informal “main roads” that are walkable and highly integrated and appear frequently on the shortest routes.

## 4.3 Spatial Configuration of Clusters

The following section outlines the location of each cluster within the neighbourhood. It also outlines if there is a specific configuration each cluster is found in, its relationship and adjacency to other clusters and what type of neighbourhood the cluster is found in. Figure 4 and Figure 5 show the location of the clusters within the neighbourhoods and the spatial configurations they form.

**Cluster 1:** ‘dead end’ street, it has low values for all syntactic measures. This presents as singular street segments branching off a main core. It is a cul-de-sac only present in informal neighbourhoods, usually adjacent to/branching off cluster 7 and 8.

**Cluster 2:** presents as a set of street segments forming a continuous aggregated/linear pattern sometimes surrounded by street segments from cluster 3 in informal neighbourhoods and cluster 4 in planned neighbourhoods. This cluster is generally located at the edges of informal neighbourhoods, at the centres of planned neighbourhoods and between main roads. It is mostly present in planned areas.

**Cluster 3:** presents as a set of connected street segments in a curvilinear/angular system. This cluster is present in both planned neighbourhoods and informal neighbourhoods. This cluster is found to be more connected than cluster 2. Mostly present in informal areas where it forms a dense grid.

**Cluster 4**: Seems to be similar configuration to cluster 1 but present in planned neighbourhoods. It is often found with cluster 2 and presents as singular or maximum 2 streets branching off the local grid.

**Cluster 5:** presents as a connected system or individual street segments. This cluster tends to align with the secondary roads (neighbourhood arteries) in planned neighbourhoods. It also presents as infill between cluster 8 in informal neighbourhoods and is connected by cluster 3 and cluster 2 in planned neighbourhoods.

**Cluster 6:** presents mostly in planned neighbourhoods. This cluster clearly aligns with the main regional highways and main roads connecting neighbourhoods.

**Cluster 7:** presents as curved/angular organic configuration in informal areas only, and in the core of historic areas. This cluster is found connected to cluster 8 and cluster

**Cluster 8:** presents as a few connected streets that roughly align with the axial integration core in informal areas. The location in the neighbourhood also seems to be related to emergence, as it highlights the canals in the infill type


Figure 4: Spatial Distribution of Clusters


Figure 5: Spatial Distribution of Clusters

### 4.4 Cluster Size and Distribution by Number and Road Length

This section explores the size and distribution of each cluster. Firstly, the distribution across the entire sample is studied, in order to find the most common 'standard'/'expected' roads. Then, the distribution is studied by neighbourhood terms of street length and number of streets to get a more holistic view of which clusters are dominant in which type (informal/planned/mixed) of neighbourhood.

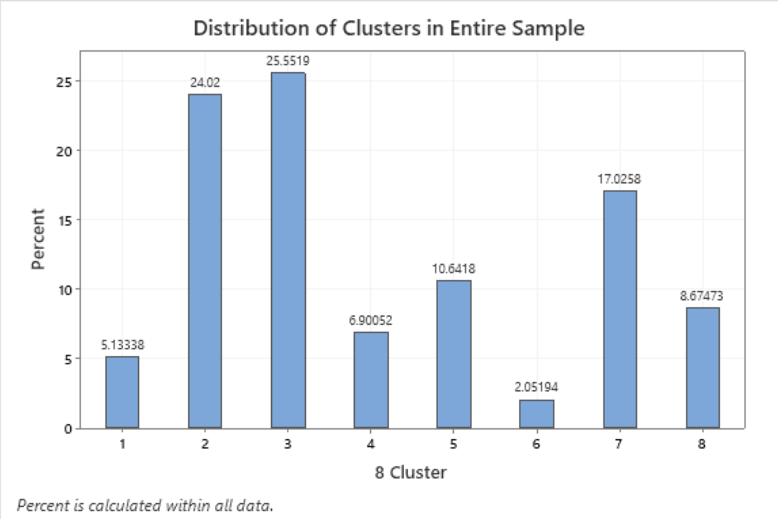



Figure 6: Cluster distribution in Entire Sample (by number of streets)

Figure 6 shows the cluster distribution across the entire sample. The largest clusters overall are 2 and 3, which make up 24% and 25% of streets, respectively. This is expected from the spatial distribution, as they represent street segments found in all neighbourhoods. The smallest cluster is cluster 6, which makes up 2.05% of streets. This is also expected as the streets highlighted in this cluster, the highways, and main streets, are not that numerous.

#### Cluster Distribution in Each Neighbourhood

This section describes the cluster distribution in each neighbourhood, studied by number of segments in a cluster as a percentage of total segments in the neighbourhood, and street length of a cluster as a percentage of total street length in the neighbourhood. Studying the street length as well as the number of segments offers a different perspective and accurate summary, as some streets may be few in number but high in length and vice versa. Table 10 shows the cluster distribution as percentage of total street segment number. Table 11 shows Cluster distribution as percentage of total Road Length and Figure 7 illustrates both distributions.

Table 10: Cluster distribution as percentage of total street segment number (%)

| | 1 | 2 | **3** | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 Ard El Lewa | 3.5 | 10.5 | **38.6** | 7.7 | 15.5 | 0.8 | 8.9 | 14.5 |
| 2 Mit Uqba | 4.7 | 6.2 | **51.4** | 8.4 | 1.1 | 0 | 28.2 | 0 |
| 3 Bulaq El Dakrour | 11.2 | 1.5 | 27.4 | 5.2 | 4.6 | 0 | 21.8 | **28.3** |
| 4 Dar El Salam | 12.4 | 2.2 | 14.8 | 2.5 | 1.7 | 0.4 | 29.5 | **36.5** |
| 5 Medieval Cairo | 10.6 | 12.4 | **35.2** | 6.8 | 0.2 | 0 | 34.6 | 0.2 |
| 6 City of the Dead | 0.5 | 13.4 | **68.4** | 9.6 | 3.4 | 3.9 | 0.8 | 0 |
| 7 Manshiyet Nasser | 4.2 | 29.5 | 26 | 5.1 | 1.5 | 0.9 | **32.1** | 0.7 |
| 8 Mohandisseen | 5.2 | 18.9 | **30.5** | 7.5 | 11.1 | 0 | 28.6 | 0 |
| 9 Zamalek | 0 | 8.1 | 1.6 | 3.9 | **86.4** | 0 | 0 | 0 |
| 10 Nasr City | 0 | 19.9 | 9.1 | 4.5 | **53** | 13.4 | 0 | 0 |
| 11 New Cairo | 0 | **64.5** | 14.5 | 5.8 | 10.2 | 1.3 | 3.5 | 0.2 |
| 13 Heliopolis | 0 | 30.6 | 19.9 | 7.3 | **34.1** | 5.8 | 2.2 | 0.1 |
| 14 Omar Ibn El Khattab | 0.5 | 27.1 | **42.9** | 18.4 | 6.3 | 3.5 | 1.4 | 0 |

Table 11: Cluster distribution as percentage of total Road Length

| | 1 | 2 | 3 | 4 | **5** | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 Ard El Lewa | 1.4 | 8.8 | 21.5 | 6.1 | **49.1** | 1.8 | 3.1 | 8.1 |
| 2 Mit Uqba | 3.6 | 7.9 | **52.5** | 8.2 | 5.3 | 0 | 22.5 | 0 |
| 3 Bulaq El Dakrour | 7 | 1.6 | **26.3** | 5.2 | 21.8 | 0 | 15.4 | 22.7 |
| 4 Dar El Salam | 9.6 | 3.5 | 17.7 | 2.6 | 6.9 | 0.6 | 25.2 | **33.9** |
| 5 Medieval Cairo | 8.2 | 15.4 | **36.6** | 5.7 | 2.1 | 0 | 31.7 | 0.3 |
| 6 City of the Dead | 0.3 | 16.8 | **59.5** | 8 | 10.5 | 4.7 | 0.2 | 0 |
| 7 Manshiyet Nasser | 3.4 | **34.6** | 23 | 6.5 | 6.8 | 2.4 | 22.7 | 0.6 |
| 8 Mohandisseen | 1.9 | **24.2** | 20.2 | 6.9 | 33.6 | 0 | 13.2 | 0 |
| 9 Zamalek | 0 | 2.8 | 0.3 | 2.5 | **94.3** | 0 | 0 | 0 |
| 10 Nasr City | 0 | 12.8 | 2.9 | 4 | **63.6** | 16.7 | 0 | 0 |
| 12 New Cairo | 0.02 | **50** | 6.2 | 4.5 | 31.9 | 5.8 | 1.4 | 0.2 |
| 13 Heliopolis | 0 | 22.6 | 10 | 7.1 | **53.1** | 6.3 | 0.9 | 0.02 |
| 14 Omar Ibn El Khattab | 0.1 | 28 | **28.5** | 15.5 | 20.9 | 6.5 | 0.5 | 0 |
| Total % | 2.5 | 23.8 | 16.4 | 6.2 | **31.9** | 4.9 | 8.5 | 5.8 |

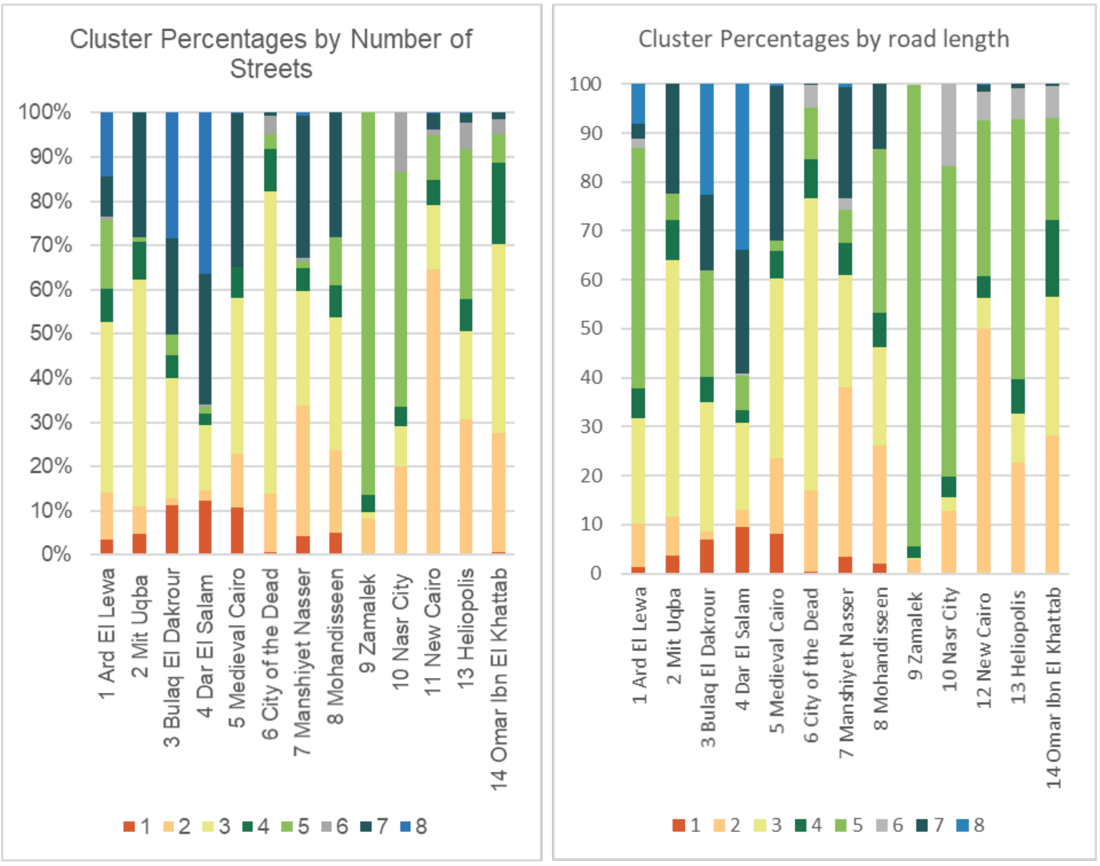



Figure 7: Cluster Distribution by number (left) and Cluster Percentages by Road Length (right)

**Cluster 1** is only present in informal areas, where it makes up less than 12.4% of the total number and 9.6% of the total length in the neighbourhoods. It is also present in Mohandisseen due to Mit Uqba being a part of the neighbourhood. This is the smallest cluster by length (but not by number) which is expected, considering it consists of small, singular streets.

**Cluster 2** is found in all neighbourhoods. It makes up 64.5% of streets by number and 50% by length in New Cairo. It also makes up 29.5% of streets by number and 34.5% by length in Manshiyet Nasser, and 27% of streets in Omar Ibn El Khattab. While the neighbourhoods do not share similar origins, curvilinear streets are found in them all.

**Cluster 3** is the largest cluster by number in 6 neighbourhoods, Ard El Lewa (38.6%), Mit Uqba (51.4%), City of the Dead (68.4%), Medieval Cairo (35.4%), Mohandisseen (30.5%) and Omar Ibn El Khattab (42.9%). This is expected as it is present in all neighbourhoods and is the largest cluster overall by number. This cluster tends to be the largest cluster in informal and mixed neighbourhoods. The exception to this is Ard El Lewa and Dar El Salam, where cluster 5 is the largest cluster by length, but not by number.

**Cluster 4** has a similar distribution to cluster 1 – consisting of 1.7% – 18% by number in all neighbourhoods and 2.5% – 15.5% by street length. However, this cluster is not unique to a particular type of neighbourhood and is present in all neighbourhoods.

**Cluster 5** is the largest in planned neighbourhoods by number. Cluster 5 is also the largest cluster overall by length, which is expected as it presents as long, straight streets. Due to their distribution and spatial location, cluster 3, 2 and 5 can be grouped together as different types of street infill/secondary connections.

**Cluster 6** is rarely present in informal settlements and is present mostly in planned settlements. This cluster overall is in number 2.05% but increases to 4.9% by length. It is highest in Nasr City, where it makes up 13.4% of streets by number and 16.7% by length. It is present in Dar El Salam, City of the Dead and Manshiyet Nasser at less than 4% of number and length, due to the highway that is adjacent to these neighbourhoods. Exceptionally, it does not highlight the highway in Ard El Lewa (0.8% by number, 3.9% by length) rather a few of the long, straight streets that connect the main streets that follow the canals together.

**Cluster 7** is found primarily in informal areas, the highest being in aggregate type (organic growth on desert land). It makes up 34.6% of streets by number and 31.7% by length in Medieval Cairo, and 32% by number and 22% by length in Manshiyet Nasser. It is also present in limited quantities (less than 2%) in mixed neighbourhoods.

**Cluster 8** is found predominantly in three informal neighbourhoods that share emergence on agricultural land, Ard El Lewa, Bulaq El Dakrour and Dar El Salam. It makes up 36% of streets by number and 33% by length in Dar El Salam, which is the highest in all the settlements. It also makes up 28.3% of streets by number and 22.7% by length in Bulaq El Dakrour, and 14.5% by number and 8% by length in Ard El Lewa.

The distribution shows that **cluster 2, 3, 4, and 5** are present in all neighbourhoods. **Cluster 1, 7 and 8** are overwhelmingly present in only informal areas, and **cluster 6** is present mostly in planned areas, or where there is a highway. The spatial and mathematical distribution also reinforces the choice of 8 clusters, as they have unique characteristics and little overlap in distribution and spatial configuration.

## 5 DISCUSSION – CREATING MEANINGFUL TYPES FROM THE CLUSTER ANALYSIS

This section aims to combine the previous observations into meaningful categories of streets and align them with a known street type/typology from the literature review, in order to name and describe each cluster. This categorisation is based on location of the cluster in the neighbourhood, spatial configuration formed (if any), cluster parameters/descriptive statistics and cluster range.

Following on from the results, clusters can be grouped together into four main categories based on the literature review and quantitative analysis; **the intra-block access, the locally important routes, the super-grid (inter-settlement arteries and highways) and integration cores.** Some of the clusters are unique in informal settlements, and so can be used in the settlement classification. The cluster categories and definitions are set out below.

**Group 1 – Intra-block Access**

This group consists of small, singular roads that are considered private access to blocks. They are usually branching off the main local grid into a block.

**Cluster 1: High Reach 'Hara'- Unique to informal:** – informal cul-de-sac, can be considered access road to private area branching off the main core of the neighbourhood.

**Cluster 4: – Low Reach 'Alley'** – small private access streets connected to local grid in planned neighbourhoods.

**Group 2 – Secondary Boulevards and Locally Important Routes**

This group connects the arteries of the neighbourhood to streets bounding residential blocks and forms the local grid between superstructures. They can present as either angular or straight, and usually act as infill. They are present in all neighbourhoods.

**Cluster 2 – Segregated/Low Reach Angular Local Street Grid**

Low integration and reach infill streets between arterial roads – angular or curved system – mostly in planned neighbourhoods.

**Cluster 3 – Integrated/High Reach Angular Local Street Grid**

High integration and reach infill streets between arterial roads - angular or curved system – mostly in informal neighbourhoods.

**Cluster 5 – Long Straight Local Street**

Long straight street with low reach – less walkable – disconnected infill in informal neighbourhoods and connected local grid in planned neighbourhoods.

**Group 3: Super-Grid**

This group represents the main highway super-grid.

**Cluster 6: Highway/Main Vehicular Road**

Main road/highway in planned areas – aligns with named highways in informal neighbourhoods.

**Group 4: Integrated Social Core**

This group is only present in informal areas and always forms a configuration. The two clusters are similar in values but are different in which type of neighbourhood they appear in, which suggests that the emergence leads to a unique street structure/configuration that is only present in informal neighbourhoods.

**Cluster 7 – High Reach Deformed dense organic grid – informal only**

Dense curved organic grid – aligned with organic/historical emergence

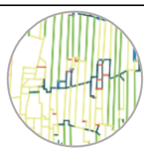
**Cluster 8: Highly Integrated informal main street – informal only**

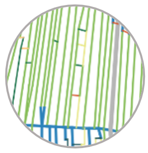
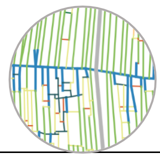
Aligns with the integration core of informal areas, found in the agricultural-canal emergence

The results highlighted eight different types of streets that are present within the sample. The first distinction is the small access street that is used for block access. The high reach 'hara' is only found in informal settlements, contrasting with the low reach 'alley', generally found in planned settlements. The highways are also highlighted as their own type of street and were often found in planned settlements. They are also occasionally highlighted in informal settlements, but only when the internal street network is connected to the highway.

Most importantly, the results uncovered two street structures that seem to be unique to informal settlements. These street structures are the dense organic grid and the informal main street. The dense organic grid is primarily found in informal settlements that have emerged as aggregate on desert land, and the informal main street is primarily in informal settlements that emerge as infill on agricultural land. This highlights the influence of the topography and emergence process in creating different types of streets. The resultant street types are summarised in Table 12.

Table 12: Summary of Street Types

| Cluster Group | Definition | Visualisation | Present in |
|---|---|---|---|
| **1 Intra-block Access** | **Small, singular roads that are considered private access to blocks** | | |
| Cluster 1 (red) | High Reach 'Hara' |  | Informal settlements only |
| Cluster 4 (dark green) | Low Reach 'Alley' |  | Mostly Planned settlements |
| **2 Secondary Boulevards** | **forms the local grid between superstructures** | | |
| Cluster 2 (orange) | Low integration, Low Reach Angular Local Street Grid |  | Mostly planned |
| Cluster 3 (yellow) | Integrated, High Reach Angular Local Street Grid |  | Mostly informal |

| | | | |
|---|---|---|---|
| Cluster 5 (green) | Long Straight Local Street |  | Both planned and informal |
| **3 Super-Grid** | **main highway super-grid** | | |
| Cluster 6 (grey) | High Choice, high integration Highway/Main Vehicular Road |  | Planned |
| **4 Integrated Social Core** | **always forms a configuration in informal areas that often aligns with the neighbourhood core** | | |
| Cluster 7 (Dark Blue) | High Reach Deformed dense organic grid |  | Informal only – mostly aggregate emergence |
| Cluster 8 (blue) | Highly Integrated informal main street |  | Informal only, mostly infill emergence |

These results can be used to inform urban intervention by highlighting which streets are necessary for the functioning of the neighbourhoods (for example, the informal main street, highway, or integrated core) and which streets have leeway for intervention – such as secondary boulevards. Suggested urban upgrading based on the street network can be undertaken by road network normalisation, preserving existing important streets, and increasing access to the rest of the city

## 6 CONCLUSIONS

The statistical classification of streets using space syntax measures can provide insight into the types of streets that exist in different settlements, which can then be used to inform urban intervention. The cluster analysis resulted in 8 clusters, which were then organised into four groups; three groups based on the literature review and one additional group from the analysis. The groups represent intra-block access, locally important routes, the super grid, and the integration core. The crucial finding is that there are street types that seem to exist only in informal settlements, which often highlight the social core of the neighbourhood, which takes different configurations depending on emergence. These street types can be preserved in urban interventions so as to not fundamentally change the neighbourhood spatial structure.

The interface of the local street network to the highway is also highlighted as important. In informal neighbourhoods, the highway tends to be disconnected from the local street network and so presents as a low-integration street. In planned neighbourhoods there is access from the local street network to the highway, so it often forms a main part of the choice network and is highly integrated. It is important to take it into consideration when designing urban intervention, as it can play a role in reconnecting the urban fabric and reducing spatial fragmentation.

Based on these conclusions, practitioners should consider the use of the highlighted clusters to inform intervention through street network normalisation and take into account the role of the highways when designing interventions. Using the segment analysis and clusters uncovered in this study presents a future avenue of work, by preserving or building upon the highlighted informal structures that are conducive to community living. The clustering process can be used to assess the potential of the existing urban fabric prior to intervention proposals in informal neighbourhoods.  This can inform a starting point on what to preserve or indicate which model of interventions is more appropriate depending on the type of fabric.

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