A CLASSIFICATION OF INFORMAL SETTLEMENTS IN CAIRO, EGYPT

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ABSTRACT

Informal settlements are a phenomenon that exists worldwide, housing over one billion people. While they provide housing for the urban poor, they can have negative effects and contribute to the spatial fragmentation of the city. The binary informal/planned classification often does not capture the complexity of the phenomenon and can negatively affect how urban interventions are carried out. In Cairo, further classification systems have been developed, as informal settlements make up a large part of the city's urban fabric and house over one quarter of the urban population. However, the physical urban characteristics of these classifications have not been meaningfully quantified, and the classification remains based on social parameters such as tenure and socio-economic status. A refined classification system based on existing physical characteristics can help inform urban interventions that are tailored to the type of informal settlement, which can potentially be more successful in addressing the negative effects of informality.

Methodology literature suggests that informal settlements have implicit rules that direct urban growth and influence the resultant urban fabric. These rules can be uncovered by studying the informal fabric quantitatively. This thesis takes a mixed method approach to provide a holistic view of informal settlements. Social studies are used to contextualise the phenomenon of informality and provide basis for the quantitative analysis. Urban morphology studies, space syntax analysis and statistical analysis are used to describe the phenomenon quantitatively and categorise blocks and streets. These methods are used to find the implicit rules of growth and unique spatial structures to inform classification.

Quantitative study of the urban blocks and street network indicate that there are some features in urban blocks and open space configurations that are more common to informal settlements, and more importantly, **some street network configurations conducive to community living seem to be unique to informal settlements and do not exist in planned settlements.** These results also indicate that pre-existing land subdivision and topography is the main driver of the resultant urban form rather than social processes. The refined classification framework results in the identification of four main types of urban fabric: infill, aggregate, mixed and planned.

This research also presents several avenues for urban intervention that builds upon existing approaches. Knowing which parts of the street network and urban fabric are necessary to support the community and have emerged due to their needs can be used to inform urban intervention and create more nuanced intervention methods.

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AUTHOR DECLARATION

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Faculty Ethics Committee on 08/06/2017.

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CHAPTER 1: INTRODUCTION

This thesis is the study of the urban fabric of informal settlements in Greater Cairo, in order to develop a classification framework that can be used to inform urban upgrading approaches. This study takes a mixed methods approach that leans heavily on the quantitative analysis of street networks and urban blocks, using methods borrowed from the fields of space syntax and urban morphology studies. Pilot social studies are also undertaken to provide some insight into the social structures of informal settlements and their social and functional integration into the rest of the city. These social studies show the need for practical urban upgrading in those settlements. The primary contributions of this thesis cover three main areas: the classification framework, methodological contributions, and designed examples of urban interventions based on the quantitative analysis. Primarily, the existing classification system for informal settlements in Cairo is built upon and refined by consolidating different classification parameters and highlighting different spatial features that are present in informal and planned settlements. The results show certain urban block and street configurations which can be used to inform classification, some of which are unique and may only be present in informal areas. The contribution is not just the developed classifications but the usage of quantitative methods to describe the informal urban fabric. Another secondary contribution is the development of a dataset of maps of informal settlements. Finally, these results can be used to inform practical urban upgrading. Practitioners could consider the use of the highlighted street structures to inform intervention, the potential of block consolidation (i.e., the joining together or splitting of urban blocks to aid functionality) and street network normalisation (i.e., the widening and aligning of streets to improve the network), and the role of the highways in acting as a connector.

1.1. Research Background: Overview of Informality

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. 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. 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. 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. This understanding comes from studying these three aspects of the informal urban fabric:

- Their historical emergence and spatial logic (existing topography, pre-existing grid)
- Their current spatial structure on a local (within neighbourhood) and global (within the city) context.
- Their relationship to the neighbourhood boundary and physical edges such as highways

This research aims to develop a comprehensive classification framework for informal settlements that considers the above three elements: emergence, syntactic and morphological structure, and boundary. The three aspects are addressed primarily through the quantification of the urban fabric, with additional historical and social studies. The

morphological units of ‘street’ and ‘urban block’ are used to quantify the urban fabric, assess the functionality and spatial structure, and are then clustered into types to inform the classification framework.

This framework can then be used to inform urban interventions that are specific to the type of informal settlement. The case study for this research includes 13 neighbourhoods in the Greater Cairo Region in Egypt. This location provides a wide range of urban types that can be studied within the same socio-cultural context.

1.2. Informal Settlements and the Problem of Binary Classification

Over one billion people live in informal settlements of various types worldwide. This number is expected to grow to two billion by 2030, which means 2 out of 5 city dwellers worldwide will live in an informal settlement (UN Habitat 2015; UN-Habitat 2007). Therefore, informal settlements cannot be considered a marginal phenomenon and should not be excluded from planning initiatives. Moreover, an important distinction needs to be made between informal settlement and slum. This distinction applies to their economic, political, and social meaning as well as the physical expression of their urban fabric. While both have emerged outside the legal framework of urban development, many informal settlements have developed over time into well serviced neighbourhoods, which is often not the case for slums. Informal settlements tend to benefit the community by absorbing rural-urban migration and providing affordable housing.

Borrowed from economics, the term ‘informality’ defines any element that is outside formal structures of economy and urban development. Being inside or outside formal structures defines the legal or illegal status of a neighbourhood. However, this tendency for a **reductive binary classification of legal versus illegal** does not capture the more complex reality of informal settlements. The definition of what constitutes “formal structure” is at the heart of this dissertation. Formal can be taken to mean ‘legal’ or ‘planned’, but it can also be taken to mean ‘having form’, in the sense that there is order and structure within it. While

most of the research on informal settlements deal with legality and illegality, a smaller part focuses on their perceived unplanned and “undesigned” nature, expressed in their physical form. Informal settlements have been mostly studied within an economic, social, and political framework but there is less research on how informality is physically and formally expressed in the urban fabric. While they may appear without planned physical structure, some spatial order can be found in the morphology and structure of streets and blocks layout. This spatial order is partially the result of the actions of the residents and their self-organising structure, but it remains dependent, to some extent, on the social, economic, and political conditions of settlement emergence. Understanding the specific morphologies of informality, and highlighting more specifically the presence of spatial order, will bring a more nuanced view of this binary classification and allow for more informed intervention and upgrading. If spatial order can be found, the other side of the research looks also at the existence of social-spatial fragmentation and how it is expressed in the urban form, as well as potential interventions that may alleviate it.

1.3. Informal Settlement Urban Intervention Methods: Physical In-Situ Upgrading

The binary legal/illegal classification has a knock-on effect on policy and can increase spatial fragmentation by creating a greater divide between planned and informal settlements. One form of spatial segregation resulting from policy can be seen in the planning of highways and the neighbourhoods that have access to them. Spatial fragmentation can cause inefficient usage of land, increased density, decreased access to the city and increased social exclusion. Spatial fragmentation and physical exclusion from formal structures are pressing issues in cities in the global south and could be addressed by targeted urban intervention.

Urban Intervention approaches can be split into broader policy approaches and physical urban upgrading in the settlements themselves. Research shows that there has not been a unified, successful approach to informal settlement upgrading. The measures of success in

informal settlement upgrading often change and are based on economic measures such as reaching targets for infrastructure or housing, rather than improvements in the community or the physical urban fabric. Most proposed solutions to urban poverty and informal settlements are not tailored to that particular community, but is imposed by external bodies, and standardised across settlements.

To address this, the United Nations recommends a human rights-based approach to settlement upgrading, with the right to remain in situ or be adequately housed nearby (United Nations 2018). To achieve the goal of in-situ upgrading, there exist several physical upgrading approaches, detailed further in Chapter 2.1. Nevertheless, none of these approaches address the scale and complexity of the issue of informal settlements, as they do not have unified methods and often focus on only one element of informal settlements.

Research suggests that physical urban upgrading can be undertaken by **preserving existing important structures** (buildings, blocks, and streets) and **increasing access to the rest of the city**. More research can help in determining which elements of the existing structure should be preserved, and what can be removed in order to improve the settlement, as well as the current state of access to the rest of the city. In order to do this, informal settlements need to be recognised as a valid form of urbanism, and research needs to be undertaken into the classification of informal settlement urban fabric. This thesis explores the morphological units (streets and blocks) of the urban fabric of informal settlements in order to inform in-situ upgrading and reconnection of the urban fabric.

1.4. Existing Global Classification Criteria

In this thesis, informal settlement is considered as a self-organised mode of production rather than a legal categorisation of the neighbourhood, which suggests that this mode of production has an implicit logic and order that is based in rules or patterns which can contribute to classification. Existing classifications mostly focus on emergence and history of informal settlements, by differentiating types of informality based on their location in the

city or the country of origin rather than their urban characteristics. This suggests that emergence and history can be used as classifying attributes. Other classification systems lead to the idea that settlement boundary can be used as a classifier. It also highlights that informal growth can occur on a formal framework, for example a pre-existing urban grid. The existing classification systems present some classifying characteristics that are built upon in this thesis, namely: emergence, current syntactic and morphological structure, and settlement boundary.

1.5. Greater Cairo as a Case Study

Greater Cairo is the largest urban area in Africa and hosts one quarter of the total population of Egypt, which makes up half of the urban population of Egypt (CAPMAS 2019). Informal settlements make up over half of Greater Cairo's urban fabric, and two thirds of the population of Cairo live in informal settlements, which makes informality the dominant form of urbanisation rather than the exception. As such, Greater Cairo, provides a unique location for study with many different forms of informality. Greater Cairo also suffers from spatial fragmentation, partly caused by the highway infrastructure. This provides the opportunity to study how the highway can act as a boundary, and the different relationships neighbourhoods can have with the highway. The selection of neighbourhoods includes both formal and informal areas in order to compare different urban morphologies and emergences, which allows for different urban conditions to be studied in the same sociocultural context.

While they supply over two thirds of all the housing produced in Cairo, informal settlements do have negative effects because they lead to the loss of agricultural land, which makes up only 4% of Egypt's landmass and is where the population has traditionally lived. They are also illegal and unplanned, so often do not have access to adequate amenities. Informal settlements are often overlooked in large scale urban planning and so large infrastructure projects often go through or around informal settlements without connecting to them. This

highlights the importance of developing suitable physical in-situ urban interventions, to address the issues that are present in over half of the city's urban fabric.

1.6. The Problem of Informal Settlement Classification: Articulation of Implicit Rules of Informal Settlement Production

The literature highlighted several important points that form the basis of inquiry in this research. Informal settlements can now be considered a permanent part of the urban fabric, and in situ development is needed. Development and upgrading depends on better understanding the spatial characteristics of informal settlements, but there are few empirical literatures that study the specific urban fabric of informal settlements.

The issue with the existing classification is that it focuses on history, tenure, and social factors. These factors may be subjective, often not recorded in any database and may not reflect the current status of the settlement. Studying the resultant urban form can remove some ambiguity from this process of classification, since it is based on already existing, physical manifestation of informality, rather than history or tenure. Studying the physical urban form can also inform not only classification but functionality and intervention approaches.

Research suggests that there is a need to understand the processes that produce urban fabric and public space. **This is important because urban block morphology and street configuration dictate if the settlement does or does not function.** Articulating the informal rules of urban block production and street network configuration can help further understanding of informal settlement and inform appropriate in situ upgrading procedures. This gap is addressed in this thesis, where informal settlement emergence and growth is studied in order to find existing structures and configurations that can be preserved in potential urban interventions.

1.7. Towards a More Targeted Classification to Inform Urban Intervention

This thesis argues that studying the spatial characteristics of informal settlements can create a more nuanced classification based on the urban block morphology and street network configuration of neighbourhoods. This further classification can be used to develop urban interventions based on the spatial form and social needs of neighbourhoods, rather than the legal/illegal binary classification. This could help in alleviating the socio-spatial segregation present in the region.

1.7.1. Refocusing on the Physical and Social Aspects of Informality

To fulfil this aim, the primary focus of this thesis is the study of physical aspects such as street network and urban fabric, both on neighbourhood level and the regional level, in order to identify structures/configurations present in the urban fabric that can inform classification. The streets and urban blocks are quantified and then clustered in order to identify potential configurations, and then combined with studies on the historical emergence and relationship to boundaries. This combination informs a classification, or taxonomy, of different types of urban fabric that is present in Greater Cairo.

A secondary, minor, line of enquiry considering the social life and social integration of informal areas into the main city is used to confirm previous studies and to provide context for the previous quantitative analysis. While this line of enquiry does not contribute to the classification, it situates the research within the socio-cultural context and illustrates some real-world impacts of informality, which supports the need for further classification and designed urban interventions

Studying the **Physical Aspects** of informality will explore and establish:

- How the physical topography, land subdivision and boundaries affect informal settlements' urban form.
- How the settlements compare to each other and planned settlements in terms of:

    - Urban morphology?
    - Street network?
    - Relationship to the main city form and regional transport network?
    - Mechanism of growth?
- How the emergence, growth, street network and urban morphology influence the classification of informal settlements into types, with a focus to find unique spatial structures present in informal settlements.

These lines of research inquiries will then be contextualised by looking at the social aspects, clarifying:

- What are the historical and social motivations that form informal settlements and how they affect the resultant urban morphology?
- To what extent are informal settlements accessed and used by non-residents and whether they are socially and spatially segregated from the rest of the city?
- How the spatial structure of informal settlements supports the community in their everyday living?

1.8. Research Design: Combining Qualitative and Quantitative Approaches

The literature review and questions outlined previously show that informality is a complex social and physical phenomenon that has the potential to be studied in different ways. This research approaches studying the street network and urban fabric through a configurational and morphological perspective. Some research into the social and community aspects of informality is also undertaken to provide a holistic view of both the social and physical aspects of informality, and to contextualise the quantitative research.

This research uses a mixed methods research design to address research questions in order to compensate for a lack of traditional fieldwork. In the case of Egypt, traditional fieldwork is difficult to undertake especially in informal settlements. With a limited access to

fieldwork, mixed methods have provided alternative creative modes of data collections, particularly for the social side of the research. This also leads to a richer breadth of data and further corroboration of ideas and findings.

The qualitative approach is used to establish themes and patterns within the data and provide the contextual social landscape in the phenomenon of informality through two targeted social studies, literature review and historical map analysis. It complements the production of quantitative data drawn from the physical form and structure of the street network and urban fabric, which describes the phenomenon numerically and statistically. Using quantitative data allows for replication of results and the results of quantitative analysis can be used within the overall qualitative approach of finding themes in informality that can potentially aid classification. Some qualitative data is quantified to aid in comparison and synthesis. The data is collated at the data interpretation and synthesis stage to allow for a holistic overview of informality through pattern recognition within both types of data.

Some methodological considerations were taken into account from the literature, including the lack of data about informal settlements. The importance of mapping informal settlements accurately was a focus since there is not much data available. The social motivations of those living there were addressed in a pilot study and tied in with how the urban fabric supports everyday living in informal areas. As well as social segregation, spatial fragmentation was addressed with regard to links with the regional highway network and access to resources and amenities.

Elaborating on existing research, three methodological steps were developed that allow to research the urban form and develop a classification system of informal settlements:

- Firstly, investigate the link between the emergence, current spatial description and social context through the literature, historic maps, and small social studies.

- Secondly, describe the urban block morphology and street network configuration quantitatively.
- Finally, the statistical classification of quantitative data into coherent description of typologies/structures of space that could be applicable to contexts outside the main sample.

The specific theoretical framework, methodological steps and research procedures are outlined in greater detail in chapter 3.

1.9. Significance of the Study: A More Comprehensive Classification

The main significance of this study is the contribution to the existing classification framework and informing further urban intervention in informal settlements worldwide, since from the literature it is clear that informal settlements are not a marginal phenomenon, and in-situ upgrading is recommended. Including a greater range of physical and social parameters to inform the classification framework will result in a more nuanced, refined classification. This classification framework shows the essential similarities and differences between types of urban fabric in Cairo, which will lead to a further understanding of informal settlements as a type of urban fabric with its own unique characteristics.

A significant original contribution is also the design of some suggested urban interventions based on the spatial structure and classification of the informal settlements in the sample. These designed intervention procedures can serve as an example to practitioners, in order to create interventions that are more targeted and appropriate. Consequently, it can prevent usage of stopgap measures or unsustainable policies. Knowing which parts of the street network are unique to informal settlements and have the highest potential to support the community can be used to inform urban intervention, which can address the negative issues of informal settlement such as spatial fragmentation and lack of connection to main transport networks.

This study will also contribute to the existing body of knowledge in the following ways:

- Increasing informal settlements' map dataset through manually traced satellite imagery, since they are often not mapped.
- Understanding the mechanisms of growth and informal settlement as a mode of production
- Identifying beneficial informal growth and existing urban structures and preserve them.
- From a methodological perspective, it will:
    - Use quantitative methods to describe the informal urban fabric.
    - Combine quantitative and qualitative data streams to inform classification.

1.10. Thesis Structure

This thesis consists of 10 chapters. Chapter 1 introduces the research problem and background. Chapter 2 outlines relevant literature for the existing classifications of informal settlements, both globally and specifically in Cairo. Chapter 3 firstly outlines the methodological framework used in this thesis and relevant previous studies that use this methodology, and secondly the specific methodological procedures and research design. Chapter 4 provides an in depth look at the neighbourhoods chosen as a case study for the quantitative analysis and presents their history and emergence and its effect on the urban fabric. Chapter 5 presents the morphological profile of the settlements through studying the urban blocks' size, shape, and functionality, and then grouping them through cluster analysis. Chapter 6 presents the configurations of the open space in informal settlements through studying the pedestrian network using axial analysis and highlights the configurations' effect on potential social interaction and access to/within the settlement. Chapter 7 presents the street network analysis and syntactic clustering of streets to find unique street structures in informal settlements. Chapter 8 presents the pilot studies that were conducted to investigate the social aspects of informality and clarify the need for intervention. Finally, chapter 9 presents the discussion of results, including the

comprehensive classification framework (taxonomy) synthesised from the results and some examples of designed urban interventions based on the quantitative analysis. Chapter 10 presents the conclusion of the study, some limitations, and avenues of future work.

The structure is as follows:

1. Introduction
2. Literature Review: Definitions of Informality
    - 2.1. Literature Review – Global Informality: Definitions and Existing Classifications
    - 2.2. Literature Review – Informality in Cairo
3. Methodology: Studying Informal Settlements
    - 3.1. Methodology Literature Review and Previous Studies
    - 3.2. Methodological Steps and Procedures
4. Case Studies: History and Emergence of 13 Settlements in Greater Cairo
5. Morphological Profile and Urban Block Clustering of Settlements
6. Configuration of Open Space in Settlements
7. Street Network Analysis and Syntactic Clustering of Settlements
8. The Social Landscape of Informal Settlements
    - 8.1. Creating Community in The City of the Dead
    - 8.2. Daily Activities Questionnaire
9. Settlement Taxonomy, Discussion of Results and Examples of Urban Interventions
10. Conclusions

CHAPTER 2: LITERATURE REVIEW: STUDYING THE DEFINITIONS AND CLASSIFICATIONS OF INFORMALITY

This chapter outlines the existing social, political, and physical definitions of informality that have been developed worldwide and in Greater Cairo. The aim is to establish the existing broad classifications of informal settlements in order to build upon and refine them. The existing approaches to urban interventions and their relation to the definition and classification are also studied.

Chapter 2.1. presents the literature on informality as a global phenomenon, as well as some of their benefits and drawbacks. It also introduces the idea that there may exist structure and implicit rules in informal settlements and discusses the existing classifications that have been proposed. These classifications include using the location and physical characteristics of informal settlements to classify them, as well as the type of boundary present and the idea that informal growth can occur on a formal framework. Some urban intervention proposals, through policy or physical intervention, are also introduced.

Chapter 2.2. outlines the history, urban growth and causes of informality in the Greater Cairo Region. The definitions used by the government and practitioners are presented, including the idea of informal settlements being defined as unplanned, which is challenged in this thesis. The classification systems that apply to Cairo are also presented, which are then expanded upon and refined in this thesis. This chapter introduces the differentiation between the physical characteristics of settlements as a way of classifying them and introduces a further classification of streets within the settlements which can contribute to a refined classification.

2.1. GLOBAL DEFINITIONS OF INFORMALITY AND URBAN INTERVENTION APPROACHES

2.1.1. Introduction

Informal settlements are present worldwide with a concentration in the Global South and developing economies. Over one billion people live in informal settlements of various types worldwide. This number is expected to grow to two billion by 2030, which means 2 out of 5 city dwellers worldwide will live in an informal settlement (UN Habitat 2015; UN-Habitat 2007). This shows that residents of informal settlements are not marginal, in the sense that they are not a small minority of city residents. However, they are treated as though they are peripheral to the city (Perlman 1976).

The term 'informality' is borrowed from economics, so it is defined by being outside formal structures of economy and urban development (Roy and AL Sayyad 2004). This leads to a binary legal/illegal classification for informal areas which has a knock-on effect on policy and can increase spatial fragmentation. However, the reality is more complicated than the binary classification of being either inside or outside formal structures. Informal settlements are not necessarily areas of poverty and are generally home to a heterogenous population (Deboulet 2016; Roy and AlSayyad 2004). Land tenure can be irregular and contested, residents may own the land but not have planning permission for the buildings (Payne 2004) or may be squatting on land they do not own (Jenkins 2006).

Informal settlements have been studied within an economic, social, and political framework (Davis 2006; Deboulet 2016; Huchzermeyer and Karam 2006; Neuwirth 2006; Payne 1999; Roy and AlSayyad 2004; Turner 1979) but there is little research on how it is physically and formally expressed in the urban fabric. Understanding the specific morphologies of informality will bring a more nuanced view of this binary classification and allow for more informed intervention and upgrading.

2.1.2. The Role of Informal Settlements in Housing the Urban Poor

Informal settlements can be primarily viewed as a result of lack of affordable housing for the urban poor and '*a response to exclusionary formal systems'* (United Nations 2018). People in search of better opportunities for themselves often migrate to the city, which is often not equipped to house them (Saunders 2011). In this case, the urban poor tends to build for themselves because of a lack of government response to building houses for the 'poorest of the poor' (Neuwirth 2006). Informal settlements can become a 'gateway to the city' for the rural poor – a solution for housing themselves and gaining access to the formal structures of the city e.g., employment, rights, public space (Saunders 2011). This means that informal settlements are not necessarily unsustainable, because the residents view them as an investment and increase in opportunity for themselves (Perlman 1976).

This view is summarised by Fernandes:

"informal settlements are caused by low income, unrealistic urban planning, lack of serviced land, lack of social housing and dysfunctional legal system" (Fernandes 2011)

However, these informal settlements can improve the quality of life of the urban poor by providing them with housing and limited access to the city (Balbo 1993).

2.1.3. Formality in the Informal – Order and Structure

Many different modes of informality exist, and the formal/informal classification can be considered a spectrum rather than a binary classification (Dovey 2019). Moving past the binary legal/illegal classification and considering informality as a spectrum can show that there is order and structure within informal settlements. Even though informal areas may seem haphazard and chaotic, the social and physical order is sophisticated due to years of trial and error (Dovey 2019; Pinches 1994; Roy and AlSayyad 2004).

The social order in informal settlements can be present as a strong sense of community and home. This is expressed by residents' associations, community centres and assigned house/street names and numbers. The social order can also be expressed as informal economy, which is an important component of global south/economies in transition (Huchzermeyer and Karam 2006; United Nations 2018).

There is also research that indicates that informal settlements are not entirely 'unplanned/undesigned' as the street and lot layouts are sometimes planned by the community that initially starts the informal settlement (Davis 2006; Dovey 2019; Martin and Mathema 2006). This organisation gives a spatial order to informal settlements, which is also dependent to some extent on the social, economic, and political conditions of settlement emergence.

2.1.4. Economic, Social and Political Meanings of Informality

The different economic, political, and social meanings of informality and their influence on the physical expression of informal settlements are examined in the following section. An important distinction is to be made between informal settlement and slum, both in the economic, political, and social meaning and in the physical expression of the urban fabric. This differentiation of definitions is important because the word 'slum' is considered negative and stigmatising and makes areas viewed as a problem to be cleared rather than a community to be assisted and preserved (Tsenkova et al. 2009; UN Habitat 2015). Many informal settlements have developed over time into well serviced neighbourhoods, and they benefit the community by absorbing rural-urban migration and providing affordable housing (Dovey and King 2011).

2.1.4.1. Legal and Economic Definition

As mentioned previously, the basic legal definition for an informal settlement is one that emerges and operates outside of formal control of the state, which does not make it synonymous with slums (Tsenkova et al. 2009). This has been recognised on a legal and

economic level, with the operational definitions from the United Nations Statistics Division and the OECD Glossary of Statistical Terms differentiating between slums and informal settlements.

Slums are defined by their lack of access to resources, such as improved water and sanitation, lack of sufficient living area and lack of housing durability (United Nations 2018). Tenure may also not be secure, but the most pressing issue in slums is the lack of basic amenities and not reaching adequate standards for human habitation (Moreno 2003).

In contrast, informal settlement definitions focus on tenure status and legality rather than suitability of settlements for living in. According to the Organisation for Economic Co-operation and Development (OECD 2001)

Informal settlements are:

1. areas where groups of housing units have been constructed on land that the occupants have no legal claim to or occupy illegally.
2. unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing).

Residents of informal areas may not have security of tenure, which presents in different modalities such as owning the land only, squatting, or informal renting. Housing that is not in compliance with building regulations may lack a permit to be built on that type of land or may be in a hazardous area. Due to their illegally built nature, informal neighbourhoods usually lack or cannot access basic services and city infrastructure in the formal city (UN Habitat 2015).

2.1.4.2. Political Meanings of Informality

The political meaning of informal settlements refers to the way that informal settlements are defined by the state and other stakeholders, including the private sector and Non-Governmental Organisations (NGOs). Political meanings are often drawn from the legal and economic definitions and influence urban interventions and upgrading in informal

settlement. Generally, the terms informal settlement and slum are used interchangeably. Conflating informal settlements with slums can help justify removal and resettlement (Gilbert 2007; Mayne 2017). Setting a goal of “cities without slums” can lead to homogenisation and gentrification – ‘cleaning up’ the informal areas and justifying removal (Perlman 2016).

Another way of defining informal settlements is referring to them as *“precarious neighbourhoods”*. Precarious is a more neutral term than ‘slum’, which lumps together different urban statuses. A precarious neighbourhood is defined by being fragile in some way, whether it is the physical fragility of buildings, the insecurity of tenure, the threat of eviction or demolition and environmental concerns from poor sanitation, overcrowding etc. Precariousness does not refer to the legality of the settlement, more the need to develop the neighbourhood and eliminate precariousness (Deboulet 2016).

In some cases, the struggle for better housing can lead to political empowerment and integration into formal institutions (Caldeira 2000; Devas 2012; Holston 2009; Huchzermeyer and Karam 2006), so it is necessary to focus the discourse on ‘rights’ of the citizen rather than their ‘needs’ – that the state should provide services because it is the residents’ right, rather than casting residents as passive recipients of services (Rocco and Ballegooijen 2018).

2.1.4.3. Social meanings, Socio-spatial Exclusion and Spatial Fragmentation

The effect of the binary legal/illegal classification system on policy can lead to socio-spatial exclusion for residents by influencing the social meanings of informality in a negative way. Negative words used to describe ‘slum, squatter, informal’ can lead to settlements being ignored which therefore can lead to socio-spatial exclusion from the city and formal structures (Dovey and King 2011; Huchzermeyer and Karam 2006). This further exacerbates issues in informal settlements and contributes to spatial fragmentation in the city (Balbo 1993; Devas 2012).

Informal urbanisation can be defined as the *'spatial expression of exclusion from citizenship'* whereby being considered 'illegal' leads to disenfranchisement (Rocco and Ballegooijen 2018) and it can also reduce access of those residents to the formal social structure of the city (Holston 2009). Another consequence of being considered illegal is that the state can 'tolerate' informal urbanisation without intervening in informal areas (Ballegooijen and Rocco 2013). This leaves residents of informal areas on the 'other side of the law' and can also reduce governments' ability to intervene as they do not have legal grounds for investment (Holston 2009). As they are considered illegal, residents are not fully recognised as citizens so have limited access to formal structures, limited representation and lack of secure tenure (Balbo 1993; Kombe and Kreibich 2000).

The negative social meaning of informal settlements also leads to a lack of recognition as a valid form of urbanism. They are often not mapped or removed from maps for socio-political reasons (Kamalipour and Dovey 2019; Roy and AlSayyad 2004; Shatkin 2004). This lack of data on informal settlements leads to an often-superficial approach to settlement upgrading (Huchzermeyer and Karam 2006).

However, studies show that informal/precarious settlements and residents are not marginal to the city, rather socially integrated and an essential component of the city – meaning they are stigmatised rather than marginalised (Deboulet 2016; Montgomery et al. 2013; Perlman 2016; Semmoud 2015). The social bonds in informal settlements mean that people remain in the settlement by choice even when they have the opportunity to move elsewhere (Perlman 1976).

Spatial Fragmentation in the City

Social segregation can lead to spatial segregation and fragmentation as a consequence of policy and can result from the physical exclusion to formal structures such as transport networks and highways (Figueroa, Greene, and Mora 2019; Graham and Marvin 2001). Cities in the Global South with a high percentage of informal settlements are generally

heterogenous and do not form a ‘single organism’ due to disordered urban growth, which leads to a discontinuous pattern and differing infrastructure and services across neighbourhoods (Rodríguez, Martínez, and Guenaga 2001). These patchwork-like patterns can be seen in aerial views in **Error! Not a valid bookmark self-reference.**.

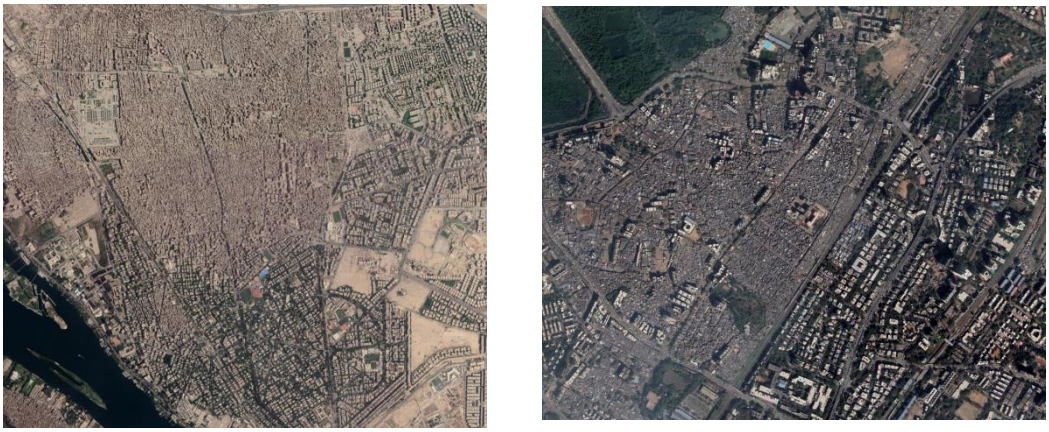


Figure 1: Examples of discontinuous urban pattern in Cairo (Left) and Mumbai (Right)

Source: Google Earth 2020

The effects of fragmentation are evident in the built environment, service provision and differing tenure systems (Kombe and Kreibich 2000). Spatial fragmentation can cause inefficient usage of land and poor road networks, increased density and decreased access to the city and public space (Balbo 1993). The monetary effects include high expense to upgrade illegal settlements (so they are not serviced as a result), losses from pirated water and electricity and untaxed residents/economy (Mitlin 2016; Tsenkova et al. 2009). Spatial fragmentation is also linked to increased sprawl, with its own set of issues (Harvey and Clark 1965; Inostroza, Baur, and Csaplovics 2013).

While informal settlements can cause spatial fragmentation, the issues faced mostly stem from the reaction of planners and the state to informal settlements. It has been shown that informal settlements are socially integrated into the city, so a physical approach to settlement upgrading can help alleviate spatial fragmentation.

2.1.5. Informal Settlement Upgrading Approaches

Informal settlement upgrading can be defined as *'any sector-based development in the settlement that results in a quantifiable improvement in the quality of life of residents'* (Abbott 2002). Most informal settlement upgrading policy worldwide focuses on reducing the housing deficit rather than improving existing informal housing assets and creating housing units by numbers rather than integrating cities and communities (Devas 2012).

Upgrading approaches have varied over time, with research into informal settlement upgrading starting around 1960 and continuing into the present day. In the late 1960s, research was conducted that recognised the informal sector as a type of urbanism (Peattie 1968; Turner and Fichter 1972) and started to promote the upgrading rather than removal of informal settlement. A paradigm shift occurred in the 1970's with a push to replace public housing provided by the government to self-help for the urban poor (Turner 1972). This caused a shift to the sites and services approach, where the state would assist with private housebuilding (Bah, Faye, and Geh 2018). However, this was perceived to have failed because it was not sustainable in the long term (Aldrich and Sandhu 1995).

In the 1980s, there was another shift towards incremental self-help and user participation, which aligned with the neoliberalist view of cutting government spending on housing. World Bank policy also shifted to emphasise infrastructure delivery and upgrading success was measured by reaching such targets (Ferguson 1996). Incremental onsite upgrading was starting to take place, but there was a regress to removal (especially in Brazil). This was due to 'mega events' such as Olympics and large scale 'global city' events, where slums negatively influenced the image of the city and were therefore removed (Perlman 2016).

The timeline above shows that there has not been a unified, successful approach to informal settlement upgrading. The measures of success in informal settlement upgrading often change and are based on economic measures such as reaching targets for infrastructure or housing, rather than improvements in the community or the physical urban fabric.

Upgrading approaches can be split into broader policy approaches and physical urban upgrading in the settlements themselves.

2.1.5.1. Informal Settlement Upgrading Through Planning Policy

Nowadays, there are three main approaches to addressing informal settlements through policy (Devas 2012).

1. Place based: upgrading of the territory of informal settlements where the urban poor are expected to live
2. Poverty based: addressing poverty levels regardless of location
3. Universal: upgrading for all regardless of location and income. This is tied to the idea of the 'right to the city', first proposed by Lefebvre (1991) and developed by David Harvey (2009).

However, most approaches to urban poverty and informal settlements are not tailored to that particular community, rather imposed by external bodies and standardised across neighbourhoods (Devas 2012). Master planning interventions cannot keep up with the pace of growth in informal areas (Balbo 1993), so governments have developed other responses to informal areas, which include in situ upgrading, onsite resettlement, eviction with or without resettlement and settlement demolition. Resettlement can often be to outskirt land with no employment. Coercive displacement is also prevalent, when residents are offered compensation to move or sell their homes and is used more often than forced evictions (Rocco and Ballegooijen 2018).

These different approaches can sometimes cause unintended consequences, such as the emergence of more informal settlements. Residents who have been resettled or displaced move back closer to their place of employment and settle there again (Durand-Lasserve 2006). An example of such counterproductive effects following regularisation and rehabilitation occurred in Morocco where housing conditions were improved but the populations displaced so there were losses overall to the community. Similar patterns were

observed in other Arab cities (Semmoud 2015). To address this, the United Nation recommends a human rights-based approach to settlement upgrading, with the **right to remain in situ** or be adequately housed nearby and to cease the use of evictions and forced resettlement (United Nations 2018).

2.1.5.2. Informal Settlement Upgrading Through Physical Urban Interventions

As well as different policy upgrading methods, there are physical settlement upgrading methods used. These fall into the general themes of:

- Building houses in the community (Aldrich and Sandhu 1995; Bah et al. 2018; Dasgupta and Lall 2009)
- Infrastructure provision (Azuela and Herrera-Martín 2009; Choguill et al 1994)
- Technology based sensing and monitoring (GIS, remote sensing, aerial photography) (Abbott 2003; Caldieron 2017; Hofmann, Taubenböck, and Werthmann 2015; Lehner and Blaschke 2019; Sietchiping 2009)
- Rehabilitation of sites and services and sometimes buildings – Sometimes accompanied by plot reallocation and road network normalisation (Choguill et al. 1994; Mitlin 2016)
- Re-blocking of plots with residents' consultation and gathering data – surveys and enumeration of people, plots, and buildings to provide a basis for upgrading and intervention (Mitlin 2016)

These approaches can be undertaken as an externally designed comprehensive upgrading or support based intervention. Comprehensive upgrading is often driven by external agencies or government and can be considered 'capital intensive intervention'. This type of urban upgrading often has drawbacks as the interventions are developed top-down and the community is not consulted. Rehousing is often funded by developers so not all settlements get equal resources which leads to an erratic upgrading approach. Generally, successes are limited and localised (Huchzermeyer and Karam 2006).

Support based interventions can be government or NGO initiated e.g., the million houses programme in Sri Lanka and holistic planning development in Favelas of Belo Horizonte. This type of community-based intervention can be more successful because the community is involved. However, there is no established common methods, rather their commonality is to *'trust the urban poor'* to make decisions for their community (Huchzermeyer 1999).

Nevertheless, none of these approaches address the scale and complexity of the issue of informal settlements, as they do not have unified methods and often focus on only one aspect of informal settlements. Abbott (2002) suggests that a theoretical approach is required to explain the process and provide a basis for other projects. He proposes a holistic planning approach 'Plano Global' that aims to clarify the relationships between all the elements of an informal settlement: community, infrastructure, and physical urban form. To establish these relationships, a technology such as GIS can be used to link physical maps with social information on residents in order to create targeted, informed interventions (Abbott 2002).

It is also suggested that physical upgrading can be undertaken by studying the evolutionary rules of urban organisation, preserving the existing structure but removing dilapidated housing and increasing access to the rest of the city (Batty 2013; Batty and Marshall 2009; Geddes 1915). More research is required into what that existing structure is that should be preserved, and what can be removed in order to improve the settlement. In order to do this, informal settlements need to be recognised as a valid form of urbanism, and research undertaken into the classification of informal settlement structures.

These approaches are taken in this thesis: social information and physical maps are combined in order to establish relationships between the different elements of informality, with the aim of finding the physical structures that should be preserved to support the community. Physical upgrading forms the basis of the intervention and can pave the way for further economic and social upgrading.

2.1.6. The Implicit Logic of Informal Settlement Morphology

A part of recognising informal settlements as a valid form of urbanism is to study their existing physical form urban blocks and street networks, their definitions, and existing classification systems based on physical characteristics. Informal settlements can now be considered permanent and in situ development is needed. This development and upgrading depend on better understanding their morphology but there is little empirical literature on this topic (Dovey and King 2011).

According to Dovey (2019) Informal settlement can be defined as the “incremental, unauthorized, and self-organized production of new urban neighbourhoods.” Informal settlements are a form of spontaneous urbanisation and need to be considered as a form of urban planning rather than an urban pathology (Deboulet 2016). Considering informal settlement as a self-organised mode of production rather than a legal categorisation of the neighbourhood suggests that this mode of production has an implicit logic and order that is based in rules or patterns; however, these rules are not easily detectable (Arefi 2011). The mechanism for production of informal settlements is still poorly understood but it is evident that there is a complex set of logics that informal settlement production follows (Dovey 2019). Self-organisation social logics are evident in informal settlements, but this has not yet been applied to the urban fabric (Ostrom 1990).

From an urban morphology perspective, buildings, plots, streets, and blocks are elements that combine to produce urban fabric (Conzen 1968; Marshall 2009; Scheer 2016) and this is the case in informal settlement. These elements are self-organised incrementally to produce the urban fabric and street network of informal settlements, as in other types of urbanisation (Batty 2013). Cities develop according to the individual physical attributes of the area, the economic reasoning, and social rules of the residents. This is reflected in the public space and street network in terms of access and connectivity, even in informal self-generated settlements (Hillier 2007). Informal areas tend to go through an expansion phase first, then consolidate into more permanent buildings and street networks (AlSayyad 2004;

Fekade 2000; Zillman 2002). ‘Informal urban fabric’ can also be a mix of formal/informal and can be considered a spectrum. One type can be in the process of becoming the other from a morphological perspective (Kamalipour and Dovey 2019).

There is limited research on informal morphology and the rules governing it (McCartney and Krishnamurthy 2018). However, there is some research on the detection and monitoring of informal settlements, which distinguishes the boundaries of informal settlements and differentiating between types of informality. This research has shown that informal settlement tends to produce small grain and labyrinthine urban fabric but does not uncover the implicit rules in informal settlement morphogenesis (Kuffer et al. 2017; Kuffer and Barrosb 2011; Roy, Bernal, and Lees 2019).

Dovey (2020) suggests that there is a need to understand the processes that produce urban fabric and public space. This is important because morphology and street configuration dictates if the settlement works or does not. This study undertaken by Dovey et al (2020) begins to show the variation in informal settlement emergence and the rules that govern it. Articulating the informal rules of urban block production and street network configuration can further understanding of informal settlement and inform appropriate in situ upgrading procedures (Dovey et al. 2020; Dovey and King 2011). This gap is addressed in this thesis, where informal settlement emergence and growth is studied in order to find existing structure and configurations that can be preserved.

2.1.7. Informal Settlement Classification Based on Physical Characteristics

As mentioned previously, the existing classification system for informal settlements is based on legality, and results in a binary legal/illegal classification. This classification differentiates between a slum and informal settlement but does not classify informal settlements further. It has been shown that informal settlements are not binary; there exists a formal – informal continuum for different elements of the city such as streets, blocks, grid. The degree of

informality does not identify legal status or substandard living conditions, but its mode of production (Dovey 2012).

There is some research into further classifications of informal settlements based on their physical attributes, but this research has mostly focused on differentiating types of informality based on their location in the city or the country of origin. There has been more focus on detection of and monitoring change in informal settlements using remote sensing/UAV/Multispectral imagery (Hofmann et al. 2015) rather than classifying informal settlements by urban configuration.

According to Balbo (1993) the fragments that make up the industrialising (global south - postcolonial) city generally consist of:

- historic city predating colonialism
- the colonial city centres
- planned districts of pre- and post- independence periods
- **illegal settlements – similar construction to planned districts but on illegally subdivided land (informal settlements)**
- squatter settlements and slums

This classification creates a distinction between the pre- and post- independence periods, and a distinction between illegal settlements and squatter settlements, based on their construction and standard of living (Balbo 1993).

According to Dovey and King (2011) informal settlement classification can be separated into categories of growth or morphological types based on location of emergence. The categories of growth can be split into:

- settling [on empty land – organic growth],
- inserting [into leftover urban spaces],
- attaching [to existing formal city – growing out of it]

This classification shows that the emergence and morphogenesis of informal areas can influence the resulting urban fabric and is the first step to classifying informal settlements based on their physical attributes. The second classification is based on location within the city and the morphology in terms of boundary.

1. **Districts –** grown enough to be its own district e.g., Kibera Nairobi, Dharavi Bombay
2. Waterfronts – marginal land between city and water (lake, river) – khlongs in Bangkok
3. **Escarpments –** steep mountain areas – favelas
4. Easements – buffer zones around formal infrastructure (railways, highways)
5. Sidewalks – pack away housing
6. **Adherences** – informal growth on formal framework – Hanoi, Santiago
7. Backstage – behind formal areas – hidden from view, china, Vietnam
8. **Enclosures –** within a formal boundary that sets a limit on expansion/visibility – cemetery in Indonesia and Egypt

This classification system shows that waterfronts, escarpments, and enclosures can all be considered a boundary for informal settlement and can influence informal settlement morphology. It also highlights that informal growth can occur on a formal framework, for example a pre-existing urban grid, and grow enough to be considered their own district.

These existing classification systems are a good starting point for further research into informal settlement morphology, however they do not study the urban morphology on an urban block level, nor do they study the attributes of the resulting street network in terms of access and connectivity. Any formal classification should also look at the structure of the urban fabric, and more specifically at how physical boundaries are expressed and participate to this classification. This is the avenue of research that this thesis will explore, in order to find existing physical structures and configurations that can inform informal upgrading.

2.1.8. Conclusions

Informal settlements have been studied within an economic, social, political framework (Davis 2006; Deboulet 2016; Huchzermeyer and Karam 2006; Neuwirth 2006; Payne 1999; Roy and AlSayyad 2004; Turner 1979) but there is little research on the specific morphologies of informality.

The binary classification system does not adequately represent the complexity of informal areas, and upgrading methods based on this system do not tackle the scale of the issue. The existing classification methods focus more on location of the settlement/emergence rather than block level urban morphology and street network attributes. Therefore, a more detailed analysis of informal settlements on the urban block and street network level is needed, as well as their emergence processes and interface with the city, in order to develop informal settlement upgrading (Dovey and King 2011).

Definitions Used in this Research

The literature presents initially the binary classification of informal/planned, **where informal settlements have emerged outside the legal framework, and planned settlements have not**. This is the basis of the classification system that will develop over the thesis:

- **Informal:** referring to the emergence of the settlement outside of the legal framework. This does not mean that it does not have morphological order/form- It can encompass many morphological types. It is not necessarily tied to poverty but can suffer from precariousness.
- **Informal Settlement** – mode of production of urban space and housing for the urban poor outside legal frameworks
- **Planned:** referring to settlements that have been planned (blocks/lots and streets simultaneously) by the government or private investors within the legal framework.

2.2. INFORMAL SETTLEMENTS IN THE GREATER CAIRO REGION

2.2.1. Introduction

Cairo is the largest city in Africa, first emerging in 643 AD (Abouseif 2007) and developing since then. One quarter of the total population of Egypt live in Cairo, which also makes up half of the urban population of Egypt (CAPMAS 2019c). Two thirds of the population of Cairo live in informal settlements, which makes informality the dominant form of urbanisation rather than the exception (Sims 2012). Informal settlements comprise 53% of the built residential surface of Cairo, and 84% of all occupied housing units (Howeidy et al. 2009). Informal housing production far outstrips formal private and public housing production (Shawkat 2020) (Figure 2), this makes Cairo a suitable case study for investigating informal settlements, since it is the dominant urban fabric, and the majority of inhabitants live in them.

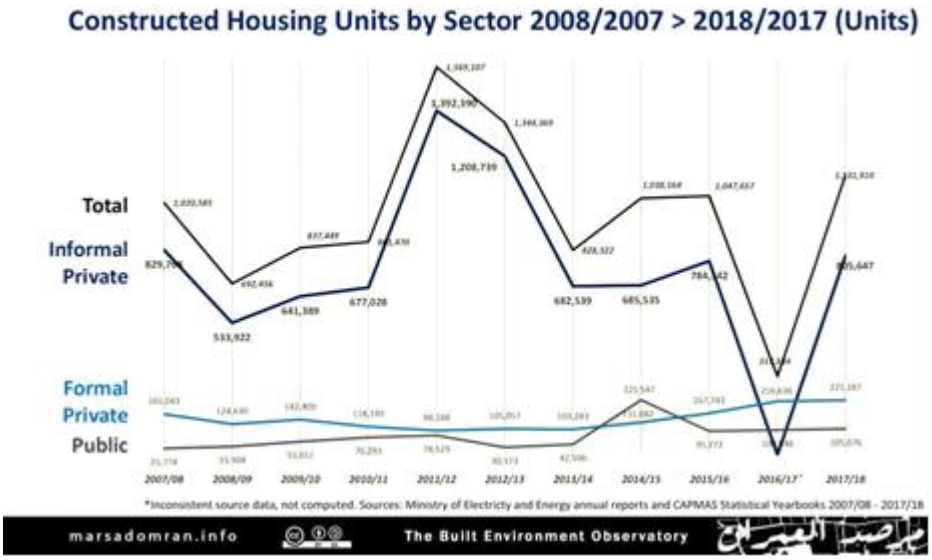


Figure 2: Graph of Constructed Housing Units in Egypt over 10 years (Shawkat 2020)

Informal settlements in Egypt are known as Ashwa'iyyat – literally translated to 'random built'. This refers to the illegal nature of informal settlements, the lack of building permits and the fact that they may not comply with building regulations. However, it has been shown

that informal settlements have an intrinsic self-generated order and high social bonds (Eldefrawi 2015; Sims 2012; Singerman & Amar 2006).

2.2.2. Definitions and Causes of Informal Settlements in Greater Cairo

2.2.2.1. Mechanism of Urban Expansion of Greater Cairo

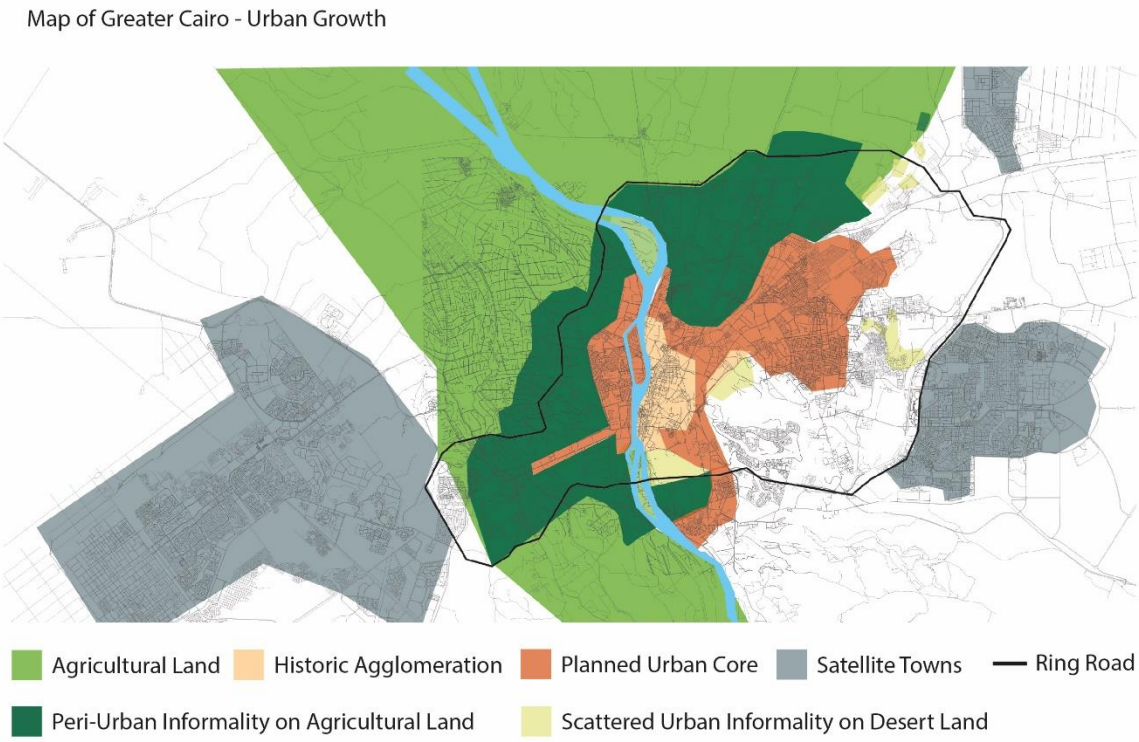


Figure 3: Urban Expansion of Cairo

Cairo's urban expansion since the 1900s (Figure 3) took place through three main mechanisms, public housing built by the government for lower income groups, planned settlements catered towards high income groups and informal settlements (Howeidy et al. 2009). 40% of Egypt's population live in urban areas and in Cairo, over half the population live in informal areas (Sims 2012).

The layers of urban growth of Cairo are summarised by Soliman (2004). He states that the urban fabric pre-1950s consisted of **rural villages and historic agglomeration**. In the 1960's after the revolution, **urban areas started to be improved** through public works. After the 1960's **scattered urban informality** started to emerge, which developed further into **peri-urban informality** on the fringe of the city on agricultural land. In the 1990's,

satellite towns were developed outside Cairo, which increased the region's boundary (Soliman 2004).

The first emergence of **scattered urban informality** on both desert and agricultural land occurred in the 1960's due to migration from rural areas into the cities, and the formal housing areas could not meet demand. Residents began to build their own housing on privately owned agricultural land on the urban fringe, which consolidated into **peri-urban informality**. Small settlements on desert land were ignored, as well as refugee camps from the 1967 and 1973 wars that eventually grew to **informal settlements on desert land** (Hegazy 2016).

Starting from 1992, a series of natural disasters indirectly caused informal settlement expansion to increase. In 1992 an unusually damaging earthquake hit Cairo, which led to 8,300 damaged or destroyed buildings and 50,000 people left homeless (El-Sayed et al. 1998). While the earthquake itself was relatively small, the poor construction of buildings in Cairo (especially illegal high-rise constructions) meant that the damage was much higher than expected. After the earthquake, those that became homeless were housed in emergency accommodation in the south and northwest of Cairo, some of which over time became **peri-urban Informal Settlements** (Degg 1993).

2.2.2.2. Legal Definitions and Causes of Informality

Informal settlements are illegal not because of squatting but the fact that the building itself may be in violation of the building code, zoning regulations, land subdivision code or lot coverage (Sioufi 1981). One of the proposed reasons for the emergence of informal settlements is that there are not enough formal housing units, but paradoxically 30% of built housing units remain empty, and Egypt is, per capita, the highest producer of housing in the world (Shawkat 2020). However, these housing units are not affordable to the urban poor so informal settlements still experience rapid growth (Arandel & El Batran 1997).

2.2.2.3. Negative Effects of Informal Settlements

While they supply over two thirds of all the housing produced in Cairo, informal settlements do have negative effects because they lead to the loss of agricultural land, which makes up only 4% of Egypt's landmass and is where the population has traditionally lived. They are also illegal and unplanned, so often do not have access to adequate amenities (El-Hefnawi 2005). Informal settlements are often overlooked in large scale urban planning and so large infrastructure projects such as highways and bridges often cut through or around informal settlements without connecting to them (Hegazy 2016; Mohamed et al. 2014; Zied Abozied & Vialard 2020). Figure 4 shows the Ring Road highway cutting through the urban fabric of an informal settlement in Greater Cairo, which illustrates the disconnection between the settlement and the highway. This leads to the segregation of informal settlements, limiting their connectivity to the rest of the city and preventing further growth beyond the boundary of the highway. This in turn leads to densification of the settlement inwards rather than growth outwards (Khalifa 2015) and can lead to spatial fragmentation of the entire city (Balbo 1993; Graham & Marvin 2001).

Often, informal settlements are not connected to utilities and facilities such as healthcare, schools, and emergency services. While they are unplanned, facilities in nearby settlements are often used (Eldefrawi 2015). Utilities are tapped into, but this often leads to poor sanitation and danger from electricity. However, the quality of the settlements themselves are often quite high, being built with concrete skeleton structure and red brick, since owners consider their building an investment. Spontaneous economic activity emerges to sustain the residents which leads to the emergence of an informal economy within the settlement (El-Batran & Arandel 1998).

Figure 4: Highway cutting through residential area in Cairo.

Source: Sima Diab for The New York Times

2.2.2.4. Government Definitions of informal Settlements and Upgrading Approaches

The first definition of informal settlements emerged in 1979 and they were viewed as illegal expansion of existing cities and viewed only through the lens of legality rather than urban characteristics (Sims et al. 2003). In 1981, the responsibility of informal settlement development was passed on to local governorates, an attempt at decentralising the process. International donors such as the World Bank supported most of the settlement upgrading projects that ran throughout the 1980's, so success was measured in provision of infrastructure and increase of housing units (El-Batran & Arandel 1998).

In 1993 the first official informal settlement upgrading plan was put in place (Arandel & El Batran 1997). This was triggered by the October 1992 earthquake in Cairo and the need to implement security measures in informal settlements to control crime and apply law. The definition of informal settlement used was *'an area where the emergence of a population*

agglomeration cannot be attributed to urban planning; therefore, it constitutes an unauthorised infringement on state or private property, which lacks the necessary permits and is partially or completely deprived of public utilities and services' (El Diwany & Gouda 2000).

The plan aimed to improve living standards and provide basic services and utilities, integrate informal settlements into the formal city, and securing control and the rule of law. These goals were divided up among government agencies and local administrative councils. This approach was unsuccessful and in 2000 another definition was adopted, and the government started a **participatory approach in upgrading informal settlements**. While the intentions of this approach were in line with global thinking on informal settlement upgrading, the reality of it was that setting up community participatory groups was difficult, so this approach was also unsuccessful (Singerman 2009).

In 2004 informal settlement belting projects were announced to restrict the expansion of current informal settlements and prevent the emergence of new ones. The National Program of Social Housing was established in 2005 which **encouraged the building of new settlements out in the desert** (Figure 5), but due to the pressure in implementing this project many housing units were built without access to the rest of the city so paradoxically led to further expansion of informal settlements. This expansion was also encouraged when in 2006 a law was passed to allow infrastructure to be connected to existing informal settlements, so people chose to remain in the informal settlements rather than move further away to the planned social housing (Hegazy 2016).

Figure 5: 6th October City under construction in the western desert.

Source: EL-Sady Photography

In 2008 a landslide in the Al-Duwayqa settlement near Manshiyet Nasser triggered another change in government policy. The Informal Settlements Development Fund was established, and another definition of informality was created to overwrite the old one. Informal settlements were classified into two types, **unplanned and unsafe.** The Unified Building Law classified unplanned settlements as *"those settlements which do not comply with **building regulations** and **land subdivision rules**, and they **do not have detailed plans**".* Unsafe areas posed a risk to life through unsuitable housing, dangerous location, or insecurity of tenure (Khalifa 2011). This shows the emergence of the thought that the urban fabric (land subdivision and construction of buildings) may be a better way of understanding informal settlements, rather than through a legal-social lens.

This thesis aims to contribute to the upgrading of informal settlements, by studying the classifications and definitions of informal settlements. This research aims to address the definitions presented of **unplanned and unsafe, with a focus on 'unplanned' neighbourhoods**. What is called 'unplanned' may have an underlying urban structure. In the case of those informal settlements that emerge on agricultural land, there already exists a **subdivision of land** that may influence the emergent informal neighbourhood. While

settlements may not have detailed plans or permits, the majority of informal housing is **well constructed** since it is viewed as an investment, there are very few shanty towns and slums (Howeidy et al. 2009). This makes the case for recognition by the state as a legitimate form of urbanisation.

The idea that informal settlements have an intrinsic order and perform well as neighbourhoods was first proposed in 1981 by Sioufi but since then it has not been quantified. This presents an avenue where this research can contribute to the definitions and classifications of informal settlements, through studying the intrinsic order of the urban fabric. It is suggested that existing settlements be legalised and upgraded, and further growth be guided in a way that is beneficial and follows building code and zoning guidelines (Sioufi 1981). This can justify an urban- physical approach to informal settlement regeneration rather than a sociological approach. To undertake this approach, more information is needed about the physical urban properties and existing classifications of informal settlements.

2.2.3. Informal Settlement Classification and Quantification Methods

The current classification, according to the Ministry of Housing, Utilities and Urban Development, there are 3 types of informal settlement in Cairo. 80% of informal areas are built on privately owned agricultural land and most commonly occurs on the urban fringes. 20% of informal areas are built on state owned desert land, the initial settlement being formal e.g., a rehousing project or refugee camp. The final type is the cemeteries, which only occur in Cairo and house a population of approximately 500,000 (Ibrahim 2015). This classification uses the emergence and history of the urban fabric of informal settlements, rather than the current social/legal conditions.

There has been further research looking at types of informal settlements and many attempts to classify them using different measures. These range from the government classification systems to NGO and academic attempts at classification. It is generally agreed that there

are two main types of informal settlements, those that emerge on agricultural land and those that emerge on desert land, with further subclassifications in each category and additional categories based on history and tenure (Arandel & El Batran 1997; Sims & Séjourné 2000; Sioufi 1981; Soliman 2004).

2.2.3.1. Informal Settlement Growth

Sioufi (1981) classifies informal settlements as either on agricultural land or desert land and gives more detail on the agricultural expansion process. Growth of informal settlements on agricultural land is a very dynamic process, not only fuelled by socioeconomic factors but also through inherited agricultural plots getting smaller, and thus it is becoming unprofitable to farm them. There were also insufficient farmers to work on the land due to migration, which led to unfavourable farming conditions. Land prices were high which incentivised selling the land to developers rather than keeping the land for farming. Initially there were small settlements built by the owners of the land, but after the expansion of these buildings the extra apartments were rented out, which fuelled speculation into the developing market and more buildings were built. The agricultural land grid clearly influences the shape and size of the blocks (Figure 6), but long, thin blocks affect the navigation of the settlement and long thin streets can affect circulation of people and emergency services (Sioufi 1981).

The stages of growth that were identified in informal settlements are:

- Horizontal expansion into agricultural or desert land
- Infill – densification on the existing grid

After the two initial growth stages, in some cases vertical expansion occurs as well as the creation of new settlements. However, the focus of this thesis is to classify existing informal areas, rather than their potential to create new settlements.

Figure 6: an example of horizonal expansion, infill, and densification on the existing agricultural grid

2.2.3.2. Informal Settlement Classification

Table 1: Summary of Informal Settlement Characteristics from Arandel, C., & El Batran, M. (1997). The informal housing development process in Egypt. University College, London, Development Planning Unit

Main Characteristics	Desert/Collective invasion	Desert/ Subdivision	Village Core	Urban Fringe
Settlement history	Occurred in the 50s: collective invasion by tribal groups or results from the eviction of a previous settlement	Since the 1980's, settlement from several groups from a limited number of locations.	Develop prior to their incorporation into the city	Results from the extension of the city
Physical pattern	Houses are huddled together; core settlement is rapidly built and consolidated to avoid risks of eviction; space is provided for streets and common facilities	Urban fabric results from the subdivision of plots on an individual basis. Little or no space is provided for common space and streets.	Street layout and urban fabric follows field boundaries and natural or manmade features (i.e., canals). Buildings built to reach at least 4 floors.	Streets are very narrow and follow field boundaries and natural or man made features

Table 1 (Continued): Summary of Informal Settlement Characteristics from Arandel, C., & El Batran, M. (1997). The informal housing development process in Egypt. University College, London, Development Planning Unit

Social organisation	Strong leadership, relies on tribal/community links	Weak, no unified leadership	Original village leadership cannot always cope with new developments. New leadership emerges	Weak leadership as settlements develop rapidly and are made up of a great variety of persons. No sense of community.
Growth pattern	Growth is rapid at first, but size remains relatively restricted	Growth is rapid and settlements can be fairly large	Urbanisation is slow at first, increases as village becomes more attractive to city dwellers	Growth is very rapid
Employment	Little opportunity within the settlement. Socioeconomic level is low.	Little opportunity within the settlement. Socioeconomic level is low.	Different between rural and new urban population. The latter tend to be better paid and have higher levels of skills	Diverse economic base, skills and educational levels
Community services	Communities are well organized and make up for the lack of government services	Few community services unless provided by the government.	Vacant land makes the creation of community centres possible	High densities leave little space for community facilities

According to Arandel and Batran (1997), there exist two main typologies of informal settlements: squatter settlements on land owned by government & informal housing on legally owned land. These typologies are further split into 4 sub-types, with further details on their history and growth, physical pattern, and social details (Table 1). This classification combines the social history and legality of the settlement and shows its effect on the urban fabric, i.e., streets and blocks.

Settlements that emerge on desert land can either be by **collective invasion** or **subdivision**. Settlements that emerge by collective invasion generally have strong leadership and sense of community, which results in fast consolidation of the settlement

through **aggregation** of buildings and community planning of streets and public space. Settlements that emerge through subdivision are often made up of different social groups, so there is no strong leadership. This leads to individual subdivision of land with little space for common spaces and streets and lack of community spaces. Both of the settlement types on desert land tend to have low economic opportunities.

Settlements that emerge on agricultural land can be classified into two types, the **village core** and **urban fringe**. The physical pattern of both types follows the field boundaries and irrigation system, **infilling** a pre-existing grid to create the urban fabric. The difference is in the location of the settlement; one type develops from an existing rural village core and the other type develops on the rural-urban fringe of the city. The village core tends to present as an **organic urban form**, but the settlements that emerge on the urban fringe have a **street network influenced by the agricultural grid**. The residents of both types are economically diverse, and the provision of community areas depends on the number of vacant lots (Arandel & El Batran 1997).

This classification system shows that the emergence and history of the settlement can influence the resultant urban fabric. **Aggregation** of buildings is the result of individual decisions, so there is little space in the settlement for common urban blocks and streets. **Infilling** results in streets and blocks that is influenced by the pre-existing grid. However, the resultant streets and blocks have not been meaningfully quantified, and so represent an avenue of research.

Table 2: Matrix of Informal Areas by Typology - from Sims, David, and Marion Séjourné. 2000. 'Residential Informality in Greater Cairo: Typologies, Representative Areas, Quantification, Valuation, and Causal Factors'. (Unpublished).

Main Typologies	**A -On Agricultural Land**	**B- On Desert Land**
Sub Typologies	A1 On Privately Owned Land	B1 On Local Administration Land
	A2 On Core Village Land	B2 On Reclaimed Land
	A3 On Government Agricultural Land A3a Agrarian Land Reform A3b Awqaf Land A3c Decree Land A3d Nile Verge Land	B3 On Decree Land B3a Development Company Concession B3b Public Sector Company Assignment B3c Co-Operative Assignment B3d Antiques Land
		B4 Armed Forces Land
		B5 Public Domain Land

Sims & Séjourné (2000) developed a series of typologies and sub typologies of informal areas based on their emergence and growth in order to quantify them and estimate the economic impact (Table 2). This was first started by a process of exclusion; the settlements that emerged pre-1950's are considered historical rather than informal, even if they displayed informal characteristics. This is due to building regulations and land reform that occurred in the 1950's that are the basis for the informal legal definition. Settlements that had evidence of subdivision (streets and plots planned at the same time) were also not considered informal. The evidence of subdivision was characterised by regular street patterns, street widths over 6 metres and buildings that comply with building regulations. Settlements that did not fit either of these criteria were considered informal.

The result of this classification was two main typologies, settlements that emerged on agricultural land or on desert land, with further sub-typologies based on tenure and ownership. This aligns with the classification proposed by Arandel & Batran (1997), but with different sub typologies. A third typology is mentioned, where settlements can be a mixture of formal and informal urban fabric. This is taken as a case-by-case basis so sub-typologies are not fully established.

The agricultural land typology is split into three types – privately owned land, core village land and government agricultural land. This typology creates a rectangular, fragmented urban fabric. Plots can be as small as one qirat (0.0175 ha or 175 m2) and follow the agricultural land pattern of long strips (ahwad) and irrigation canals (missa') that are converted to streets. This again reinforces the idea that the emergence can influence the resultant urban blocks and streets.

The second typology, emergence on desert land, led to the development of 5 different sub-typologies, again based on tenure and ownership. Desert settlements can emerge on local administration land, reclaimed land, decree land, armed forces land or public domain land. However, it is not shown how the sub-typologies can influence the physical characteristics of the settlement (Sims & Séjourné 2000).

Table 3: Developed Matrix of Informal Areas by Typology from Soliman, Ahmed M. 2004. 'Tilting at Sphinxes: Locating Urban Informality in Egyptian Cities'. Pp. 171–208 in Urban Informality: Transnational Perspectives from the Middle East, Latin America, and South Asia

Main Typologies	**A -On Agricultural Land**	**B- On Desert Land**	**C – Hybrid/Exformal**
Sub Typologies	A1 On Privately Owned Land	B1 On Local Administration Land	**C1 public housing** C1a municipalities C1b Co-operatives C1c Public Sector Companies C1d Development Companies C1e Armed Forces/Police
	A2 On Core Village Land	B2 On Reclaimed Land	
	A3 On Government Agricultural Land A3a Agrarian Land Reform A3b Awqaf Land A3c Decree Land A3d Nile Verge Land	**B3 On Decree Land** B3a Development Company Concession B3b Public Sector Company Assignment B3c Co-Operative Assignment B3d Antiques Land	
			C2 Units under rent control
		B4 Armed Forces Land	C3 Units in ex-permit buildings
		B5 Public Domain Land	C4 Units in Historic City with Confused Status

Soliman (2004) suggests 3 typologies (Table 3), developed with Sims in 1996 and aligning with previous classification systems based on legality and emergence.

- Agricultural land – semi-informal
- Desert land – squatter
- Hybrid – exformal

Settlement on agricultural land is considered 'semi-informal' because the residents formally own the land they are building on, but the buildings themselves are illegal. Settlement on desert land is considered fully illegal squatting. Hybrid settlements are a mixture of informal and formal, often passing between formal and informal over time.

Further sub-typologies were developed for type C – Hybrid. One classification is formal settlements which have been appropriated and grew informally, such as the historic core of Cairo which is a settlement in its own right but has severely deteriorated over time and became informal (exformal). This classification also includes informal building in formal areas on a small scale, such as additions without permits to planned buildings (Soliman, 2004). The resultant streets and blocks of this type can vary depending on the initial conditions of the neighbourhood and the informal additions.

The Potential for Street Types to Aid in Classification

As previously suggested, the road infrastructure plays an important role in the development and structure of informal neighbourhoods. It reinforces the importance of the street network in creating and maintaining the informality of areas and should be included in their classification. One research project based on Al Matariya exformal settlement by Soliman (2012) shows that the street network can be classified into three types of street:

- **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. The emergence and implicit rules that are potentially present in informal areas may lead to unique street types in informal areas, which may also influence classification, so this presents an avenue of research.

2.2.4. Conclusions

All of the previously mentioned classification systems are based on the emergence and tenure of the settlement, rather than the specific resulting morphologies and street networks. The criteria used can be somewhat ambiguous and may not be immediately apparent from observation of the neighbourhood, such as tenure and historical emergence. Most of the classification systems use the emergence and history of the informal settlement to classify them, but there is little research in quantifying the resultant urban form on a block and street level. This thesis will study informal areas on a block and street level, in order to add to these classification systems and so inform potential urban interventions. Quantifying the resulting morphologies and street networks can allow for a more nuanced approach to classification and therefore urban upgrading.

Definitions and Classifications in Thesis

This chapter expanded on the binary classification by including some physical characteristics, history, and morphology of the settlements. This resulted in splitting the informal classification to include emergence on agricultural land or desert land. A third classification was added, the mixed type. It defined planned settlements as those with evidence of subdivision. It also added a timestamp to settlements to be considered informal, they have to have emerged post 1950’s, after the introduction of planning regulations.

Neighbourhood level classification

- Informal
    - Agricultural (urban fringe infill)
    - Agricultural (historic village extension – pre 1950s)
- Desert (aggregate)
- Planned – evidence of subdivision
- Mixed – also referred to as exformal or hybrid - on a case-by-case basis – based on history and emergence
    - Planned and informal fabric together
    - Historically planned but turned informal

Street level classification –

This chapter also highlighted the potential for streets to be classified into different types, which may be related to the type of settlement.

These classifications are based on the study by Soliman (2012) in Matariya:

- Inter-settlement arteries
- Narrow streets bounding residential block
- Intra block access (hara, darb, alley)

A further category was added to highlight the transport infrastructure that informal settlements may or may not be connected to

- Highways (with or without access)

CHAPTER 3 – METHODOLOGY: STUDYING INFORMAL SETTLEMENTS' PHYSICAL CHARACTERISTICS

The previous literature review in chapter 2 has highlighted the importance of combining both the physical and historical-social aspects of informality in a classification system and clarifying the relationship between them. This chapter will first detail the different approaches used to study the urban fabric in general, and then more specifically informal settlements. It will also explain the specific methodological steps and procedures used in this research. In doing so, it clarifies the relevance of both quantitative and qualitative methods and their contribution to developing a classification system.

Chapter 3.1 outlines the two main theoretical approaches used in this thesis: the typo-morphological approach and the configurational approach. The configurational approach aims to measure the relationships between elements of the city in order to find out the rules behind the resulting configurations, both spatial and social. The typo-morphological approach brings together different social and spatial aspects of the urban fabric to create a comprehensive classification by finding themes and meaning within the data. Both these approaches are combined, firstly to describe the urban fabric quantitatively and uncover implicit rules and unique structures, then to combine qualitative and quantitative data to inform type.

Chapter 3.2 outlines the methodological procedure of this research. As outlined in chapter 1, the methodological approach firstly investigates the link between the emergence, current spatial description and social context through the literature and historic maps. Secondly, the urban block morphology and street network configuration are described quantitatively. Finally, quantitative data is classified into coherent categories of typologies/structures of space to aid classification. The pilot social studies illustrate the need for targeted urban interventions. The specific steps are outlined in this chapter.

3.1 LITERATURE REVIEW OF APPROACHES USED TO STUDY URBAN FABRIC

3.1.1. Approaches Used to Study Urban Morphology

This research primarily explores three main aspects of informal settlements:

- Their historical emergence and spatial logic
- Their current spatial structure and the functionality of its streets' and blocks' configurations
- Their relationship to the neighbourhood boundary and physical edges such as highways

The methodological approach used to study the urban fabric needed to consider the historical context and rules of development of informal settlements, as well as study their existing structure. The representation of the boundary and the interface between it and the local street structure also needs to be considered.

Kropf (2018) suggests that cities display self-organising behaviour based on the social and cultural conditions, which results in emergent structures in the urban form (Kropf 2018). The city can be also understood as a juxtaposition of two states, natural movement, and natural occupation. These two states can be expressed in the physical form of the city as streets (open space for movement) and blocks (places of physically, rather than legally, defined occupation) (Hillier et al. 1993; Marcus 2001).

To create the city, the streets and blocks come together in a **configuration that has occurred following implicit rules**. This suggests that it is important to study both the **socio-historical context that establishes the implicit rules of self-organisation**, and the **resulting configuration** of spaces. This encourages the combination of qualitative data

such as historical and social context, with the quantitative data of the resulting configurations to inform classification.

The study of the physical elements (streets and blocks) of the city is common across all approaches to studying the city from a morphological perspective (Gauthier and Gilliland 2006; Kropf 2009). Gauthier (2006) proposes that approaches to studying the city can be mapped into two categories. The first category is cognitive (explaining the city) vs normative (finding 'norms' to support decision making). The second category is internalist (regarding the city as an independent system) vs externalist (the city is a passive product of external forces). A combination of internalist and externalist approaches is needed, firstly to study **the external forces and historical context that shape the city**, and then the **resulting internal structures that form an independent system**. To study both the external forces that shape the city and the resulting internal configurations, the approaches discussed here are the **configurational approach** and the **typo-morphological approach**.

Based on this mapping system, the typo-morphological approach has a dual nature, where it is both cognitive and normative - it can be used in decision making and considers the city as an independent system that is influenced by external forces (Gauthier and Gilliland 2006). The typo-morphological approach can be used to study the implicit rules of development and historical context of emergence. It also allows for combining qualitative and quantitative attributes to inform classification and can inform decision making in urban intervention.

The configurational approach falls under the cognitive-internalist category, which means that they consider the city as an artefact to be studied, and that spatial form is a system, independent of external forces. Peponis and Wineman (2002) argue that it is possible to identify underlying structures in the street network and urban public space that reflect the usage of spaces and people's behaviour in them. The configurational approach provides insight into structures that can exist on the local level, which can highlight the degree to

which informal settlements fulfil the needs of the residents. It can also highlight structures that exist on the global level that can inform neighbourhood classification.

In this thesis, a combination of the typo-morphological and configurational approach is taken. The configurational approach is used to study the configurations of physical elements as independent systems which are described quantitatively, then the typo-morphological approach is used to study the historical context of neighbourhoods and combine data streams to create types, or classifications. Studying the historical context and social rules of informal settlements allows the conditions and rules of emergence to be uncovered and incorporated into the classification system. Studying the resulting configurations can be used to find unique spatial structures present in informal areas which can be used for classification and to assess the functionality of the settlement.

3.1.1.1. Typo-Morphological Approach to Inform a Classification System

Typologies and classifications are considered essential elements in the study of urban morphology as they allow for the understanding of the urban form as one entity shaped by social forces and enable the comparison between urban forms (Moudon 1997). Harvey (1969) argues that using types and classifications allows researchers to make sense of large amounts of information from the real world, and to bring together different data streams and variables into one whole (Harvey 1969). These variables can be quantitative or qualitative (historic-geographical), and a combination of both is used to inform the creation of types of informal settlements. The classification of neighbourhoods can be used as a comparative method to highlight similarities and differences of urban forms that may look different or have been produced differently.

The typo-morphological approach uses the historical physical and spatial description of the urban form to create a comprehensive classification by finding types within the urban form (Gauthier 2005). It is important to study informal settlements using their historical physical and spatial description, as this often influences the resulting urban fabric. Informal settlements grow rapidly, and there is a historical mechanism to the growth that should be

highlighted since it may influence the rules of emergence and can be used to aid in classification.

This approach was first pioneered by Saverio Muratori and developed further by Gianfranco Caniggia. It examines the structure and history of a particular urban form in order to understand its emergence and growth. The unique structures found in that urban form are identified as types, which are tied to the cultural and social conditions of emergence. Types can exist on all scales, from a building to the urban scale (Caniggia and Maffei 2001; Cataldi 2003).

An important concept in the typo-morphological approach is that any urban form first emerges as a response to a human need in a specific socio-cultural context. Different contexts lead to a diversification of forms, as different local processes and desires lead to different forms (Caniggia and Maffei 2001). This approach also emphasises the existence of rules that govern spatial processes and the implicit presence of social norms in the physical city (Gauthier 2005). Examining different aspects of the urban form to uncover the rules of growth and incorporating the cultural and social conditions of emergence adds another layer of refinement to existing classifications.

However, this approach has mostly focused on centuries old urban forms in Europe (Muratori 1959; Levy 1999) and is essentially qualitative and heuristic; there is no unified theoretical framework in creating type. Therefore, it may not be suitable as the only approach in studying informal growth outside a European context and may not be suitable alone to create quantitative descriptions of spatial elements. However, modern urban forms have been studied using the typo-morphological approach with success (Gilliland and Gauthier 2006). Expanding the definition and methods of type to include **morphological phenomena such as geometric qualities as well as social processes** will allow this approach to be applied in more modern contexts (Gauthier 2005). In this thesis, it is necessary to combine the typo-morphological approach with the configurational approach to study the existing urban fabric as well as the conditions of emergence.

3.1.2. Quantitative Methods and The Configurational Approach

Quantitative methods to study morphological phenomena such as geometric qualities can be incorporated into creating a classification. Quantitative methods can be used to allow for a precise numerical description of elements of the urban form, which in turn allows for more informed classification and urban upgrading (Moudon 1997; Talen 2003). Quantitative methods also allow for numerical comparison of one form with another, which is an essential component of urban morphology study, in order to understand the similarities and differences between classifications (Kropf 2009; Wilkinson and Willoughby 1962).

There have been quantitative approaches to studying the city, starting with the work of Martin and March (1972), stating that spatial structures can be modelled and that the grid is a generator of urban form (Martin and March 1972). This led to the configurational approach to study the city, pioneered by Hillier and Hanson (1984) and Steadman (March and Steadman 1971; Steadman 1983). The configurational approach aims to measure the relationships between elements of the city in order to find out the rules behind the resulting configurations, both spatial and social. This is accomplished by representing spaces through their topological relationships and applying mathematical models based on human behaviour to quantify that relationship (Hillier and Hanson 1984; Steadman 1983). By modelling the usage of spaces by humans, this approach **implicitly includes the relation between social behaviour and physical form.**

3.1.2.1. The Configuration of Urban Blocks and Their Role in the Functionality of the Settlement

The size, shape and configuration of urban blocks of a settlement play an important role in the current spatial structure and functionality of a neighbourhood. The urban block is considered the area that is surrounded by the streets. They are the space for buildings/functions within the street network of a city (Frey 1999), and the space for natural

occupation, one of the two main states of the city (Marcus 2001) The size and shape of each block influences its suitability to accommodate necessary functions in the city. Some studies have been carried out to find parameters that define the most suitable size, shape and density of blocks, the criteria are explained below:

- Very large and long blocks impede walkability and navigability as well as reducing opportunities for encounters (Jacobs 1961)
- Very small blocks are less resilient over time and cannot accommodate different functions (Siksna 1997)
- Very irregular shaped blocks (with dead ends) impede navigability (Vialard 2013).
- Small, square blocks (80-110m) provide optimal variety in land use and are suitable for vehicle and pedestrian activities in the street network (Siksna 1997)
- A minimum block face of 214 feet (65.2m) to accommodate modern building footprints (Steadman 2014).
- The settlement should be a maximum of 60% built area (Perry 1929).
- The distribution of blocks should tend toward log normal 'long tail' distribution, with many smaller blocks and fewer larger ones (Jiang and Liu 2012; Usui 2018).

Therefore, the optimal urban fabric should have a diversity of block sizes, consisting of a majority of small- medium sized, regular blocks, and fewer larger blocks. Blocks should accommodate functions, but not impede walkability/connectivity. There should also be 40% open space, including streets, in the urban fabric. In order to apply these criteria and assess the functionality of the settlement, the size and shape of urban blocks is studied. The exact procedures and measured are detailed in chapter 3.2.

3.1.2.2. The Configuration of Streets – Space Syntax

Space Syntax is defined as *"A research program that investigates the relationship between human societies and space from the perspective of a general theory of the structure of inhabited space in all its diverse forms…"* (Bafna 2003). It is the study of how human

behaviour and societal structure is reflected in space and spatial relationships, and vice versa. The inseparability of the social city and the physical city is a crucial aspect of space syntax analysis. The social city is 'either side' of the physical city; first creating the physical city then using it after creation (Hillier and Vaughan 2007), which shows the social logic behind spatial relations and how spatial form can generate or inhibit social encounters. Space Syntax aims to show *'a direct relation - rather than a symbolic one - to social life'* (Hillier and Hanson 1984).

One of the critical findings in space syntax was the correlation between spatial configuration and pedestrian movement in the city, known as 'natural movement' (Hillier et al. 1993). This is particularly important in contexts where validating results of configurational models through field observations might be difficult. Natural movement is defined as *"the proportion of movement that is determined by the configuration of space itself, rather than by the presence of specific attractors or magnets"* (Hillier et al 1993). The findings of this study show that space syntax measures are a valid predictor of pedestrian movement, and that the configuration of urban environments play a large role in pedestrian flows (Hillier 2007; Hillier et al. 1993). This is important because it can accurately represent how people in informal settlements use the space without observing them, and how the configuration of the space is specific or not to that type of informal settlement.

This concept has also been studied by Peponis et al (1989) who argued that the description of how spaces are accessible through change of direction creates a 'structure of accessibility'. This structure determines the distribution of pedestrian movement. The most accessible spaces create an urban core, which is a collective destination for those using the system. The urban core can highlight the most accessible, and therefore important to community functioning, spaces in an urban system where people meet, buy goods, access services etc. (Peponis et al. 1989). These analyses can highlight the spaces that are necessary for community functioning in informal settlements, so therefore could potentially be preserved in any urban intervention.

3.1.3.2 Representation and Analysis Methods in the Space Syntax Field

Space Syntax can be applied to both the public open space and street network in the urban form, which can be represented and measured in different ways. The main analysis methods of space syntax rely on continuous space being split into discrete units, known as 'configured space'. These can then be labelled with different functions and usages. Initially, the topological relationships of spaces can be represented by using a justified graph, or J-graph (Figure 7). Each space is represented by a node, and the topological step connecting the node represents a line of movement. By representing space in this way, the graph can show how 'deep' or 'shallow' a space is in relation to all the other spaces in the system i.e., how easy, or difficult it is to access that space (Hillier and Hanson 1984).

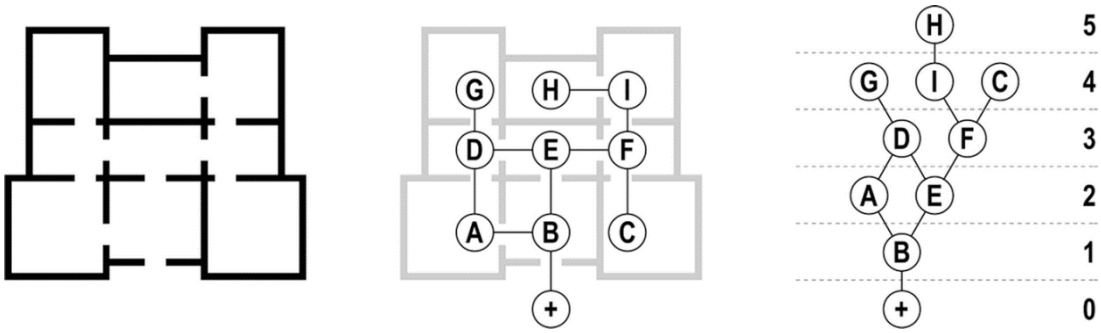


Figure 7: J-graph of rooms in a building.

Source: *Dawes, Michael J., and Michael J. Ostwald. "Space Syntax: Mathematics and the Social Logic of Architecture." In Handbook of the Mathematics of the Arts and Sciences, 1–12. Springer*

This representation can show the relationships and hierarchies between the people that use that specific space, whether it be rooms in a building or the larger urban fabric. It can also show the likelihood of chance encounters between inhabitants and strangers and also the degree of control an inhabitant may have on their space. The degree of control is represented in the 'depth' measure; the further away, or deeper, a space is from the starting point, the more intervening spaces there are and the higher the level of privacy and control the user has in that space (Hillier and Hanson 1984)

There are three main types of topological map used in space syntax analysis: convex map, axial map, and segment map. Convex spaces are used to represent the occurrence of

activity (fewest and fattest spaces e.g., in a building) while axial and segment lines are used to represent connection and movement in open space. The next section describes the generation and usage of the axial and segment maps in studying movement in open space.

3.1.3.3 The Axial Map and Integration Core

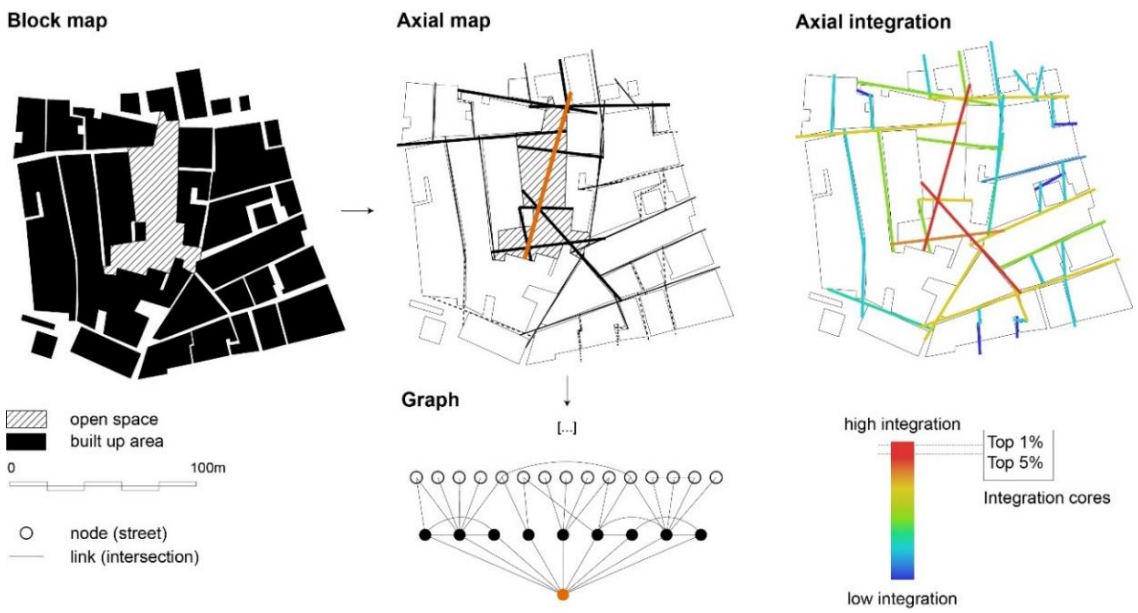


Figure 8: Steps to extracting the axial map from the block map and showing the axial integration core. *Image first published in Zied Abozied, Eman, and Alice Vialard. 2020. 'Reintegrating Informal Settlements into the Greater Cairo Region of Egypt through the Regional Highway Network'. Regional Studies, Regional Science 7(1):333–45.*

The axial map is a representation of potential for movement in open public space. This representation is well suited to urban forms in which the public space is not solely defined by the street network, which is the case of the informal settlements. As exemplified in Figure 8, each axial line depicts the maximum extension of a point in space and correspond with the longest line that can traverse an open space, so each line represents one individual space. The network of lines can be represented using a j-graph, where each line is represented by a node and each topological step by a link, which shows the relative depth of spaces (Hillier and Hanson 1984).

The integration measure is the inverse of the depth, where shallow spaces are more accessible, therefore have a higher integration value. In contrast, low integration means that the street is harder to reach which leads to poor usage (Hillier and Hanson 1984). A highly integrated system can potentially support the community in its encounters and access to services, which in turn fulfils their needs.

The Axial Integration Core

Looking at historical and organic cities, research has shown that some configurations are associated with certain social behaviours. If these configurations are found in self-organised urban form, it can indicate that these spaces are necessary to support the social life of the community, so they can be preserved in urban intervention. As well as the measures for individual spaces, the axial map can also be used to study the global configuration of urban open space. The global configuration can highlight different forms of the most integrated streets, which are known as the integration core. The integration core is the set of the most integrated streets that have the most potential for movement, which usually corresponds with the neighbourhood centre and can take various configurations (Figure 9) (Hillier 1999; Hillier and Hanson 1984; Peponis et al. 1989).

Studies have identified two configurations of the integration core that are conducive to community life and social interaction, the deformed wheel (3) (Hillier and Hanson 1984; Hillier and Stonor 2010) and the live centre (1) (Hillier 1999). The deformed wheel consists of a highly integrated core, integrated streets surrounding the neighbourhood (edges) and branches (spokes) connecting the edges to the core (Hillier and Stonor 2010). This is thought to be an optimal network as it allows access to its centre while connecting to the

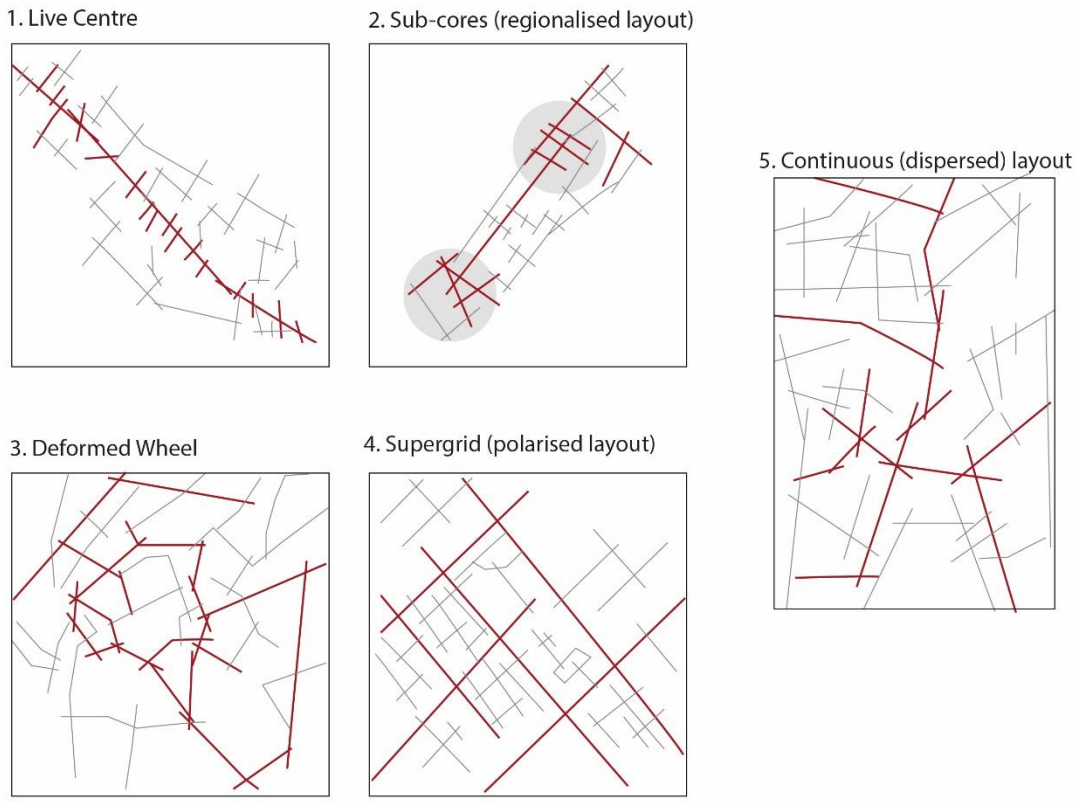


Figure 9: Different Configurations of the Integration Core

surrounding neighbourhoods through the streets on the edge of the neighbourhood. The live centre presents as one long and straight street, which usually corresponds to a high street, intercepted by many smaller streets. Due to its central location and interception by local small streets, the live centres can join different local street networks. This can intensify interactions and movement on the live centre (Hillier 1999).

Three other configurations can provide insight into how different parts of the neighbourhood are accessed, and where encounters and congregation are more probable. The regionalised layout (2) highlights the sub-cores of the neighbourhood with a connection between them. This layout can indicate the different subsections of the neighbourhood that are not necessarily enclosed but are differentiated in some way. The polarised layout (4) shows that there is a large urban grid super-imposed onto a smaller or more fragmented grid. This layout can highlight the presence of different, disparate street networks within a neighbourhood. The continuous layout (5) shows the integration core continuously

dispersed throughout the neighbourhood, which provides access to other sections easily and increases the opportunity for encounter (Peponis et al. 1989).

All of the configurations of the axial integration core can provide insight into how the open space is used by pedestrians, and if the spatial structure can support the community in fulfilling its daily activities that require accessing the rest of the neighbourhood and community spaces. The deformed wheel and live centre can also indicate healthy community functioning and increased opportunity for encounters. Using This analysis method to highlight the integration core is suitable for studying how the community can use the open space without observing them, because pedestrian flows are highly correlated with the integration core.

3.1.3.4 The Segment Map

The street network can also be represented as a series of line segments that are derived from the street centreline map (Turner 2007) or division of the axial line into segments (Hillier and Iida 2005) (Figure 10). The segment representation contrasts from the axial map as it corresponds to a type of representation associated with the planned street rather than the open public space. The rigidly defined street network is often present in planned cities, while the street network in informal settlements may be less defined, and open public space is used for movement.

The segment map represents each street as a series of segments and intersections, where one street segment is the line between two intersections. The representation of the street network as individual segments rather than one axial line can allow for a more fine-grain analysis of the street network and a more accurate representation of the highway boundary. Segment maps also allow for more analysis types than axial maps (Hillier and Iida 2005).

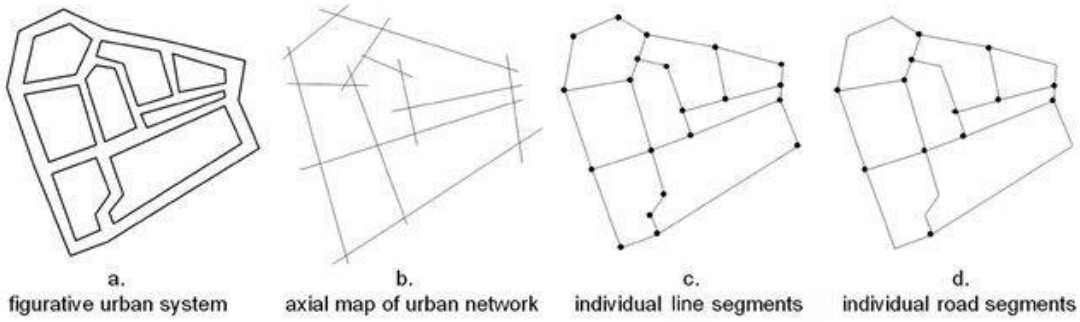


Figure 10: Generation of the segment map.

Source: Ozbil, Ayse. (2013). Modelling walking behaviour in cities based on street network and land-use characteristics: The case of Istanbul. METU Journal of the Faculty of Architecture.

The main measures used in segment analysis include angular integration, angular choice, and metric and directional reach. Angular Integration is similar to the integration value in the axial map and measures the relative depth in terms of angular change, which can be adjusted as needed and compared across different systems (Hillier and Iida 2005; Turner 2007). Angular choice measures how often a segment falls on the shortest path between any two segments in the system. This can show the straightest (least angular deviation) routes in a system (Hillier and Iida 2005). Choice can be normalised as Normalised Angular Choice, which takes into account the depth of the segment in the system, which accounts for segregated areas (Hillier, Yang, and Turner 2012). The reach measure takes into account metric distance in urban configurations, not just their topological relationship. There are two types of reach, metric reach, and directional reach. Metric reach measures the distance that can be accessed from a segment within a certain metric radius. Directional reach measures the distance that can be accessed from a segment within a certain number of turns (Peponis, Bafna, and Zhang 2008). Acknowledging metric distance is important because it contextualises the configuration from a human point of view. This is important since vehicular usage is comparatively low in informal settlements (CAPMAS 2015), so a configuration may work well topologically but the distances are too great to reasonably travel on foot.

When tested, the values for axial lines and segment lines proved to be similar (Turner 2007). However, each representation provides a different perspective to the street use. The axial line aligns more with the pedestrian experience, as it represents a more natural movement that may not necessarily align with a street centreline. Segment line representation aligns with the vehicular experience and includes highways in the analysis, as the road centreline is a close representation to how vehicles use the street (Vialard 2015).

In this thesis both representations are used, in order to cover both perspectives of the street users. In planned settlements, there tends to be a dominant vehicular network since this is the most common movement within the settlement. In informal settlements, the dominant network tends to be pedestrian, with a lesser importance on vehicular access. As well as this, the literature previously suggests that there exists different street hierarchies and usages within settlements, some of which are primarily used by either pedestrians or vehicles. Therefore, it is important to study the street network from both perspectives as there may exist two networks that may not always be connected. The specific methodological steps and measures are discussed in chapter 3.2.

3.1.3. Quantitative Classification Methods

The previous studies using the typo-morphological approach have discussed qualitative classification of urban forms, which are usually based on form and use (Steadman 2014). Classification can also be undertaken using quantitative methods by using unsupervised machine learning procedures to categorise large amounts of data using clustering methods (Berghauser Pont et al. 2019; Gil et al. 2009; Vialard 2014). Using quantitative methods has the advantage of quantifying what may be known intuitively. Quantitative methods can also classify large amounts of data into meaningful categories that may not be immediately apparent using qualitative methods.

The following section discusses different methods that can be used for quantitative classification. Colannino et al (2011) use factor and cluster classification to classify built up

structures in Barcelona. They used the shape of urban blocks as the variable to cluster. The results indicated that using geometric characteristics to create clusters allowed for the identification of different neighbourhood configurations, and for the classification of neighbourhoods outside the sample into these configurations (Colaninno et al. 2011). Song and Knaap (2007) use factor analysis and cluster analysis based on different measures of the street network and parcel-level attributes. The results show that neighbourhoods can be measured and described quantitatively, and that statistical analysis can be used to identify types within the data (Song and Knaap 2007).

K means clustering is used by Berghauser Pont et al (2019) with multi-variable geometric attributes of the streets, plots, and buildings. This type of clustering can be used when the parameters and the number of clusters is unknown. The number of clusters can be defined experimentally until an optimum number is reached. The number of clusters should sufficiently group similar data points without having too many/too small categories. This analysis provided insight into the characteristics of the urban elements and the relationship between them (Berghauser Pont et al. 2019).

K means clustering is used in this thesis to group the previous quantitative data streams into understandable clusters. This is because the cluster definition and potential number of typologies in informal settlements is not known and has not been previously studied. K means clustering allows for experimentation in the number and definition of clustering, and a heuristic approach to grouping different urban elements.

Quantitative Data to inform Type

Two elements of the urban form are studied quantitatively, that reflect the two states of being in an urban form – movement and occupation. One of the data streams used to inform the type is the urban block. In the case of informal settlements, the urban block is where natural occupation occurs, which is a self-generated space to fulfil the needs of the residents, rather than that defined by the legality (Marcus 2001). The size and shape of the

block is directly related to the function (Siksna 1997), so these two variables are studied. The other data stream is the street configuration. According to Peponis et al (1989), an essential component of urban typology is the accessibility and configuration of spaces, which are necessarily linked to the usage of such spaces and pedestrian movement. What is most important in this is the idea of an 'urban core' or integration core *(see section 3.1.3.3 The Axial Map and Integration Core)* which can be used to inform type. These two data streams are taken on a neighbourhood level to inform the type of that neighbourhood. Qualitative aspects such as the history of emergence and social conditions are also used to inform type.

3.1.4. Urban Blocks and Street Network Research in Informal Settlements

Several studies using the above methods have been carried out in informal settlements around the world. These studies have taken place in Santiago, Jeddah, Agra, Dar Es Salaam and Cairo. The following studies highlight the different consolidation processes of informal settlements, the importance of edge movement in consolidating settlements into the urban form (Hillier, Greene, and Desyllas 2000), proposed interventions in aligning the core of informal areas with the city-wide grid (Karimi et al. 2007) and some of the limitations and challenges in designing urban interventions in informal settlements (Kohlert 2007; Parham 2012). All these case studies have clear parallels with Greater Cairo; the city also suffers from spatial fragmentation that can be addressed through consolidation and targeted urban intervention. These studies also show that space syntax and urban block analysis are suitable for use in informal settlements that do not have legally defined streets and blocks because the analysis is based on the physical attributes of the neighbourhoods – street network configuration and urban block geometry.

The earliest studies conducted in 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 – similar to some settlements in Cairo as shown by the previous street hierarchy studies in chapter 2.2) 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, Greene, and Mora 2019).

These three studies show that:

a) the street network configuration on both a vehicular and pedestrian level influences informal settlement consolidation

b) the vehicular transport network (highway) can cause spatial fragmentation by design

c) different informal settlements have different consolidation processes which are influenced by several variables, including history of emergence, location, street network configuration, etc.

These findings can be applied to Greater Cairo as it has been shown that informal settlements have different emergences (see chapter 2), and so may require different consolidation processes and intervention methods. There also exists both pedestrian and vehicular networks in Cairo, so this justifies the analysis of both the pedestrian (axial) network and the vehicular (segment) network in this thesis. It also highlights the importance of incorporating qualitative data such as historical analysis and social studies into the study.

Informal settlements can also benefit from targeted, research based urban interventions. A study conducted by Karimi et al (2007) on informal areas in central Jeddah proposes limited physical interventions in informal settlements to promote gradual self-improvement of the settlement rather than removal. These settlements in Jeddah, Saudi Arabia, suffer from fragmentation of their spatial structure and are not connected to the rest of the city. The study suggests that one of the optimum interventions is **the alignment of the inner core of informal settlements to the city-wide spatial grid** (Karimi et al. 2007). This is also supported by the work of Peponis et al (2015), which 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).

This represents an avenue of urban intervention – reconnecting local street networks to the primary super-grid.

Karimi et al (2007) also categorised streets into three types: primary boulevards, secondary boulevards, and locally important routes. Local routes can 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. The main policy regarding unplanned areas is removal but using space syntax analysis can develop interventions to reconnect the unplanned areas to the rest of the city. This study also adds three potential street classifications - primary boulevards, secondary boulevards, and locally important routes.

The street network configuration is also linked with activities that take place on streets. A comparative study by Parham (2012) was undertaken in Agra and shows that micro scale activities are closely linked with local street structures, and that a more detailed representation of the streets using segment map would be beneficial in finding the locations of micro scale activities. This study also highlights some important methodological challenges in informal settlement analysis. One of the main issues is accurate data collection for both physical and socio-economic factors (Parham 2012). This challenge is also encountered in this thesis and addressed accordingly.

Kohlert (2007) uses a combination of historical analysis and space syntax analysis to redesign the harbour area of Dar Es Salaam. Design recommendations bring together the results of the surrounding street configuration analysis and the historical context of the harbour. This shows a successful combination of qualitative and quantitative approaches, as well as a practical application of space syntax in a semi-informal context (Kohlert 2007). The combination of qualitative and quantitative approaches is also taken in this thesis, as it

adds another layer of depth to the analysis and works towards the *Plano Global* for informal settlement upgrading.

3.1.4.1. Space Syntax and Urban Morphology Studies in Egypt

Space syntax and urban morphology has been applied in several studies to both informal and planned settlements in Egypt. Some studies use space syntax to prioritise informal settlements for upgrading (Ismail, Bakr, and Anas 2016), addressing distance in informal settlement analysis (Salheen 2003; Salheen and Forsyth 2001), evaluating wayfinding and people's movement in informal areas (Mohamed 2012, 2016; Mohareb 2009) and studying spatial segregation (Mohamed 2010; Mohamed et al. 2014). Most studies that investigate the specific morphology of informal settlements qualitatively are discussed in the previous chapter 2. Dovey et al (2020) analyse the specific morphology of informal settlements quantitatively and conclude that urban upgrading is dependent on understanding the morphology of informal settlements (Dovey et al. 2020). The consensus in these studies is that the urban fabric of informal areas can be successfully studied using quantitative methods.

Ismail, Bakr, and Anas (2016) use space syntax and GIS in Fayoum city to analyse informal settlements by combining social demographic and street network configuration data. The aim was to create a Coexistence Potential index that measures two variables called *Effectiveness of Intervention* and *Neediness for intervention*, based on social data such as income level and the street network configuration. The results show that intervention on the local level should be prioritised and supported by quantitative methodology, as well as political will (Ismail et al. 2016).

Metric distance is combined with questionnaires to explore the validity and use of space syntax in two studies by Salheen and Forsyth (2003; 2001). These studies show that space syntax can be reliably used to predict pedestrian movement in Cairo. A fine grain analysis is needed, as it was found that micro-scale space use varied across the length of the street. This was addressed by using segment analysis to split the street and by considering

distance by using a Metric Axial Model (Salheen 2003; Salheen and Forsyth 2001). The segment analysis and metric reach are used for the same purpose in this thesis, a fine grain analysis of streets.

Mohamed (2012, 2016) and Mohareb (2009) have studied the effectiveness and accuracy of space syntax analysis in informal and historical areas of Cairo, by using qualitative observation and questionnaires. Mohamed (2012) showed that when there was no effective street hierarchy (same width to all streets) axial analysis is less effective in Cairo (Mohamed 2012). Mohamed (2016) used virtual gate observation and people counting in informal settlements that represent the main typologies in Cairo – agricultural and desert land. The analysis showed that main streets with commercial interests have higher movement than alleys and dead ends. The analysis also showed a significant positive correlation between angular integration and pedestrian movement and that the spatial configuration affects the pedestrian movement (Mohamed 2016). Mohareb (2009) used a combined method of space syntax, field survey and questionnaire to study pedestrian movement in Historical Cairo. His analysis showed that 67% of the spatial configuration analysis is correlated with the actual pedestrian movement, which increased to 75% when historical buildings and monuments were considered (Mohareb 2009). These studies show that pedestrian movement correlates with space syntax analysis, which makes it a suitable method for use in informal areas.

Mohamed et al (2013, 2014) study how the spatial configuration of Greater Cairo influences spatial and economic segregation of informal settlements. These two studies show that informal settlements have a strong internal spatial structure but are not connected to the wider city (Mohamed et al. 2014). This can be tied back to the idea of a super-grid of primary roads (Peponis et al. 2015), in this case highways, that span the city. When informal settlements are not connected to this super-grid, the consequence is spatial and economic segregation. Reconnection can potentially alleviate some of these issues. This also

reinforces the idea that there is a street hierarchy which has the potential to inform classification i.e., the differentiation between super-grid and the local internal streets.

These studies also highlight the importance of boundary and the highway network. In most cases, the administrative boundary assigned by the government do not line up with the spatial edges (boundary) of informal settlements. Informal settlements are also generally located alongside a physical boundary – a highway, road, or railway, and are often poorly connected to these edges (Mohamed et al. 2013). The highway edges have the highest global choice values and make up Cairo's main transport links, but the highway bypasses informal areas. This leads to further spatial and social segregation for informal settlements (Mohamed et al. 2014). These two studies highlight the importance of analysing informal areas based on their internal local structure, but also on their relationship to the nearest highway and/or definable edge. Based on this, Zied and Vialard (2020) suggest that the highways can be used as integrators if they meet the correct conditions such as being ground level and crossable by pedestrians (Zied Abozied and Vialard 2020).

In their study of the morphogenesis of informal settlements, Dovey et al (2020) analyse several informal settlements from around the world. The case study in Cairo, Al Baragheil, emerged in 2000s with an urban morphology that aligned with the existing agricultural grid. They then went on to quantify this morphology using the size and shape of the resulting urban blocks. It was shown that the blocks are not entirely aligned to the original fields but influenced strongly by them. The resultant blocks tended to be 15-25 m wide, with 4 -6m streets between them. Some streets extended over 700m with no cross-permeability and over 76% of the land was built up (Dovey et al. 2020). This reinforced the idea that informal settlement produces very dense urbanisation with little open space (Sims 2012). This also highlights how the building becomes the urban block in informal settlement, which supports the study of the urban block rather than the building in this thesis. The context of informal settlements produces diverse urban forms, and the initial land subdivision or natural topography has an influence on the outcome of informal settlement. This means that

informal settlement is not one specific morphology but has a range of variations based on the emergence, history, and growth of the settlement (Dovey et al. 2020).

All these studies reinforce the idea that informal settlements have different structures, configurations, and variations, based on their initial topographic conditions, boundary, and connection to the rest of the city. The importance of spatial configuration is highlighted, as well as its role in spatial segregation and connection to major transport networks and the rest of the city.

3.1.5. Feasibility of Social Studies in Informal Settlements in Cairo – The Changing Landscape of Social Research

As mentioned in chapter 2.1 it is important to combine both physical and social data streams in order to create a holistic approach to informal settlement upgrading and investigate the relationships between different aspects of the neighbourhoods. This is also recommended by Clifton et al (2008) who suggested a multidisciplinary approach in order to effectively contribute to policy (Clifton et al. 2008). However, because of sensitivities around fieldwork there has been difficulty in conducting social studies in Cairo.

There have been some studies that use interviews and observations to study community and social bonds in Cairo and the social integration into the city. Most of these have been carried out in the late 1990s and early 2000s (Arandel and El Batran 1997; Piffero 2009; Sims, Sejourne, and El Shorbagi 2003; Sims and Séjourné 2000) which focused on a specific set of accessible informal settlements (City of the Dead, Manshiyet Nasser, Bulaq El Dakrour, Dar El Salam, Mit Uqba), that were used to researchers and allowed access to their neighbourhoods.

Abouelmagd (2020), Alaa El Din (2019) and Logan (2020) all reported difficulty in fieldwork and sensitivity in conducting interviews. Their access to the neighbourhoods was eventually cut off once residents became wary of the researchers. However, it seems to be easier to do social research as part of an urban upgrading project, where there is a tangible change

and benefit to the residents (10Tooba 2015; Elazzazy and Zaazaa 2017; Piffero 2009; Shehayeb and Eid 2007).

These difficulties prompted a different approach in this thesis. It was important to carry out targeted social studies in order to provide a holistic view of informal settlements which contextualises the spatial research and provides insight into the social logic and spatial structure of informal settlements. This led to creative data collection, such as online questionnaires and data sharing and collaboration, that was less limited by access to the field. This also meant that the thesis leans heavily on the quantitative analysis of informal settlements with the social studies providing additional context to the quantitative analysis.

3.1.6. Limitations and Methodological Challenges

The literature has highlighted several methodological challenges that were taken into consideration. Firstly, data availability may be limited, and data collection may be difficult due to a lack of mapping and other sources. Secondly, the lack of access to the field prompted creative data collection. Finally, combining quantitative and qualitative data streams may have issues, so this was also considered in the research synthesis phase.

3.2. METHODOLOGICAL STEPS AND PROCEDURES

3.2.1. Research Design

The literature review and questions outlined previously show that informality is a complex social and physical phenomenon that has the potential to be studied in different ways. As mentioned previously much of the research conducted has focused mostly on the social and economic causes and effects of informality rather than on the physical aspects. When physical aspects of informal areas are studied, there tends to be a focus on environmental quality, building quality and infrastructure provision rather than the street network and urban fabric. This research approaches studying the street network and urban fabric through a syntactical and morphological perspective. Some research into the social and community aspects of informality is also undertaken to provide a holistic view of both the social and physical aspects of informality.

This research uses a mixed methods research design (Creswell, 2002; Denzin, 1978) to address research questions. Mixed methods are an appropriate tool when research questions cannot be answered by using one paradigm. The similarity of findings from using different methods in one study can aid in validation of the results. Using mixed methods can also reduce bias that comes with particular data sources, methods and the researchers own biases. Biases can include data sources that do not acknowledge informality in its full extent and confirmation biases from the researchers. In the case of Egypt, using mixed methods can allow for creative data collection when traditional fieldwork is difficult. This leads to a richer breadth of data and further corroboration of ideas and findings.

This study uses the qualitative approach of searching for meaning and themes in the social phenomenon of informality while using quantitative data drawn from the street network and urban fabric to describe the phenomenon numerically. Using quantitative data allows for replication of results and the results of quantitative analysis can be used within the overall qualitative approach of finding themes in informality that can potentially aid classification.

This research uses a concurrent strategy of inquiry (Creswell, 2002) where both quantitative and qualitative data is gathered to address the research questions. The approach taken in this study is quantitative dominant with qualitative data contextualising the findings from the quantitative analysis. Some qualitative data is quantified to aid in comparison and synthesis. The data is collated at the data interpretation and synthesis stage to allow for a holistic overview of informality through pattern recognition within both types of data.

3.2.2. Research Methods

The research questions are broadly split into two categories: physical aspects in informal areas and historical-social aspects in informal areas. These two aspects are then brought together to inform classification. This splits the research project into two phases which are then brought together in the final phase of thematic analysis, which is the process of finding patterns and meaning within the data. Overall, a case study approach is taken, with Cairo being the primary case study and settlements within being secondary case studies. The first phase addresses the social life in Cairo and informal areas through qualitative analysis in the form of historical maps and literature analysis, questionnaires, interviews, and observations. The second phase studies the urban fabric and street network using quantitative space syntax and urban morphology analysis which results in a numerical and visual description of each settlement. Research synthesis is performed after gathering the physical data of settlements and the social data about life in Cairo, which is explained further in section 3.2.6 in this chapter. From this analysis features that can inform typologies can be extracted, used to develop a classification framework and to inform urban interventions.

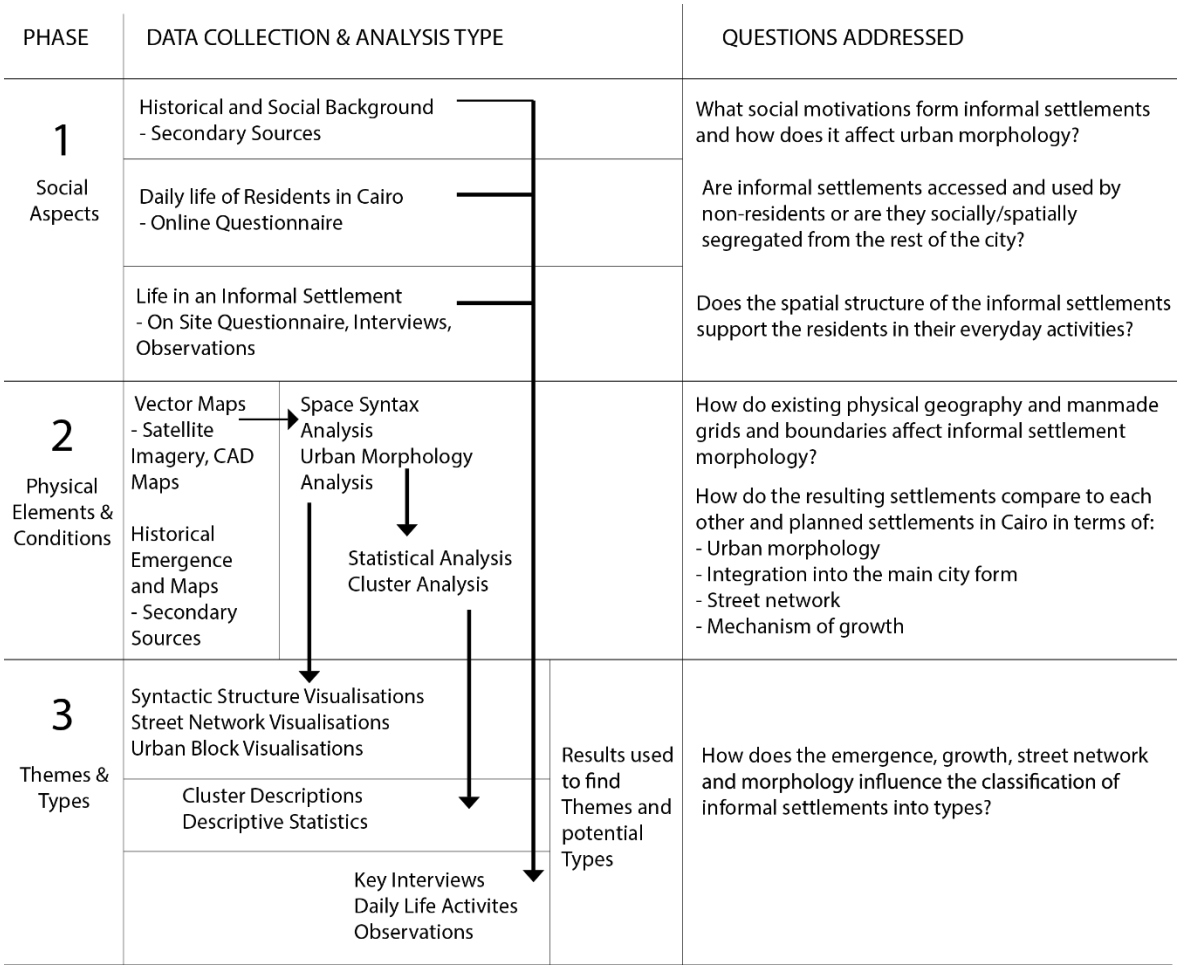


Figure 11: Summary of Methodological Steps

Figure 11 presents methodological steps, tools and procedures of data collection and analysis in this thesis. Firstly, the general background of Cairo was studied in order to decide on an initial classification of settlements and to choose a wide range of case studies that accurately represent the different urban conditions that are present in Cairo. Secondly, the data collection process was split into two parts which occurred simultaneously. The first part gathered data about the daily activities of Cairo's residents and their relationship to informal areas, and also about how people live in informal areas. The second part focused on gathering map data that accurately reflects the urban conditions in Cairo in order to create models for quantitative analysis.

Two studies that address the social issues of socio-spatial integration and life in informal settlements were carried out to understand the social context in informal areas and the rest of Cairo. The first study was carried out in the City of the Dead, the cemetery turned informal settlement. This study focused on how a sense of community was achieved in a settlement not designed for living, and how the urban fabric influences the sense of community. The second study was a questionnaire that looked at how people move in the city to carry out their daily activities such as going to work or school, shopping, and socialising. Together, these studies provide an insight into how informal settlements are lived in and if they are socially and spatially integrated into the city. They also provide context for the quantitative study and a basis for the physical reintegration of informal settlements into the city. This is discussed further in the 'Social Research Procedures' section below.

In order to study the physical fabric of the city, accurate and precise models needed to be created. To do this, CAD maps were cross-referenced with historical maps and satellite imagery and updated to reflect the current urban fabric. These CAD maps were then split into two types of model, one that represented the urban blocks in a settlement and one that represented the street centrelines. The concepts of a street and a block were further defined, as in informal areas it is not always clear what constitutes a street and a block. These definitions and further information about the process is discussed in section 'Map Data Collection' below.

The models created were used in space syntax and urban morphology analysis. From the model of the urban blocks, variables such as size and shape of the blocks were extracted. This model was also used to create the axial map which allowed to study the integration core of each settlement. The segment map was created from the street centreline map and then analysed to produce the integration, reach and choice variables (as defined in Chapter 3.1) of the streets. The data was collated in GIS and each variable attributed to the block or street using a Global ID, which creates a database that can be used for statistical analysis. The data was also visualised in order to find patterns and themes within it. The reasoning

and steps for this process are discussed further in the section ‘Space Syntax and Urban Morphology Analysis’.

The database produced was then used to extract descriptive statistics about each settlement and for cluster analysis. The descriptive statistics provides insight into properties of the streets and blocks that could then be used for classification of settlements and assessing their suitability for use. K-means cluster analysis was used to cluster streets and blocks by the variables extracted from the space syntax and urban morphology analysis. This provides insight on the type of street and block that make up a planned or informal settlement. Clusters that are only present in one type of settlements can also help with classification by allowing differentiation between typologies. The relationship between settlements and highways was addressed and whether it changes if a settlement is planned or informal. The highway has been shown to be a boundary for some settlements and providing access can be a step toward physical reintegration. The output of the research are the classification of the settlements and exploration into what defines an informal settlement from a morphological and syntactical perspective, while taking into account the social and historical context.

3.2.3. Space Syntax and Urban Morphology Analysis

The process for of creating and analysing models of the street network and urban blocks is presented in this section. It discusses the analysis type selection and justification, the model creation procedure, the measure selection and the analysis process. Figure 12 illustrates the workflow for the analysis, the initial features, resultant models, measures used and the specific variables and units.

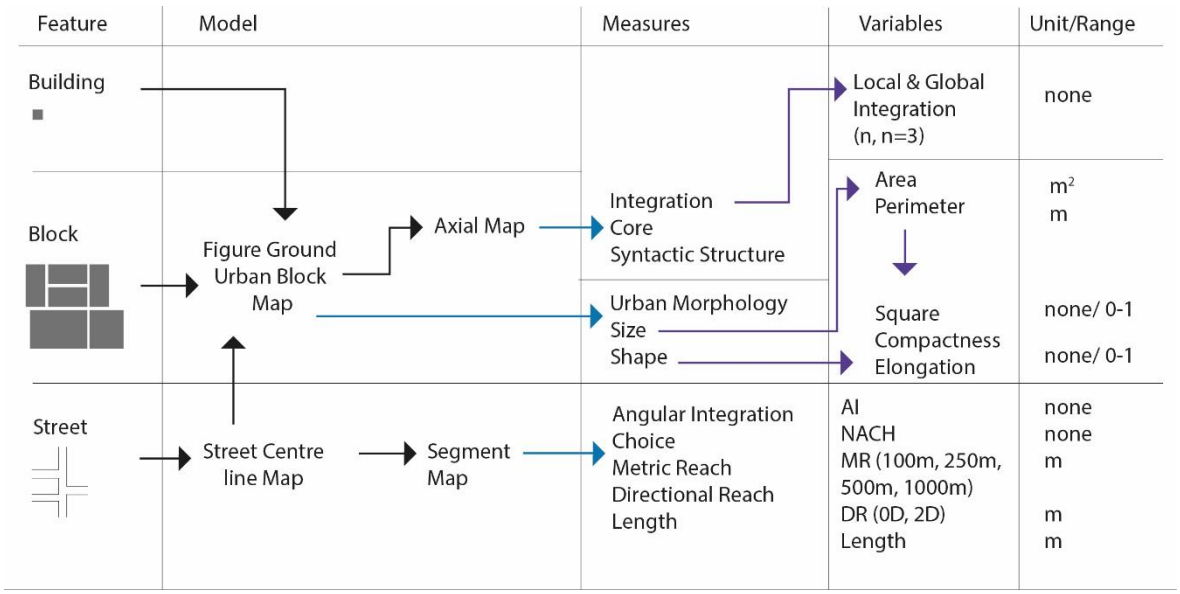


Figure 12: Workflow for Space Syntax and Urban Morphology analysis

3.2.3.1. Map Data Collection

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 in AutoCAD, taking into account distortion caused by perspective and shadows in the satellite imagery. This

was addressed by also taking measurements off Google Maps, being sure to trace the building/block outline and not the shadow and standardising road widths.

Initial definitions of blocks and streets were created to standardise map updating, based on the initial morphological types presented in the literature review in chapter 2.2. Three morphological types reflect the emergence of the settlement and define the block and street in that type of settlement (Figure 13). *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.

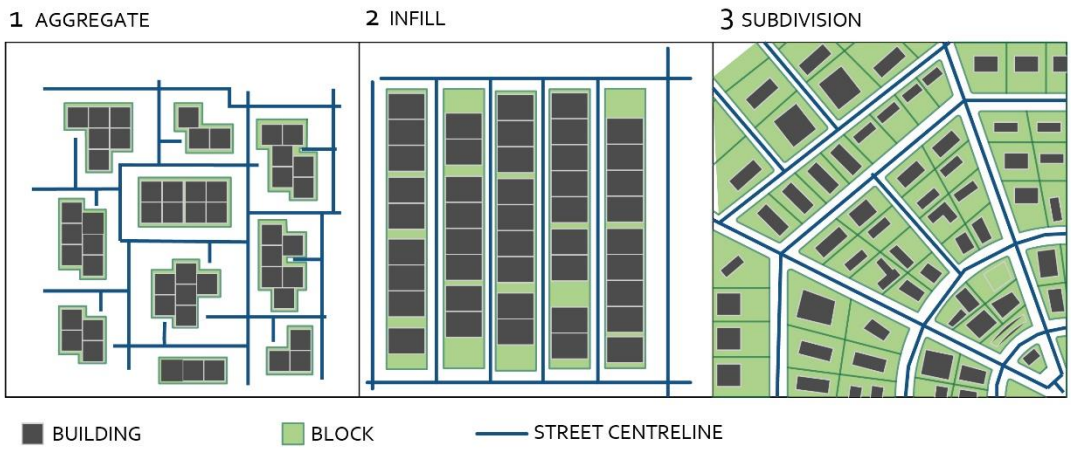


Figure 13: Emergence Types

Deciding on an emergence type was a very important step in the map updating process. As most of the maps were incomplete, the emergence type helped to fill in incomplete elements. For example, in most informal areas only the building CAD map was available, so the type could be inferred from studying historical maps and then updating the current map using the emergence type to define streets and blocks. In some planned areas only the street centreline map was available, so blocks were defined by offsetting the street centreline to a road width measured from satellite imagery and rounded to the nearest metre. A limitation to this method is that there will be some researchers bias, as it would be a judgement call on what emergence type a settlement would fall under based on incomplete information.

After the maps were updated, they were split into separate layers containing the buildings, urban blocks, and street centreline. All other excess data (signs, pavements, greenery, annotations, etc) were removed. It is important to note that informal areas can grow and change very quickly. Therefore, so the produced maps are accurate only between years 2017 and 2019 but may not be fully accurate after that. The end result of this data collection is a vector (CAD) map of each case study showing the urban blocks, and street centrelines, and, when available, the buildings when available.

3.2.3.2. Model Creation and Analysis Process

In order to analyse the settlements, vector models need to be created that represent the street network and the urban blocks. The three types of model created are the segment map for the street network, the urban block figure ground map and the axial map generated from the urban blocks. The following section illustrates how these models were created, justification for model usage and the process to select measures and extract them from the models.

The Urban Block Figure Ground Map

The urban block figure ground map is used to analyse the effect the size and shape of blocks can have on the settlement, and to classify blocks into clusters in order to aid in

classification of settlements. This map represents the areas that are not used for movement in the settlement, i.e., built up areas, parks, private land etc. In informal settlements, clusters of buildings which may or may not have private alleyways are considered as urban blocks. In planned settlements, any area not designated as a street is considered an urban block, even if there may be private access pathways between buildings. This definition of urban block is used to separate between public areas of movement and private areas of movement (alleyways, private entrances, the hara in informal areas), as this study is focused on analysing and classifying settlements from the point of view of a visitor, in order to minimise the effect of experience with the street network for shortcuts etc.

Creation Process

The urban block figure ground map was created from the vector (CAD) map of each case study. The layer containing the urban blocks defined above was separated. The geometry was simplified into lines to aid in analysis, as curves and points may affect the analysis. The end result was a polygon shapefile which could have data attributed to it that represented the urban blocks in each settlement. Like the segment maps, each block had a unique ID, settlement ID and unique Global ID to keep data organised and attributed to the correct block.

Variable Selection, Calculation and Analysis Process

As mentioned previously, the size and shape of urban blocks can affect social processes and how the settlement functions. To measure the size of blocks, the area and perimeter were chosen. The perimeter was used to calculate the average block face length of the block, by dividing the perimeter by four, assuming a quadrilateral shape. To measure shape, measures originally used in geographic research to measure the shape of natural elements

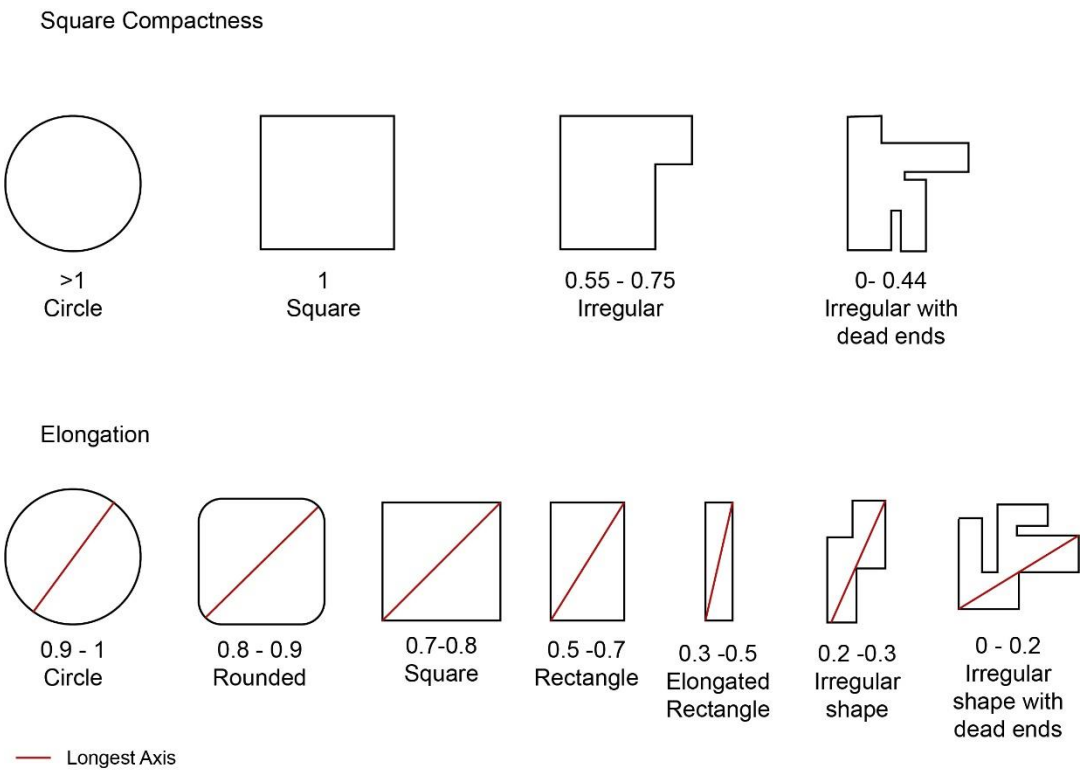


Figure 14: Diagram showing example shapes and ranges

Table 4: Square Compactness ranges

Value	**Indication**
>1	Square tending to circle
1	Square
0.55 – 0.75	Irregular shape with no dead ends
0 – 0.44	Very irregular shape with dead ends

Table 5: Elongation Ranges

Value	**Indication**
>1	Circular/curved
0.8 – 0.9	Oval/Rounded Square
0.7 - 0.8	Square
0.5 – 0.7	Rectangular
0.3 – 0.5	Elongated Rectangle
0.2 – 0.3	Irregular shape
0 – 0.1	Extremely irregular with dead ends

are used. Square compactness, adapted by Steadman from MacEachren's index of compactness (MacEachren, 1985; Steadman et al., 2000; Vialard, 2013) and elongation, developed by Schumm to measure river drainage basins (Schumm, 1956) were chosen. Square compactness measures the block's tendency towards a square using the area and perimeter of the block. Elongation is the ratio of the diameter of a circle of the same area as the block to the longest axis of a block, which measures the blocks tendency towards a circle. Together they can give insight into whether the block is square or rectangular and into its regularity/irregularity. The ranges of these measures used are presented in Table 4: Square Compactness ranges and Table 5: Elongation Ranges. Figure 14 also provides a visual representation of these value ranges.

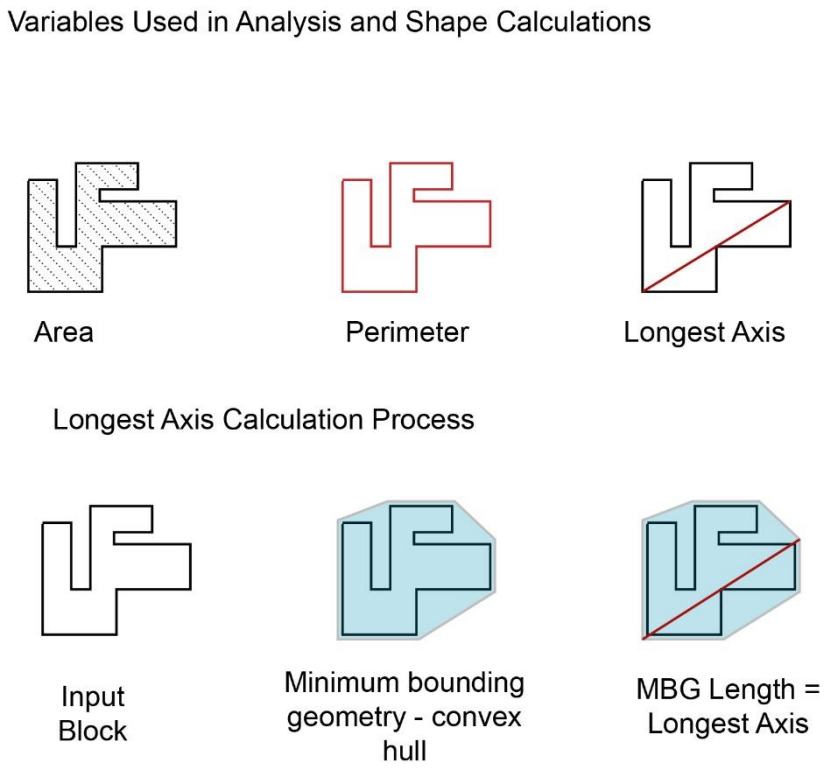


Figure 15: Diagram of Input Block and how each variable is calculated

Figure 15 illustrates the variables used in the analysis and shape calculations. To collect data about the size of the blocks, the area and perimeter are calculated in ArcGIS using the 'Calculate Geometry Attributes' geoprocessing tool through the attribute table. Another variable, the longest axis – the longest line that can be drawn within a polygon, is also used

to calculate elongation. To calculate the longest axis, the ‘Minimum Bounding Geometry’ geoprocessing tool was used. This tool creates polygons that enclose each input block. The geometry chosen was ‘convex hull’ which is the minimal polygon that can enclose the input block using the vertices of the input block. This tool also calculates the longest axis by calculating the variable ‘Minimum Bounding Geometry Length’ which is the longest distance between any two vertices of the convex hull, and therefore the input block. The end result is the polygon shapefile with the length, perimeter and longest axis attributed to each block.

The equations used to calculate the square compactness and elongation are as follows:

Equation 1: Square Compactness

$$16 * \frac{Area}{Perimeter^2}$$

Equation 2: Elongation

$$\frac{Area/\pi}{Longest\ Axis}$$

The end result is the shapefile with the data attributed and a spreadsheet containing all the variables and IDs that can be used for statistical analysis.

The Axial Map

The axial map is used to represent the potential for pedestrian movement in the open space of each settlement. This open space is defined as any space outside the urban blocks that allows movement through it to the next open space. This method of representing movement is useful for informal settlements which may not have a clear street network, such as the aggregate type which follows the buildings logic, as it does not rely on the street centreline map and can more accurately represent pedestrian movement. The only variable used in the axial map is integration, in order to represent the integration core and syntactic structure of the settlement. Angular integration is already measured in the segment map, so the axial integration is only used to generate descriptive statistics for each settlement and not in the cluster analysis.

Creation Process

The axial map was generated in DepthmapX software using the vector (CAD) map of the urban blocks. The end result is a map of the longest, fewest lines (See chapter 3.1.2.2 The Configuration of Streets – Space Syntax for visualisation) that can then have data attributed to it through analysis and visualisation.

Analysis Process

The analysis process for the axial map is firstly extracting and attributing the integration variable to each line, then finding the descriptive statistics and segmenting the data to create visualisations of the syntactic structure. DepthmapX software was used to analyse the axial map using the 'Run axial graph analysis' tool. This tool calculates the integration, among other variables. Since settlements have both local (internal) and global (external) structures, this analysis included choice and was ran at a global (n) and local (n=3) level. Global integration helps to visualise the primary street network and potential connection points in the settlement and local integration can indicate shorter journeys (fewer steps) within the settlement.

The next step was to use the database of the axial map extracted from DepthmapX for statistical analysis. To find the integration core, the percentile of the integration variable that most accurately reflects it had to be calculated. As the settlements analysed are large and complex systems, the percentiles chosen are between 1% and 10% depending on the size and number of spaces in the settlement. As well as this, descriptive statistics for the integration variable are generated from this database.

This data and the axial map were used to create diagrams to represent the integration core for the thematic analysis and statistical comparison across settlements.

The Segment Map

The segment map represents the street network of each settlement as a series of line segments. This model was chosen as it is more flexible in analysis than an axial map, and more types of analyses can only be done using a segment map.

Creation Process

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; Stavroulaki et al., 2019))was used as a final step to clean the map from any geometry that may be missed visually and prepare it for analysis.

Measure Selection and Analysis Process

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 2007a). 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 data was also saved externally as a spreadsheet for statistical analysis.

3.2.4. Statistical Analysis

After the segment map and urban block shapefile databases were extracted from QGIS, statistical analysis was performed. The purpose of statistical analysis is twofold; to provide insight into each settlement and compare variables across settlements, and to find themes that can inform types, which can then be used to classify settlements.

The statistical analysis is split into two parts: extracting descriptive statistics from both the settlements and the clusters and the cluster analysis. Descriptive statistics are helpful in comparing across settlements and clusters and finding trends in informal and planned areas. The purpose of the cluster analysis is to help classify elements in the settlement. This clustering is used in the thematic analysis to help inform potential types. Clustering can provide insight into which types of street and block are found in each settlement, and the specific structures they can form.

3.2.4.1. Descriptive Statistics for Settlements and Clusters

Descriptive statistics are used to measure the central tendency and variability (spread/dispersion) of data across settlements and clusters. They are used to summarise large quantitative datasets into an easily understandable form and to compare variables across settlements (Holcomb, 2016). Descriptive statistics can highlight patterns in the data, especially when comparing between settlements, which can then be used in the thematic analysis to inform types.

Descriptive statistics were extracted for each settlement and for each cluster. This allows insight into which variables and ranges define the settlement type and cluster. The statistic used to measure central tendency is the mean. The statistics used to measure the variability are standard deviation, co-efficient of variation and the minimum and maximum. The central tendency of the data gives insight into the average conditions of that particular settlement or cluster, and the variability shows the range of conditions present while highlighting any outliers. By summarising the average condition and the range of conditions, insight is provided into how the settlement functions and relates to other settlements. The average condition and range of conditions within a cluster helped to define the cluster and aid in future classifications.

The process for extracting descriptive statistics used the previously optimised data sets from the attribute tables of the shape files of the settlements. The data sets were firstly split by settlement, then by cluster, in Minitab Statistical Software and descriptive statistics extracted using the 'Display Descriptive Statistics' function for both settlements and cluster. The mean, co-efficient of variation, minimum and maximum were found for all the variables. In the segment map data set, the variables were Angular Integration, NACH and Metric and Directional Reach at different radii. In the urban blocks, the variables used were area, perimeter, square compactness, and elongation. In the axial maps, the variables used were global and local integration. The descriptive statistics were collated into tables by settlement and by cluster, and then used in the thematic analysis to compare between settlements and define clusters.

3.2.4.2. Cluster Analysis

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. For the segment map, eight clusters were found to be the optimum k. for the urban blocks, 5 clusters plus outlier category were found to be optimum, making 6 clusters total for the urban blocks.

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.

3.2.5. Social Research Procedures

Research into the daily lives of Cairenes was conducted to help provide a holistic view of informal areas beyond the physical elements. The main purpose was to investigate attitudes of Cairo's residents towards informal areas, whether they are living in a planned area or in an informal area. Examining people's attitudes and usage of informal areas can provide a basis for urban intervention and social justification for the physical integration of informal areas into the main city form.

This data was collected over two studies: an on-site collaborative study in the City of the Dead and an online study focusing on the daily activities of Cairo's residents. The study in the City of the Dead was done collaboratively with researchers in Egypt in the field and focused on how the informal urban fabric affects or supports their daily activities, and how residents create a sense of community in an area not designed for the living. The online study consisted of a questionnaire that was circulated via Facebook and focused on where

in Cairo people lived and carried out their daily activities such as going to work, shopping, errands, and leisure activities. The research procedures, ethics and sampling of each study are outlined in the sections below.

3.2.5.1. Creating Community in the City of the Dead

This study focuses on how community is created in the informal settlement of Cairo's "City of the Dead", a large cemetery in historical Cairo, and how spatial structure can support the creation and the maintenance of the "sense of community" in an urban fabric that was not designed to accommodate community's everyday living. People living there maintain strong social bonds and have a strong sense of community, despite living in an urban area that, on the surface, does not accommodate public spaces, community areas and space for everyday living (Hamza 2001). This study can provide insight into how the urban fabric and street network can support a community, and also investigate the attitudes and experiences of those living in this informal settlement. The City of the Dead was chosen as a case study since it can be accessed by researchers easier than other areas and it is a unique informal area.

The method of this study is based on Lefebvre's idea of "social space" which introduced urban space as a tool of investigation for society (Lefebvre 1991). This idea is also supported by Hillier and Vaughan, the spatial structure of the city reflects its social structure, and vice versa (Hillier and Vaughan 2007). The study combines space syntax analysis and urban morphology studies with qualitative methods to create a holistic view of both the physical spatial relationships and the sense of community in the City of the Dead. These analyses can show how spatial structure and urban morphology can help or hinder the process of creating community and everyday life. This study was also used as a test to combine both quantitative and qualitative data.

Procedure

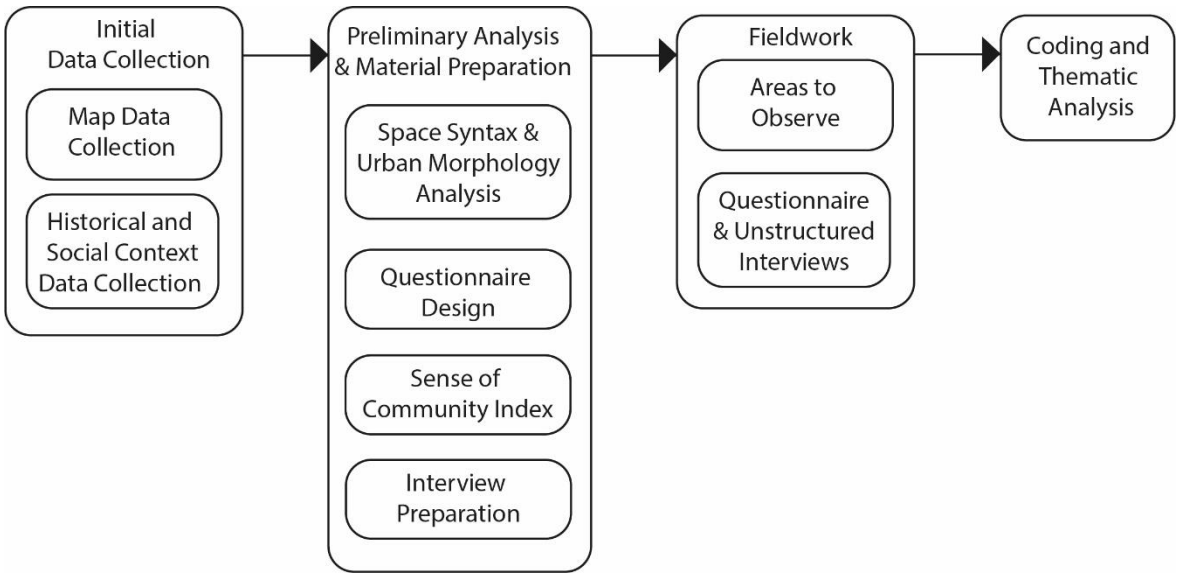


Figure 16: City of the Dead Study Procedure

This study was carried out in late 2017 to end of 2018. Figure 16 illustrates the procedure for this study, which was split into four phases. The first phase focused on gathering preliminary data about the case study and producing a vector map for the analysis. In the second phase the space syntax and urban morphology analysis was undertaken which is used to inform the areas of observation in the fieldwork. The questionnaire and interview materials were also prepared for the fieldwork. The third phase was the fieldwork undertaken in Cairo and the final phase was bringing together the urban fabric analysis and the results of the fieldwork to find themes within them that can address the study aims.

After the initial map data collection, space syntax analysis was used to analyse the street network configuration, while urban morphology studies examine how the settlement has been adapted to suit the living. Then, direct observation and interviews with local residents provide insight into their daily lives and daily spatial negotiations and will also address how they have appropriated space to suit their needs, and if they have made a conscious effort to do so. These analyses will indicate whether or not the spatial structure and morphological

attributes of the settlements support the maintaining of a sense of community, or if the residents have to find alternative approaches to sustaining their everyday lives and creating their own public space.

This study was undertaken collaboratively with Reem Saad, a researcher in Egypt as part of their master's thesis. The initial data collection and material preparation was completed together and the researcher in Egypt undertook the fieldwork as they already had access to the site. The final coding and thematic analysis phases were also completed collaboratively.

Initial Data Collection

The initial data collection phase consisted of map data collection and studying the historical and social context of the City of the Dead. The map data was sourced from CAPMAS (Central Agency for Public Mobilization and Statistics) using their online GIS platform and updated using satellite imagery from 2017. The end result was a vector map that can be used for street network and urban morphology analysis and to inform the areas in which to undertake observations in the field. Studying the social and historical context also informs fieldwork by providing ethical considerations for the researchers and defining the study area. The end result of this phase is the vector map and a summary of the background of the City of the Dead.

Preliminary Settlement Analysis and Fieldwork Material Preparation

After the initial data collection phase was completed the analysis of the physical aspects of the settlement began, and the materials for fieldwork were prepared. The purpose of the preliminary analysis of the urban fabric and street network is to firstly, describe the settlement syntactically and morphologically and secondly, to identify areas of interest for observations. The end result of the preliminary analysis was the syntactic structure of the settlement, insight into the urban block sizes and shapes and a map indicating areas of interest for observation.

The three materials prepared for fieldwork were a sense of community questionnaire, unstructured interview guidelines and observation guidelines. The interview guidelines covered demographic questions and daily life questions. The questionnaire aimed to study specifically the sense of community in the City of the Dead. This questionnaire was adapted from the Sense of Community Index 2 (SCI-2) which is based on the theory of 'Sense of Community' by McMillan and Chavis (1986) which bases the 'sense of community' on four elements; membership, influence, meeting needs and shared emotional connection. This revised index was chosen as it has been used extensively in different parts of the world and across different cultures, and has been a strong predictor of behaviours (Chavis et al., 2008). The 24-item questionnaire was translated into Arabic and administered in the field alongside unstructured interviews. Full copies of the fieldwork materials are available in the Appendix A.

Fieldwork

This section sets out the initial fieldwork design and data collection procedures. The fieldwork was carried out by the researcher Reem Saad between late 2017 and mid-2018. The initial fieldwork plan was quite flexible and able to respond to constraints that are presented in the site. The first steps were to gain access to the site, then gather respondents, then conduct the questionnaires and interviews and to complete observations. The following is a summary account of the fieldwork procedures and limitations as reported by the researcher in the field, a full account can be found in the thesis '*Space and Everyday Life in the Cairo's City of the Dead'* (Saad 2019).

Access to the site was provided by a charity in Manshiyet Nasser that introduced the researcher to a family that lived in the City of the Dead, provided that no identifying information about them is revealed. Visits with the family continued for one month but were

then stopped when the family became uncomfortable with participating. During this time observations on their daily lives were gathered through participant observation.

The fieldwork continued through infrequent visits over one year and took the form of walking around the neighbourhood, making observations and conducting non structured interviews in everyday settings with participants. Participants were selected by convenience and by who allowed the researcher to interview them. This involved visiting women in their homes and talking to men at their workplaces. The questionnaires were administered during some of these interviews and the interviews were recorded and transcribed.

The end product of the fieldwork was six responses to the sense of community index and six interviews. Several photographs of the site and residences were taken, and observations recorded in a research log. All participant information was anonymised by use of a pseudonym and photographs and observations are not linked to a specific participant in order to protect their identity.

Coding and Data Analysis

The data analysis for the fieldwork and physical elements was initially carried out separately then synthesised. The field interviews and observations were initially coded, and themes found within them based around everyday life and sense of community. The observations were also mapped onto the initial areas of interest map where possible. The answers from the second questionnaire were scored and calculated according to the guidelines in the index. The data synthesis addressed the main aim of the study on how the spatial structure of the neighbourhood can contribute to the sense of community felt by participants.

Ethics and Limitations

The main limitations encountered in this study were lack of access and participants, sensitivity of the context and generalisability. The site was difficult to access due to general suspicion toward researchers in Cairo, but this was overcome by involving a gatekeeper. However, since the context of an informal area and research into people's private everyday

existence is quite sensitive, not many participants were recruited. The gender of the researchers also limited access to some male spaces but allowed access to female spaces and people's homes. The results of the study are specific to the City of the Dead and cannot be easily generalised; the results are only from a few residents of one out of three cemeteries, which is one of numerous informal areas in Cairo. Nevertheless, valuable insight was provided into people's everyday lives, their attitudes toward living in an informal area and their perception of the community.

3.2.5.2. Daily Lives of Cairenes Questionnaire

This questionnaire was designed to investigate people's attitudes towards informal areas and whether they go to informal areas for goods and services despite living in planned areas. The purpose of this study is to gauge social perceptions of informal areas and potentially justify physical integration of informal areas. The secondary purpose is to create movement maps across Cairo of those participants that travel from their neighbourhoods for work, school, or other reasons. This shows how people traverse the city and can provide insight into which areas benefit from being well integrated, and where both informal and planned transport links exist.

Procedure

Figure 17 illustrates the procedure followed in this study. Firstly, the questionnaire was designed based on the purposes defined above, taking into account ethical and language considerations. The questionnaire was then tested with a small number of participants and revised where necessary. Afterwards, participants were recruited through targeted advertising and word of mouth and the questionnaire was distributed online. After questionnaire completion the raw results were coded and analysed and the final output was a summary of key open-ended questions, quantified results of closed questions and movement maps showing people's journeys across Cairo.

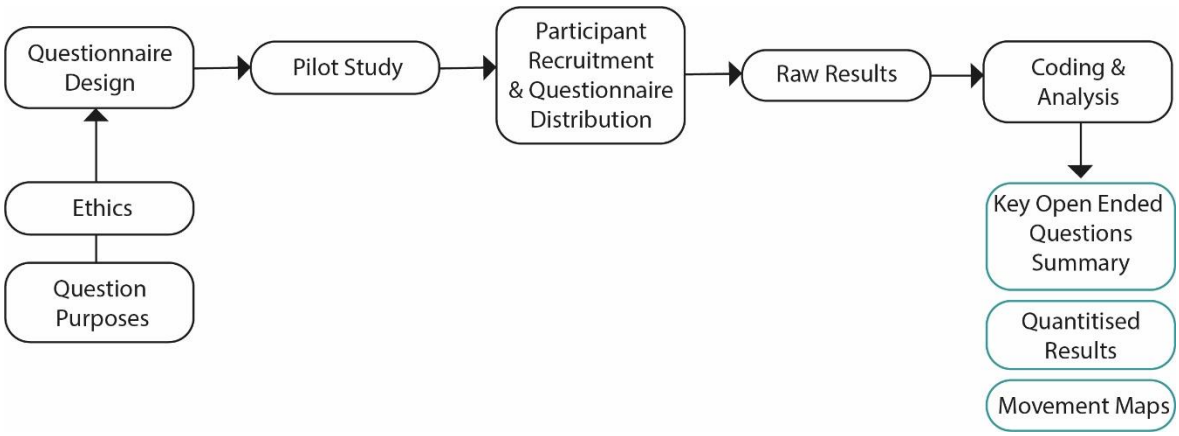


Figure 17: Questionnaire Procedure

Questionnaire Design and Pilot Study

The questionnaire aimed to address specifically the following questions:

1. Do participants access services/work in their area or outside of it?
2. How many participants remained in their childhood neighbourhood? Is this more common in the informal areas?
3. Do people live near their workplace? Is this more common in the informal area?
4. How many participants use informal transport links? How do these compare to formal transport?

All the questions were designed to be mapped the movement patterns analysed to see where services were accessed and how people travel across neighbourhoods to access the services they need, as well as the availability of services in planned and informal settlements. Mapping results from participants' past and their present can also provide insight into migration from one neighbourhood to another.

The final questionnaire consisted of 20 questions split into three parts. Two questions collected demographic data from the respondents, five questions were about their childhood activities and thirteen questions about their current lifestyle. The questions were mostly short answer open ended questions to allow for unexpected answers. The questionnaire

was designed in English then translated into Arabic by the researcher and delivered in Arabic to ensure all participants could understand it. English is widely spoken in Egypt, but Arabic is the native language of most, if not all, Egyptians. A copy of the full questionnaire in Arabic and English is available in Appendix A.

Participant Recruitment and Questionnaire Distribution

The final questionnaire was published using Google Forms and distributed over Facebook. Participants were recruited over Facebook by using targeted advertising and Facebook groups. The demographic targeted through advertising was people living in Cairo between the ages of 18 and 65 and the questionnaire was also posted in large community groups based in Cairo. Participants were also encouraged to share the questionnaire through their own networks. Facebook was chosen as the recruitment tool and distribution method as it is difficult to gather respondents in Cairo through another channel. Egypt also has a very high mobile phone and social media permeation ratio at 106 mobile phones per 100 people at the time of the study (World Bank 2017). This resulted in a convenience sample of 110 people who were mostly younger than 30, which also reflects Cairo's age demographics of a young population (CAPMAS 2019a).

The study aims and researcher information was presented at the start of the questionnaire and participants were asked to either consent and continue to the questionnaire or choose to not fill it in. Participants were not required to provide any personal or identifying information, only gender and age range for demographic purposes. They were also encouraged to not give a full address for any of the location-based questions, only the district or street name. This allowed mapping to be generalised by district rather than by specific addresses, and also protected the privacy of the participants.

Coding and Analysis

After the questionnaire received all the responses, the coding phase was performed in Excel for both closed and open-ended questions. Firstly, the closed questions that do not have a

location as the answer were coded separately according to the answer options presented. For location-based questions (residence, work, shopping, etc), each location provided was recorded as an option then the number of answers that state that location was tallied. These location options were then further categorised into planned or informal areas. Questions concerning transportation were coded by transport type, then further categorised by private, formal, and informal transportation.

After coding was completed the percentage of each category was calculated and stored in the spreadsheet. These percentages were then visualised using bar charts and pie charts to aid in data interpretation. The final step of the analysis was creating movement maps and cartograms for the questions that have location-based answers. As well as the visualisations, a short summary of open-ended questions was written to support data interpretation.

In the data interpretation stage the visualisations and movement maps were used to find trends in where people live now and where they moved to as adults and noting the difference between those who were born in informal areas and those born in planned areas. Mapping people's journey from home to work can provide insight into how transport is used, where job opportunities are, and the distance people are willing to travel to work. Cartograms can also show where the more popular areas are to live, work and access amenities and services. The results of the data interpretation stage are provided in chapter 8.2.

Ethics and Limitations

The ethics of this study were carefully considered before undertaking it. The ethical considerations mainly included data and identity protection for the participants and avoiding negative reactions towards the researcher. Participants were not required to provide any identifying information and after the questionnaire completion the data was stored on the researcher's computer and deleted from the cloud. The Google Forms platform also

complies with EU data protection laws so personal data related to IP addresses cannot be accessed by a third party. While the questionnaire is concerned with the daily lives of participants, the culture that surrounds research in Egypt may mean that some people may be suspicious or find it intrusive that there is being research conducted at all. The questionnaire did receive some concerning comments from people who did not participate and in order to avoid issues it was taken down and deleted from the internet after 110 people participated.

The limitations of this study are mainly verification of participants, sampling, and generalisation. Since the questionnaire is distributed online it makes it difficult to verify that participants are who they say they are. This was mitigated by using targeted advertising and checking the location of respondents before including their responses in the analysis. Not being able to choose who participates may skew the data as well but this was also addressed by checking the demographics that have answered already and then actively targeting advertising to those who have not. The sample size of 110 is small when compared to the population of Cairo, so it may be difficult to generalise the findings. However, the questionnaire still provided valuable insight into people's movement and attitudes to informality which fulfilled the purpose of the study, even though it may not be fully generalisable.

3.2.6. Research Synthesis

After the initial analysis phase is complete, the resultant descriptive statistics, visualisations (cartograms and histograms) and initial observations are organised by settlement and by cluster. Each settlement dataset contains the descriptive statistics for the street network and urban blocks and visualisations of each street network and urban block variable. This is the first step in interpreting the results of the analysis and providing a unified view of each settlement and cluster.

The thematic analysis is part of the typo-morphological approach in finding types for classification. The aim is to combine the history of the settlement, the statistical analysis and space syntax analysis to find themes in order to create types. The end goal is a classification framework that can be added to and developed based on physical characteristics of settlements and can be used to classify settlements that are outside the sample.

This is done by firstly classifying the settlements loosely based on their emergence and history in the literature, which allows for a starting point in classification. After that, neighbourhood level findings are attributed to each classification, in order to inform them further and quantify the specific conditions of informality in each classification. This leads to a neighbourhood level classification into type based on history, emergence, numerical parameters of the street network and urban blocks and overall street configuration. This adds more detail and nuance into the original classifications presented in the literature review. Secondly, the neighbourhood is studied on an intra-neighbourhood level, to find structures in the street network and urban block. These internal neighbourhood structures can provide insight into the functionality of the street network and how it fulfils the needs of the residents. Structures that are unique to informal settlements can also be used to inform classification.

SYNTACTIC AND MORPHOLOGICAL ANALYSIS OF SETTLEMENTS

The following four chapters present the sample of neighbourhoods chosen for quantitative analysis and the results of the quantitative urban block, open space and street network analysis. The aim of these chapters is to firstly describe the settlements quantitatively and then classify the data in order to find unique spatial structures that can be used to inform classification and could potentially be used in urban intervention.

Chapter 4 presents the sample of neighbourhoods used in this study, as well as the profiles of the boundaries of each neighbourhood. The sample consists of 13 neighbourhoods, with the initial classification of seven informal, four planned and two mixed. The reason for this selection is to highlight the differences and similarities between planned, informal and mixed neighbourhoods. They interface with five highways and are bounded by different manmade and natural boundaries. The historical emergence of the neighbourhoods is studied to determine the influence of historical and social conditions on the urban fabric. This is the first step in refining the classification, where a distinction between types of informality starts to emerge more clearly. This distinction is primarily based on the type of land, desert or agricultural, that the settlements emerge on.

Chapter 5 presents the morphological profile of the settlements through analysing the geometric properties of the urban blocks and clustering them into categories. The size and shape of urban blocks are analysed and then used in the cluster analysis. The analysis shows that there is a distinction between planned and informal settlements in terms of morphological profile, and that informal settlements can be identified by what is not present, i.e., the large blocks that can accommodate civic and community functions. While there is not a unique urban block present in informal settlements, this again informs the classification by highlighting the most common block type present in informal areas.

Chapter 6 presents the configurations of open space of the settlements, as derived from the axial analysis. The aim of this was to study how pedestrians use the open space to move around the neighbourhoods. The analysis shows that informal settlements tend to have open space configurations that are more conducive to social interactions. This is also supported by the previous study in the City of the Dead. The results also provide a refinement to the classification by highlighting the difference in open space configurations between planned and informal settlements.

Chapter 7 presents the analysis of the street network and the clustering of streets. This follows the suggestions in chapter 2 that different types of streets can be found and used in classification. The aim is to analyse the street network using the street centreline, in order to study the usage and configuration of the street network, and potentially find unique spatial structures that can inform classification. The integration, choice and reach of streets is analysed and then used in the cluster analysis. The analysis presents eight types of street that are present across the sample. One type is highlighted as the highways, which indicates their importance in the city and their presence in mostly planned settlements. Two types of street configurations seem to be only present in informal areas and correspond strongly to the social core of the neighbourhoods. It is suggested that these unique street configurations can be used to refine the classification system, and also used to inform urban intervention.

CHAPTER 4: CASE STUDIES AND HISTORICAL ANALYSIS OF SETTLEMENTS

As described in chapter 2, the urbanism of the Greater Cairo Region provides a wide range of informal and planned neighbourhoods. Based on observation and previous classification studies mentioned in Chapter 2.2 these neighbourhoods are initially classified into three categories, informal, planned, and mixed neighbourhoods. A total of thirteen case studies provides a set of neighbourhoods to exemplify each category; seven initially classified as informal, four are planned and two are mixed. Mixed neighbourhoods consist of both planned and informally built areas but considered as one settlement. Providing an initial neighbourhood level classification based on literature and historical maps is the starting point for further analysis of each settlement on a street and block level.

The following section provides an overview of the boundaries of the Greater Cairo Region, the main highways of the region and the location of the case studies within the region. The criteria for case study selection and the different types of boundary are also discussed. Each case study is named by its most prominent area but may also contain other administrative areas.

4.1. Greater Cairo Region as a Study Area

Greater Cairo 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 as presented in the literature review.

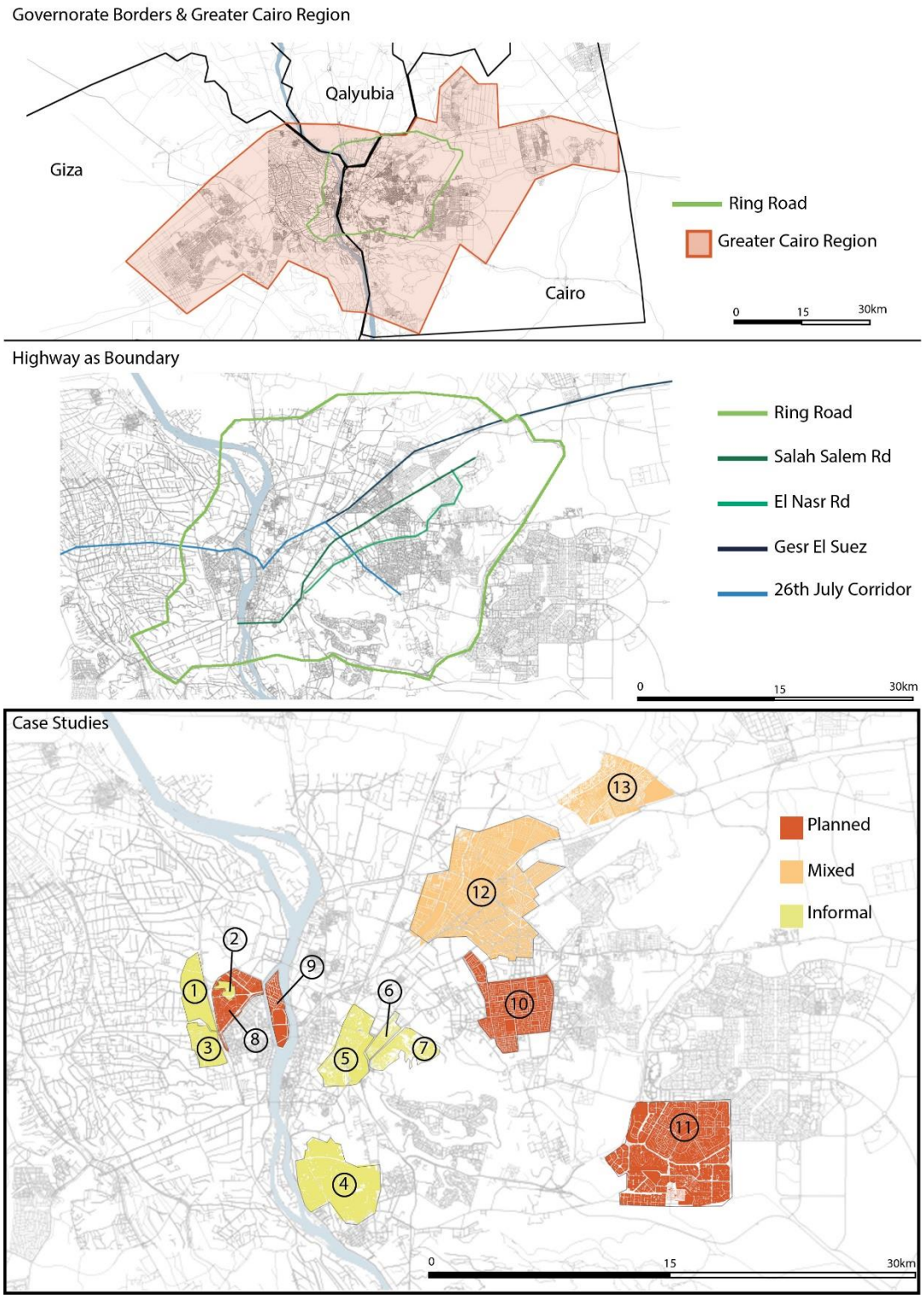


Figure 18: Diagram Showing the Extents of The Greater Cairo Region (Top), The Main Highway Network (Middle) And the Neighbourhood Case Studies (Bottom)

This section sets out the boundaries of the Greater Cairo Region, the main highways and the location and type of the case studies. The Greater Cairo Region is spread over three Governorates, Cairo, Giza and Qaliyubia (Figure 18). There is no centralised administration for the Greater Cairo Region and each governorate makes decisions for their districts. In terms of the extents of the region, it is generally considered to cover the most urbanised areas of the governorates. The boundary indicated spans from 6th October City in the western desert of Giza, the satellite cities in the eastern desert of Cairo, to *Ma'adi* district and Wadi Degla Nature Reserve in south Cairo, and Shubra and the Ring Road in north Cairo and Qaliyubia (Arandel & El Batran 1997; GOPP 2012). This very dense urbanisation is surrounded by agricultural land and villages. Of the case studies chosen, eight are in the Cairo Governorate and five in the Giza governorate.

4.2. The Role of the Highway as a Boundary

In the region the highways act as a boundary for growth, and as connector between districts and cities. Highways tend to be used atypically since car ownership is lower in Greater Cairo than in other socioeconomically equivalent cities (CAPMAS 2015). This leads to people walking along them, needing to cross them, and creating informal transport links to access the highway network. Therefore, the vehicular based system is used by pedestrians and public transport where it was not initially designed to be used in this way.

Some argue that the highway design strategy excludes informal areas from the regional transport network and is designed as a boundary to prevent growth (Figueroa et al. 2019; Mohamed et al. 2014). The Ring Road was built to circulate Greater Cairo, connect satellite cities, and prevent informal areas on the periphery from growing further (Hegazy 2016). In the selected case studies, the highways tend to pass through or around informal areas. However, planned settlements tend to be incorporated into the design and have vehicular access to the highways.

4.3. Selection Criteria and Further Classification

The **main criteria** for choosing case study neighbourhoods is their representation of different types of urbanisation. Based on historical maps and emergence studies, the three main categories are split further. Informal areas can be categorised as emerging on agricultural land, desert land or were a historic settlement that turned informal over time (Arandel & El Batran 1997; Sioufi 1981). Planned areas are categorised as a planned neighbourhood in the city core or a satellite town (Sims 2015) based on evidence of subdivision (Sims & Séjourné 2000). Mixed areas can be a combination of different typologies. The historical maps and rationale of selecting the neighbourhood's category are presented where relevant in each case study description.

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.

4.4. Setting the Neighbourhood Boundary

Through observation three types of boundary are identified that may be used to set the boundary of each neighbourhood. The boundary types are split into perceived boundaries, physical boundaries, and administrative boundaries. Perceived boundaries include social and community perception of where their neighbourhood ends, which can be difficult to quantify (Deboulet 2009). Physical boundaries can be split into natural and manmade boundaries. Natural boundaries include the Nile river and the Moqattam cliff edge, while man made boundaries include infrastructure such as highways, bridges, railways, and the historic extents of a neighbourhood e.g., walls and canals. In this thesis, physical boundaries are considered those that are not easily crossed, but perceived boundaries can be crossed.

Administrative boundaries are set by the governorate and classify the neighbourhood into different categories for census and decision-making purposes, which are based on location and number of residents. Informal settlements are usually considered to be part of the neighbouring planned area for administrative purposes. Some older informal areas have been legitimised in the most recent census and assigned their own administrative district.

4.5. Case Studies' Urban Form and Physical Attributes

This section sets out the figure ground map of each selected case study within its wider context and includes information about each case study such as its history, its initial classification based on legality, its boundary, and its specificity to the study. Satellite imagery of the urban fabric is also included to aid in visualisation. The highways are indicated where relevant. The rationale for each case study boundary is also provided when necessary.

4.5.1. Ard El Lewa (1)

Ard El Lewa is an informal settlement built on previously agricultural land on the western bank of the Nile. This settlement is bounded in the west by the Ring Road highway and in the east by the planned settlement Mohandisseen and the Al Zomor Canal, which prevents it from expanding and has caused increased density within the settlement (Figure 19). The 26th of July highway also cuts through the settlement, separating it into two parts with limited pedestrian bridge crossings. The residents took administration of the settlement in 1999 and have built their own access ramp to the Ring Road highway (Patelli 2016). Ard El Lewa has grown very rapidly over the past 16 years and has a very distinctive urban fabric, characterised by long, thin urban blocks based on the agricultural grid. The street network

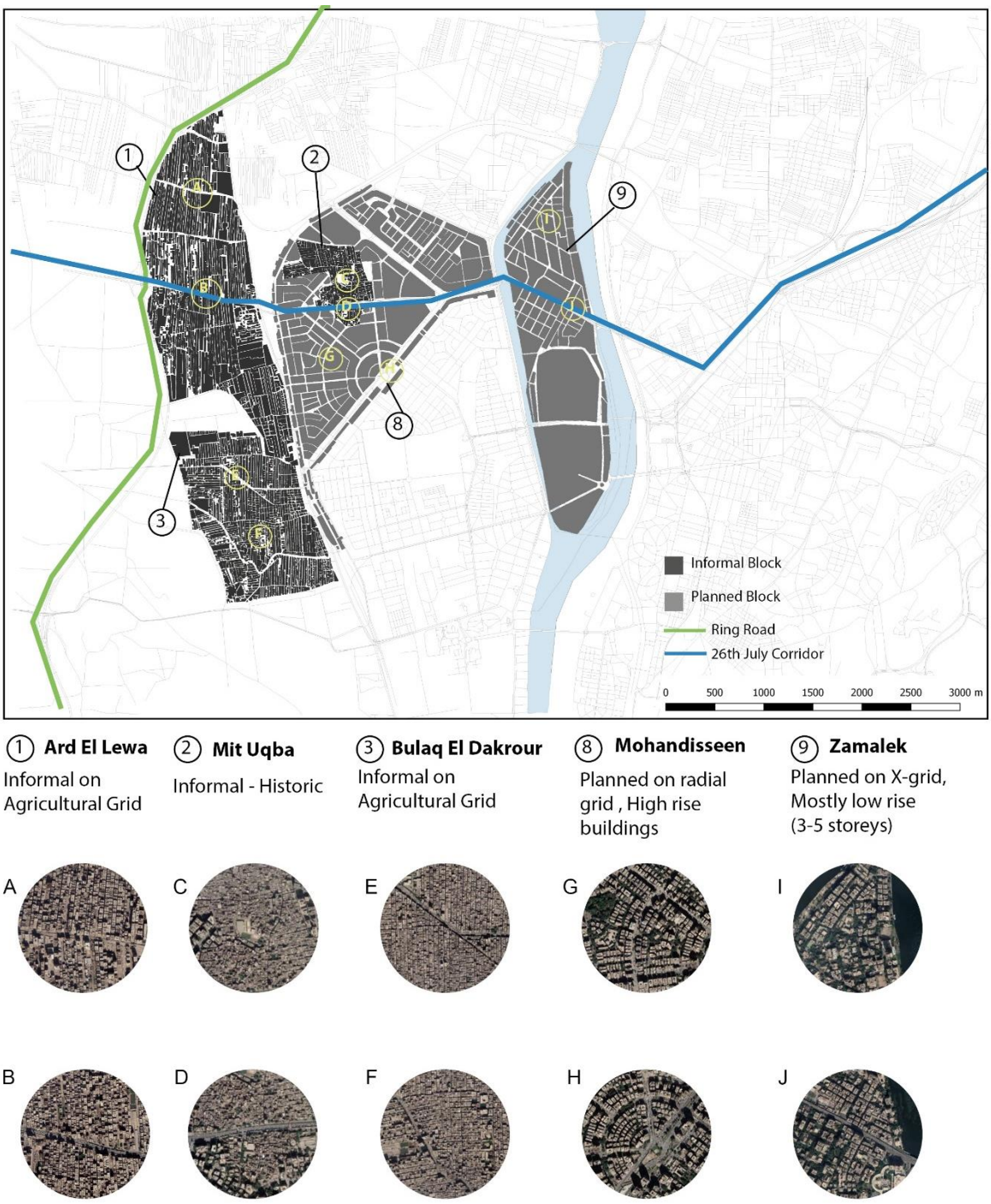
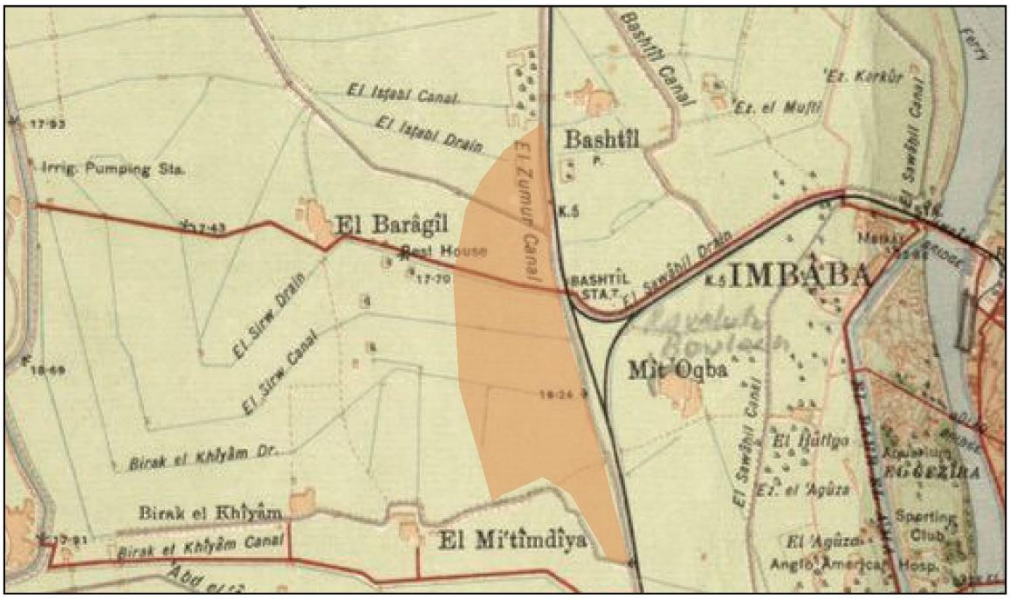


Figure 19: Diagram showing 5 case studies, Ard El Lewa, Mit Uqba, Bulaq El Dakrour, Mohandisseen, Zamalek

is shaped by old irrigation canals and has T-junctions where roads meet due to the agricultural grid (Figure 20) (Zied & Vialard 2017). This settlement exemplifies informal growth on agricultural land, and it has a strong sense of community within it.

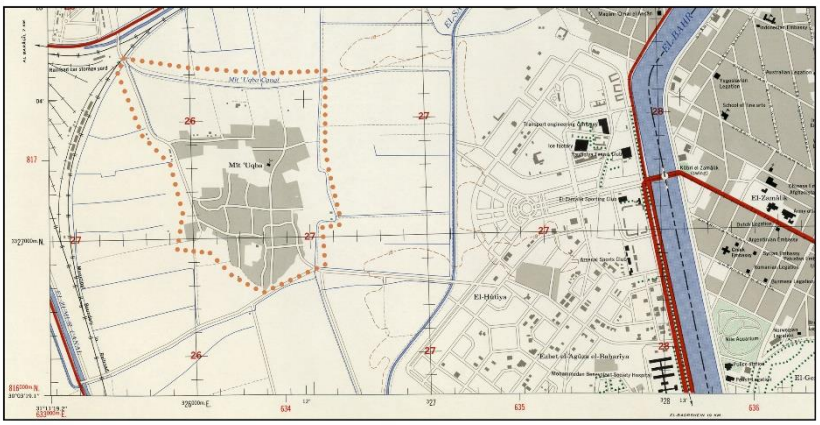


Source: Egypt. Maslahat Al-Misāhah. (1925) Cairo & Environs. [Cairo: Survey of Egypt] [Map] Retrieved from the Library of Congress

Figure 20: Historical Map of Ard El Lewa showing boundaries and canals

4.5.2. Mit Uqba (2)

Mit Uqba was originally a historic village that emerged in the 1800s on the western bank of the Nile to manage the surrounding agricultural land. Figure 21 shows the extents of Mit



Source: Cairo (1959) Prepared by US Army Map Service, Corps of Engineers. [Map] Retrieved from the University of Texas

Figure 21: Historical Map of Mit Uqba Showing location and canal system

Uqba and where it will eventually grow, and its boundary by the Mit Uqba canal. It has an organic/historic urban morphology but has grown informally over time. It still contains some historic low-rise housing, a Souq (traditional market) and sporting club area. Between the 1950's and 1970's the planned settlement Mohandisseen was gradually built around it and stopped Mit Uqba from expanding any further. The 26th of July Axis highway runs through Mit Uqba, splitting one part of the settlement from the other. Mit Uqba does not have access to the highway, meaning that it is segregated from the surrounding urban fabric (Tadamun 2013). The boundary of Mit Uqba is very clear as the urban morphology is drastically different from the surrounding planned settlement. Mit Uqba was chosen as it is a historic area completely surrounded by a planned settlement, so it is an opportunity to study the interface between two distinct urban morphologies and potential reconnection to the rest of the city.

4.5.3. Bulaq El Dakrour (3)

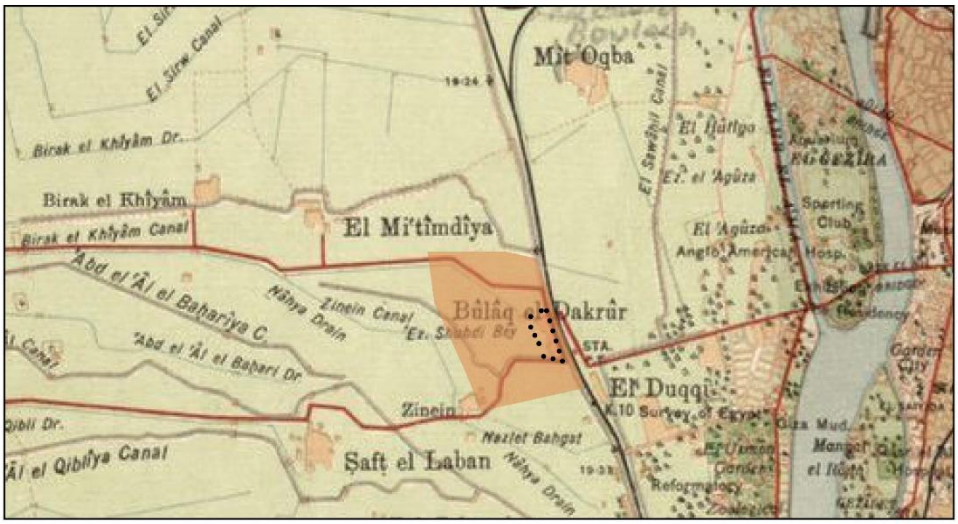


Figure 22: Historical Map of Bulaq El Dakrour showing boundary selection and canals

Bulaq El Dakrour is a partially historic informal area on the western bank of the Nile. It was previously a small village with surrounding agricultural land and a clear irrigation canal system (Figure 22). Since the 1980's it has experienced similar growth to Ard El Lewa and

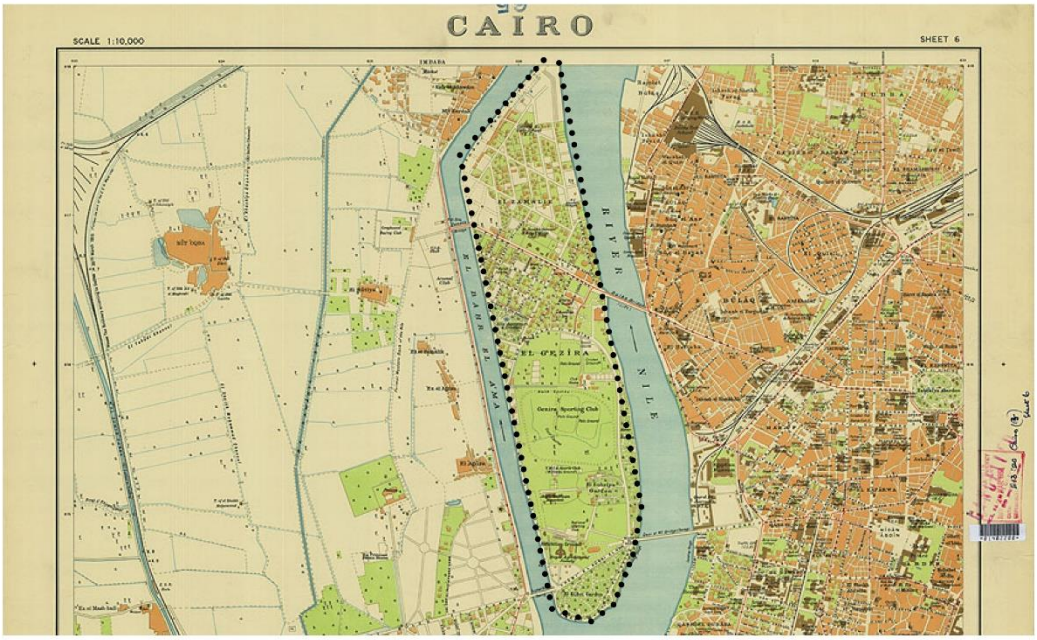
has a similar urban morphology based on the agricultural grid (Piffero 2009). The boundaries of this settlement are indistinct, so the boundary chosen was based on historical maps of the settlement. It is bounded by the ex-canal Al Zomor Street in the east, Ard El Lewa in the north and Masraf Street (masraf means drainage in Arabic) in the west. The historical boundaries of the adjacent Zinayn settlement are also used in the west. This settlement was chosen because it is another example of informal growth on agricultural land with a street network influenced by the canal system in a different way than Ard El Lewa.

4.5.4. Mohandisseen (8)

Mohandisseen is an affluent neighbourhood in the Agouza administrative district in Giza. It was originally built as subsidised housing for engineers, and the Arabic name literally translates to “engineers”. The initial construction in the 1950s was low-storey villas and mansions, but with additional migration and the *Infitah* policy in the 1970s it became high rise apartment blocks which dominate the neighbourhood today. The neighbourhood is clearly bounded by main roads Sudan St and Gam'et el Duwal el Arabya (Arab League St). The 26th of July Corridor highway runs through the neighbourhood which provides access to the rest of the city. The historic/informal village Mit Uqba is surrounded by Mohandisseen and does not have access to the 26th of July Corridor, which limits its access to the rest of the city (Beattie 2005). This neighbourhood was chosen because it is a good example of post-revolutionary urbanism in Cairo and a typical example of planned neighbourhoods originating at that time. Having the historic village of Mit Uqba within it also means that this neighbourhood can be used as a case study for intervention, reconnecting the historic area with the rest of the city.

4.5.5. Zamalek (9)

Zamalek is the largest neighbourhood on Gezira Island in the Nile. While technically the Island is split into Zamalek and Gezira neighbourhoods, the entire island is colloquially known as Zamalek. This is reflected in the analysis where the island is analysed as a whole. Under the Khedivate the island was a botanical garden known as "Jardin des Plantes"



Zamalek Island clearly bounded by river and showing gardens and palaces in 1929

Source: The British Library. (2012). Cairo, General Survey 1929, 1:10.000 (Sheet 6).

Figure 23: Zamalek in 1929

(Garden of Plants). After 1922 the urbanisation of the island began to increase, and the northern part of the island became Zamalek, containing villas and palaces (Figure 23). Over time more low-rise apartment buildings were built but the neighbourhood retained its urban character of a leafy green neighbourhood. In the present day, the north and middle of the island are urbanised, and the south part contains a large park, sporting clubs, the Cairo Opera House and other cultural sites. The island is served by 3 bridges connecting it to the east and west banks of the Nile (Beattie 2005). This case study was chosen because of the unique urban condition of a planned settlement on an island and an example of early 19th century urbanism in Cairo.

4.5.6. Dar El Salam (4)

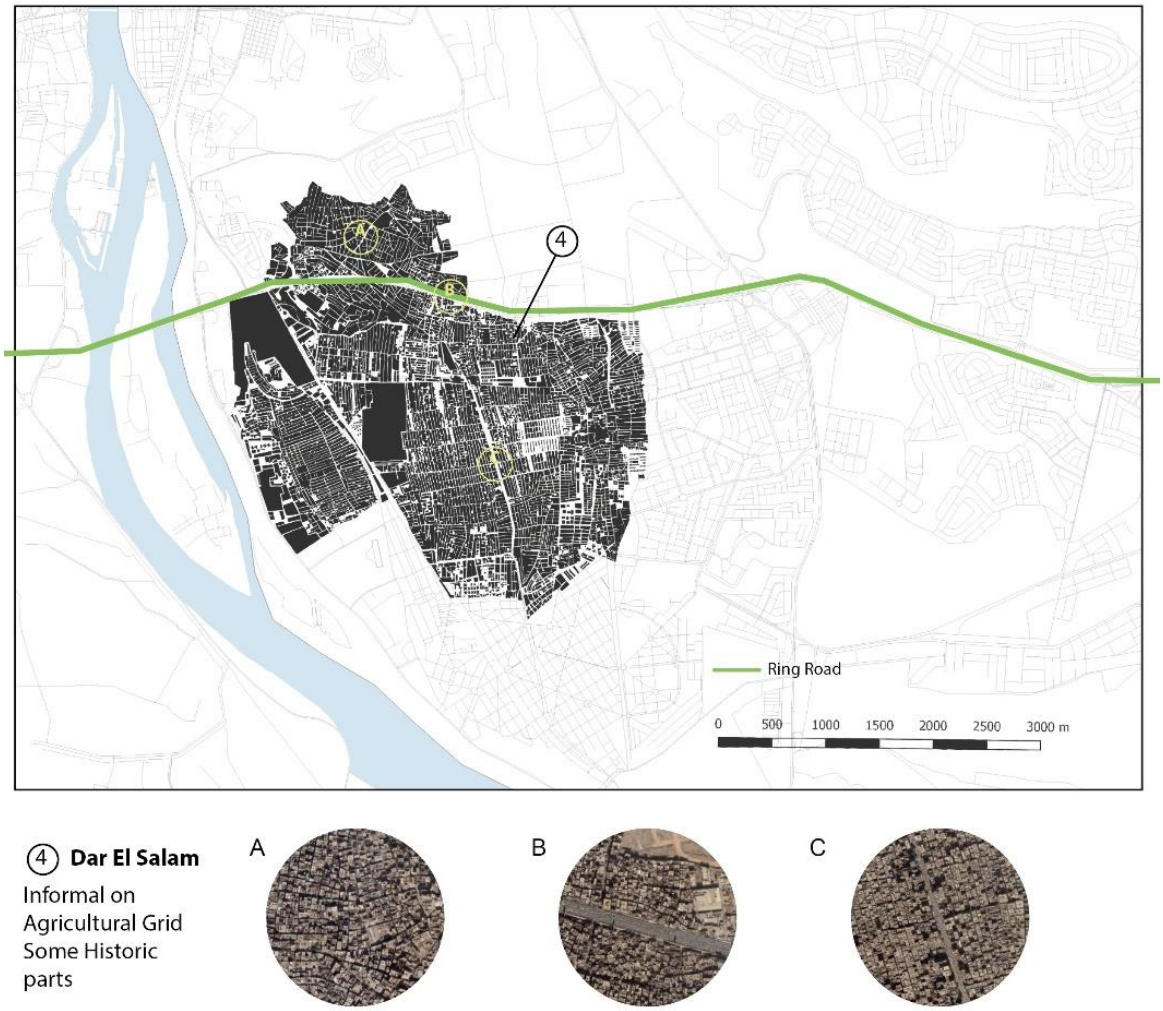
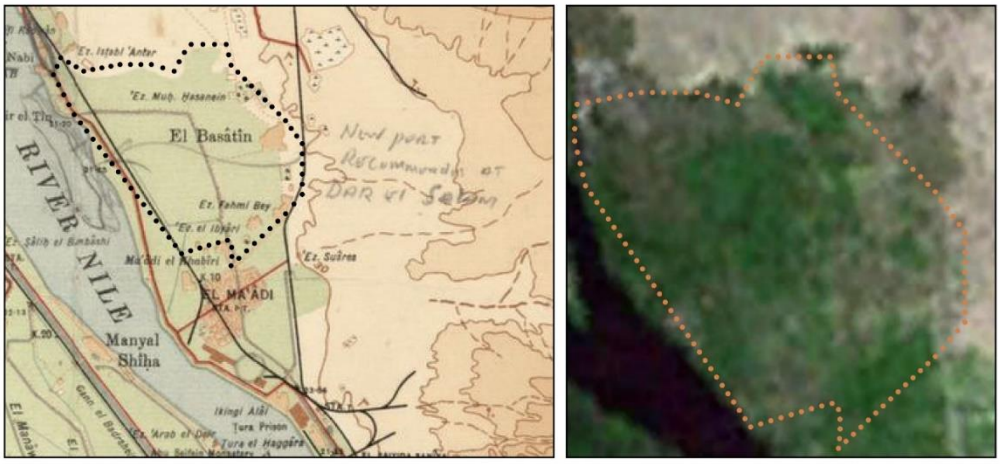


Figure 24: Figure Ground Map of Dar El Salam showing urban fabric and highway

Dar El Salam (Figure 24) is the largest informal settlement in Cairo. There is not much information about its emergence but historical maps from the Perry-Castañeda Library and Google Earth show that the area was unsettled agricultural and desert land until at least 1972 (Figure 25).

This situates its emergence in the late 1970s/early 1980s which coincides with the Sadat Infitah policy. After the settlement had emerged, it was recognised by the government and some services such as electricity and waste removal were provided. There is also a school and a hospital in the neighbourhood and nearby is the affluent neighbourhood Ma'adi (Sims



Source: Egypt. Left - Maslahat Al-Misāhah. (1925) Cairo & Environs. [Cairo: Survey of Egypt] [Map] Retrieved from the Library of Congress
Right - Cairo, Egypt (2020) Prepared by US Geographical Survey, 1972 [Map], Retrieved from Google Earth

Figure 25: Dar El Salam Historical Development

& Séjourné 2000). The Ring Road highway cuts through the neighbourhood and separates it into two regions. This settlement was chosen as it is an example of an informal area that has been partially legitimised, and that it was built on both agricultural and desert land, leading to two distinct urban morphologies in one settlement.

4.5.7. Medieval Cairo (5)

Medieval Cairo is the original historic core of Cairo and is also known as Islamic or Fatimid Cairo (Figure 26). It was originally built in 969 AD starting with Al-Muizz Street, which is lined with many mosques and madrasas. It has grown informally since then and has a partially historic and partially informal urban morphology. While 'Old Cairo' is quite large, the area chosen for analysis is bounded by the old city walls, the citadel, and Port Said Rd. There is a modern road with bridge (Al Azhar Bridge off Salah Salem) that runs through the settlement, separating it into two areas that are morphologically similar. The urban morphology of this area is much less dense than the surrounding informal areas, so it is clear where the settlement ends (Figure 28). This area is also a protected UNESCO world heritage site since 1979 (Abouseif 2007). Medieval Cairo was chosen as a case study as it can provide insight into the original urban morphology of Cairo and how informal growth can

be managed over time. This settlement can also be a test for minor interventions that address issues such as overcrowding without affecting the protected areas.

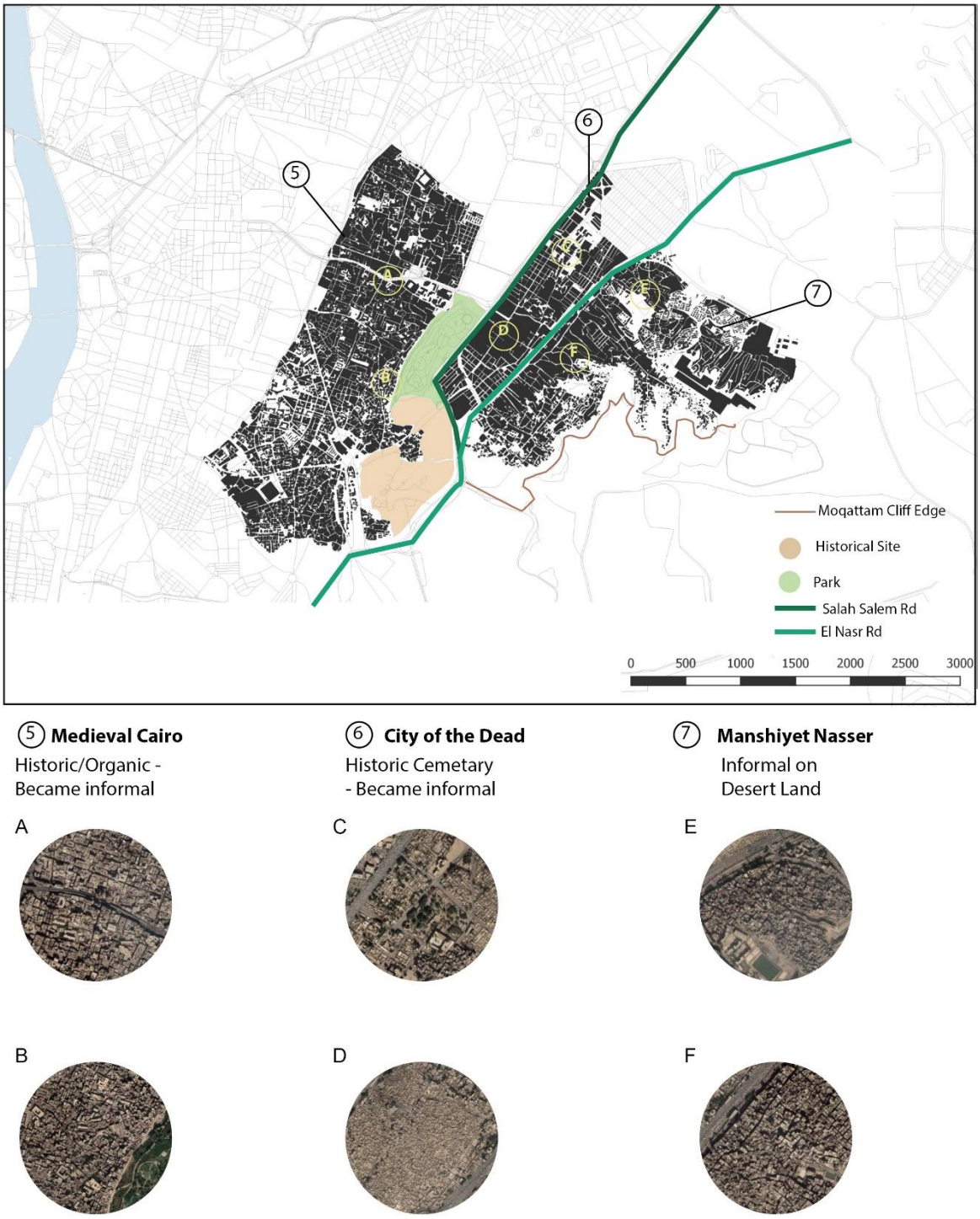
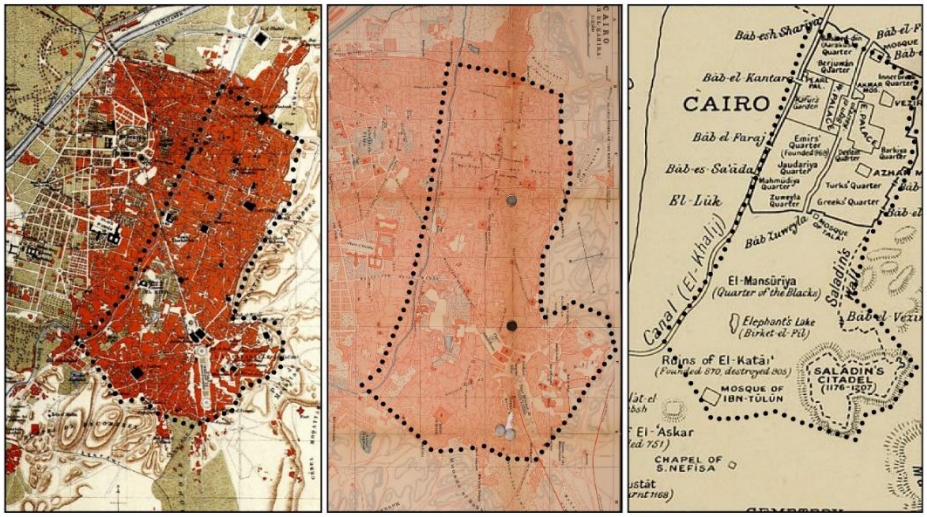


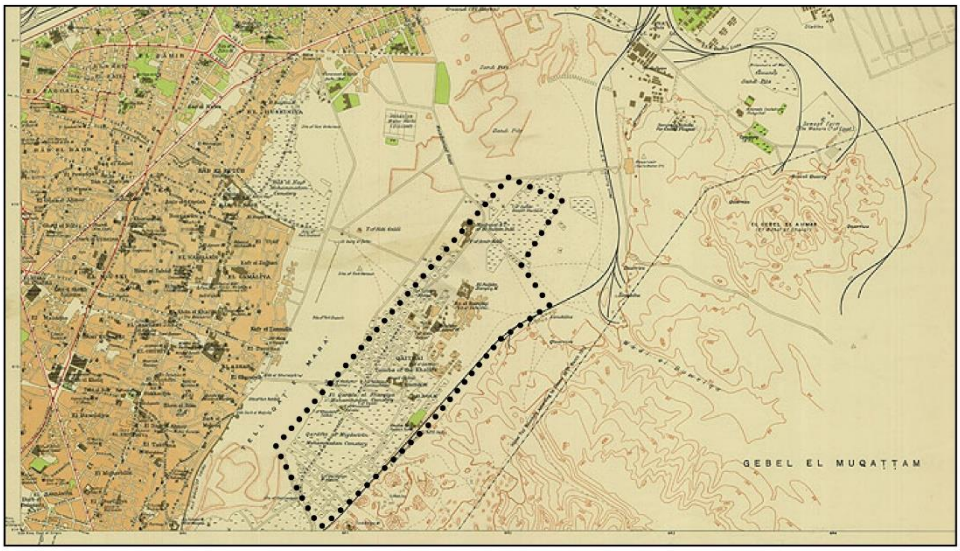
Figure 26: Diagram showing figure ground map of three neighbourhoods, Medieval Cairo, City of the Dead and Manshiyet Nasser



..... Medieval Cairo boundaries set by city walls and City Canal (Al Khalij)
Mohamed Ali Boulevard and Mosque a new addition during Khedivate Rule (1805 to 1882)

Source: Right - Map of Cairo (1933) Alexander Nicohosoff, Published by Establis. des Arts Graphiques, Alexandria, Egypt
Middle - Map of Cairo in Egypt (1885) in Handbook for Travellers, Karl Baedeker Publishing, Germany
Left - Map of Cairo in 1170, in Saladin and the fall of the Kingdom of Jerusalem (1898), Stanley Lane-Poole, London Putnam

Figure 28: Diagram showing the historical development of Medieval Cairo



..... City of the Dead (Al Qarafa) Boundary before it became a place for people to live
Manhisyet Nasser not yet emerged

Source: The British Library. (2012). Cairo, General Survey 1929, 1:10.000 (Sheet 7).

Figure 27: City of the Dead Extents in 1929

4.5.8. City of the Dead (6)

The City of the Dead (Figure 27), also known as the North Cairo Necropolis or the Qarafa, is a cemetery that was founded in 642 AD and is a UNESCO world heritage site. In the 1960's it became an informal settlement due to migration into Cairo and a lack of affordable housing for rural migrants. The population of the settlement increased after the 1992 earthquake and it is now a well-established community. The settlement is clearly bounded by the cemetery walls and the Salah Salem highway (Hamza 2001). This settlement was chosen since it is a unique example of informality and was a suitable location to conduct a social questionnaire as the residents are familiar with researchers in the area.

4.5.9. Manshiyet Nasser (7)

Manshiyet Nasser (Figure 26) is an informal settlement built on desert land at the base of Muqattam Cliff in Cairo. It emerged in the 1950's and its growth has been limited by the cliff edge and the Salah Salem highway. It is also known as 'Garbage City' as it is where the majority of Cairo's waste is collected to and recycled by the residents, forming a large part of the settlement's economy (Assaad 1996). It lacks infrastructure such as running water but contains apartment buildings and shops. In 2008 there was a major landslide down the side of Muqattam cliff; a part of the settlement was destroyed. Despite the settlement being declared unsafe, residents who lost their homes in the landslide have not been rehoused and still live nearby (Reuters 2008). It is one of the more well-known informal areas and has access to The Cave Monastery which is a church built into the side of the cliff. This settlement was chosen as it is an example of informal building on desert land and has a distinct character and internal informal economy.

4.5.10. Nasr City (10)

Figure 29: Nasr City Figure Ground Map with highways

Nasr City (Figure 29) was originally established outside Cairo in the 1960s as a new capital city after the 1952 revolution. It followed the current planning trends of the time and was composed of 'super blocks' that contain high-rise apartment buildings and designated green spaces, intersected with highways on a grid street system. Some government buildings and monuments were moved to Nasr City and remain there today (Singerman & Amar 2006).

Nowadays Nasr City has been totally absorbed into the Greater Cairo Region and is the largest district in Cairo. It has become very overcrowded, mainly due to having too many

housing units for the street network to support. There are also a large number of shopping malls and leisure spaces which attract visitors from outside the district which further increases overcrowding and traffic problems. Despite its issues, it remains well connected to the rest of the city due to the highways and an attractive place for people to visit, work and live (Elshahad 2015). The district is clearly bounded by the street network and the case study area chosen is based on the original plans. This case study was chosen because it exemplifies an initially self-contained district being absorbed by the rest of the city and remaining well connected despite its issues.

4.5.11. New Cairo (11)

New Cairo (Figure 30) is a satellite city established outside Cairo in 2000. This satellite city and others were built to help alleviate overcrowding and congestion in Downtown Cairo and other districts which had been absorbed into the city (Sims 2015). New Cairo is composed of a number of districts in varying stages of development; the ones that have been chosen as part of the case study are the oldest and most established parts bounded by the Al Tes'een Road (90th Road) in the north, Tala'at Harb Axis in the east, East Katameya Road in the south and the Ring Road in the west. This area includes the 5th Settlement, a gated community of villas and leisure spaces, the 3rd settlement, a less affluent area that resembles an informal area but was actually planned, and a number of other smaller compounds and gated communities (New Cities Egypt 2000). This case study was chosen to study the connection of satellite cities with the main city and to study how planned

compounds and communities with very different urban morphologies coexist within the same street network.

Figure 30: New Cairo Figure Ground map, highway, and urban fabric

4.5.12. Heliopolis (12)

This mixed case study (Figure 31) consists of the suburb Heliopolis (Misr Al Jadeedah) and the surrounding historic sha'abi areas of Al Matariyya, Ain Shams, Zaytoun and Amiriah that have grown informally. Heliopolis was established in 1905 (Figure 32) as a new affluent suburb of Cairo by Baron Empain and Boghos Nubar. Heliopolis had its own unique architectural style known as Heliopolis Style which was based on Moorish revival and neoclassical architectural styles. This allowed for large, climate-controlled apartment blocks and palaces that are still preserved to this day. In the original plans, Heliopolis had a horse racing track, a golf course, and a large park. After the 1952 revolution the racetrack was put

out of use and apartment buildings built on the golf course, which is now known as the Ard El Golf neighbourhood (Beattie 2005; Goldschmidt 2008).

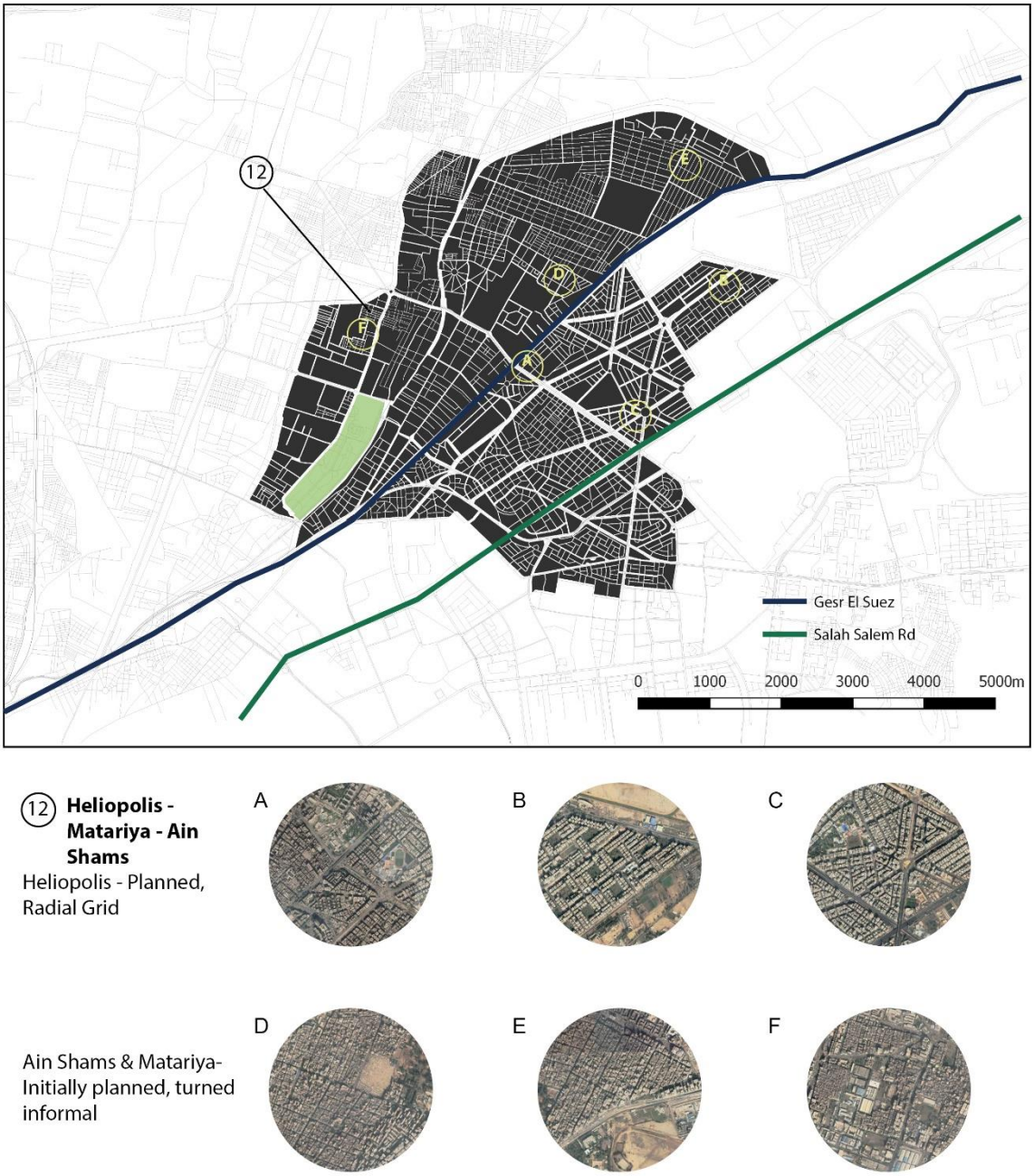
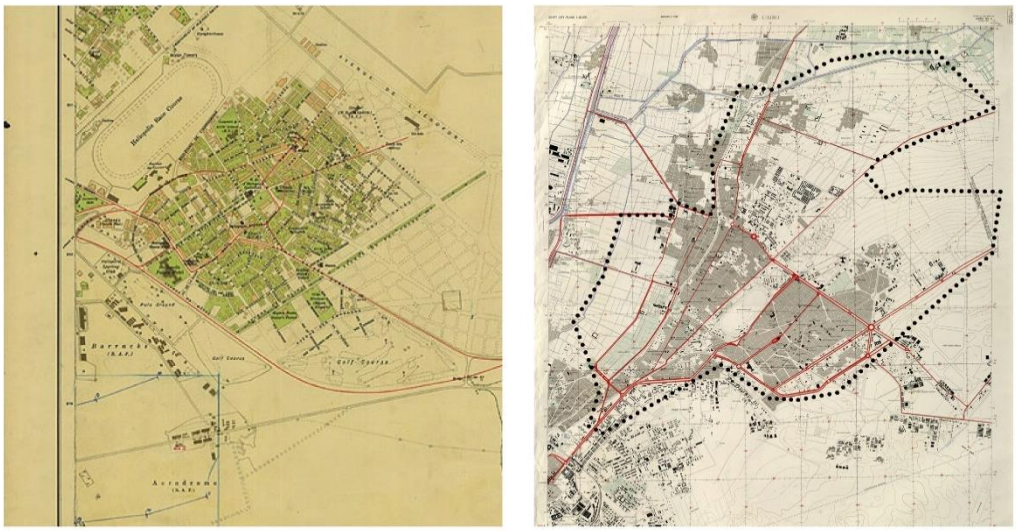


Figure 31: Figure Ground map of Heliopolis showing the mixed urban fabric and highway

Al Matariya and Ain Shams were built on the ancient Egyptian city of Heliopolis. There are still archaeological sites within the neighbourhoods, with the Matariya Obelisk being the most prominent. Initially they mostly comprised of low-rise apartment blocks and villas, but nowadays they are areas for low-income housing that have grown informally due to lack of



Original Extents of Heliopolis suburb in 1929

•••• Eventual Spread of Heliopolis, Matariya, Ain Shams, bounded by Canal and train tracks

Source: Cairo (1959) Prepared by US Army Map Service, Corps of Engineers. [Map] Retrieved from the University of Texas

Figure 32: Historical Development of Heliopolis, showing mixed settlements and boundary

building regulations. As they are not totally informal areas there is some infrastructure such as electricity and water supply, but this often does not extend to the informally built parts of the neighbourhoods (Soliman 2012).

In the present day, Heliopolis is still an affluent area to live in and contains shopping, work and leisure activities that attract visitors from outside the neighbourhood. The surrounding informal areas provide housing and services to their residents. The informal and planned areas are all connected to the primary street network and can access nearby services. The Salah Salem and Gesr El Suez highways pass through both the planned and informal areas and both areas have access to the highways and therefore the rest of the city. Heliopolis and the surrounding areas are studied together because they are an example of informal and planned areas that are well connected to each other, unlike other planned and informal areas in close proximity. Studying how these neighbourhoods' function together can shed light on how to reconnect informal areas to the rest of the city.

4.5.13. Omar Ibn El Khattab (13)

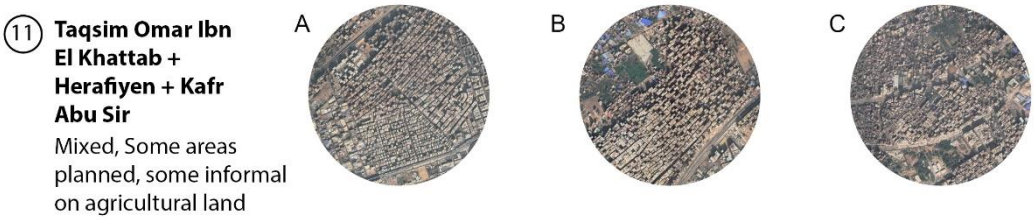


Figure 33: Figure ground map of Omar Ibn El Khattab, the highways, and the urban fabric

This mixed case study (Figure 33) consists of the planned neighbourhood Taqseem Omar ibn El Khattab, the informal area Herafiyeen (Craftsmen City) and informal ex-agricultural village of Kafr Abu Sir. There is little information and research on these areas, so the majority of information has been collected by the researcher from experience in the area. The boundaries between them are indistinct and walking between the planned and informal areas is possible. The settlements all have access to the Gesr El Suez highway which provides access to the rest of the city.

The planned neighbourhood Taqsim Omar ibn El Khattab was established in early 2000s as a middle-class neighbourhood. Initially it was low-rise apartment blocks with small shops

and an appropriately sized street network but due to lack of oversight the neighbourhood began to grow informally. People were building without planning permission on empty plots, extending buildings without permission, and using spaces for different purposes, such as underground garages as commercial storage. Over time this informal building and lack of maintenance led to the overcrowding of the neighbourhood and decline of living standards. The neighbourhood is close to industrial areas which also increases pollution.

Herafiyeen is a neighbourhood that is mostly made up of car mechanic workshops and small residential units. It serves both planned and informal areas. This area was previously industrial, and the government moved the car mechanic workshops from Heliopolis to Herafiyeen in the late 1980s. Over time, the area grew informally and nowadays suffers from overcrowding and inadequate infrastructure even though it is an important part of the car mechanic industry in Cairo and the rest of Egypt (Elyachar et al. 2005).

Kafr Abu Sir is an ex-agricultural village that was on the edge of Cairo. This area was agricultural land which over time was built up informally. Some of the agricultural grid remains but it does not have as much of an effect on the urban morphology as in Ard El Lewa and other agricultural settlements. This settlement suffers from a lack of infrastructure and does not have an adequate electricity supply, water supply and sewage system. The sewage goes directly into Al-Rashah canal which causes pollution in the surrounding area. Living standards are very low as it is less urbanised and maintained than older informal settlements.

This mixed case study is defined by the outer extents of each neighbourhood and the Gesr El Suez highway. This case study was chosen because it represents newer planned and informal areas that may have different emergences and morphologies but suffer from the same issues, such as pollution and lack of infrastructure. It can also show how these settlements function together as a single entity and whether it is possible to improve living standards in the entire area through urban interventions.

4.5.14. Summary

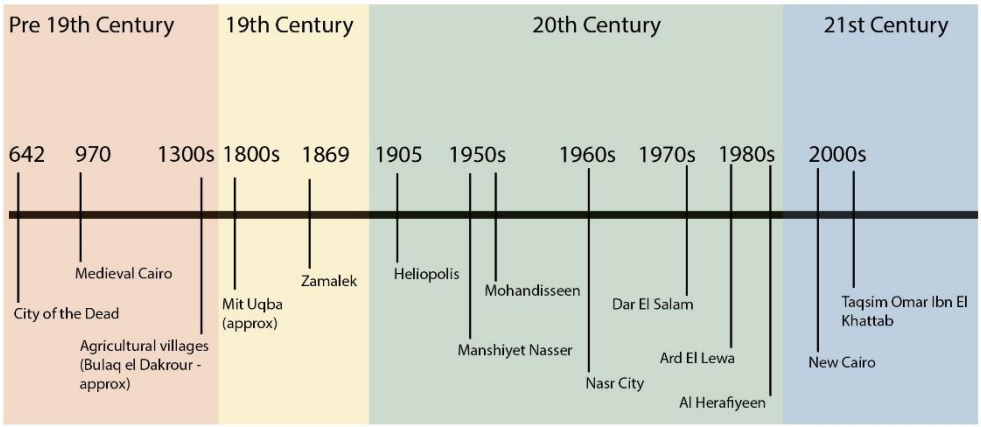


Figure 34: Timeline of Settlement Emergence

To summarise, 13 case studies in total are selected that have emerged at different times of Cairo's history (Figure 34). Of these cases, seven are considered informal. Ard El Lewa, represents informal growth on agricultural land with the physical boundary of the highway and ex-canal. Bulaq El Dakrour represents informal growth on agricultural land with a historic/perceived boundary. Dar El Salam represents growth on both desert and agricultural land with a historic/perceived boundary. City of the Dead and Medieval Cairo represent historic areas (that were initially planned in some way) that have become informal over time and have a man-made historical boundary. Mit Uqba is also a historical village (organic growth) that became informal over time and is bounded by the canal and Mohandisseen. Manshiyet Nasser represents informal growth on desert land that is bounded by the highway and cliff edge.

Four cases are considered planned. Zamalek represents planned building bound by the physical natural boundary of the Nile. Nasr City is a planned suburb bounded by the initial master plan and administrative boundary. New Cairo represents a satellite town with a clear man-made boundary of the highways and administrative boundary. Mohandisseen is bound by the highway and contains Mit Uqba in it.

Two cases are considered mixed. Heliopolis, Matariya and Ain Shams form one case study made up of three interconnected neighbourhoods. Its boundary is historic, based on the

initial plans of Heliopolis and the canal by Matariya and Ain Shams. Taqsim Omar Ibn El Khattab, Herafiyeen and Kafr Abu Sir form another case study, bound by the highway and agricultural fields.

Table 6 provides a summary of the characteristics of each neighbourhood based on their initial classification, their date of emergence (some are still developing such as Ard El Lewa), the type of boundary and the population density of the district.

Table 6: Summary table for the case study neighbourhoods

ID	Name	Initial Classification	Date of Emergence	Type of Boundary	Administrative Districts and population density (CAPMAS)	Notes
1	Ard El Lewa	Informal/ Agricultural (urban fringe infill)	1980's	Man made	Imbaba/Al Ajouza 59,381/km2	Residents took over administration in 1999
2	Mit Uqba	Informal/ Agricultural (historic village extension)	1800's	Historic/ Perceived	Al Ajouza 39,164/km²	Historic village surrounded by planned area
3	Bulaq El Dakrour	Informal/ Agricultural (historic village extension)	1313 AD, informal in 1980's	Historic/ Perceived	Bulaq El Dakrour 76,856/km²	Not to be confused with Bulaq Abu El Ela which is a port on the Nile
4	Dar El Salam	Informal/ Agricultural (urban fringe infill)	1970's	Historic/ Perceived	Dar El Salam 96,309/km²	Highest population density in Cairo
5	Medieval Cairo (Islamic Cairo)	Exformal - Historically, planned but turned informal	969 AD, grew informally	Historic/ Perceived	Ad-Darb al-Aḥmar/ Al-Khalīfah/ As-Sayyidah Zaynab 32,300/km²	Original core of Cairo
6	City of the Dead (Cairo Necropolis)	Exformal - Historically, planned but turned informal	642 AD, informal in 1960's	Manmade / Historic/ Perceived	Manshiyat Nasser 46,694/km²	Cemetery turned informal settlement
7	Manshiyet Nasser (Garbage City)	Informal/ Desert (aggregate)	1950's	Physical – cliff edge	Manshiyat Nasser 46,694/km²	Declared unsafe in 2008 after landslide
8	Mohandisseen	Planned – evidence of subdivision	1950's	Man made	Al Ajouza 39,164/km²	Planned in 1950's to house engineers

Table 6 (continued): Summary table for the case study neighbourhoods

9	Zamalek	Planned – evidence of subdivision	1869	Physical – river	Zamalek 5,589/km²	Was gardens and palace in 1869 now is affluent district
10	Nasr City	Planned – evidence of subdivision	1960's	Manmade / Administrative	Madinat an-Nasr 1 8,487/km²	Established in 1960's during Nasser regime as new capital city for Egypt
11	New Cairo	Planned – evidence of subdivision	2000's	Manmade / Administrative	Al-Qahira al-Jadīdah 1 and 3 1,534/km²	New satellite city – became one of most affluent districts in the city
12	Heliopolis, Al Matariya and Ain Shams	Mixed/ Planned and informal fabric together	1905	Historic/ Perceived	Misr al-Jadida, Az-Zaytoun, Al-Amīrīīah, Al-Maṭariyah, Ain Shams, Al Nuzha 76,187/km² informal, 14,753/km² planned	Heliopolis was an affluent suburb with surrounding housing for workers. Became partially informal after loose building regulations
13	Taqseem Omar Ibn El Khattab	Mixed/ Planned and informal fabric together	2000's	Man made	As-Salām 1 22,926/km²	Partially planned, adjacent to agricultural village and informal workshop area

4.6. Highway Description and Physical Attributes

The presentation of these 13 neighbourhoods has shown the importance of the highway network as a boundary or an axis for development. Their physical characteristics also play an important role in disconnecting or connecting neighbourhoods depending if they are accessible to their surroundings and if they can be traversed or not by car or on foot.

The highways below are the ones which interface with the selected case studies as a boundary or a connector (Table 7 and Figure 35). Five highways are presented along with their characteristics and physical expression. This information has been collected through various grey literature sources and the researcher's own experience.

Table 7: Summary table of highway characteristics

Highway Name	Type (Elevated/Ground Level)	Approx. Length	Notes on accessibility
Ring Road	Elevated	110km	Not accessible without ramp, unsafe for pedestrians
Salah Salem	Ground Level	18km	Can be crossed by pedestrians, some barriers present
El Nasr Rd	Elevated	28km	Not accessible without ramp, unsafe for pedestrians
Gesr El Suez	Ground Level	20km	Can be crossed by pedestrians, some barriers present
26th July Corridor	Ground Level with some elevated bridges	40km	Pedestrian bridges in informal areas, can be crossed

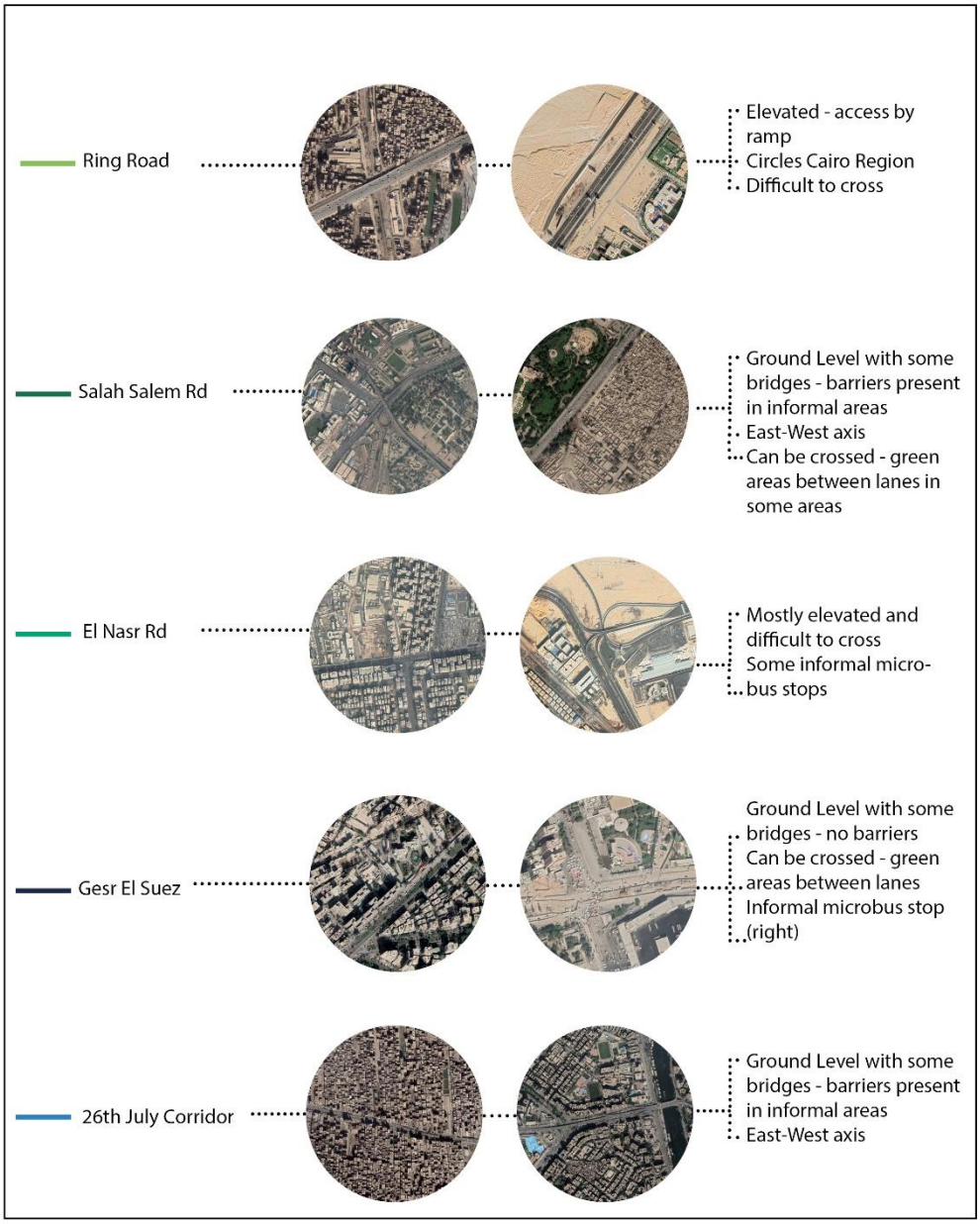


Figure 35: Characteristics of each highway

The **Ring Road** highway is a 110km circular route that was completed in early 2000s and circles the Greater Cairo Region as it was in 2000. It was initially built to prevent the growth of informal areas on Cairo's periphery and to reduce traffic inside the city. However, it was unsuccessful in limiting growth as the informal urbanisation continued on the other side of the highway (AlSayyad 2011). Generally, this highway is **elevated and only accessible by ramps within a neighbourhood**. This has led to lack of access to this highway in informal areas, as only planned areas have access ramps. Even though the highway is one of the main transport routes of the region, it has no pedestrian bridges, walkways or protected stops for public transport.

Salah Salem is one of the main urban transport corridors in Greater Cairo. It starts at Cairo International Airport and ends at El Monib Metro station in Giza. It passes through both planned and informal neighbourhoods and is **generally crossable and not elevated**. Barriers are present in some informal areas to prevent access, and generally planned areas have access (ElKhateeb 2018).

El Nasr Road also starts at Cairo International Airport and ends where it re-joins Salah Salem Road near Old Cairo. It is an alternative route to travel to Nasr City without having to go through Salah Salem and central Cairo traffic. It is **generally elevated and only accessible via a ramp**. It does not have pedestrian crossings or bridges, even though there are informal microbus stops along the road. These stops are not protected from traffic so using this road is dangerous for pedestrians and public transport.

Gesr El Suez is named after the train that used to follow this route to the Suez governorate. It starts on the northeast side of Cairo by the Ring Road and reaches Heliopolis. This highway is one of the oldest in Cairo and is not elevated. It is **crossable** as there are some green areas between lanes and in some places, there are pedestrian crossings and protected transport stops. Both planned and informal transport methods use this road, and it is generally safe for pedestrians (Elyachar et al. 2005).

The 26th of July Corridor connects Giza with the Cairo-Alexandria national highway. It starts at 6th October City in Giza and crosses the Nile River into Cairo. It is **generally ground level** but is connected by flyover bridges in some areas (ACE Consulting Engineers 1998). When traversing planned settlements there is generally access to the road, but in informal areas there are **barriers preventing access**. However, there are some pedestrian crossings and bridges in informal areas, so it is not completely inaccessible.

4.7. Conclusion

This chapter presented Greater Cairo as a case study for investigation into informal settlements. The case study consists of 13 neighbourhoods, seven considered informal, four considered planned and two are considered mixed. The highways' physical characteristics and interface with the neighbourhoods are also presented.

Limitations

One of the main difficulties in this study was finding data on informal settlements, so therefore the **second criteria** for settlement selection was data availability. The chosen cases are in the most urbanised part of the Greater Cairo Region, which has been partially surveyed by CAPMAS and other organisations (CAPMAS, 2018; Google, Maxar Technologies, 2016; OpenStreetMap contributors, 2018). Cases were chosen based on the availability of surveys to make sure that the urban representation (and therefore analysis) was accurate. Cases with no base survey were avoided due to accuracy and time constraints.

CHAPTER 5: MORPHOLOGICAL PROFILE OF SETTLEMENTS AND CATEGORISATION OF URBAN BLOCKS

5.1. Introduction

As defined previously in chapter 3, the urban blocks are considered the places of natural occupation (Marcus 2001), where activities other than movement take place. Urban blocks are considered an essential component of any urban fabric. The definition of the urban block used is the area that is surrounded by streets. They are the space for buildings/functions within the street network of a city (Frey 1999). Urban blocks are defined differently in informal and planned areas, which is based on historic emergence and morphology studies as outlined previously in Chapter 3.2, Figure 13: Emergence Types.

In this research, urban blocks are primarily studied to assess suitability of the settlement to accommodate necessary functions and amenities. They are also studied to assess resilience over time and their potential to adapt to changes. Some functions, such as schools and other public buildings, require large buildings which in turn require large block sizes. Other functions such as housing may require smaller buildings, so studying the form and size of blocks can indicate whether the blocks are suitable for the required functions in a neighbourhood. Secondly, urban blocks can be part of the unique characteristics for classification of settlements into types. Certain block sizes and shapes may be more prevalent in informal settlements, so they can be used for classification.

This chapter focuses on the study of the **size** and **shape** of the urban blocks using descriptive statistics and related back to the functionality criteria, which have been described in Section 3.1.2.1. Then, the **block cluster categorisation** based on the size and shape are presented, along with the parameters of each cluster and their distribution within the settlements, which is used to find a meaningful description of the clusters.

5.2. Results of the Urban Block Analysis

5.2.1. Size of Urban Blocks

The size of the blocks is studied using two measures – area and average block face. The area and perimeter are also used to calculate the shape measures. The area can be used to assess what functions can fit in urban blocks and average block face length can provide insight into walkability. Diagrams are presented using the same scale legend to aid in comparability and histograms show the distribution of values within each settlement (Figure 36 and Figure 37).

The first set of size and shape measures establishes the formal profile of blocks according to the area and perimeter of the footprint of the urban block (Table 8). The profile includes the mean area value of each settlement in hectares (ha) and the average block face in metres (m). It also includes the standard deviation and the co-efficient of variation (ratio of standard deviation to the mean as a percentage), which indicate the extent of variability within the data. The minimum and maximum are also included to indicate the range within the data, and to compare between the smallest and largest blocks in each settlement.

The number of blocks in each settlement ranges from 85 to 3482 blocks across the entire sample. In **informal settlements**, this range is 244 to 3482 blocks. In **planned settlements** this range is 85 to 1064 blocks. **Mixed settlements** have a range from 1108 to 1961 blocks. This shows that informal settlements tend to have more numerous blocks than planned settlements, with mixed neighbourhoods somewhere in between.

Table 8: Urban Block Size Descriptive Statistics

Initial Type	Variable	N	Mean	StDev	CoefVar %	Min	Max
Informal/ Agricultural (urban fringe infill)	1 Ard El Lewa						
	Average Block Face (m)	649	89.9	75.75	84.17	10.1	667
	Block Area (ha)	649	0.34	0.47	136.29	0.01	5.26

Table 8: Urban Block Size Descriptive Statistics (continued)							
Informal/ Agricultural (historic village aggregate extension)	2 Mit Uqba						
	Average Block Face (m)	244	46.2	43.8	94.80	5.1	346.1
	Block Area (ha)	244	0.14	0.18	125.92	0.0026	1.26
Informal/ Agricultural (historic village extension) – infill	3 Bulaq El Dakrour						
	Average Block Face (m)	846	54.89	42.6	77.64	6.125	303.8
	Block Area (ha)	846	0.23	0.46	198.77	0.0004	9.33
Informal/ Agricultural (urban fringe infill)	4 Dar El Salam						
	Average Block Face (m)	3482	51.1	42.8	83.77	1.94	976
	Block Area (ha)	3482	0.19	0.82	422.71	0.0004	37.9
Exformal - Historically, planned but turned informal – aggregate	5 Medieval Cairo						
	Average Block Face (m)	1729	54.47	72.155	132.47	3.94	839.2
	Block Area (ha)	1729	0.25	1.39	546.98	0.0003	38.93
Exformal - Historically, planned but turned informal	6 City of the Dead						
	Average Block Face (m)	467	45.68	29.99	65.65	3.85	342
	Block Area (ha)	467	0.25	0.66	268.81	0.0006	11.94
Informal/ Desert (aggregate)	7 Manshiyet Nasser						
	Average Block Face (m)	1300	34.6	58.1	168.09	1.44	702.1
	Block Area (ha)	1300	0.13	0.46	361.36	0.0002	8.54
Planned – evidence of subdivision	8 Mohandisseen						
	Average Block Face (m)	442	78.6	65.05	82.76	5.1	395.2
	Block Area (ha)	442	0.68	1.27	187.44	0.0026	15.52
Planned – evidence of subdivision	9 Zamalek						
	Average Block Face (m)	85	142.5	111.5	78.22	31.12	791.4
	Block Area (ha)	85	2.44	6.69	274.10	0.098	45.29
Planned – evidence of subdivision	10 Nasr City						
	Average Block Face (m)	564	138.8	82.88	59.72	6.4	760.1
	Block Area (ha)	564	1.66	2.67	160.67	0.003	45.89
Planned Satellite City – evidence of subdivision	11 New Cairo						
	Average Block Face (m)	1064	146.5	205	139.96	11.4	5224
	Block Area (ha)	1064	2.02	5.48	270.62	0.012	136.97
Mixed/ Planned and informal fabric together	12 Heliopolis						
	Average Block Face (m)	1961	105.6	82.4	78.03	13.75	1599.6
	Block Area (ha)	1961	1.11	2.76	248.00	0.0129	79.65
Mixed/ Planned and informal fabric together	13 Omar Ibn El Khattab						
	Average Block Face (m)	1108	99.2	102.55	103.37	7.7	1486.4
	Block Area (ha)	1108	0.71	3.21	450.31	0.005	101.5

Area of Urban Blocks

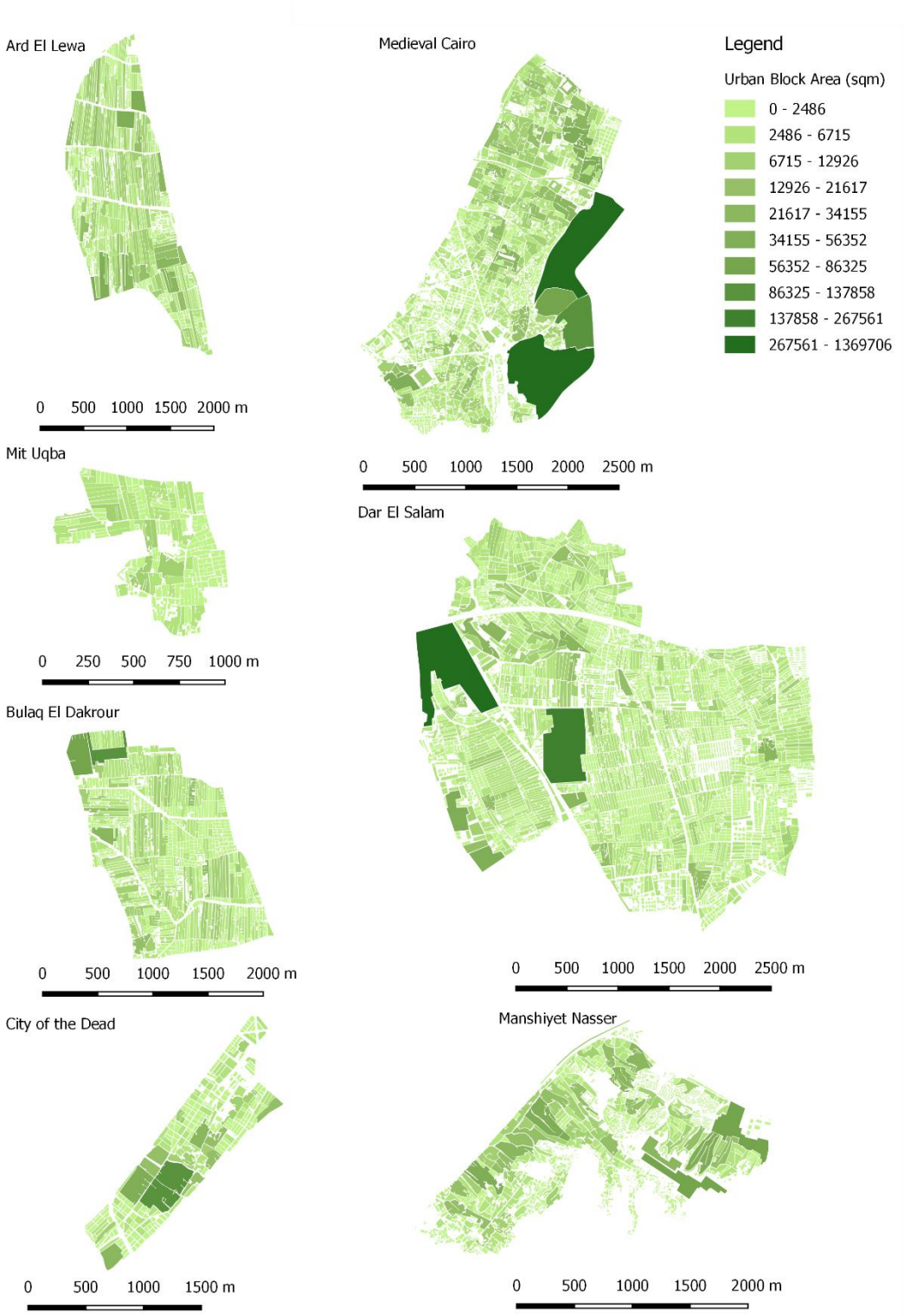


Figure 36: Diagrams of Urban Block Area Part 1

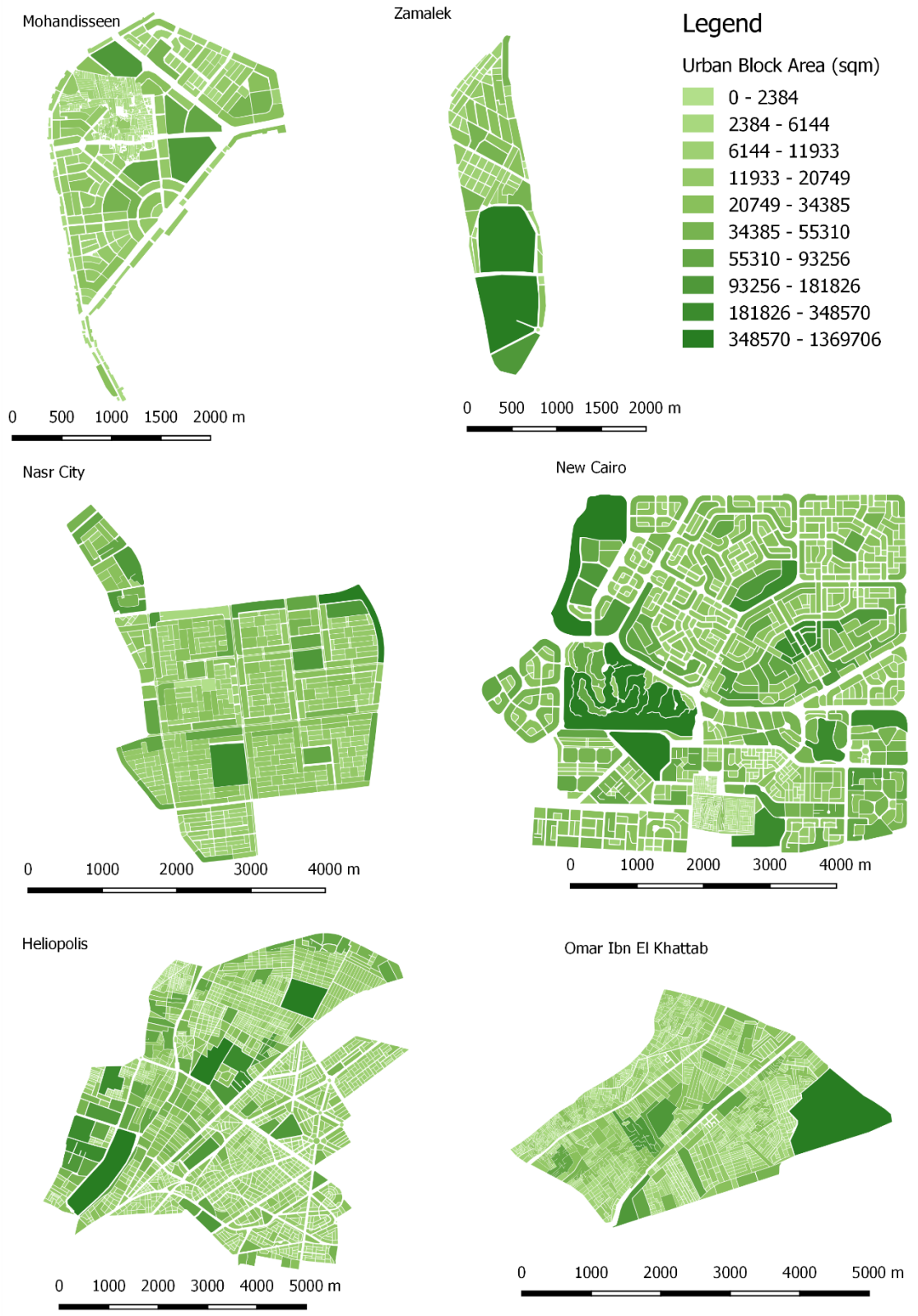


Figure 37: Diagrams of Urban Block Area Part 2

The minimum and maximum block area across the whole sample ranges from 0.0026 ha to 136.97 ha. This range includes industrial areas, parks, and the citadel, which are outliers in block area. The mean block area ranges from 0.13 ha to 2.44 ha, which shows that the smallest mean block area is 19 times smaller than the largest. In **informal settlements** the mean block area ranges from 0.13 ha to 0.34ha. In **informal- infill**, the mean block area ranges from 0.19ha to 0.34ha, and in **informal-aggregate** the mean block area ranges from 0.13ha to 0.25ha. This highlights the difference between the aggregate and the infill block types, where infill tends to result in larger blocks. In **planned settlements** the mean block area ranges from 0.68 ha to 2.44 ha. This shows that the smallest mean area in planned settlements is double the size of the largest mean area in informal settlements. This captures the difference between the urban block as defined by aggregated and infilled buildings versus defined by the street network. The 0.68 ha mean in Mohandisseen is skewed slightly lower than other planned settlements due to Mit Uqba being a part of the urban fabric. In **mixed settlements** the mean block area is 0.71 ha to 1.11 ha, which lies within the range for planned settlements, as it is a mixture of informal and planned fabric.

The variability of the block areas is measured by the standard deviation, which is in hectares, and the co-efficient of variation, which is expressed as a percentage. The standard deviation is affected by the size of the settlement, while the co-efficient of variation is comparable across settlements. Across the whole sample, the standard deviation ranges from 0.18 ha to 6.69 ha, and the co-efficient of variation ranges from 125% to 546%. In **informal settlements** the standard deviation ranges from 0.18 ha to 1.39 ha, and the co-efficient of variation ranges from 125% to 546%. In **informal- infill**, standard deviation ranges from 0.46ha to 0.82 ha, and the co-efficient of variation ranges from 136% to 422%. In **informal-aggregate** standard deviation ranges from 0.18 ha to 1.39 ha, and the co-efficient of variation ranges from 125% to 546%. In informal settlements the very high standard deviation and co-efficient of variation can be explained by the large blocks containing industrial areas and historic areas. In **planned settlements** the standard

deviation ranges from 1.27ha to 6.69 ha, and the co-efficient of variation ranges from 160% to 274%. In **mixed settlements** the standard deviation ranges from 2.76 ha to 3.21 ha, and the co-efficient of variation ranges from 248% to 450%. This shows that informal areas have higher variability of block area, while planned settlements are more homogenous. Mixed settlements are somewhere in the middle of planned and informal settlements.

The distribution of block area, with the outliers over 8 ha removed (Figure 38), provides further insight into the variability of block area within the sample. The outliers that are removed represent exceptional blocks such as industrial areas, sports clubs, historic areas, and fenced parks. This allows insight into the more common block areas that contain housing and public buildings.

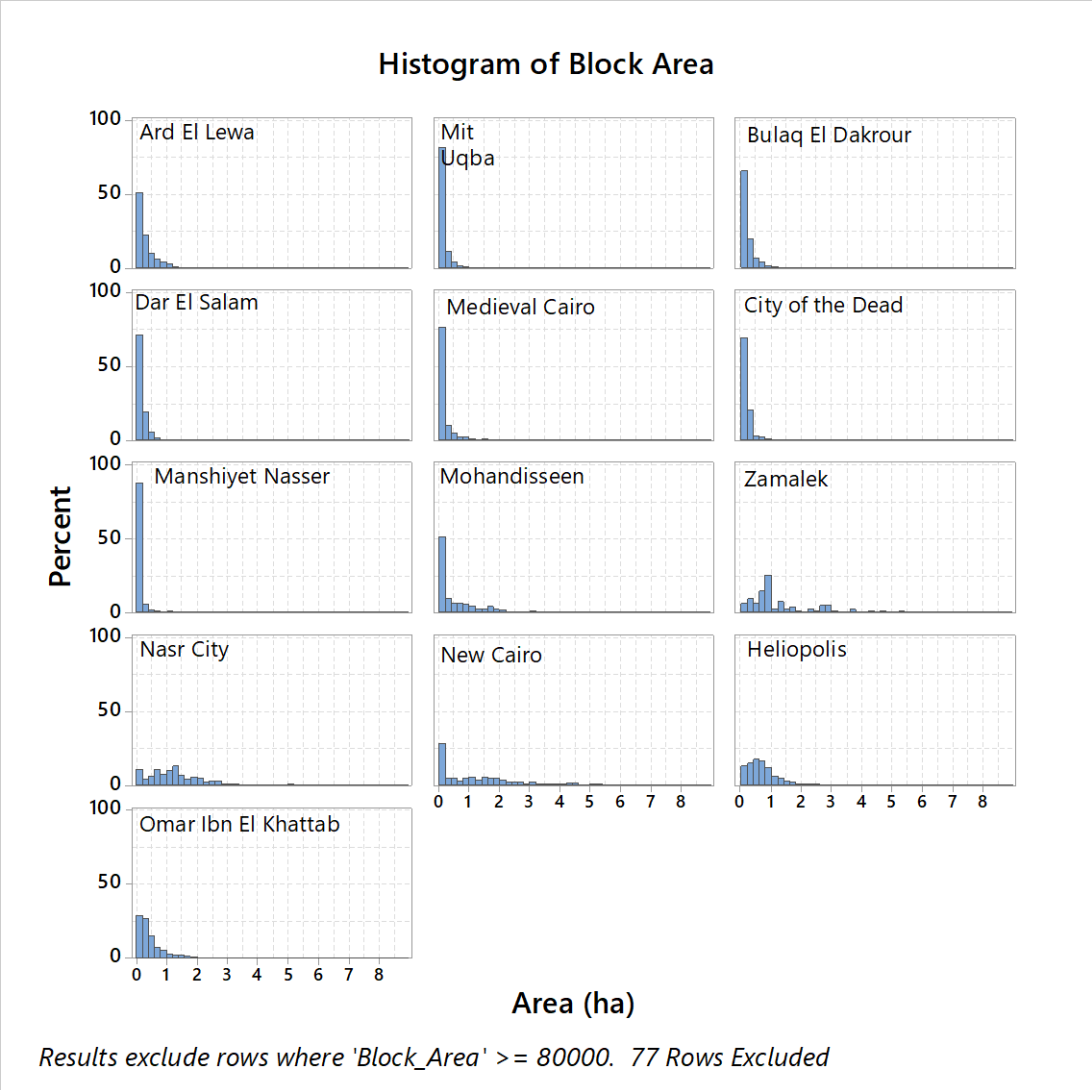


Figure 38: Histogram of Block Area in Ha

Most blocks in informal settlements are below 2 ha in area, with 90% below 1 ha. The blocks larger than 2 ha are below 1% of the total. The distribution of block size in informal settlements tends to be left skewed which indicates that blocks are mostly small with very few large blocks. This aligns with their emergence as housing only – there are few large blocks to accommodate other functions.

In planned settlements, there is more variation in block size. In Mohandisseen, a long-tail distribution starts to emerge due to the smaller block sizes of Mit Uqba within the settlement. However, in Zamalek and Nasr City, most blocks are between 1 and 2 ha in area, which indicates that there are few small blocks. In New Cairo, there is a long-tail distribution but again this can be attributed to the 'informal like' planned social housing Third Settlement within the neighbourhood that has smaller blocks than the rest of the neighbourhood.

In mixed settlements the variation in block area lies between informal and planned settlements. The majority of blocks have an area less than 1 ha, but there is a long tail that extends to 3 ha, which can accommodate larger functions. This is more apparent in Omar Ibn El Khattab, where there are many smaller blocks with fewer larger blocks.

Block Face Length

The block face length ranges from 1.44m to 5224m across the whole sample. In informal settlements this ranges from 1.44m to 976m. The very low minimum can be attributed to fragmented/narrow blocks in informal settlements. In Informal settlements, the range is 1.44m to 976m. In planned settlements, the range is from 5.1m to 5224m. This shows that planned blocks tend to have a higher average block face length than informal blocks.

The mean block face across the whole sample ranges from 34.6m to 146.5m. In **informal settlements** the mean block face ranges from 34.6m to 89.9m. In **Informal-infill**, the range is 51.1m to 89.9m. In **informal aggregate** this ranges from 34.6m to 54.47m. This shows that the blocks that are formed by building aggregate are generally smaller in block face length than those which emerged on an agricultural grid. In **planned settlements,** the block

face length ranges from 78.6m to 146.5m. This shows that the smallest mean block face in planned settlements is almost double the size of the smallest mean block face in informal settlements. In **mixed settlements** the mean block face ranges from 99.2m to 105.6m, which falls in the range for planned settlements, but is less than the longest mean block face.

Across the whole sample, the standard deviation ranges from 29.99m to 205m and co-efficient of variation ranges from 59% to 168%. In **Informal Settlements** the standard deviation ranges from 29.99m to 75.75m and co-efficient of variation ranges from 65% to 132%. In **Informal-infill** the standard deviation ranges from 42.6m to 75.75m and co-efficient of variation ranges from 77% to 84.17%. This shows that there is not a lot of variation in block face length in infill type. In **informal-aggregate** the standard deviation ranges from 29.99m to 72.15m and co-efficient of variation ranges from 65% to 168%. This shows much wider variability in block face length in aggregate type. This can be due to the difference in emergence, where blocks that emerge on an agricultural grid result in blocks that are more homogeneous, and those that emerge by building aggregation are more fragmented and can be different sizes.

In **planned settlements** the standard deviation ranges from 65.05m to 205m and co-efficient of variation ranges from 59% to 139%. This shows some variability in block face length. In **mixed settlements** the standard deviation ranges from 82.4 to 102.55m and co-efficient of variation ranges from 78% to 103%. The higher variability can be attributed to the mixed urban fabric, where blocks that emerged informally are smaller than those that were planned.

Urban Block Size Results Summary

The results show that informal settlements tend to have smaller, more numerous blocks, with a few larger blocks that tend to be outliers for specific public functions such as parks or historical areas. This was expected since informal settlements are a product of

incremental building and the future functions of the settlement were not taken into consideration. The average block face of blocks in informal settlements is also small which indicates they are more walkable, but unable to accommodate modern building footprints. The mean block face length in neighbourhoods classed as ‘infill’ tends to be higher, which indicates that blocks are longer, potentially due to the agricultural grid. There starts to emerge a quantifiable difference between informal settlement types based on the area and block face length. Once outliers are accounted for, the variability in informal settlements is fairly low and shows similar distribution, which indicates a smaller range of block sizes. The block size outliers include Dar El Salam and Medieval Cairo due to industrial areas and the citadel.

In planned areas there tends to be fewer and larger blocks. There is more variance in block size and a higher mean for both area and perimeter. Some planned blocks are very large (>100,000sq m area and >500m block face length), especially in Nasr City and the New Cairo gated community. This reflects the street networks’ design for vehicular use rather than pedestrian use, as the length of these blocks impedes walkability.

In mixed neighbourhoods the block size has both informal and planned characteristics. There are smaller, more numerous blocks than in planned settlements, but the distribution of block size is like that of planned settlements. While none of the settlements have a true long tail distribution, the mixed settlements come the closest in doing so and having suitably diverse block sizes.

5.2.2. Shape of Urban Blocks

The second aspect of blocks that will impact the type of function it can accommodate is its shape. Depending on its shape, a large block could impact the ability to cross it and may not be walkable. For a smaller block, an irregular shape with dead ends can impede navigability and reduce the general intelligibility of the neighbourhood. Very elongated blocks prevent crossing and may not be able to accommodate functions due to reduced block face length on one side.

The shape of urban blocks is studied using two measures, square compactness, and elongation, the formulas for them were explained in more detail in chapter 3. Square compactness measures the blocks tendency towards a square and elongation measures the tendency towards a circle. The measures are normalised which leads to one scale for all and a smaller range of values for comparison.

Interpretation of Shape Results

Table 9 presents the descriptive statistics of the urban block shape measures. Figure 39 presents the distribution of shape and figures 40, 41, 42 and 43 present the diagrams of shape measures.

Table 9: Urban Block Shape Descriptive Statistics

Initial Type	Variable	N	Mean	StDev	CoefVar	Min	Max
Informal/ Agricultural (urban fringe infill)	**1 Ard El Lewa**						
	Sq. Compactness	653	0.52	0.27	53.3	0.06	1.00
	Elongation	653	0.29	0.27	89.5	0.00	1.92
Informal Agriculture (historic village extension)	**2 Mit Uqba**						
	Sq. Compactness	244	0.72	0.24	33.56	0.08	1.01
	Elongation	244	0.32	0.06	18.58	0.15	0.41
Informal/ Agricultural (historic village extension) – infill	**3 Bulaq El Dakrour**						
	Sq. Compactness	846	0.72	0.25	34.91	0.10	1.19
	Elongation	846	0.29	0.08	26.93	0.09	0.44
Informal/ Agricultural (urban fringe infill)	**4 Dar El Salam**						
	Sq. Compactness	3482	0.67	0.23	34.76	0.09	1.09
	Elongation	3482	0.31	0.07	21.31	0.11	0.42
Exformal - Historically, planned but turned informal – aggregate	**5 Medieval Cairo**						
	Sq. Compactness	1729	0.65	0.25	38.58	0.06	1.27
	Elongation	1729	0.33	0.05	16.11	0.08	0.5
Exformal - Historically, planned but turned informal Subdivision /aggregate	**6 City of the Dead**						
	Sq. Compactness	467	0.85	0.17	20.33	0.19	1.15
	Elongation	467	0.34	0.06	16.97	0.13	0.43
Informal/ Desert (aggregate)	**7 Manshiyet Nasser**						
	Sq. Compactness	1300	0.71	0.23	32.26	0.05	1.27
	Elongation	1300	0.33	0.06	17.32	0.06	0.5
Planned – evidence of subdivision	**8 Mohandisseen**						
	Sq. Compactness	442	0.75	0.21	28.66	0.08	1.05
	Elongation	442	0.32	0.06	17.57	0.15	0.42

Table 9: Urban Block Shape Descriptive Statistics							
Planned – evidence of subdivision	**9 Zamalek**						
	Sq. Compactness	85	0.77	0.19	24.64	0.20	1.17
	Elongation	85	0.31	0.06	20.01	0.13	0.46
Planned – evidence of subdivision	**10 Nasr City**						
	Sq. Compactness	564	0.75	0.22	28.71	0.03	1.16
	Elongation	564	0.31	0.09	28.05	0.05	1.49
Planned Satellite City – evidence of subdivision	**11 New Cairo**						
	Sq. Compactness	1064	0.73	0.22	29.56	0.05	1.25
	Elongation	1064	0.31	0.06	19.18	0.09	0.49
Mixed/ Planned and informal fabric together	**12 Heliopolis**						
	Sq. Compactness	1961	0.79	0.18	22.63	0.05	1.27
	Elongation	1961	0.32	0.06	17.44	0.08	0.5
Mixed/ Planned and informal fabric together	**13 Omar Ibn El Khattab**						
	Sq. Compactness	1108	0.66	0.26	38.59	0.05	1.05
	Elongation	1108	0.31	0.06	19.68	0.07	0.42

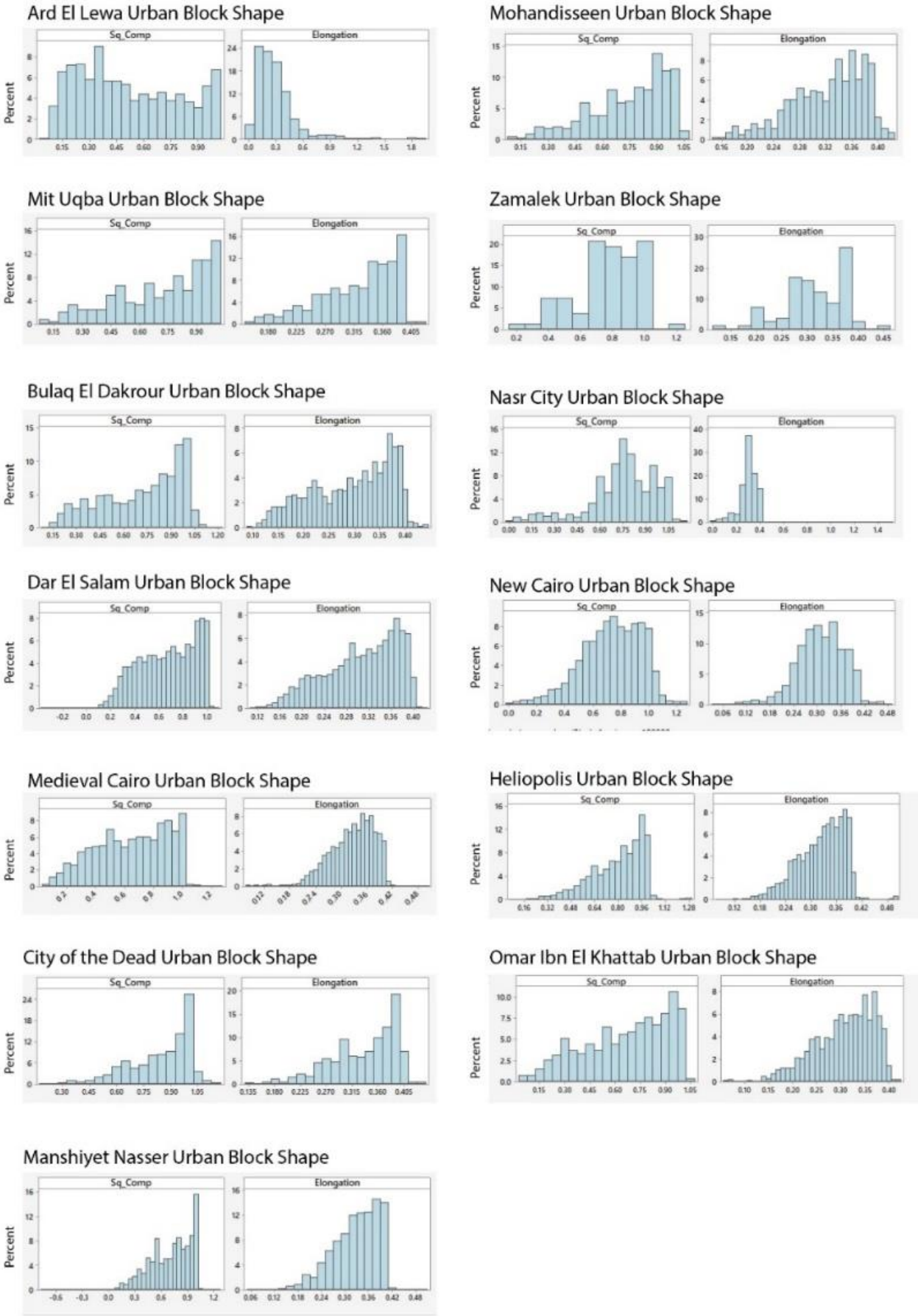


Figure 39: Histogram of Block Shape Distribution

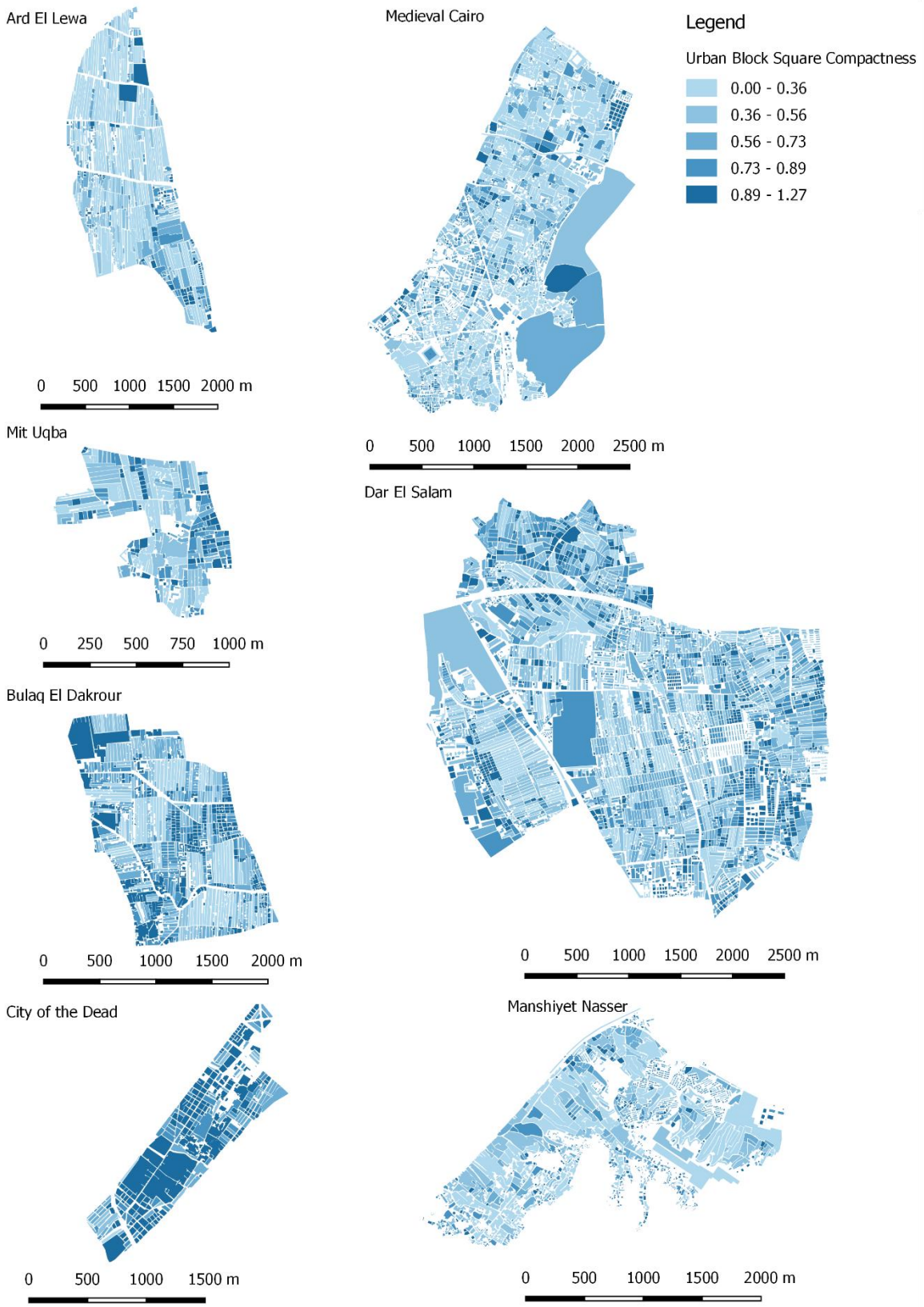


Figure 40: Diagram of Urban Block Square Compactness Part 1

Figure 41: Diagram of Urban Block Square Compactness Part 2

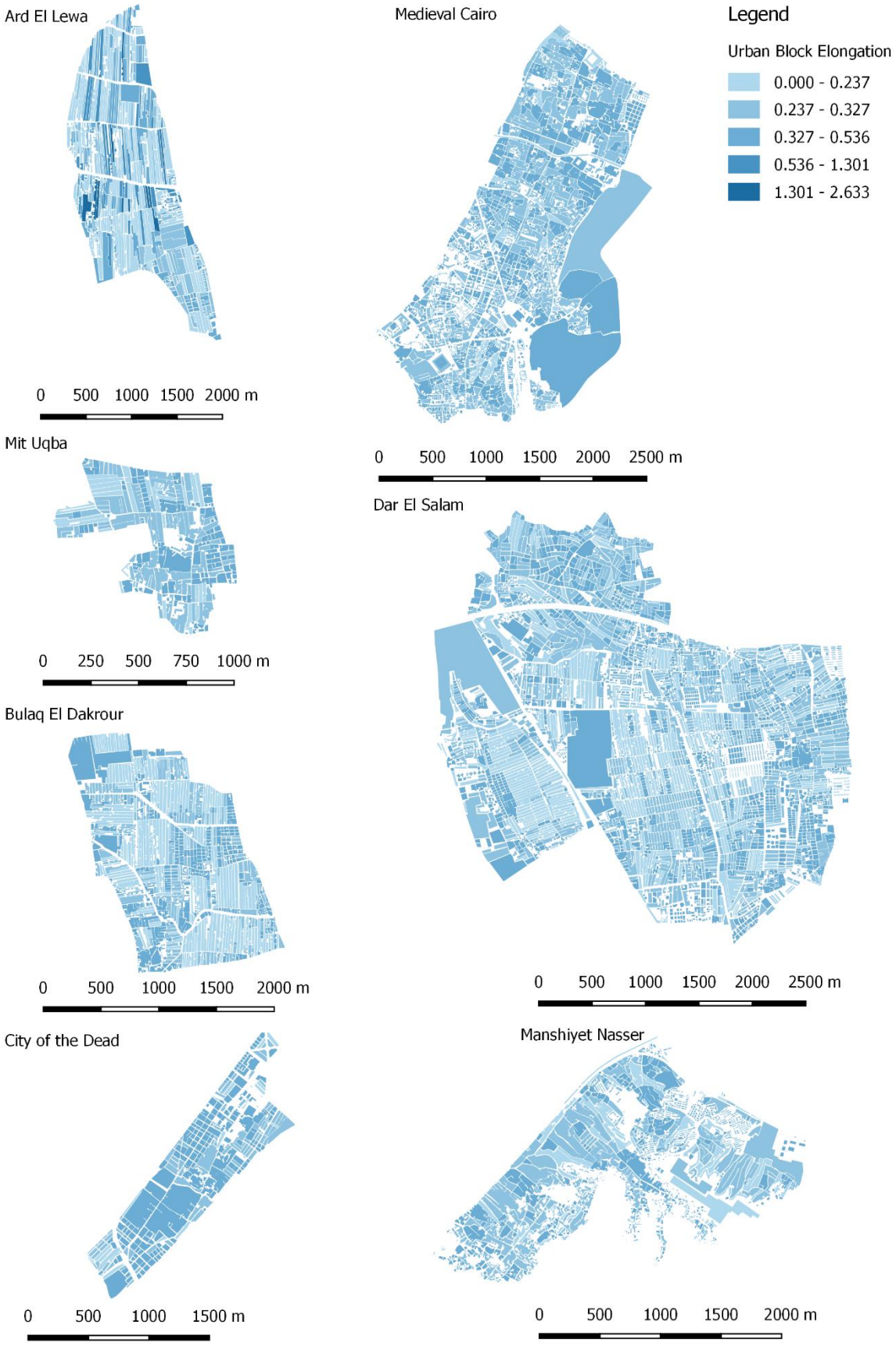


Figure 42: Diagram of Urban Block Elongation part 1

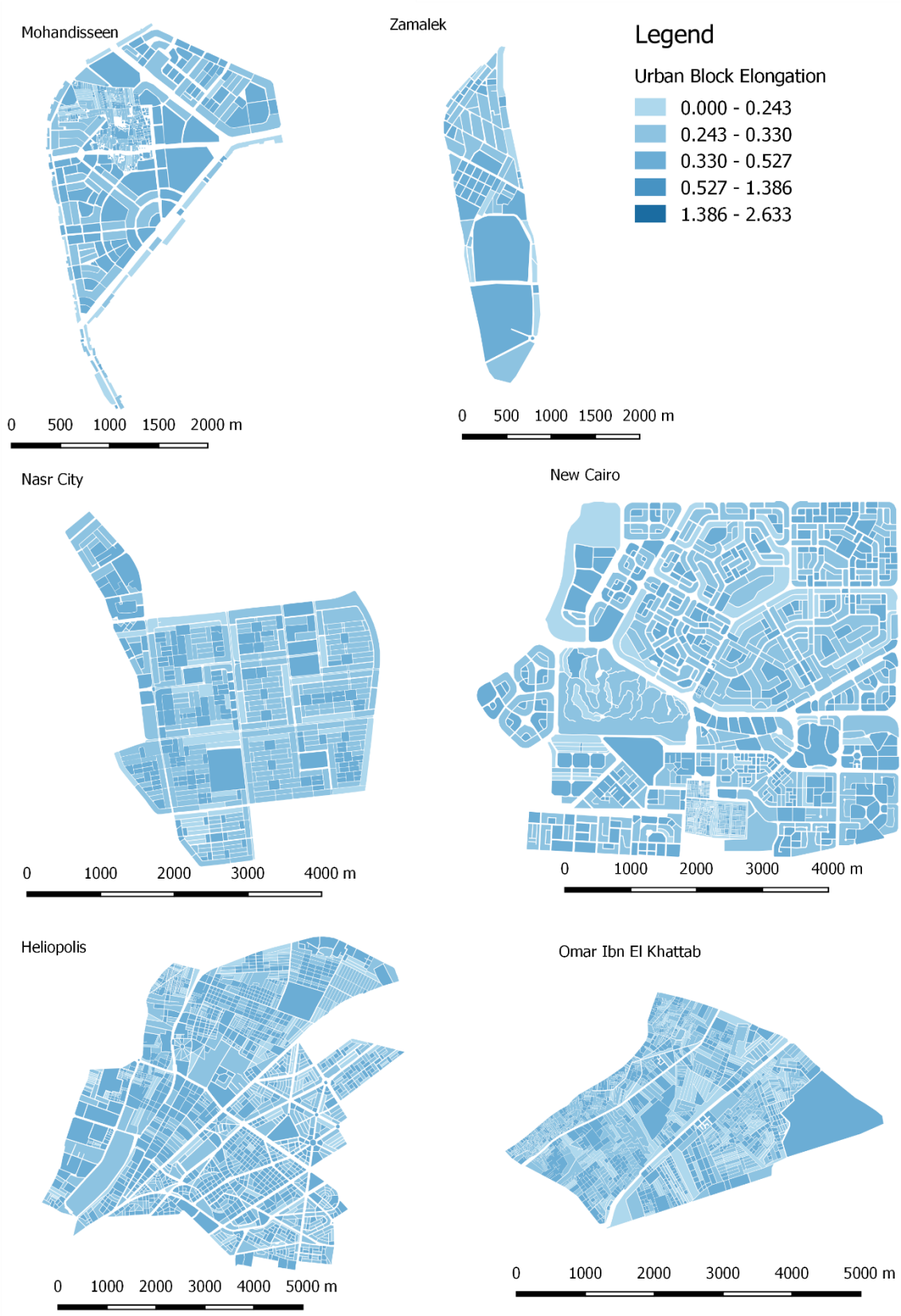


Figure 43: Diagram of Urban Block Elongation Part 2

Across the entire sample, the range of square compactness is from 0.035 to 1.27, which is expected. In **informal settlements**, the range of square compactness is 0.05 to 1.27, which indicates a wide variety of block shapes. In **informal-infill** the range is from 0.06 to 1.19. In **informal-aggregate** the range is from 0.05 to 1.27. In planned settlements the range is from 0.03 to 1.25. In mixed settlements the range is from 0.05 to 1.27. The values that are greater than 1 indicate a curvilinear element to the shape of the urban block.

The mean square compactness across the whole sample ranges from 0.52 to 0.85. The mean square compactness in **informal settlements** ranges from 0.52 to 0.85. In **informal-infill** the mean square compactness ranges from 0.51 – 0.72. In **informal-aggregate** the mean square compactness ranges from 0.65 to 0.85. In **planned settlements** the mean square compactness ranges from 0.73 to 0.75. In **mixed settlements** mean square compactness ranges from 0.66 to 0.79.

Across the whole sample the standard deviation of the square compactness ranges from 0.17 to 0.27. The co-efficient of variation ranges from 20.33% to 53.3%. These values are similar across the whole sample (between 0.21 and 0.25 standard deviation and 28% to 38% co-efficient of variation) apart from three exceptions. Ard El Lewa has the highest standard deviation (0.27) and co-efficient of variation (53.3%). This indicates a wide range of block shapes, which can be explained by Ard El Lewa having many highly elongated blocks but also some squarer blocks. The City of the Dead has very low standard deviation (0.17) and co-efficient of variation (20.33%) which can be attributed to its very regular, square blocks designed as funerary houses. Heliopolis also has relatively low standard deviation (0.18) and co-efficient of variation (22.63%), which indicates a narrow range of block shapes and a more homogenous urban fabric.

The elongation values show a similar trend to the square compactness values. The **informal infill** is most elongated (0.29 -0.3) by a small margin. **Informal-aggregate** and **planned** settlements have similar values (0.3-0.33), with aggregate types on the lower end of the range, having slightly more irregular shape. The distribution is generally between

0.15-0.4 with most values between 0.24 -0.36, which was expected as it is unlikely there are curved/circular blocks or zero value blocks.

When the shape of urban blocks is studied, a distinction between different types of emergence of informal settlements becomes apparent. The square compactness of **informal-infill** tends to be lower (0.51 – 0.71) which indicates elongated rectangles with some dead ends. The **informal-aggregate** emergence type shows a medium square compactness of 0.64 – 0.84, which indicates regular rectangular blocks. The minimum and maximum values for Medieval Cairo and Manshiyet Nasser, two aggregate settlements, are extremely similar, indicating that they have similarly shaped blocks. The values for **planned settlements** are similar (0.74 – 0.77) which indicates square/rectangular blocks, with less variation in shape between settlements. In mixed neighbourhoods the results lie in between the ranges for the informal and planned settlements (0.66 – 0.79).

The distribution and variability (Figure 39) of block shapes is similar in all neighbourhoods. The distribution is left skewed and tends to show more rectangular/square blocks. This is expected as this shape is the natural limit of block shape i.e., it would be unusual to see a perfectly circular block. The range of the mean is also similar in all neighbourhoods (0.65 – 0.8). The exception to this distribution is Ard El Lewa, which shows an even distribution of all values and a low mean of 0.51. This indicates that this neighbourhood has a higher range of block shapes that are generally more elongated.

The shape of the blocks shows less variation across types than the size of the blocks, with less distinction between planned and informal settlements. The exception to this is the elongated blocks that result from infill on agricultural land.

5.2.3. Comparison to the Functionality Criteria

Informal settlements tend to have blocks that are too small to accommodate modern building footprints (less than 65.2m). The exception to this is Ard El Lewa, which has an average block face of 89.9m, however, these blocks are very elongated, so may impede

walkability and crossing. Planned settlements have larger blocks that can accommodate many functions (greater than 65.2m) but some block faces are larger than 110m (in Zamalek, Nasr City and New Cairo) which may impede walkability.

The shape of the blocks across the entire sample tends to be between an elongated rectangle and a square. There is very little irregularity apart from a few blocks found in some informal-aggregate settlements. This indicates that the shape of the blocks is generally suitable to accommodate functions and enable walkability and navigability in the neighbourhoods.

None of the neighbourhoods have a true long-tail distribution. In informal neighbourhoods there is a lack of large blocks, and in planned neighbourhoods there is a lack of smaller blocks. This could be due to the self-organising nature of informal settlements resulting in smaller blocks for housing use. However, planned neighbourhoods have larger blocks that are designed to accommodate modern building footprints and community buildings. Mixed neighbourhoods come close to achieving a long-tail distribution, especially Omar Ibn El Khattab.

5.3. Results of the Clustering Analysis

The descriptive statistics have highlighted some differences between the primary classification of settlements, which seem to indicate that specific formal block properties are associated with a certain type of neighbourhood. The cluster analysis allows the combination of the various properties of shape and size of blocks to determine block types based on their morphology. When the cluster distribution is compared across all the neighbourhoods, it can be established if some block types are associated with a specific urban form. It will inform the primary classification and may provide a more nuanced view by highlighting the absence of some block types in a neighbourhood or common block types across the neighbourhoods.

The clustering process used k-means clustering, which is suitable for use when the parameters and number of clusters is unknown. The number of clusters was determined experimentally, with a few iterations and testing before the final cluster number was found. The final clustering procedure manually excluded blocks over 100,000m^2 and placed them into their own clusters. The remaining data was then clustered with k = 4 – 7. The optimum number of clusters was found to be 5, which is supported by the elbow graph results (Figure 44). For the urban blocks, this results in 13,956 blocks being grouped into 6 clusters: 5 clusters determined by the k-means clustering and one cluster determined manually by grouping outliers.

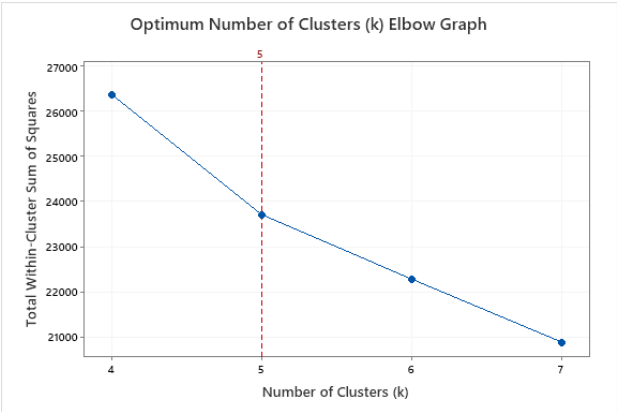


Figure 44: Elbow Graph for urban block clustering

The following sections set out the summary of the cluster descriptions, their definitions using the variables and their distribution both spatially and numerically.

5.3.1 Basic Cluster Descriptions Using Descriptive Statistics

The cluster analysis results in 5 clusters, and one cluster added manually for a total of 6 – one containing outliers, one of large blocks, two of medium blocks and two of small blocks. The cluster descriptive statistics are presented below, with the aim of finding the variables that most influence that cluster classification.

Table 10: Cluster 0 Descriptive Statistics

Variable	Total Count	Mean	StDev	CoefVar	Minimum	Maximum
Average Block Face (m)	53	743.75	726.5	97.68	312.5	5224.3
Block_Area (ha)	53	**26.38**	24.39	92.45	10.28	136.97
Sq_Comp	53	**0.67**	0.29	44.27	0.05	1.08
Elongation	53	**0.32**	0.06	18.78	0.17	0.41

Cluster 0 (Table 10) consists of size outliers above 10ha, selected manually and excluded from k-means clustering. This cluster is the smallest cluster with 53 blocks across the whole sample. It also has the largest areas as expected with wide variation, 10.28 ha to 136.97ha. The mean elongation and square compactness are considered high which indicates regular blocks.

Table 11: Cluster one descriptive statistics

Variable	Total Count	Mean	StDev	CoefVar	Minimum	Maximum
Average Block Face (m)	345	319.25	120	37.65	192.1	1064.35
Block_Area (ha)	345	**4.84**	**1.66**	34.24	1.81	9.88
Sq_Comp	345	0.59	0.28	47.07	0.05	1.16
Elongation	345	0.29	0.07	22.46	0.07	0.48

Cluster one (Table 11) is the second smallest cluster with 345 blocks. There is a high variation in square compactness (0.28 standard deviation and 47% co-efficient of variation) which indicates this cluster includes blocks of varying shapes. There is lower variation in area (37.65% co-efficient of variation), so this cluster is primarily defined by the area of blocks. This cluster consists of large, fairly regular blocks.

Table 12: Cluster two descriptive statistics

Variable	Total Count	Mean	StDev	CoefVar (%)	Minimum	Maximum
Average Block Face (m)	1746	137.45	32.75	23.83	93.54	239.9
Block_Area (ha)	1746	1.51	0.66	43.61	0.65	3.75
Sq_Comp	1746	**0.79**	**0.14**	**17.75**	0.48	1.27
Elongation	1746	**0.32**	**0.06**	**18.21**	0.17	1.76

Cluster two (Table 12) is the third largest cluster by number with 1746 blocks. There is low variation in perimeter (23.83 co-efficient of variation), square compactness (17.75 co-efficient of variation) and elongation (18.21 co-efficient of variation) which indicates a smaller range of values. The mean for perimeter (549.80m) is medium, square compactness (0.79) and elongation are comparatively high (0.32) which indicates medium sized regular blocks.

Table 13: Cluster three descriptive statistics

Variable	Total Count	Mean	StDev	CoefVar	Minimum	Maximum
Average Block Face (m)	1116	173.9	64.8	37.27	16.43	488.13
Block_Area (ha)	1116	0.79	0.47	59.32	0.02	2.63
Sq_Comp	1116	**0.27**	**0.10**	**37.85**	0.05	0.77
Elongation	1116	**0.26**	**0.18**	**68.78**	0.05	2.63

Cluster three (Table 13) is the fourth largest cluster by number, with 1116 blocks. It has a high range of elongation (68.78 co-efficient of variation) which indicates blocks of varying shapes within this cluster. It also has the lowest square compactness (0.27) and elongation (0.26) which also indicates irregularity in shape. Compared to cluster two, the mean perimeter is higher, and the mean area is lower, which also indicates irregular shape.

Table 14: Cluster four descriptive statistics

Variable	Total Count	Mean	StDev	CoefVar	Minimum	Maximum
Average Block Face (m)	6546	**35.89**	**23.14**	64.50	0.32	95
Block_Area (ha)	6546	**0.16**	**0.19**	121.36	0	0.99
Sq_Comp	6546	**0.89**	**0.09**	11.03	0.57	1.27
Elongation	6546	**0.35**	**0.04**	12.39	0.01	0.98

Cluster four (Table 14) is the largest cluster by number with 6546 blocks. This indicates a wide distribution and presence in most settlements. This cluster has the smallest mean area (0.16ha) and average block face (35.89m) which shows that the blocks in this cluster are the smallest in the whole sample. There is a narrow range of all values except area, and high square compactness (0.89) which indicates that the blocks can be varying in area and less than 1 ha but are mostly regular shaped tending towards a square.

Table 15: Cluster five descriptive statistics

Variable	Total Count	Mean	StDev	CoefVar	Minimum	Maximum
Average Block Face (m)	4150	**56.47**	26.7	47.24	0.43	127.66
Block_Area (ha)	4150	**0.19**	0.16	84.49	0	0.87
Sq_Comp	4150	**0.51**	0.12	**23.90**	0.01	0.73
Elongation	4150	0.27	0.08	**29.71**	0.03	1.92

Cluster five (Table 15) has a low mean area and block face length, which indicates smaller blocks. The maximum area is less than cluster 4 but the maximum block face length is higher, which indicates irregular perimeter within a similar area. It also has the lowest mean square compactness (0.51) which indicates irregular shape. There is small variation in both square compactness (23.9% co-efficient of variation) and elongation (29.71% co-efficient of variation) which indicates that this cluster primarily contains irregular shaped blocks with a small area.

Cluster Definitions Summary

- Cluster 0 – outliers (OT) (area over 100,000m2/ 10 ha) – 53 blocks over entire sample
- Cluster 1 (LR) – Large, fairly regular with some curves/angles
- Cluster 2 (MR) – medium regular – square/rectangular
- Cluster 3 (MI) – medium irregular – elongated or dead ends
- Cluster 4 (SR)– small regular – square/rectangular
- Cluster 5 (SI) – small irregular – elongated/dead ends

Table 16: Cluster Value Ranges

	0 OT	**1 LR**	**2 MR**	**3 MI**	**4 SR**	**5 SI**
Average Block Face (m)	312.5-5224.2	192.1-1064.4	93.54-239.8	16.43 - 488.13	0.32-95.05	0.42-127.5
Block Area (ha)	10.28-136.97	1.81-9.88	0.65-3.75	0.02-2.63	0-0.99	0-0.87
Square Compactness	0.05-1.08	0.05-1.17	0.48-1.27	0.05-0.77	0.57-1.27	0.01-0.73
Elongation	0.17-0.41	0.07-0.48	0.17-1.76	0.05-2.63	0.01-0.98	0.28-1.92

The resultant definitions using the variable ranges in Table 16 across clusters can be used to classify blocks that are outside the sample. The ranges and descriptive statistics are used to extract meaning from the clusters and assign meaningful verbal descriptions to them, as well as the numerical descriptions.

5.3.2. Cluster Distribution by Area, Number, and Spatial Positioning

The distribution of clusters can provide insight into which neighbourhoods contain which clusters by number, by area and by spatial positioning. This can indicate whether there are specific block clusters that are more common in informal or planned neighbourhoods, which can aid in finding distinctions between neighbourhood types and eventual classification. Both number and area are used because they can indicate different things, for example

some blocks may be high in number but low in area, so they are not dominant in that neighbourhood, and vice versa. This section compares spatial distribution across informal and planned areas to find if there is any cluster that is dominant in that particular type.

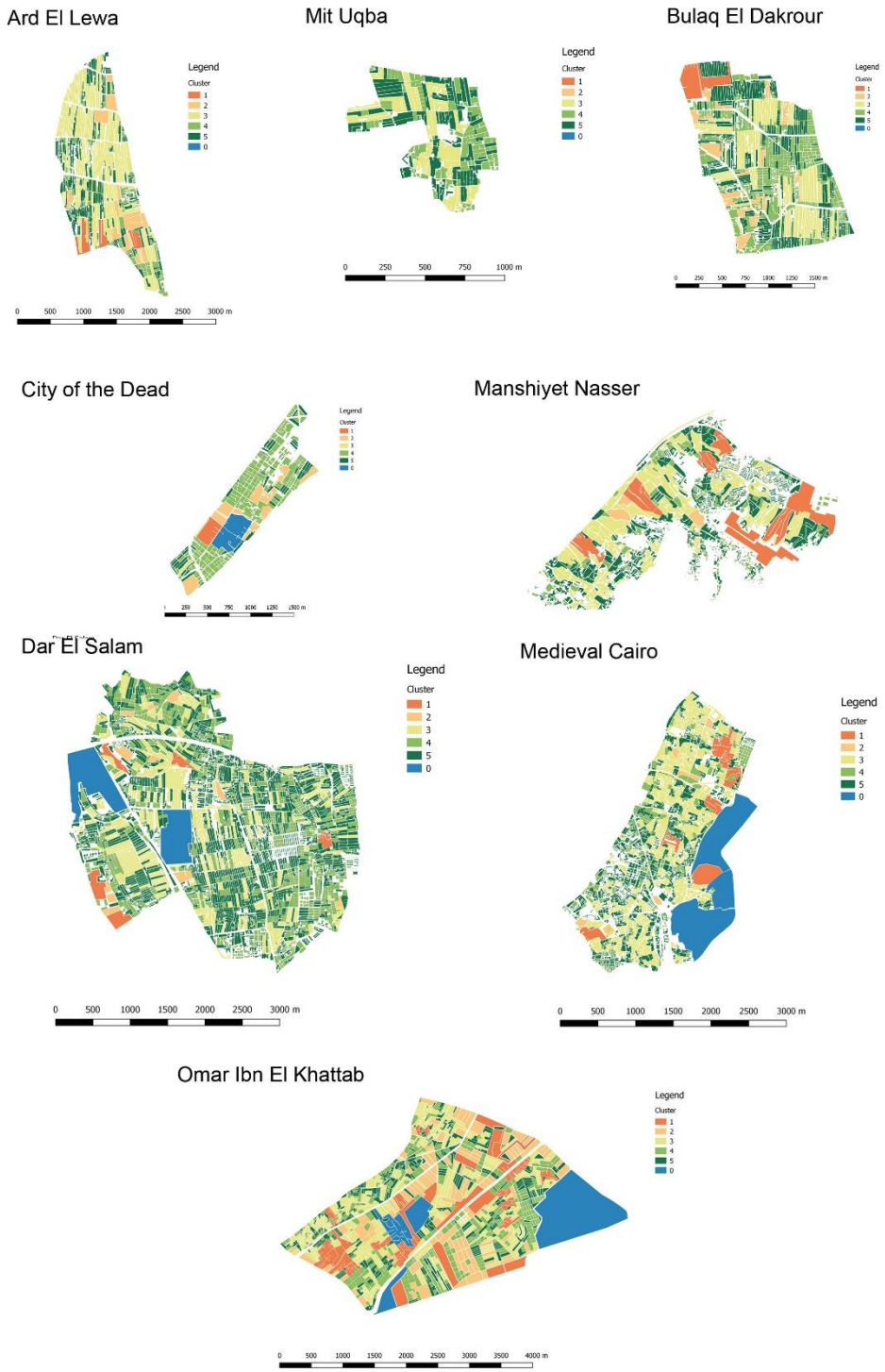


Figure 45: Urban Block Clusters Part 1

Figure 46: Urban Block Clusters Part 2

Figure 45 and Figure 46 show the spatial distribution of clusters within the neighbourhoods. It is clear that informal areas are dominated by cluster 4 (SR) and 5 (SI) (small regular and small irregular) while planned areas are dominated by cluster 1 (LR) and 2 (MR) (large regular, medium regular). This aligns with the expectation that blocks are smaller in informal areas due to their unplanned nature.

Distribution by number and area of blocks

Table 17: Cluster percentages by total area of cluster/total block area

	0 OT	1 LR	2 MR	3 MI	4 SR	5 SI
1 Ard El Lewa	0	5.3	11.5	**52.1**	8.5	22.6
2 Mit Uqba	0	0	0	**32.5**	26.6	40.9
3 Bulaq El Dakrour	0	8.2	10.8	23.3	**27.5**	30.2
4 Dar El Salam	9.6	2.8	2.4	21.5	24.5	**39.2**
5 Medieval Cairo	22.9	7.4	2.6	34.4	11.1	21.6
6 City of the Dead	10.4	4.4	20.4	1.1	**50.6**	13.1
7 Manshiyet Nasser	0	22.4	2.7	**34.4**	11.8	28.7
8 Mohandisseen	8.9	14.5	52	7.4	9.7	7.5
9 Zamalek	48.3	14.8	**28.6**	1.7	5.2	1.4
10 Nasr City	13.9	18.7	57.9	2.4	6.4	0.7
12 New Cairo	21.8	35.9	35.6	2.4	3.5	0.8
13 Heliopolis	16.2	18.6	40	3.7	17.4	4.1
14 Omar Ibn El Khattab	17.8	15.4	16.7	21.8	16.6	11.7
TOTALS	16.6	19.9	31.3	10.4	12.6	9.2

Table 18: Cluster Percentages by number – number of blocks in cluster /total block number

	0 OT	1 LR	2 MR	3 MI	4 SR	5 SI
1 Ard El Lewa	0	0.46	2.3	27.7	28.9	**40.64**
2 Mit Uqba	0	0	0	7.4	**59.4**	33.2
3 Bulaq El Dakrour	0	0.3	2.1	8.7	**58**	30.9
4 Dar El Salam	0.06	0.14	0.32	7.35	**50.66**	41.47
5 Medieval Cairo	0.23	0.46	0.69	10.62	**47.9**	40.1
6 City of the Dead	0.21	0.21	3	0.42	**76.8**	19.36
7 Manshiyet Nasser	0	0.62	0.23	4.85	**58.8**	35.5
8 Mohandisseen	0.45	2	22.85	6.4	**45.9**	22.4
9 Zamalek	3.5	9.4	**49.4**	3.5	25.9	8.3
10 Nasr City	1.23	6	**60.14**	5.11	21.52	6
12 New Cairo	1.5	14.8	**39.6**	4.13	23.28	16.69
13 Heliopolis	0.71	4	34	3.65	**46.3**	11.34
14 Omar Ibn El Khattab	0.36	2.7	9.1	15.13	**45**	27.71

Table 17 shows the distribution of the blocks by area, Table 18 shows the distribution of blocks by number, and Figure 47 illustrates the percentages of each. According to the distribution by number (table 18), 40 to 60% of total block number seem to determine the main block type in each settlement. Overall, by number, the sample is dominated by cluster 4 (SR). Cluster 4 is the main block type in nine settlements, and no settlement contains less

than 20% of its blocks classified as cluster 4 (SR). This indicates that this cluster of small, regular blocks may represent a standard or 'traditional' block that is present across the city.

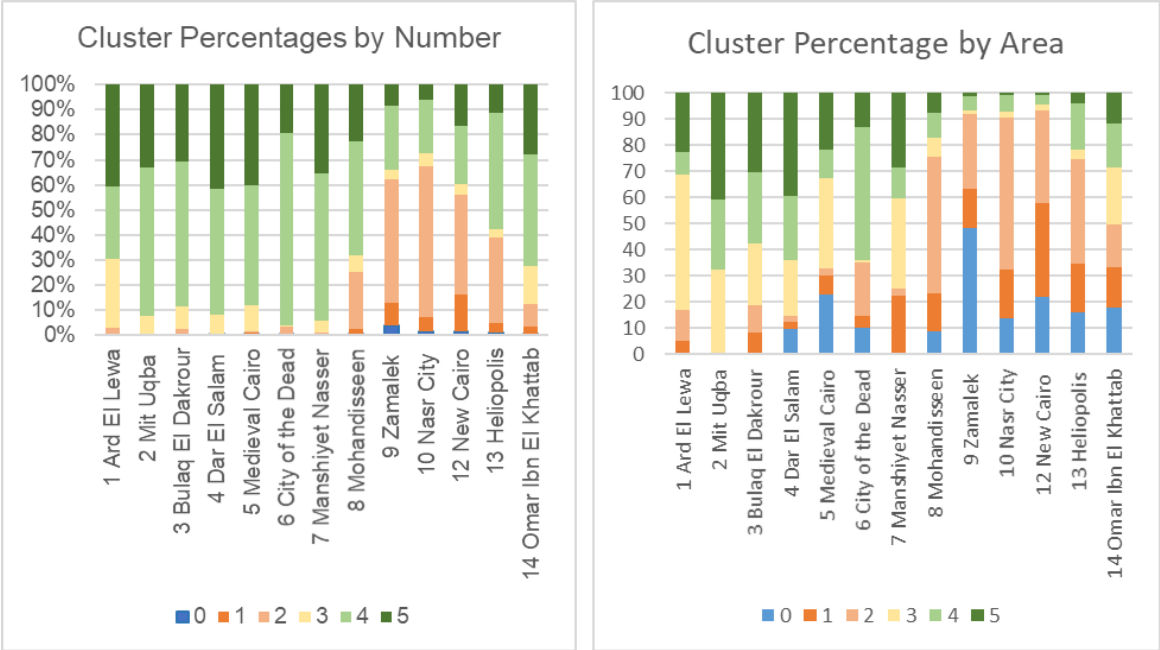


Figure 47: Chart showing the distribution of the clusters by number of blocks and area of blocks

In informal settlements, the main block type is cluster 4 (SR), apart from in Ard El Lewa where the main type is cluster 5 (SI). In planned settlements the main block type is cluster 2 (MR), except in Mohandisseen where it is cluster 4. The main block type in mixed settlements is also cluster 4 (SR).

The distribution of blocks by area, spatial location and number is set out in the below section:

Cluster 0 – Size outliers:

Cluster 0 is rarely present in informal areas. Very large blocks are absent from Ard El Lewa, Mit Uqba, Bulaq El Dakrour and Manshiyet Nasser. This cluster makes up less than 10% area in Dar El Salam and Zamalek has the highest amount of this cluster by number and area.

Cluster 1 - Large, fairly regular with some curves/angles:

Cluster 1 is also rarely present in informal areas. It is not present in Mit Uqba and it makes up less than 10% area in Ard El Lewa, Bulaq, Dar El Salam, Medieval Cairo and City of the Dead. New Cairo has the highest by number and area. Interestingly, this cluster is present in Manshiyet Nasser, which may be tied to the large blocks that form organically on desert land.

Cluster 2 - medium regular – square/rectangular:

Cluster 2 is rarely present in informal areas. It is not present in Mit Uqba, it makes up less than 10% area in Dar El Salam, Medieval Cairo and Manshiyet Nasser. Nasr City has the most by area and number.

Cluster 3 - medium irregular – elongated or dead ends:

Cluster 3 is present in all neighbourhoods across the sample, but mostly in informal neighbourhoods. It is the largest cluster by area and found in the majority of settlements. It is the highest by number and area in Ard El Lewa which may be related to the agricultural grid generating medium sized elongated blocks. It is lowest by number and area in City of the Dead and it makes up less than 10% of the area in Mohandisseen, Zamalek, Nasr City, New Cairo, and Heliopolis.

Cluster 4 - small regular – square/rectangular:

Cluster 4 is also present across the entire sample. It makes up the majority of blocks (40-70%) in Mit Uqba, Bulaq El Dakrour, Dar El Salam, Medieval Cairo, City of the Dead, Manshiyet Nasser, Mohandisseen, Heliopolis and Omar Ibn El Khattab. In all settlements at least 20% of blocks by number belong to cluster 4. It is the highest by number and area in the City of the Dead, which is expected as this settlement was initially designed as small, square plots for courtyard burial houses. It is lowest by number is Nasr City and lowest by

area in New Cairo, both of which contain much larger blocks. It makes up less than 10% of the area in Ard El Lewa, Mohandisseen and Zamalek.

Cluster 5 - small irregular – elongated/dead ends:

Cluster 5 is present across the entire sample, concentrated in informal areas. It is the smallest cluster by area which is expected as it consists of blocks small in area. It is the cluster highest by number Dar El Salam and highest by area in City of the Dead. It is lowest by number and area in Nasr City and makes up less than 10% of area in Mohandisseen, Zamalek, New Cairo, and Heliopolis.

Summary

The cluster analysis resulted in 6 clusters, 1 outlier cluster and 5 clusters determined by k-means. The clusters are as follows:

- Cluster 0 – outliers (OT) (area over 100,000m2) – 53 blocks over entire sample
- Cluster 1 (LR) – Large, fairly regular with some curves/angles
- Cluster 2 (MR) – medium regular – square/rectangular
- Cluster 3 (MI) – medium irregular – elongated or dead ends
- Cluster 4 (SR)– small regular – square/rectangular
- Cluster 5 (SI) – small irregular – elongated/dead ends

Cluster 4 is made up of small-regular blocks and is present in all settlements, with no settlement containing less than 20% cluster 4. This indicates that it may be the standard or traditional block in the city.

5.4. Open Space in the Neighbourhoods

This section explores the amount of open space in the neighbourhoods. It is important to study the percentage of open space since it can provide insight on the space available for public movement and activities in the neighbourhood. Table 19 shows the percentage of

open space in each neighbourhood. The density of each case study was calculated by dividing the area of blocks by the total area of the neighbourhood. While this method may be crude, the fine grain built up area data is unavailable for these neighbourhoods. This method is more accurate for informal areas as the blocks are completely built up. In planned areas, it should take into account that some blocks may contain private open space.

Table 19: Percentages of Open Space in each neighbourhood

Neighbourhood	Total Area (ha) **Source: Google Earth**	Total Block area (ha) **Source: Author Elaboration (GIS)**	Open public space incl. streets (%)
1 Ard El Lewa	335.7	224.3	33.2
2 Mit Uqba	44.7	34.53	22.7
3 Bulaq El Dakrour	218.94	196.2	10.3
4 Dar El Salam	741.1	674.5	8.9
5 Medieval Cairo	500.6	438.2	12.5
6 City of the Dead	150.9	115.3	23.6
7 Manshiyet Nasser	292.6	163.9	43.9
8 Mohandisseen	372.7	298.9	19.7
9 Zamalek	258.9	207.6	20.5
10 Nasr City	1025.7	939.8	8.4
11 New Cairo	2240.9	2154	3.9
12 Heliopolis	2953.8	2181.3	26.1
13 Omar Ibn El Khattab	1179	789.2	33.1

The results show that no neighbourhood except Manshiyet Nasser achieves the 40% open space recommendation set out previously - all suffer from a **lack of open public space.** The neighbourhood with highest open public space is Manshiyet Nasser (43.9%), then Ard El Lewa (33.2%) and Omar Ibn El Khattab (33.1%). The lowest is in New Cairo (3.9%) which seems to be only the vehicular roads as the blocks are gated communities which may have private open spaces.

However, there is still some ambiguity of defining the block by building and street and may be a limitation in this work. It is assumed all open space in informal neighbourhoods (where the block is defined by the building) can be accessed by the public, but in planned settlements (where the block is defined by the street) there is no public access through the blocks. This may not be the case, so the configuration of public space is also studied. This analysis presents the avenue of studying the properties and configuration of open space in more detail, which is covered in the next chapter.

5.5. Conclusions

Based on the previous size, shape, and cluster analysis some tentative conclusions can be drawn. Informal neighbourhoods tend to have smaller, more numerous blocks, while planned neighbourhoods have fewer, larger blocks. This was expected based on the literature and emergence studies done previously. Table 20 summarises the cluster descriptions and their locations in settlements

Table 20: Summary of Cluster Descriptions

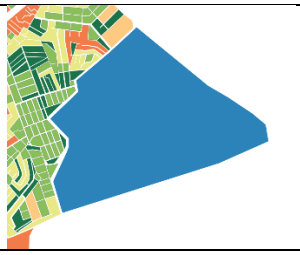
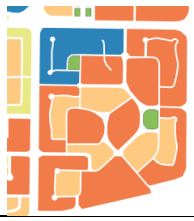
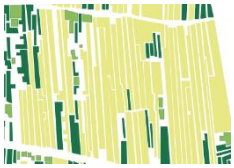
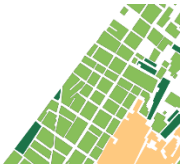
Cluster	Cluster Description	Visualisation	Found In
0	Outliers with Area above 10 ha (blue)		Exceptional Block for certain functions e.g., park, historic area, sporting club – rarely in informal areas
1	Large Blocks – fairly regular in shape with some variation (dark orange)		Mostly in planned neighbourhoods - rarely in informal areas
2	Medium Size regular blocks (light orange)		Mostly in planned neighbourhoods - rarely in informal areas

Table 20 (continued): Summary of Cluster Descriptions

3	Medium Size irregular or elongated Blocks (yellow)		Mostly in Informal neighbourhoods but found in all
4	Small Regular Blocks (light green)		Found in All neighbourhoods
5	Small Irregular blocks (dark green)		Mostly in Informal neighbourhoods

All neighbourhoods in the sample suffer from a lack of open, public space. The large size of blocks in some planned neighbourhoods such as New Cairo and Nasr City can impede walkability and navigability by pedestrians. The small, irregular blocks present in some informal neighbourhoods such as Dar El Salam can be less resilient over time and cannot accommodate different functions. However, all neighbourhoods in the sample have some small- medium, regular blocks which can accommodate various functions.

The block type common to all settlements is cluster 4 SR which represents at least 20% of the blocks in each settlement, and between 40% - 60% in most settlements. This can be thought of to represent the typical block (or can have the role of traditional block) and can be compared to traditional blocks in other cities, and the “ideal” block size.

There is no specific unique block cluster for informal areas, so therefore they can be categorised by what is not present – i.e., the large even blocks for other functions outside of housing. It is suggested that the street network configuration could be more influential in differentiating between types of informal and planned areas.

To summarise:

- The original classification is not completely challenged by the morphological block classification: informal, mixed, and planned tend to follow similar patterns as presented by the original classification.
- There is starting to emerge a differentiation between different types of informality e.g., informal-infill and informal-aggregate.
- The analysis identifies a block type that is commonly present in all neighbourhoods– cluster 4 – SR.
- Mixed neighbourhoods are examples of balanced neighbourhoods, Omar Ibn El Khattab in particular. There exists a potential for accommodating varied functions in mixed settlement.

CHAPTER 6: CONFIGURATION OF OPEN SPACE OF SETTLEMENTS

6.1. Introduction

This chapter focuses on analysing movement from a pedestrian perspective, following the logic of movement in open space rather than on a predefined street network. Axial analysis is used to look specifically at pedestrian movement and the integration core of the settlement. Both local and global integration measures are used in this analysis. The global integration measure uses an infinite radius so it can be used to represent the syntactic structure of the settlement and its whole potential for movement. Local integration measure uses a set number of steps/turns to create a representation of potential movement within that number of steps/turns. In this case, the radius is set to three turns (root + two topological steps).

6.2. Spatial Structure and Integration Core

In this section, the syntactic structure and integration core of each settlement is studied. For each settlement, both global and local integration core are identified and explained in terms of configuration. As stated previously in chapter 3.1, the integration core is the network of the most highly integrated streets in a system. This network tends to correspond with the centre of neighbourhood and can be presented in five main configurations. The effect of the neighbourhood boundary and the highway connection on the pedestrian network are also described.

6.2.1. Ard El Lewa

Table 21: Integration Values for Ard El Lewa

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.08	0.19	17.5	0.63	1.78
Int_R3	2.15	0.61	28.5	0.68	4.37

Figure 48 shows the global and local integration cores of Ard El Lewa. In Ard El Lewa, the presence of strong boundaries through and around the settlements creates a split in the neighbourhood, and each part of the neighbourhood seems to function independently (Zied and Vialard 2020). The global integration core has the potential to become a deformed wheel, there is centre and branch movement but little edge movement. This indicates that some areas of the settlement may be segregated from the rest, as the branches of the integration core do not reach there. The global integration core of Ard El Lewa is centred

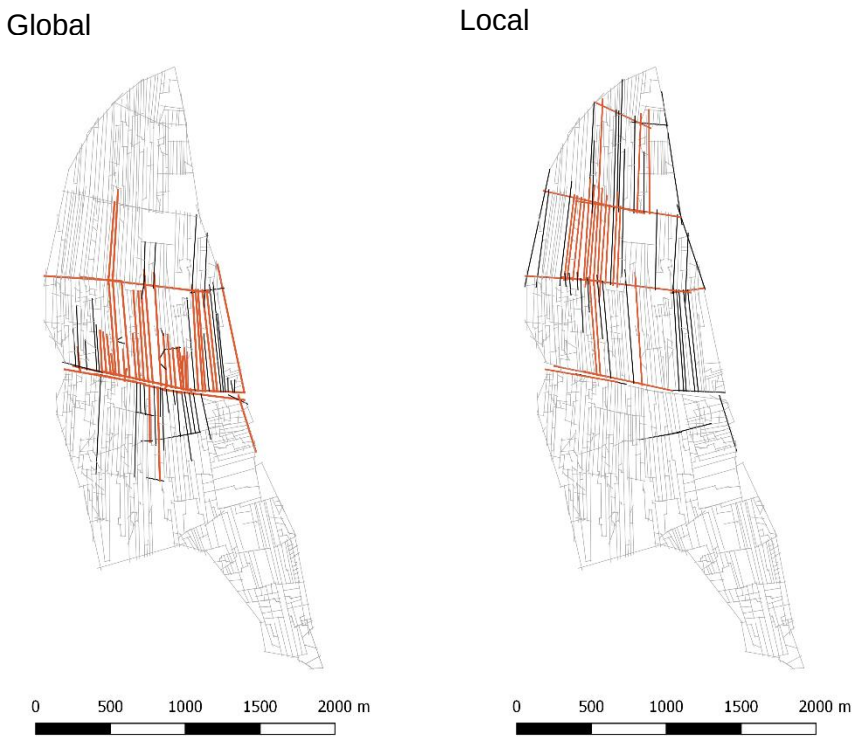


Figure 48: Local and Global Integration Cores for Ard El Lewa

around the highway that cuts through the settlement, following the two pedestrian paths that are parallel to the highway. It presents a potential live centre (local densification) that is interrupted by the highway. The branches of the core reach mostly into the northern part of the settlement, with some branches in the southern part. There is little edge movement on the right side of the settlement (Al Zomor Canal) and no edge movement on the left where the Ring Road prevents further expansion. There is no clear north-south axis that spans the entire settlement, and the east-west axis in the north follows the ex-canal.

The local integration core indicates that the northern part of the settlement has the most potential for movement. The most integrated streets follow the ex-canal pattern, with the north-south streets connecting them. The most integrated streets do not reach the south part of the settlement, which can indicate that it may be difficult to reach the south part from the other parts of the settlement, further segregating it.

Overall, the integration core presents as a local system segregated from the surroundings, but there is formation of a dense local core in development. This analysis highlights the issue of there being bias towards north-south axes with many streets, without indicating which is more important. East-west axes are strong and clear but few.

Table 21 shows the integration values for Ard El Lewa. The global integration value has a range of 0.63 - 1.78, with a mean of 1.08. The standard deviation is 0.19, and the co-efficient of variation is 17.5%. The local integration value has a range of 0.68 – 4.37, and a mean of 2.15. The standard deviation is 0.61, and the co-efficient of variation is 28.5%. The integration values show that on a global level the system is integrated with low standard deviation, which indicates that there are no areas of extreme segregation or integration. On a local level, the mean integration is higher indicating there are some very easily accessible streets within 3 steps, more so than on a global level. The standard deviation is also higher which means that there are areas of segregation, as shown in the visualisation.

6.2.2. Mit Uqba

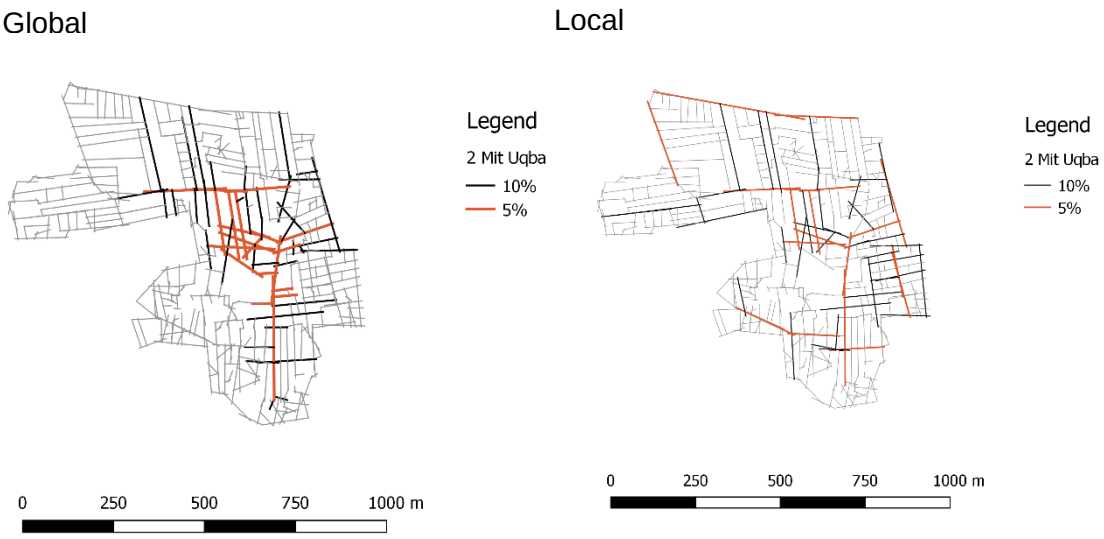


Figure 49: Local and Global Integration Cores for Ard El Lewa

Table 22: Integration values for Mit Uqba

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.09	0.19	17.9	0.63	1.71
Int_R3	1.95	0.48	24.5	0.33	3.19

Figure 49 shows the global and local integration cores of Mit Uqba. This analysis was carried out using a map of Mit Uqba before the highway was built and the neighbourhood split. The global integration core of Mit Uqba (left) presents as **a partial deformed wheel at the global scale but a full deformed wheel at the local scale.** This indicates that the neighbourhood has the potential to be easily navigable and accessible by pedestrians. There is little edge movement at the global level, but this can be due to the surrounding Mohandisseen neighbourhood having a different street network and preventing connection. In both local and global level, the core corresponds with the real-life centre of the neighbourhood, where there is a marketplace and a sporting club. This structure indicates a 'healthy neighbourhood' where the core is accessible from different parts of the

neighbourhood. **The main street of Mit Uqba (south) also presents potential to act as a live centre at the global scale.** While it is not connecting two different street networks, the main road is accessible by intersecting streets that lead to other parts of the settlement.

Table 22 shows the integration values of Mit Uqba. The global integration value has a range of 0.63 - 1.71, with a mean of 1.09. The standard deviation is 0.19, and the co-efficient of variation is 17.9%. The local integration value has a range of 0.33 – 3.19, and a mean of 1.95. The standard deviation is 0.48, and the co-efficient of variation is 24.5%. The integration values show that the neighbourhood is slightly more integrated on a local level than on a global level, but that locally there are some areas of segregation due to the high standard deviation. It is similar to Ard El Lewa in this aspect, but it is much less pronounced.

6.2.3. Bulaq El Dakrour

Figure 50 shows the integration cores of Bulaq El Dakrour. On a global level, the integration core in Bulaq El Dakrour presents as a partial deformed wheel, with the main core roughly aligned with the centre of the neighbourhood. Branches reach the edges of the neighbourhood and there is slight edge movement on either side of the neighbourhood. On a local level, the deformed wheel becomes more pronounced, with further edge movement

Figure 50: Global and Local Integration Cores for Bulaq El Dakrour

on three edges of the neighbourhood and clearer branches. This can indicate that most parts of the neighbourhood are easily accessible within three topological steps, and therefore more accessible to pedestrians. The main street in the centre of the settlement can be considered a live centre, since it has many local streets intersecting it. It is important to note that on both a global and local level, the most integrated streets follow the ex-canal system that previously irrigated the agricultural land. This can shed light on the process of growth of the neighbourhood and the influence of the canals and agricultural grid on the resulting street network.

Table 23: Integration Values for Bulaq El Dakrour

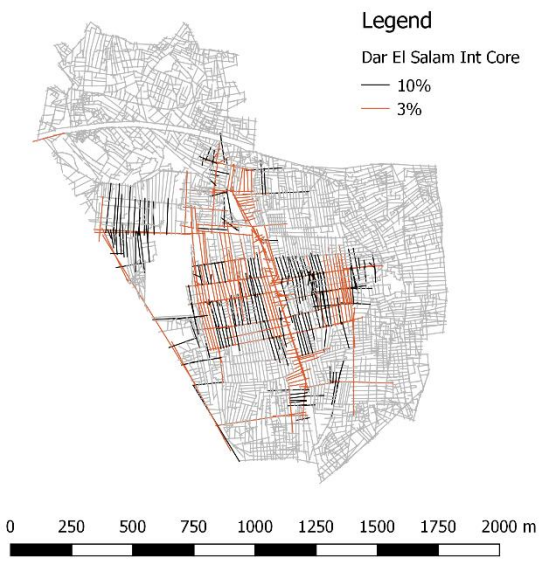
Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.49	0.25	16.6	0.73	2.39
Int_R3	2.39	0.62	26.2	0.85	4.58

Table 23 shows the integration values of Bulaq El Dakrour. The global integration value has a range of 0.73 – 2.39, with a mean of 1.49. The standard deviation is 0.25, and the co-efficient of variation is 16.6%. The local integration value has a range of 0.85 – 4.58, and a mean of 2.39. The standard deviation is 0.62, and the co-efficient of variation is 26.2%. The integration values show a similar trend to the other neighbourhoods, where the neighbourhood is more locally integrated than globally integrated. All integration values are

similar to those of Ard El Lewa, which may be because they have similar processes of emergence and growth on an agricultural grid. However, in this case the global standard deviation and co-efficient of variation is higher, which can indicate that there are some segregated areas.

6.2.4. Dar El Salam

Global



Local

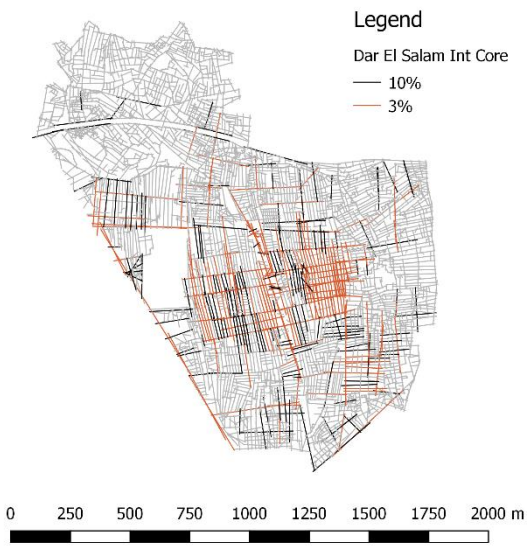


Figure 51: Global and Local Integration Cores of Dar El Salam

Table 24: Integration Values for Dar El Salam

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.07	0.19	18.6	0.55	1.72
Int_R3	2.39	0.62	26.1	0.33	4.69

In Dar El Salam there are two distinct street networks due to its emergence and growth on both desert and agricultural land. There is also an industrial area to the west of the neighbourhood, but this is separated from the main neighbourhood by train tracks, so it has been excluded from this analysis.

Figure 51 shows the local and global integration cores. On a global level the integration core is centred around the main street of the neighbourhood, which presents as a partial live centre. This live centre does not connect two different street networks, but it connects either side of the settlement. Branching is limited to the centre of the neighbourhood and there is little edge movement by the side of the train tracks. The integration core does not extend to the northern part of the settlement where there is a different street network pattern. This is due to the highway disrupting the pedestrian access to the northern part of the settlement. On a local level, the integration core is still centred in the middle of the neighbourhood but there are more branches into the rest of the neighbourhood which connect to the edges in some places. There are also other smaller sub-cores highlighted on a local level. There is also slightly more edge movement along the highway and at the south of the neighbourhood where it meets Ma'adi. The integration core also extends slightly to the northern part of the settlement. This indicates that the neighbourhood is locally accessible (within 3 steps) but not necessarily globally connected.

Table 24 shows the integration values for Dar El Salam. The global integration value has a range of 0.55 – 1.72, with a mean of 1.07. The standard deviation is 0.19, and the co-efficient of variation is 18.6%. The local integration value has a range of 0.33 – 4.68, and a mean of 2.39. The standard deviation is 0.62, and the co-efficient of variation is 26.1%. These values are similar to Ard El Lewa; the integration values follow a similar trend in that local integration is higher than global integration. Globally the standard deviation and co-efficient of variation are low so this indicates that there are not very many segregated areas. However, all the global integration values are low compared to previous neighbourhoods, so this shows that the entire network is less integrated than similar neighbourhoods. Locally, the standard deviation is higher, but this can be explained by a decrease in the minimum integration on a local level. This is also seen in Mit Uqba which has a similar structure to the northern (desert) part of Dar El Salam, so this decrease could be related to the type of growth, as it is not seen in the neighbourhoods on an agricultural grid.

6.2.5. Medieval Cairo

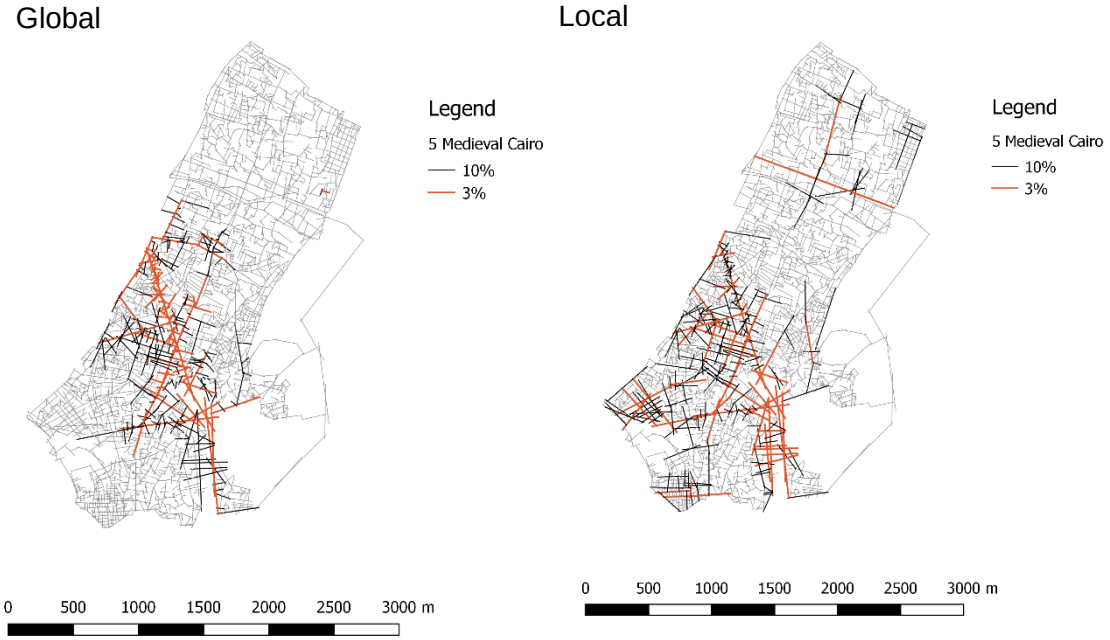


Figure 52: Local and Global Integration core for Medieval Cairo

Table 25: Integration Values for Medieval Cairo

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	0.88	0.17	19.4	0.49	1.40
Int_R3	2.03	0.68	33.7	0.33	4.48

The urban fabric and street network in Medieval Cairo are defined by its historic boundaries, the city wall, citadel and main thoroughfare, *Al Muizz* Street. Figure 51 illustrates the integration core. The global integration core in Medieval Cairo presents as a live centre around the Mohamed Ali Pasha Boulevard, with several strong branches intersecting to create a centre in the south of the neighbourhood. There is some edge movement limited to the west of the neighbourhood. The global integration core does not reach the north part of the neighbourhood, indicating that it is less accessible to pedestrians. This can be due to the main road that cuts through the neighbourhood, which has limited pedestrian crossing opportunities. One of these branches partially covers *Al Muizz* St but does not extend to the northern part of the settlement. This is similar to Dar El Salam, where the highway disrupts the pedestrian network.

On a local level the integration core becomes more regionalised, with smaller sub-cores emerging in the southern part of the neighbourhood and connected by branches, one of which covers *Al Muizz* Street. A smaller sub-core emerges in the north of the neighbourhood, also covering Al Muizz St and the street parallel to the highway. On a local level, the historic main thoroughfare is accessible in most areas, but it does not connect the two parts of the settlement.

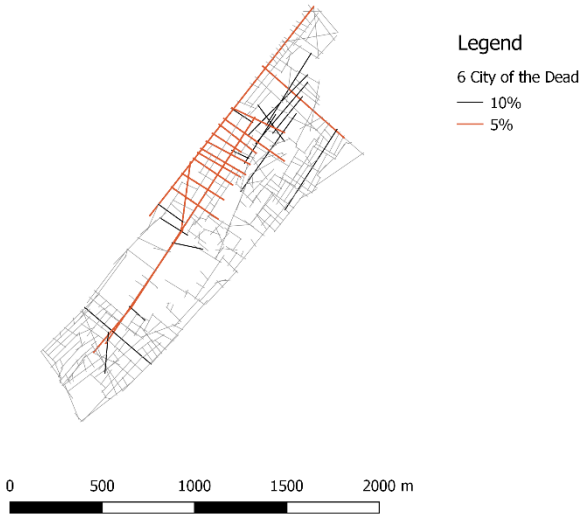
Table 25 shows the integration values for Medieval Cairo. The global integration value has a range of 0.49 – 1.40, with a mean of 0.88. The standard deviation is 0.17, and the co-efficient of variation is 19.4%. The local integration value has a range of 0.33 – 4.48, and a mean of 2.03. The standard deviation is 0.62, and the co-efficient of variation is 33.7%. The integration values are all lower than in other neighbourhoods, indicating that this neighbourhood is less accessible than others. On a global level, the standard deviation and co-efficient of variation are low, so the entire neighbourhood is similarly integrated with no extremely segregated areas. On a local level, the standard deviation increases but this could be due to the decrease in minimum integration. This is like other neighbourhoods that have emerged on desert land, which can indicate that there is some area of the street network, connected with emergence, that is less accessible on a local level.

6.2.6. City of the Dead

The City of the Dead is a unique case because it was initially designed as a cemetery and became informal over time. The initial grid morphology is still evident except in the centre of the settlement where the built-up area has become denser. Figure 53 shows the integration cores of City of the Dead. On a global level, the integration core presents as a partial live centre in the northern part, where there is access to both the highway and the inner neighbourhood. It has a clear centre that follows the central thoroughfare of the neighbourhood. Branches extend into each part of the neighbourhood and there is edge movement on the western side of the neighbourhood where it meets the Salah Salem highway, the main point of vehicular access to the neighbourhood. On a local level, the

integration core becomes more regionalised, with two sub-cores present. The core still follows the main thoroughfare and spans the length of the neighbourhood. Smaller cores emerge in the north and south of the neighbourhood, with branches that span from east to west. Edge movement is increased and present on both sides of the neighbourhood.

Global



Local

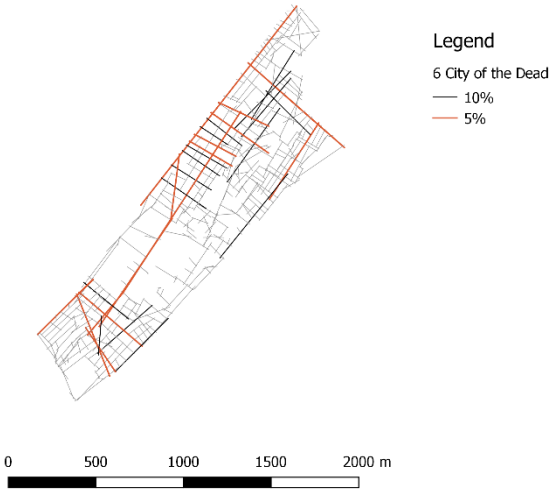


Figure 53: City of the Dead Integration Cores

Table 26: City of the Dead Integration Values

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.47	0.28	19.0	0.81	2.35
Int_R3	2.29	0.55	24.1	0.42	3.95

Table 26 shows the City of the Dead integration values. The global integration value has a range of 0.81 – 2.35, with a mean of 1.47. The standard deviation is 0.28, and the co-efficient of variation is 19%. The local integration value has a range of 0.42 – 3.95, and a mean of 2.29. The standard deviation is 0.55, and the co-efficient of variation is 24.1%. The integration values are similar to those of neighbourhoods on an agricultural grid. This could be due to the more regular, initially planned, grid in this neighbourhood. Standard deviation

is fairly low which indicates that there are not many segregated areas. This is reinforced by the integration core visualisation which shows the core permeating most of the neighbourhood. Local integration values are higher than global integration values, which follows the trend set by previous neighbourhoods.

6.2.7. Manshiyet Nasser

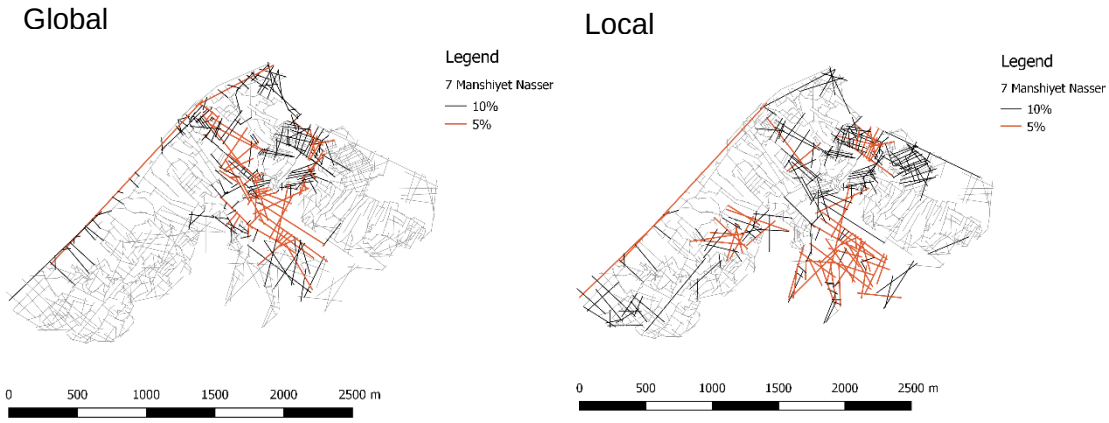


Figure 54: Manshiyet Nasser Integration Core

Table 27: Manshiyet Nasser Integration Values

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	0.94	0.15	16.5	0.50	1.32
Int_R3	2.41	0.87	36.13	0.33	5.43

Figure 54 shows the integration core of Manshiyet Nasser. The global integration core in Manshiyet Nasser presents as an elongated core at the global scale and a series of disconnected sub-cores at the local scale. The core is near the northeast of the neighbourhood where there is a sporting club/playing field and some open space. Some branches extend to the south of the settlement near the cliff face and the edge movement is limited to the road parallel to El Nasr Rd Highway. There is no branching that reaches the western part of the neighbourhood, indicating that it may be less accessible.

On a local level, the integration core is more regionalised, with smaller sub-cores appearing by the cliff edge and in the east and west of the neighbourhood. Branches are increased

and one branch follows the main thoroughfare in the west of the neighbourhood. Edge movement is also increased on the road parallel to El Nasr Road highway and on the eastern edge of the neighbourhood, which corresponds with the main vehicular access route to the neighbourhood. This indicates that all these areas are well integrated within three topological steps, so are easier to access for pedestrians.

Table 27 shows the integration values of Manshiyet Nasser. The global integration value has a range of 0.5 – 1.32, with a mean of 0.94. The standard deviation is 0.15, and the co-efficient of variation is 16.5%. The local integration value has a range of 0.33 – 5.43, and a mean of 2.41. The standard deviation is 0.55, and the co-efficient of variation is 24.1%. Integration values show a similar trend to previous settlements, with local values being higher than global values. In global integration the standard deviation is low, indicating that there are few segregated areas. Local integration values show a similar trend to other neighbourhoods built on desert land, with a higher standard deviation due to a lower minimum and increased maximum. This reinforces the idea that emergence on desert land can lead to a street network with more segregated areas when compared to emergence on an agricultural grid.

6.2.8. Mohandisseen

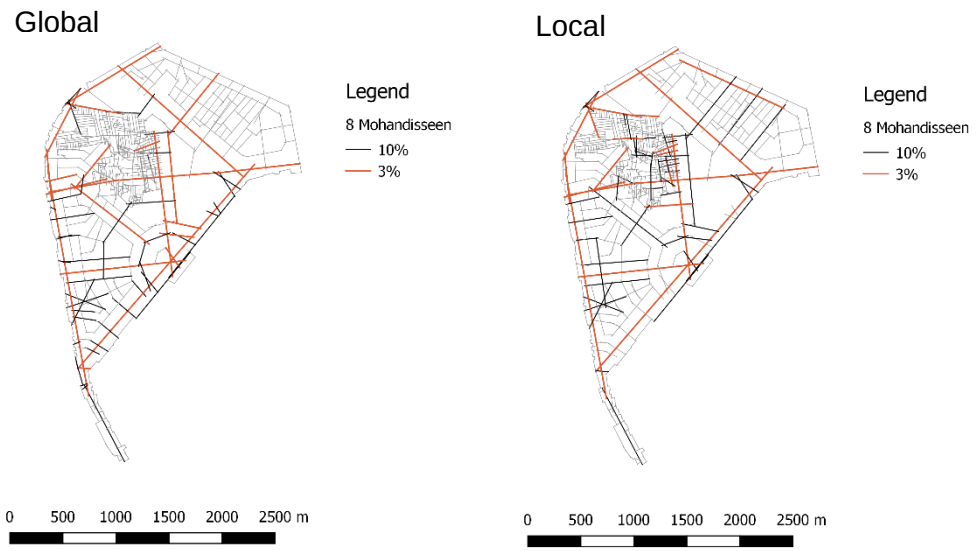


Figure 55: Mohandisseen Integration Core

Table 28: Integration Values of Mohandisseen

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.35	0.25	18.7	0.68	2.28
Int_R3	2.00	0.62	30.9	0.33	3.86

This analysis is carried out using the modern map of Mohandisseen and Mit Uqba, with the highway cutting through Mit Uqba. Figure 55 shows the integration core of Mohandisseen. The integration core in Mohandisseen does not present a clear centre, and is continuous throughout the neighbourhood, following the main vehicular routes. Branches follow the radial street network and edge movement is present around the neighbourhood. The global integration core does not extend to Mit Uqba, the informal area within Mohandisseen. However, there is some edge movement at the north of Mit Uqba, indicating that it is possible for pedestrians to access Mohandisseen easily from that side, rather than along the highway.

On a local level, the integration core still follows the main vehicular routes rather than align with the neighbourhood centre. The integration core of Mit Uqba is now visible, which is expected as it would be accessible to pedestrians within the three-step radius. Edge movement is increased on all sides of the neighbourhood, and on the side of Mit Uqba.

Table 28 shows the integration values of Mohandisseen. The global integration value has a range of 0.68 – 2.28, with a mean of 1.35. The standard deviation is 0.25, and the co-efficient of variation is 18.7%. The local integration value has a range of 0.33 – 3.86, and a mean of 2.0. The standard deviation is 0.62, and the co-efficient of variation is 30.9%. Integration values show that global integration is slightly higher than in previous informal neighbourhoods (except City of the Dead, which was initially planned), but local integration is lower. This indicates that it might be more difficult for pedestrians to access parts of the neighbourhood. This is reinforced by the integration core following vehicular routes rather than presenting as a deformed wheel. The minimum local integration is influenced by Mit

Uqba rather than any part of Mohandisseen, which has also increased local standard deviation.

6.2.9. Zamalek

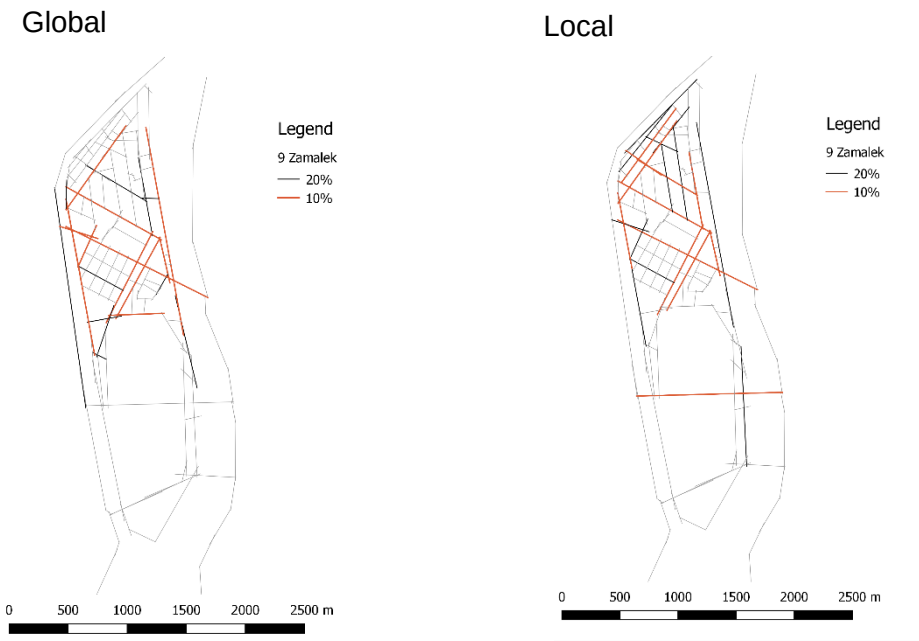


Figure 56: Integration Core of Zamalek

Table 29: Zamalek Integration Values

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.38	0.30	21.9	0.61	2.23
Int_R3	2.02	0.51	25.2	0.85	3.36

Figure 56 presents the integration core in Zamalek. Both the local and global integration cores present continuous cores that follow the main vehicular routes in the neighbourhood. One of the most integrated streets is the 26th of July Corridor highway, which is highlighted in both global and local integration core. The neighbourhood seems to be well integrated overall and accessible for pedestrians.

Table 29 presents the integration values for Zamalek. The global integration value has a range of 0.61 – 2.23 with a mean of 1.38. The standard deviation is 0.30, and the co-efficient

of variation is 21.9%. The local integration value has a range of 0.85 – 3.36, and a mean of 2.02. The standard deviation is 0.51, and the co-efficient of variation is 25.2%. The integration values follow the trend of local integration being higher than global integration, with values similar to that of Mohandisseen. The standard deviation is slightly higher than other settlements indicating that there may be some segregated areas. This is expected due to the large sporting club and army area that are inaccessible to pedestrians. Local integration is lower than in informal areas and similar to Mohandisseen.

6.2.10 Nasr City

Figure 57: Integration Core in Nasr City

Table 30: Nasr City Integration Values

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.49	0.30	20.3	0.81	2.80
Int_R3	2.14	0.53	24.9	0.86	3.81

Figure 57 shows the integration core. In Nasr City, like previous planned settlements, the integration core is continuous and follows the main vehicular routes, which in this case are the main highways that make up the neighbourhood super-grid. There is some branching

off these main roads into the residential areas to provide access. Edge movement is limited to the El Nasr Road highway, which is expected due to the rest of the integration core following main vehicular routes.

Table 30 shows the integration values in Nasr City. The global integration value has a range of 0.81 – 2.8 with a mean of 1.49. The standard deviation is 0.30, and the co-efficient of variation is 20.3%. The local integration value has a range of 0.86 – 3.81, and a mean of 2.14. The standard deviation is 0.53, and the co-efficient of variation is 24.9%. Integration values are similar to other planned settlements. Local integration is slightly higher, meaning that areas are more accessible within three topological steps. Global integration standard deviation is higher than in informal areas, which can indicate that there are some areas that are more segregated. Local integration standard deviation is similar to Zamalek, even though there are no blocked off areas. This could indicate that planned neighbourhoods have some locally segregated zones.

6.2.11. New Cairo

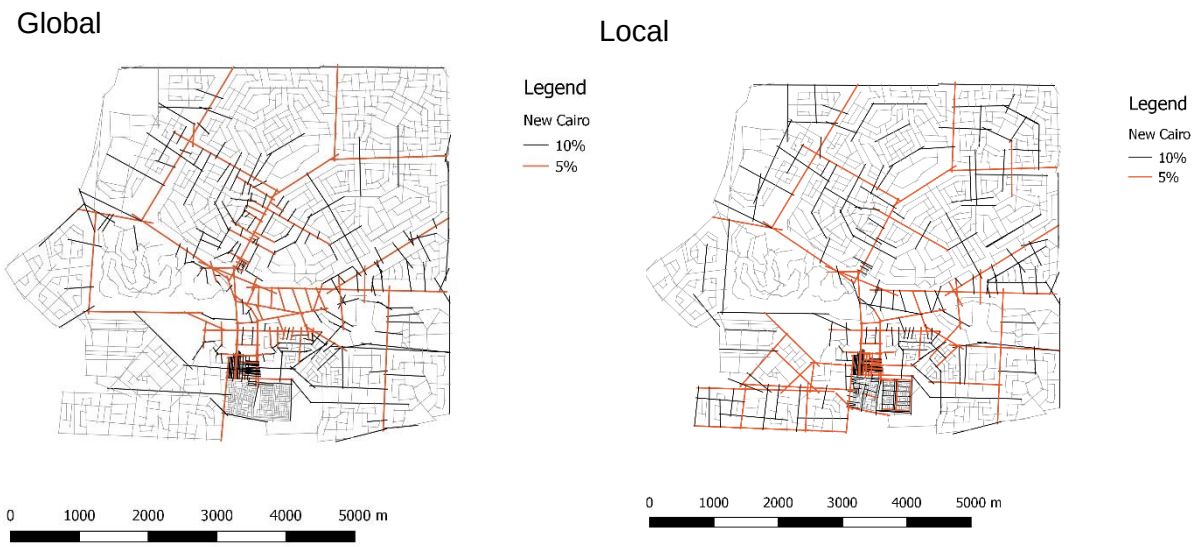


Figure 58: Integration Core of New Cairo

Table 31: Integration Values of New Cairo

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.11	0.24	21.8	0.23	1.94
Int_R3	1.88	0.59	31.7	0.33	3.75

Figure 58 illustrates the integration core. In New Cairo, both the local and global integration core follow the main vehicular routes in the neighbourhood. It presents as a continuous layout with some branches into the residential parts of the neighbourhood. There is some edge movement, and the Ring Road highway is not highlighted, which is unexpected in this case. While it is not a pedestrian path, it is the main highway in the area. Edge movement is present in the north of the neighbourhood, following Al-Tes'een Street, another main vehicular route. On a local level, branching is increased into the residential areas and there is more movement at the edge of the neighbourhood.

In both the local and global integration core there is a network of highly integrated streets centred around the Third Settlement, the planned neighbourhood that resembles an informal area. This could be due to the blocks being smaller and the streets closer together, leading to further connectivity and therefore higher integration. This can indicate that this area is more accessible for pedestrians than other parts of the neighbourhood, which is expected as it is designed for lower income residents that may not own a vehicle.

Table 31 shows the integration values. The global integration value has a range of 0.23 – 1.94 with a mean of 1.11. The standard deviation is 0.24, and the co-efficient of variation is 21.8%. The local integration value has a range of 0.33 – 3.75, and a mean of 1.88. The standard deviation is 0.59, and the co-efficient of variation is 31.7%. Integration levels are similar to those of other planned settlements, with local integration being slightly higher than global integration. Local integration mean is lower than other planned areas, meaning that this neighbourhood may be less accessible to pedestrians. This is expected as it was

designed for a higher socioeconomic class who are assumed to own a vehicle. The minimum integration value is the same as in organic-historic informal areas. The minimum is present in the curvilinear road network in the compound in the west of the neighbourhood. This could indicate that it is not emergence that influences this specific value, but rather the eventual curvilinear morphology of the street network that emerges on desert land.

6.2.12. Heliopolis

Global

Local

Figure 59: Integration Core of Heliopolis

Table 32: Integration Values of Heliopolis

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.78	0.35	19.5	1.06	3.51
Int_R3	2.62	0.63	23.9	0.81	5.02

This case study is considered mixed as it has both planned and informal street networks. The planned neighbourhood is on the eastern side and the informal neighbourhoods are on the western side. Figure 59 illustrates the integration core. The global integration core presents as a clear **live centre**, with the main Gesr El Suez highway being intersected by streets from both street networks, therefore connecting the two different networks. Branches extend from the live centre into each part of the neighbourhoods, creating clear east-west

axes. There are also some other north-south branches within each neighbourhood, as well as the live centre.

The local integration core presents as a live centre with further branching into each neighbourhood. In the planned neighbourhood, the integration core follows the main vehicular routes and the clear radial street network pattern, allowing access to all parts of the neighbourhood. Branches extend into the informal neighbourhoods from the live centre and create a clear east-west axis. Some branches also create a north-south axis. Overall, both global and local integration cores indicate a well-connected, integrated, and pedestrian accessible street network.

Table 32 presents the integration values. The global integration value has a range of 1.06 – 3.51 with a mean of 1.78. The standard deviation is 0.35, and the co-efficient of variation is 19.5%. The local integration value has a range of 0.81 – 5.02, and a mean of 2.62. The standard deviation is 0.63, and the co-efficient of variation is 23.9%. Both global and local mean integration values are the highest out of all other neighbourhoods in the sample, regardless of type. This shows that these neighbourhoods are both globally connected and locally accessible. Standard deviation is similar to other planned areas, but it is increased slightly due to the high maximum integration. The minimum integration is similar to other planned settlements, which indicates that in both informal and planned areas of the neighbourhood there are no extremely segregated areas. The most integrated street is the Gesr El Suez highway, which is expected as it is the live centre. This case shows that it is possible to connect planned and informal areas, and this improves the pedestrian network in both areas.

6.2.13. Omar Ibn El Khattab

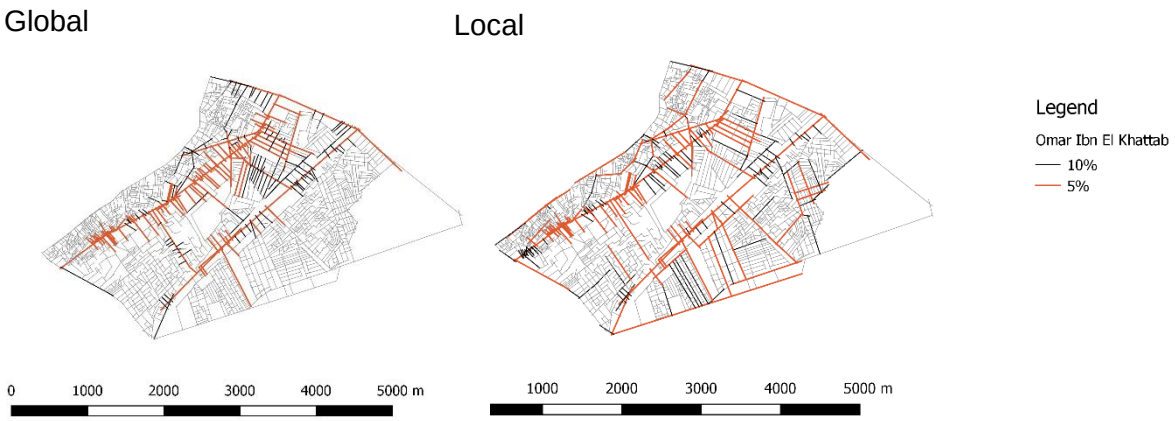


Figure 60: Integration Core of Omar Ibn El Khattab

Table 33: Integration values for Omar Ibn El Khattab

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.10	0.22	19.6	0.46	1.88
Int_R3	1.83	0.67	36.6	0.33	4.35

Omar Ibn El Khattab is another example of a mixed neighbourhood, with the planned areas in the south and informal areas (ex-agricultural village) in the north. Figure 60 presents the integration core. The global and local integration core presents as two live centres. The live centre follows the vehicular route in the planned area. Some branching connects the two main routes, creating east-west access. There is also some edge movement along the north. The local integration core is more successful connecting to the south edge of the neighbourhood. This can indicate that the neighbourhoods are accessible by pedestrians from each of the main roads.

Locally, branches reach across the neighbourhood and connect to the nearest main road. There is no edge movement present on all sides of the neighbourhood, especially in the south along Gesr El Suez Highway. In the informal agricultural area, the local integration core follows the main curved road, which seems to be influenced by the canal system, as

in other agricultural informal areas. This indicates that each part of the neighbourhood is locally accessible by its residents, and it is clear which are the main roads in each area.

Table 33 presents the integration values. The global integration value has a range of 0.46 – 1.88 with a mean of 1.10. The standard deviation is 0.22, and the co-efficient of variation is 19.6%. The local integration value has a range of 0.33 – 4.35, and a mean of 1.83. The standard deviation is 0.67, and the co-efficient of variation is 36.6%. The integration values mean is lower than that of planned neighbourhoods, but higher than informal neighbourhoods. Standard deviation and co-efficient of variation are also between those of informal areas and planned areas and indicate that there are no extremely segregated areas. The maximum integration is found on the live centre road in the north of the neighbourhood, which is expected. Minimum local integration is the same as other historic/organic informal settlements, which reinforces the idea that the emergence and eventual configuration influenced this value. When compared with the other mixed neighbourhood of Heliopolis, this neighbourhood is not as well integrated and accessible, but still has some elements of successful connection between different street networks such as the live centre.

6.3. Conclusions

Table 34 sets out the summary of the results and includes the name of the settlement, the mean global and local integration value and the configuration of each.

Table 34: Summary Table of Axial Analysis

Neighbourhood	**Int_Global**	**Global Core Configuration**	**Int_R3**	**Local Core Configuration**
Ard El Lewa	1.08	Local densification (potential live centre)	2.15	Shift – more developed deformed wheel
Mit Uqba	1.09	Partial deformed wheel	1.95	Deformed wheel
Bulaq El Dakrour	1.49	Partial deformed wheel	2.39	More continuous layout – deformed wheel still present
Dar El Salam	1.07	Partial live centre	2.39	More regionalised – sub-cores emerging
Medieval Cairo	**0.88**	Live centre (or elongated)	2.03	Live centre + multiple sub-cores

Table 34 (continued): Summary Table of Axial Analysis

City of the dead	1.47	Live centre	2.29	Live centre (unchanged) – sub-cores emerging
Manshiyet Nasser	0.94	Elongated	2.41	Multiple sub-cores
Mohandisseen	1.35	Continuous – following vehicular roads	2.00	Continuous – following vehicular roads
Zamalek	1.38	Continuous – following vehicular roads	2.02	Continuous – following vehicular roads
Nasr City	1.49	Continuous – following vehicular roads	2.14	Continuous – following vehicular roads
New Cairo	1.11	Continuous – following vehicular roads	**1.88**	Continuous – following vehicular roads
Heliopolis	**1.78**	Live centre	**2.62**	Live centre + dispersed (no edge)
Omar Ibn El Khattab	1.10	2 live centres	**1.83**	2 live centres + edge highlighted

The axial analysis presents the street network following the logic of pedestrian movement. Different emergences and types of neighbourhood influence the pedestrian network, and there is a noticeable difference between how the pedestrian network presents in informal and planned areas. Highways sometimes disrupt the pedestrian network in informal areas, but in planned areas they tend to be part of the integration core. There are also some recurring elements which can be used to classify settlements.

In informal-agricultural neighbourhoods, the integration core tends to **present one of the configurations conducive to community encounters, either a partial deformed wheel or live centre**. The values tend to be high local integration and lower global integration. The main roads tend to follow the ex-canal pattern, which shows that the agricultural grid influenced emergence and growth. In informal-historic neighbourhoods that emerge on desert land, the integration core tends to be a deformed wheel with less edge movement or contain a live centre. Both the local and global integration is lower than that of informal-agricultural neighbourhoods, but the standard deviation tends to be lower, which indicates that there are no extremely segregated areas. The minimum local integration for all the informal-historic neighbourhoods is the same, indicating that this value may be related to

the curvilinear/organic street network. Generally, in informal neighbourhoods, the local integration core is often a configuration that is more conducive to community encounters than the global integration core.

In planned neighbourhoods the integration core is generally continuous throughout the settlement and follows the main vehicular routes. The global integration tends to be higher than in informal areas, but the local integration tends to be lower. This indicates that the neighbourhoods are easily accessible in a larger movement radius but may be less accessible within a small radius for pedestrians.

In mixed neighbourhoods the integration core tends to present as a live centre with branching into each side of the neighbourhood. Both the global and local integration are high, meaning that the neighbourhood can be accessible within a large or small radius of movement. The mixed neighbourhoods also show the possibility of connecting different street networks by creating a live centre.

The highway also plays a role in the configuration of the pedestrian network. In informal neighbourhoods, the highway often disrupts the pedestrian network and can prevent pedestrians from accessing different parts of the neighbourhood, such as in Ard El Lewa and Dar El Salam. When the highway is on the edge of the informal neighbourhood, access can vary. The pedestrian street parallel to the highway is often highly integrated. In planned settlements, the highway is generally part of the integration core and easily accessed from the neighbourhood.

This analysis highlights the different movement networks that are present within the neighbourhoods. The networks may overlap, or they may present differently. The pedestrian network can also be interrupted by the vehicular network. The next chapter studies the street network from the vehicular point of view.

CHAPTER 7: STREET NETWORK ANALYSIS AND SYNTACTIC CLUSTERING OF STREETS

7.1. Introduction

In this chapter, the street network is studied from a vehicular point of view using a segment map analysis as it is based on street centrelines. This representation includes the highways that were omitted from axial analysis, and shows loops, flyovers and bridges. Additionally, it models the connection of the highway to the local grid more accurately to study the interface between them.

The street centreline definition is different in planned and informal areas. In planned areas, the segment lines are derived from the streets that are available on the initial vector map. In informal areas the segment lines are derived from the available streets on Google Earth or Open Street Map. When this is not available, the street centreline is taken as the centre of open space between blocks.

Each measure has been selected in order to investigate a specific element of the street network. They can be broadly grouped into integration, choice, and reach, and are described in detail in Chapter 3.2. 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).

The cluster analysis is used to find trends in a large unstructured dataset and combine findings from individual variables, essentially to address the question: *are there unique street network configurations/street types in informal areas to aid in classification?*

The cluster analysis uses k-means clustering. This is useful when the number of clusters and cluster parameters is unknown. The k is determined experimentally then validated by the elbow graph. The clusters are then studied by variable ranges, distribution and spatial configuration. After this, the clusters can be given meaningful verbal descriptions which can relate back to previous categorisation of streets in the literature.

The following sections outline the **findings** of the segment analysis, presented by measure to aid comparison between settlements. **Trends and themes** in informal and planned areas

are presented. After this, the **cluster analysis** based on the segment analysis values is presented and characterised, along with descriptions of the characteristics of each cluster.

7.2. Results of the Street Segment Analysis

This section outlines the findings of the segment analysis presented by measure.

7.2.1. Angular Integration

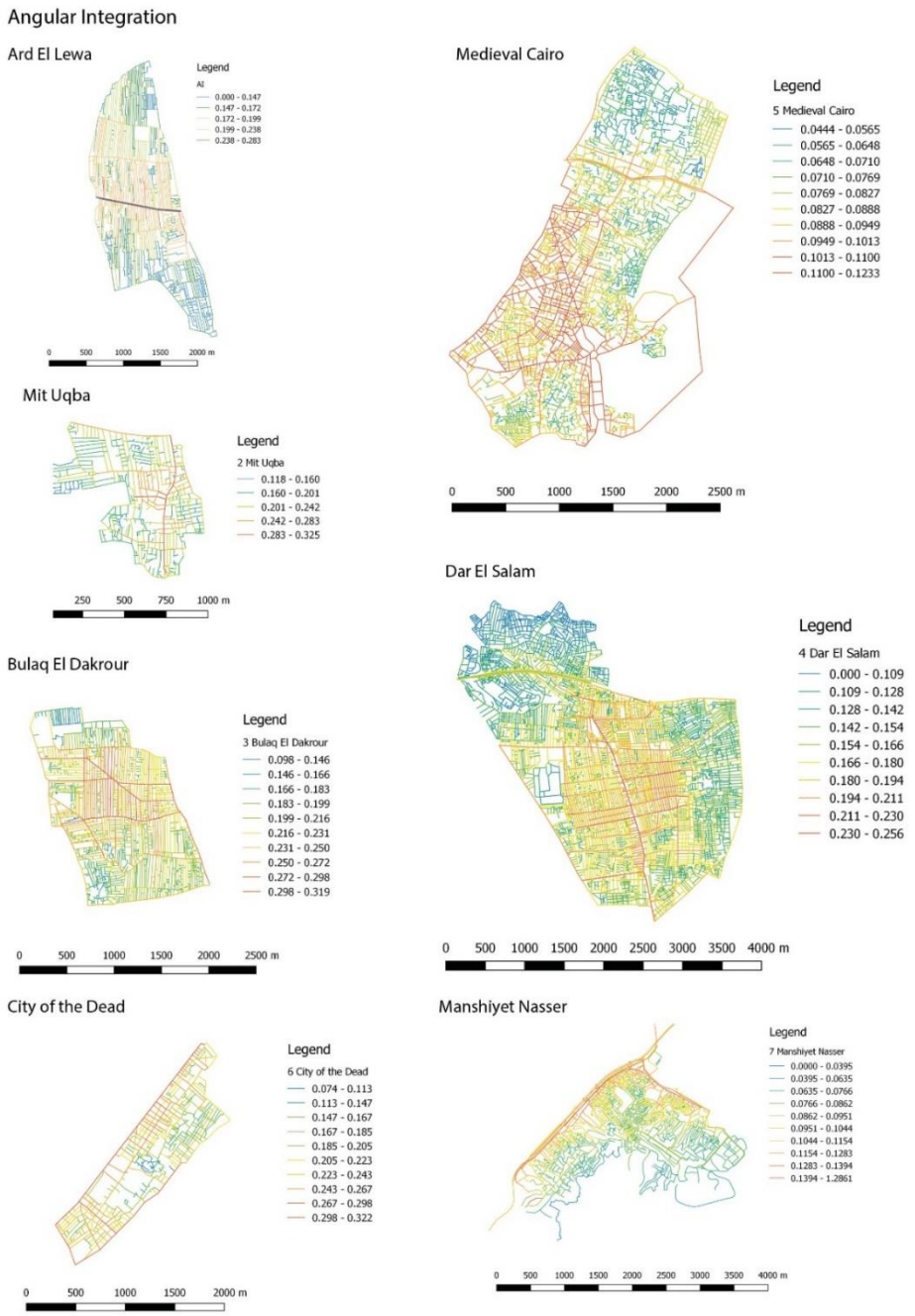


Figure 61: Angular Integration Part 1

Figure 62: Angular Integration Part 2

Table 35: Angular Integration Values of All Neighbourhoods

Initial Type	Neighbourhood	Mean	StDev	CoefVar	Minimum	Maximum
Informal/ Agricultural (urban fringe infill)	1 Ard El Lewa	0.18	0.04	20.0	0.00	0.28
Informal/ Agricultural (historic village aggregate extension)	2 Mit Uqba	0.21	0.04	18.6	0	0.33
Informal/ Agricultural (historic village extension) – infill	3 Bulaq El Dakrour	0.22	0.04	20.3	0	0.32
Informal/ Agricultural (urban fringe infill)	4 Dar El Salam	0.16	0.03	19.1	0	0.26
Exformal - Historically, planned but turned informal – aggregate	5 Medieval Cairo	0.08	0.02	26.0	0	0.76
Exformal - Historically, planned but turned informal – aggregate	6 City of the Dead	0.21	0.04	20.9	0.00	0.32
Informal/ Desert (aggregate)	7 Manshiyet Nasser	0.09	0.03	34.7	0.0	1.29
Planned – evidence of subdivision	8 Mohandisseen	0.21	0.04	18.9	0.0	0.29
Planned – evidence of subdivision	9 Zamalek	0.43	0.08	18.9	0	0.60
Planned – evidence of subdivision	10 Nasr City	0.24	0.04	18.9	0.0	0.36
Planned – evidence of subdivision	11 New Cairo	0.11	0.03	23.2	0	0.99
Mixed/ Planned and informal fabric together	12 Heliopolis	0.17	0.03	18.4	0	0.27
Mixed/ Planned and informal fabric together	13 Omar Ibn El Khattab	0.15	0.18	119.3	0	3.402

The results of the angular integration (Table 35) are similar to the results of the axial network integration, especially in informal areas. Across the whole sample, mean angular integration values range from 0.08 to 0.43 with the lowest values representative of very organic street network structure, such as Manshiyet Nasser and Medieval Cairo. In informal settlements, mean angular integration values range from 0.08 to 0.22. In informal-infill settlements, mean angular integration values range from 0.16 to 0.22. In informal-aggregate settlements, mean angular integration values range from 0.08 to 0.21, the highest value being City of the Dead, which was initially planned. These values show the distinction between informal-infill and informal-aggregate neighbourhood, with the informal-infill generally having a higher integration value. The type of neighbourhood with the lowest mean integration is those that have an organic street network structure, such as Manshiyet Nasser and Medieval Cairo. In planned areas, mean angular integration values range from 0.11 to 0.43. In mixed areas, mean angular integration values range from 0.15 to 0.17. This shows that mixed neighbourhoods are within the range for planned areas. Planned neighbourhoods tend to be slightly more integrated than informal neighbourhoods, as shown by the higher mean integration. This could be due to their planned street network which does not have many segregated areas.

For all neighbourhoods, the standard deviation is between 0.03 and 0.08, and the co-efficient of variation is between 18.6% and 34.7%, which indicates that the variability of the integration measure is not high within the neighbourhood. The exception to this is Omar Ibn El Khattab, a mixed neighbourhood with a standard deviation of 0.18 and co-efficient of variation of 119.3%. The high variability in Omar Ibn El Khattab indicates a polarized neighbourhood as it shows a strong distinction between the most integrated vehicular streets and the majority of small, segregated streets with few streets with values in-between. By contrast, the gradient exists in Heliopolis starting from the main highway with decreasing values towards the edges. Most of the informal neighbourhoods have this gradient from

highly integrated streets to less integrated to segregated parts, which is less clear in planned neighbourhoods.

Figure 61 and Figure 62 shows that the most integrated street segments include the main roads within informal settlements, as well as highways within planned settlements, highlighting the highways' potential role as connectors. In informal areas that emerged on an agricultural grid, the most integrated street segments are the ones following the grid system inherited from the structure of the canals. This can be seen most clearly in Ard El Lewa and Bulaq El Dakrour. Mit Uqba, an ex-agricultural village, also shows a clear structure with the main road leading to the neighbourhood core and to the edge of the neighbourhood where it links with Mohandisseen.

In Ard El Lewa, the highway running through the neighbourhood is disconnected from the rest of the street network. This is also the case for Dar El Salam, which also reinforces the assumption that there are two overlayed networks, one for pedestrians and one for vehicles, and that the highway can cause disconnection in the pedestrian network. When the highway is accessible from the neighbourhood, such as in Manshiyet Nasser and City of the Dead, it becomes the most integrated road. This is also the case in planned and mixed neighbourhoods with connection to the highway. The most integrated streets are either the highway or the main vehicular routes that lead to the highway. This consistency also highlights the presence of a highway super-grid, which can be picked up by the analysis even when each neighbourhood is analysed individually.

7.2.2. Normalised Angular Choice (NACH) – A Measure of Structure

The NACH measure highlights the spatial structure of the neighbourhoods and can shed light on the emergence of the neighbourhood and the resultant dominant street network and street hierarchy.

Figure 63: Normalised Angular Choice (NACH) Part 1

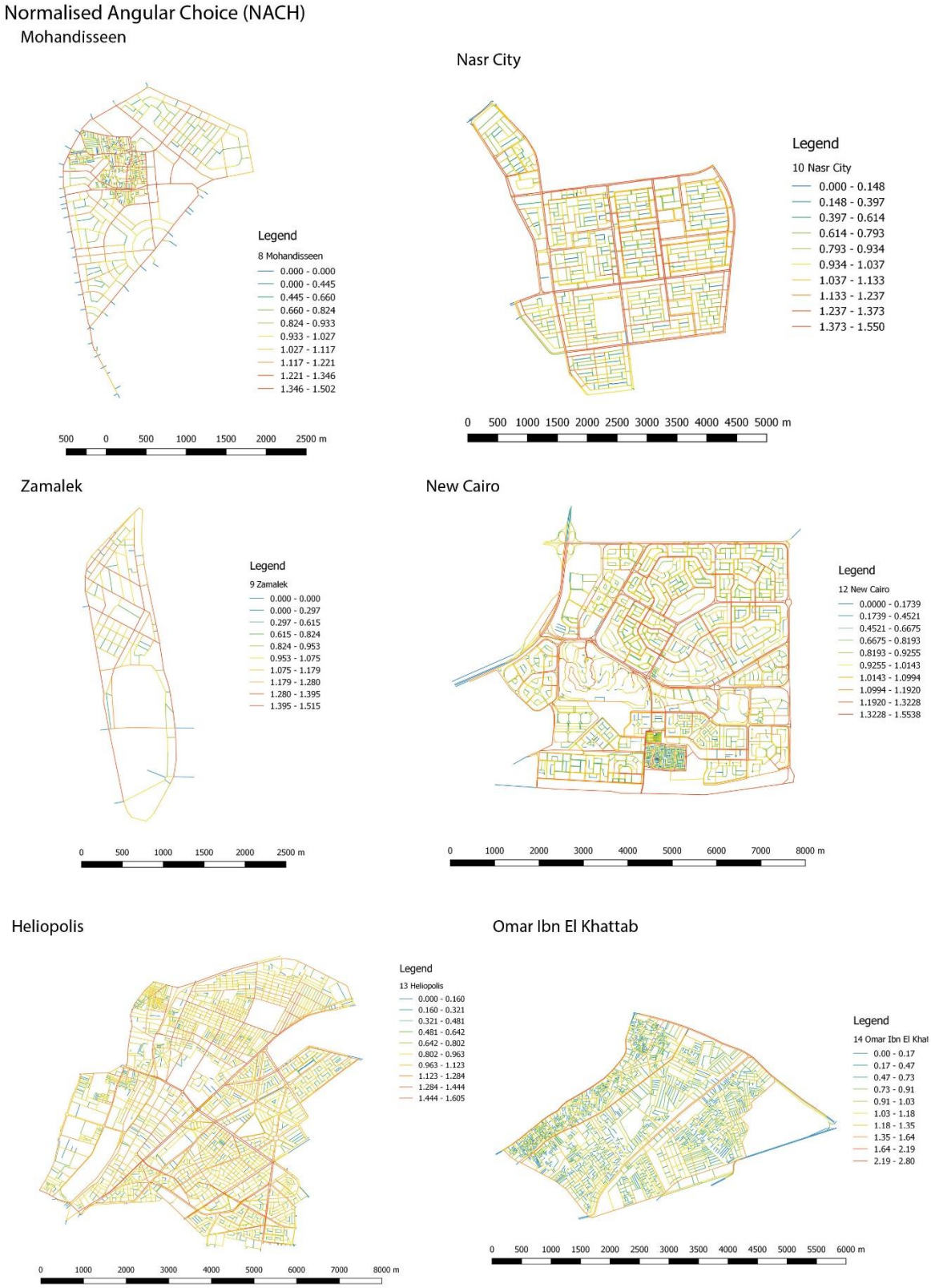


Figure 64: Normalised Angular Choice (NACH) Part 2

Table 36: Normalised Angular Choice Descriptive Statistics

Initial Type	Neighbourhood	Mean	StDev	CoefVar	Min	Max
Informal/ Agricultural (urban fringe infill)	1 Ard El Lewa	0.96	0.32	33.0	0.00	1.6
Informal/ Agricultural (historic village aggregate extension)	2 Mit Uqba	0.94	0.39	41.3	0	1.6
Informal/ Agricultural (historic village extension) – infill	3 Bulaq El Dakrour	0.94	0.42	44.5	0	1.57
Informal/ Agricultural (urban fringe infill)	4 Dar El Salam	0.92	0.39	42.5	0	1.62
Exformal - Historically, planned but turned informal – aggregate	5 Medieval Cairo	0.84	0.37	44.9	0	1.46
Exformal - Historically, planned but turned informal – aggregate	6 City of the Dead	0.99	0.35	35.4	0.00	1.58
Informal/ Desert (aggregate)	7 Manshiyet Nasser	0.94	0.32	34.2	0.0	1.52
Planned – evidence of subdivision	8 Mohandisseen	0.94	0.37	39.8	0.0	1.50
Planned – evidence of subdivision	9 Zamalek	1.09	0.32	29.3	0	1.51
Planned – evidence of subdivision	10 Nasr City	1.03	0.28	26.8	0.0	1.55
Planned – evidence of subdivision	11 New Cairo	0.97	0.25	26.0	0	1.55
Mixed/ Planned and informal fabric together	12 Heliopolis	0.98	0.29	29.3	0	1.604
Mixed/ Planned and informal fabric together	13 Omar Ibn El Khattab	0.87	0.43	48.7	0	2.8

Table 36 shows the normalised angular choice descriptive statistics. Across the whole sample, the NACH varies from minimum 0 to a maximum of 2.8. In informal settlements, the range is from 0 to 1.62. In planned settlements the range is 0 to 1.55. In mixed

settlements the range is from 0 to 2.8. The mean NACH ranges from 0.92 to 1.09. In informal settlements, the mean NACH range is from 0.84 to 0.99. In informal-infill the range is 0.92 to 0.96. In informal-aggregate the mean NACH range is 0.84 to 0.99. In planned settlements the mean NACH range is 0.94 to 1.09. In mixed settlements the mean NACH range is from 0.87 to 0.98.

Across the whole sample, the standard deviation ranges from 0.25 to 0.43, and the co-efficient of variation ranges from 26% to 48.7%. In informal settlements, the standard deviation ranges from 0.32 to 0.42, and the co-efficient of variation ranges from 33% to 44.9%. In planned settlements, the standard deviation ranges from 0.25 to 0.37, and the co-efficient of variation ranges from 26% to 39.8%. In mixed settlements the standard deviation ranges from 0.29 to 0.43, and the co-efficient of variation ranges from 29.3% to 48.7%.

The NACH values are fairly similar in all neighbourhoods, which is expected as it is assumed that all neighbourhoods have an internal structure tied to emergence. The variability is also similar across neighbourhoods, with informal settlements having slightly higher variability. The exception to this is Omar Ibn El Khattab, which has the highest variability in NACH, 0.43 standard deviation and 48.7% co-efficient of variation. This can be attributed to the polarised street structure, where the high choice highways co-exist with the low choice, fragmented organic street structure of the informal part of the neighbourhood.

The NACH visualisation in Figure 63 and Figure 64 highlights the main spatial structure of the neighbourhoods. In Ard El Lewa, Mit Uqba and Dar El Salam the high NACH values clearly highlight the **agricultural grid** as the spatial structure of the neighbourhood, with the irrigation canals and paths between plots as the shortest paths in the neighbourhoods. In Mit Uqba and Medieval Cairo the **historic core** is highlighted, which are not necessarily the most integrated streets, rather the first ones to have emerged (most direct routes). This is the case in Medieval Cairo, where *Al Muizz* street is highlighted as the shortest route and was in fact the first street to be created. There is a similar trend in the City of the Dead,

where the designed grid is highlighted as the spatial structure. In planned areas the **main vehicular streets** are highlighted. There is a very clear street hierarchy visible using NACH in all neighbourhoods.

7.2.3. Reach

The reach measure is calculated in metres, so it takes into consideration the size of the neighbourhood, not just topography/configuration. It can highlight areas of density, provide insight into walkability and the spatial structure of the neighbourhood. The measures used are Directional Reach (DR) to study the structure of the neighbourhoods, and Metric Reach (MR) to study the density. **Directional Reach** is calculated by setting the number of turns and the angle that is considered a turn. In this case, zero directional change (DR_0D) and two directional changes (DR_2D) with angle set at **10 degrees** (Peponis, Bafna, and Zhang 2008). **Metric Reach** is calculated for 100m, 250m, 500m and 1000m radius. This is to investigate different types of movement in the neighbourhood. The specific methodological steps have been previously explained in Section 3.2.3.2.

Directional Reach

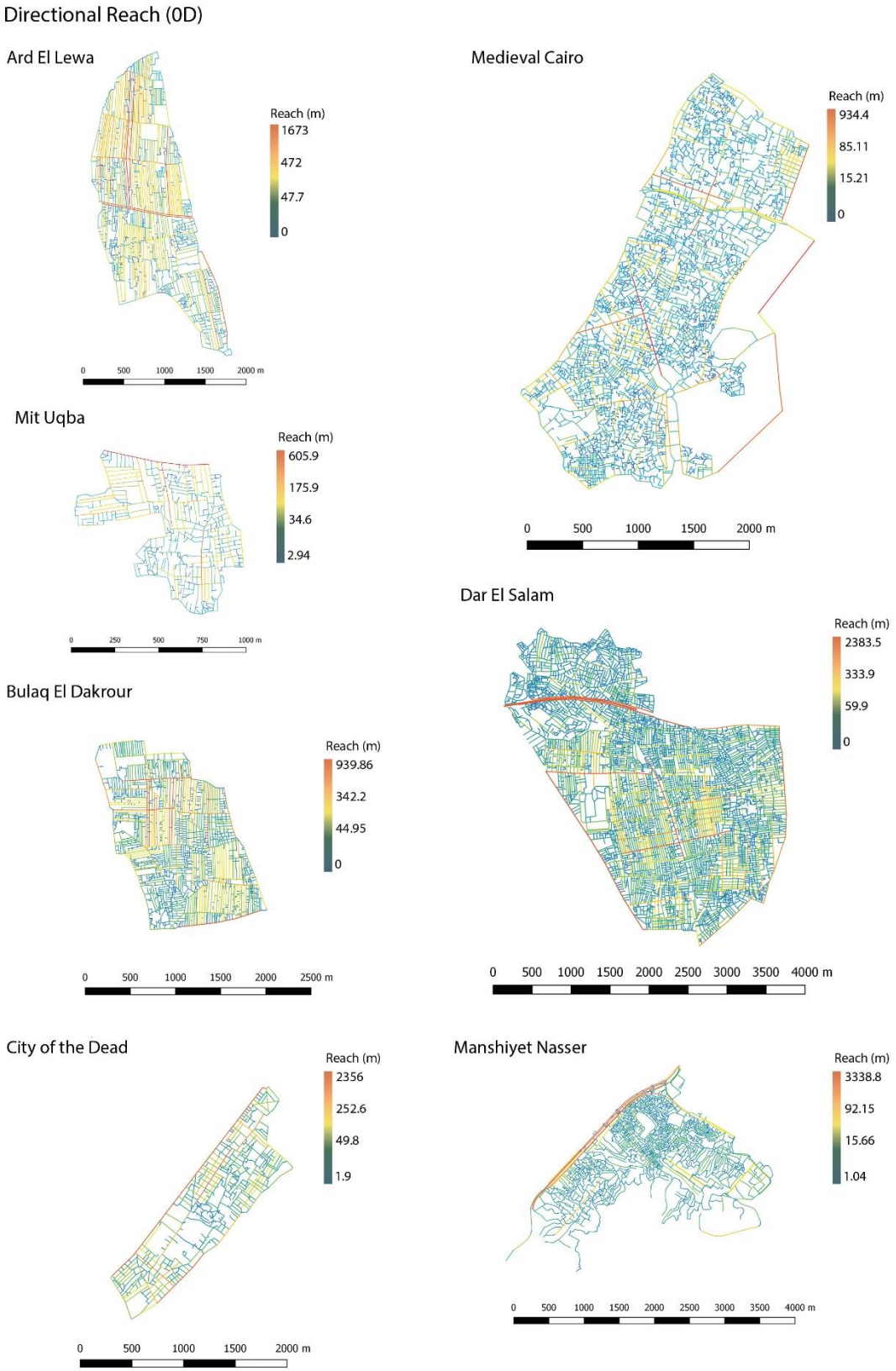


Figure 65: Directional Reach at 0 Directional Change

Figure 66: Directional Reach at 0 Directional Change

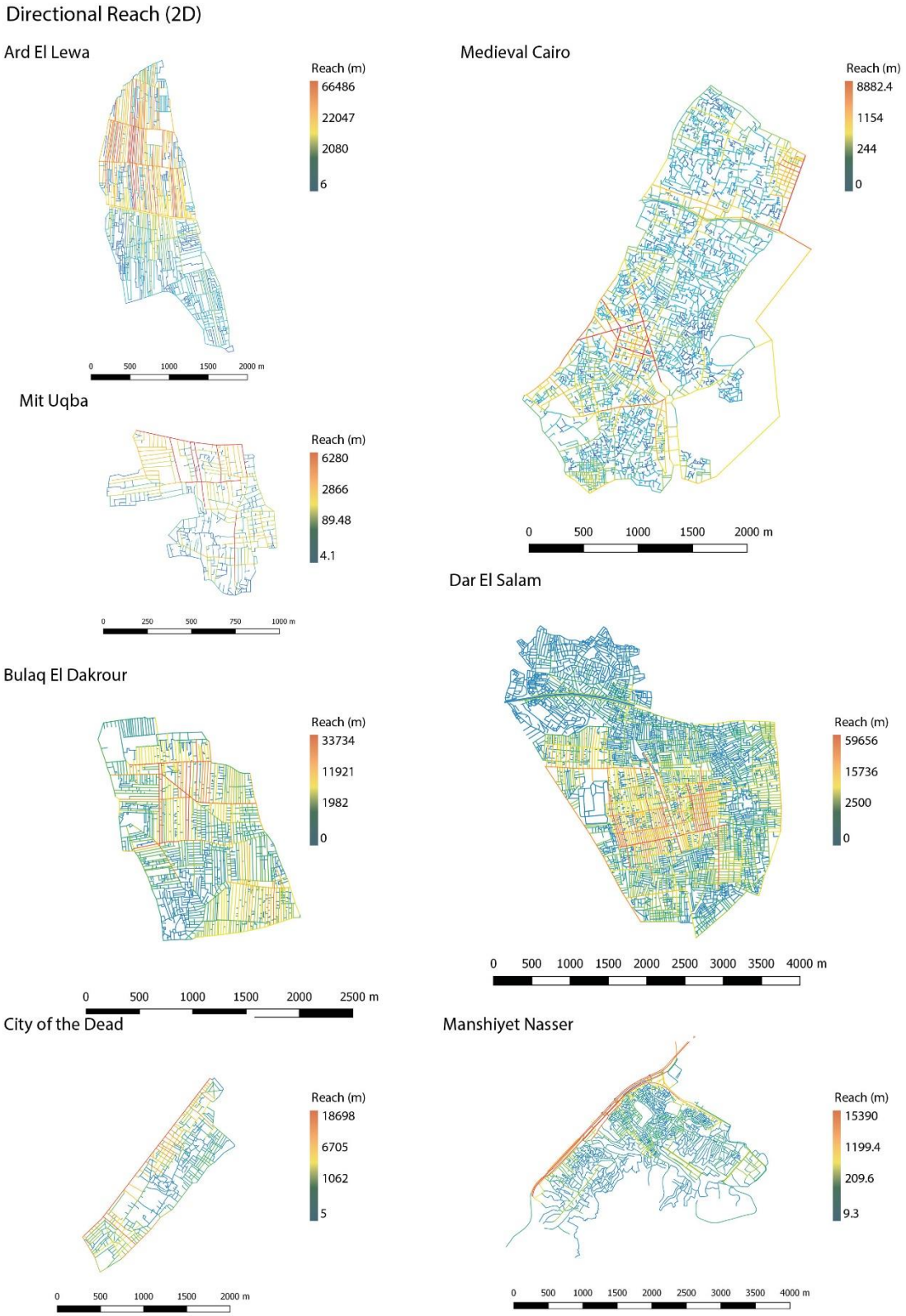


Figure 67: Directional Reach at Two Directional Change

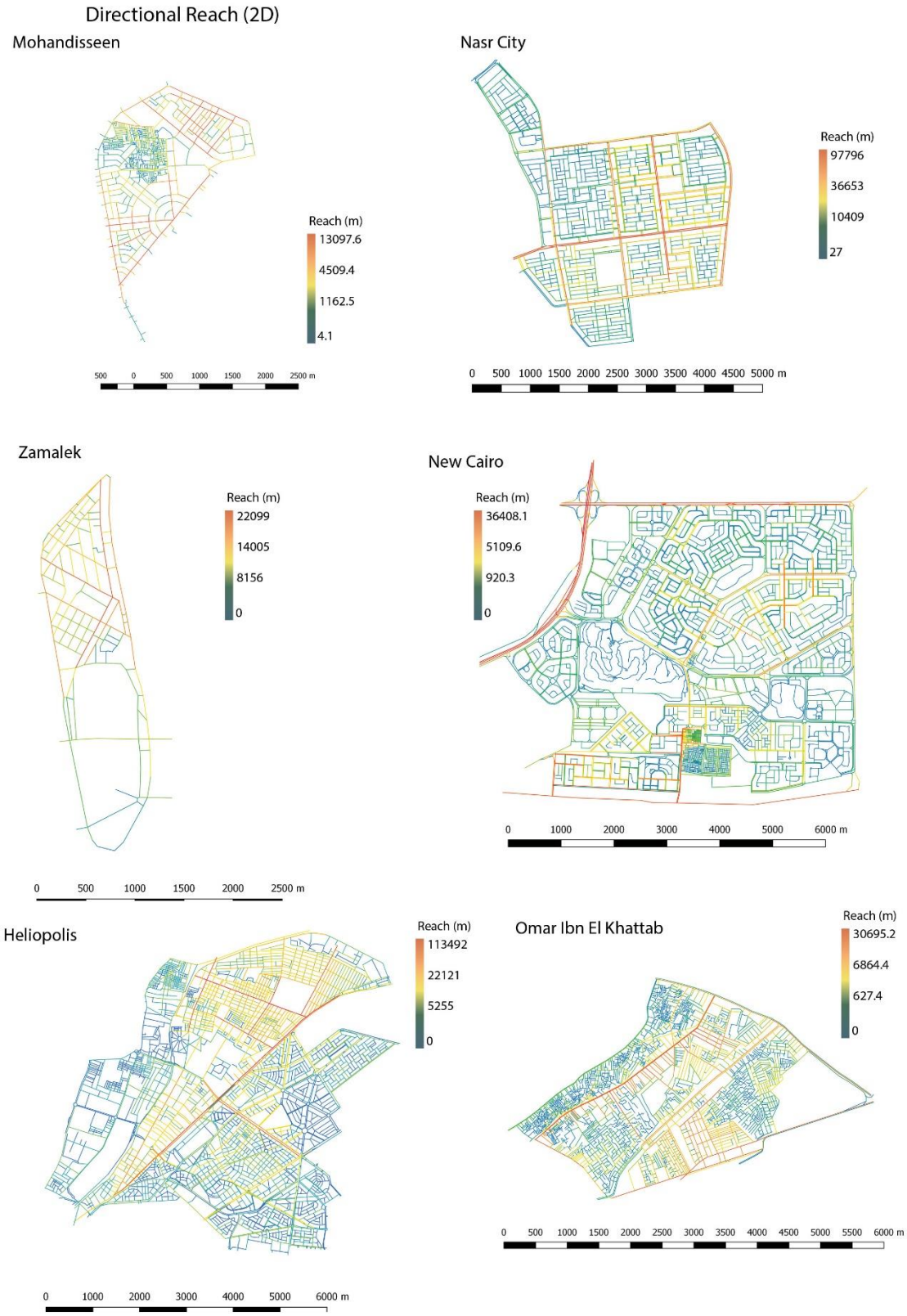


Figure 68: Directional Reach at Two Directional Change

Table 37: Directional Reach Descriptive Statistics

		0 Directional Change		**2 Directional Changes**	
Initial Type	Neighbourhood	Mean (m)	CoefVar (%)	Mean (m)	CoefVar (%)
Informal/ Agricultural (urban fringe infill)	1 Ard El Lewa	307	114	12,463	124
Informal/ Agricultural (historic village aggregate extension)	2 Mit Uqba	117	98	2093	72
Informal/ Agricultural (historic village extension) – infill	3 Bulaq El Dakrour	220	95	7751	91
Informal/ Agricultural (urban fringe infill)	4 Dar El Salam	268	128	10,628	106
Exformal - Historically, planned but turned informal – aggregate	5 Medieval Cairo	76	155	1001	133
Exformal - Historically, planned but turned informal – aggregate	6 City of the Dead	248	183	4457	100
Informal/ Desert (aggregate)	7 Manshiyet Nasser	155	289	1451	190
Planned – evidence of subdivision	8 Mohandisseen	213	146	3374	88
Planned – evidence of subdivision	9 Zamalek	624	76	11,138	42
Planned – evidence of subdivision	10 Nasr City	843	104	26,036	80
Planned – evidence of subdivision	11 New Cairo	354	206	4115	127
Mixed/ Planned and informal fabric together	12 Heliopolis	608	144	16,958	111
Mixed/ Planned and informal fabric together	13 Omar Ibn El Khattab	300	197	4753	121

Directional Change – Zero

Across the entire sample, the mean directional reach at zero directional change ranges from 76m to 843m (Table 37). In informal neighbourhoods, the mean reach is higher in the neighbourhoods that have emerged on agricultural land (infill) (220m to 307m) than those that have emerged on desert land (76.01m-155.08m). This is due to the subdivision of agricultural land on elongated plots, resulting in straight paths. The mean reach is lower than in planned settlements, potentially due to T-junctions in the agricultural grid (not long

straight lines) and the street network not perfectly aligning with fields. On historic and desert land (aggregate), the emergent curvilinear/organic form leads to a low reach with zero directional change. The exception to this is City of the Dead (248.5m), which was previously planned so the analysis highlights the square planned grid.

The mean reach is much higher in mixed (n=2, 454m) and planned neighbourhoods (n=4, 508m) than in informal neighbourhoods (n=7,199m). The exception is New Cairo where mean reach is 353.91m. This is due to the form of the neighbourhood, the curvilinear roads of New Cairo do not reach as far as the long straight vehicular roads in Nasr City, Zamalek and Heliopolis. Mohandisseen has a low mean reach of 213m due to the inclusion of Mit Uqba in the neighbourhood.

The co-efficient of variation ranges from 76% to 289% across the whole sample. In informal areas, it ranges from 95% to 289%. In planned areas, it ranges from 76% to 206%. There does not seem to be a relation between the type of neighbourhood and the variability of the reach value, which indicates that the neighbourhoods are a mixture of straight and non-straight streets, which is expected.

In all neighbourhoods, the streets with the highest reach tend to be the planned highway or the main roads within the settlement. This is expected as these are the most connected roads (Figure 65 and Figure 66). The mean reach at zero directional change seems to be related to the emergence of the neighbourhood.

Directional Change – Two

Across the whole sample, the mean directional reach at two directional changes ranges from 1001m to 26,036m (Table 37). In informal settlements, the mean directional reach ranges from 2093m to 12,463m. In informal infill settlements, the mean directional reach ranges from 7751m to 12,463m. In informal-aggregate settlements, the mean directional reach ranges from 1001m to 4457m. This difference was expected since the settlements that are infill on agricultural land tend to have longer, straighter streets. In planned

settlements, the mean directional reach ranges from 3374m to 26,036m. In mixed settlements, the mean directional reach ranges from 4753 m to 16,958m. The values for the mixed settlements fall into the range for planned settlements, which is expected as their emergences are similar.

The co-efficient of variation ranges from 42% to 190%. There does not seem to be a pattern relating the variability to the type of settlement, since it is expected that all neighbourhoods are a mixture of straight and non-straight streets.

With two directional change the analysis starts to highlight the spatial structure of the neighbourhoods (Figure 67 and Figure 68). In the planned neighbourhoods, the vehicular paths that were shown to be the main roads are highlighted as having high reach. The analysis also highlights the ex-canal system in neighbourhoods that have emerged on an agricultural grid, as well as the neighbourhood core in neighbourhoods that have emerged organically on desert land.

In planned neighbourhoods the street with the highest reach tends to be a highway. When the highway is accessible in informal areas, such as in City of the Dead and Manshiyet Nasser, it tends to have the highest reach in the neighbourhoods. In contrast, when the highway is not accessible from the neighbourhood, such as Ard El Lewa, Dar El Salam and Medieval Cairo, it has very low reach. Streets that have high directional reach at 2 directional change also tend to have high integration and choice, so all the results of this analysis are fairly similar to the previous.

Metric Reach

Unlike the directional reach measure which can highlight the spatial structure, the metric reach measure highlights the density and potential walkability of settlements. The following section describes the differences found in metric reach, and therefore density, between radii and between different types of settlement. Figure 69, Figure 70, Figure 71 and Figure 72, illustrate the neighbourhood visualisations and Table 38 contains the descriptive statistics.

Figure 69: Metric Reach

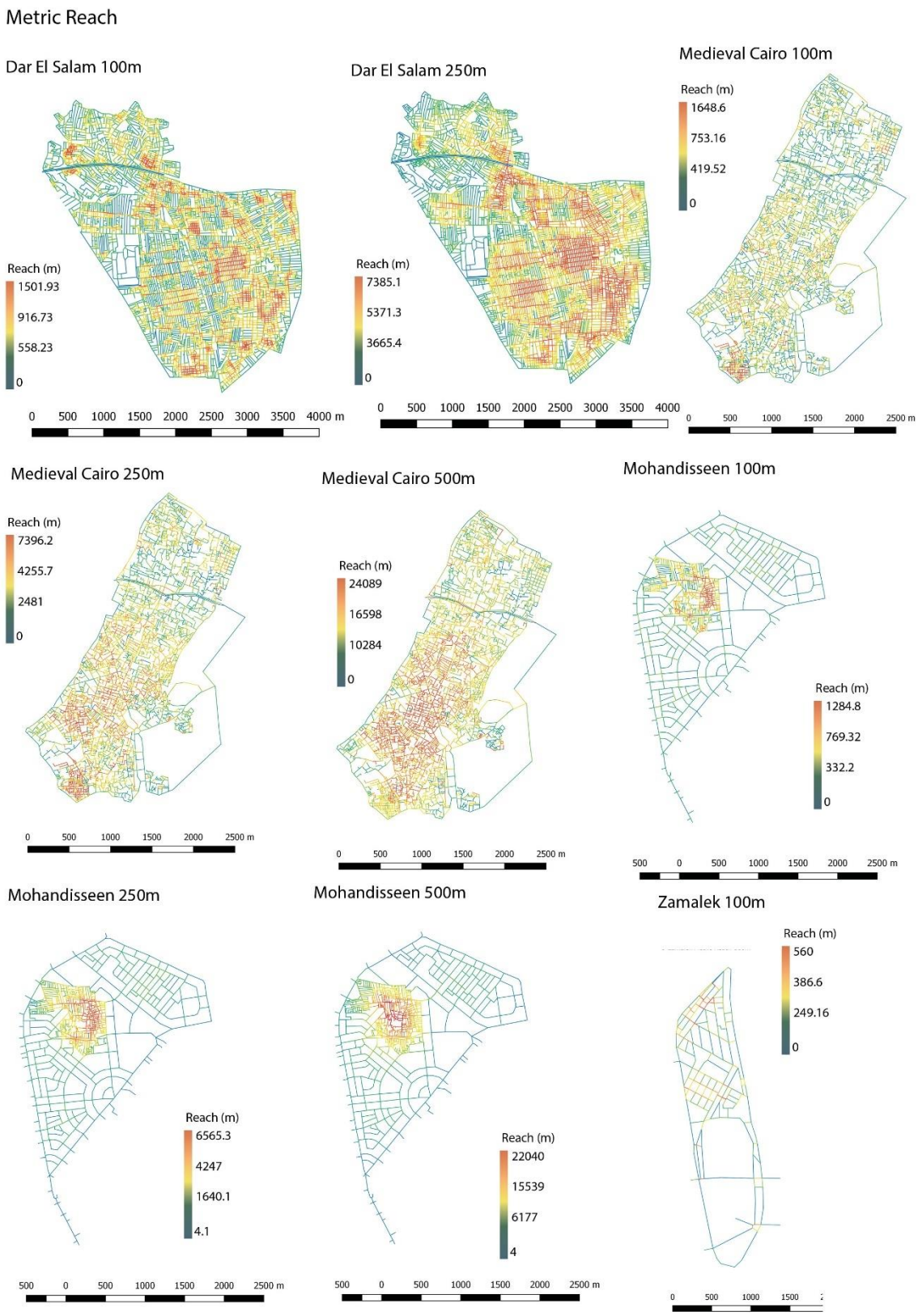


Figure 70: Metric Reach

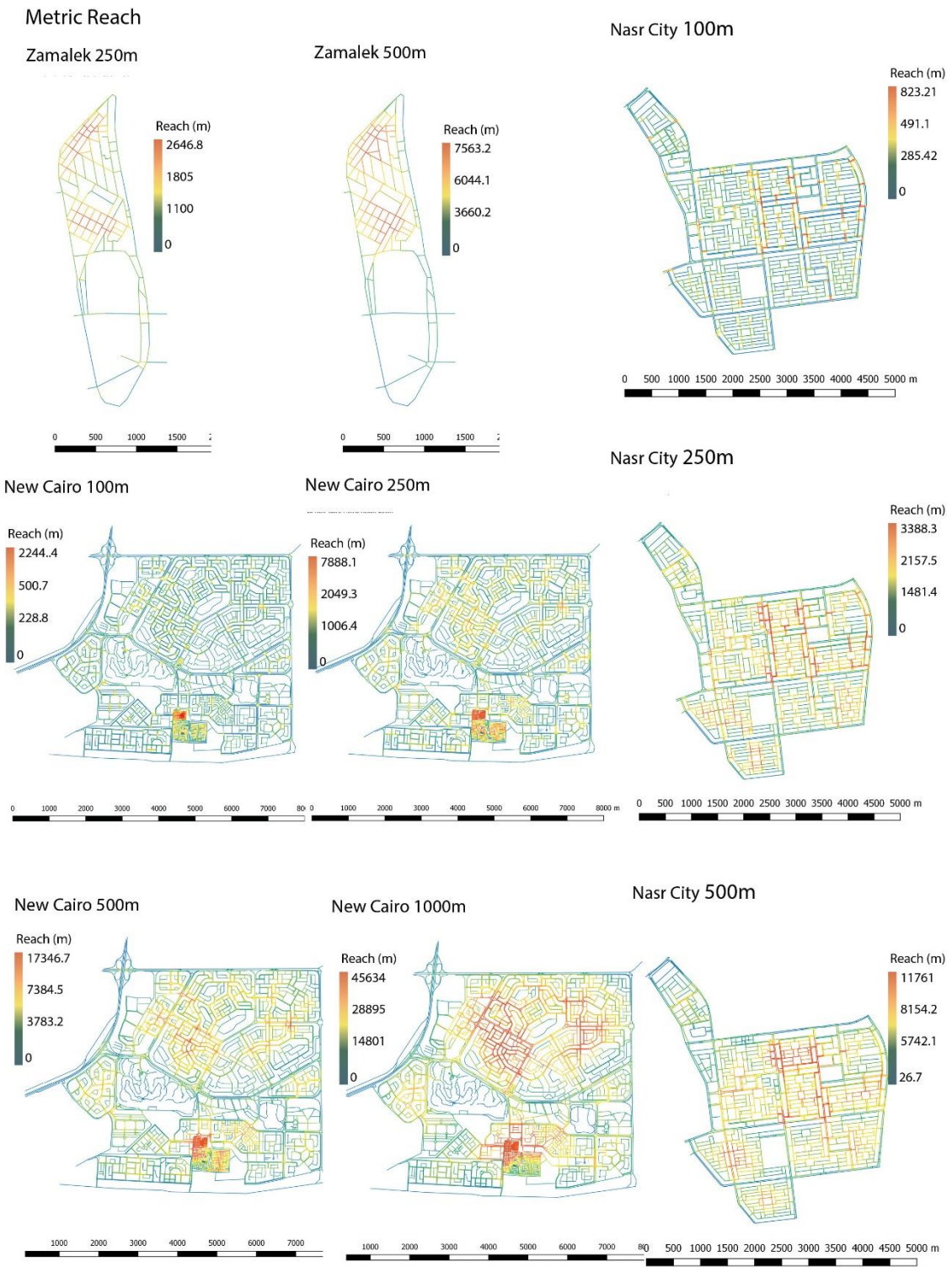


Figure 71: Metric Reach

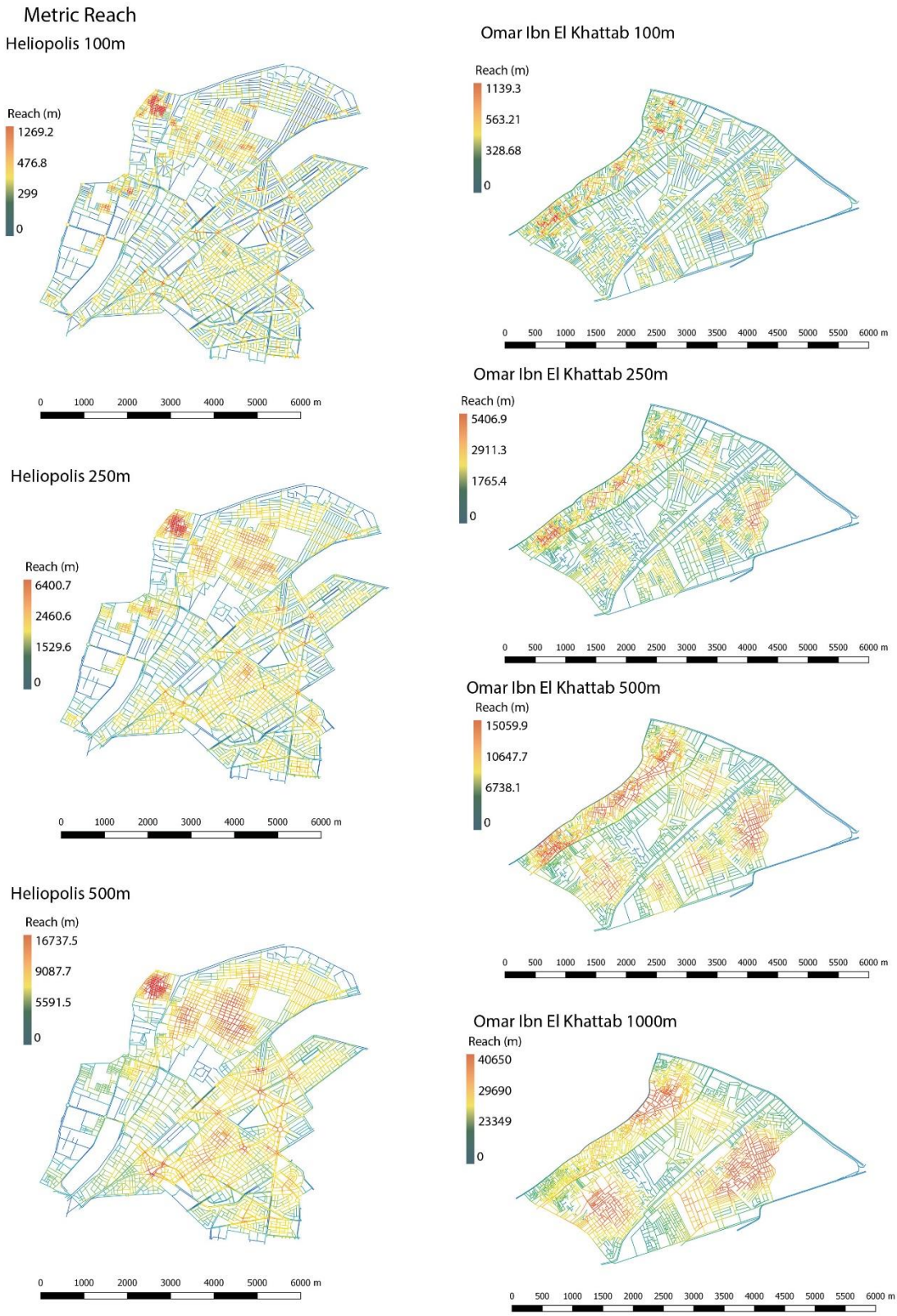


Figure 72: Metric Reach

Table 38: Metric Reach by Radius

		Radius							
		100m		**250m**		**500m**		**1000m**	
Initial Type	Neigh-bourhood	Mean (m)	Coef Var (%)	Mean (m)	Coef Var (%)	Mean (m)	Coef Var (%)	Mean (m)	Coef Var (%)
Informal/ Agricultural (urban fringe infill)	1 Ard El Lewa	532	48	2861	42	4159	37	42,362	35
Informal/ Agricultural (historic village aggregate extension)	2 Mit Uqba	716	34	3758	32	12,121	29	24,907	10
Informal/ Agricultural (historic village extension) – infill	3 Bulaq El Dakrour	671	41	3977	34	16,462	31	57,039	29
Informal/ Agricultural (urban fringe infill)	4 Dar El Salam	731	34	4443	28	18,072	28	67,229	31
Exformal - Historically, planned but turned informal – aggregate	5 Medieval Cairo	598	43	3399	38	13,188	35	47,601	33
Exformal - Historically, planned but turned informal – aggregate	6 City of the Dead	547	31	2953	31	99,68	27	24,147	22
Informal/ Desert (aggregate)	7 Manshiyet Nasser	563	48	3113	51	11,527	46	38,756	40
Planned – evidence of subdivision	8 Mohandis seen	560	50	3082	51	11,310	47	32,541	33
Planned – evidence of subdivision	9 Zamalek	290	49	1451	37	4796	33	13,320	29
Planned – evidence of subdivision	10 Nasr City	368	51	1824	29.7	6915	27	25,333	27
Planned – evidence of subdivision	11 New Cairo	393	70	1694	66	5749	51	21,836	44
Mixed/ Planned and informal fabric together	12 Heliopolis	394	47	2064.5	41	7476	35	27,256	31
Mixed/ Planned and informal fabric together	13 Omar Ibn El Khattab	450	40	2355.0	38	8548	32	26,269	23

100m – 250m Radius

At 100m radius, the equivalent of 2 minutes' walk, the reach measure highlights the local cores within informal neighbourhoods, rather than the overall global structure. The mean reach is between 532m and 731m for all informal neighbourhoods, which indicates that there is a high distance that can be reached by pedestrians. In informal-infill neighbourhoods, the mean reach at 100m is 531m to 731m, which is similar to the mean reach in informal organic/desert neighbourhoods (547.4m – 716.1m), indicating that the informal neighbourhoods are walkable at a low radius.

At 250m radius, the equivalent of 5min walk, the areas highlighted by the reach measure starts to align with the centre of neighbourhood and main roads in informal areas. The mean reach is between 2861m and 4443m for all informal areas, again indicating high walkability. In informal-infill neighbourhoods, the mean reach at 250m is 2861m and 4443m, which is higher than the mean reach in informal organic/desert neighbourhoods (2953.4m – 3977.7m), reinforcing the idea that emergence can influence eventual density. In both 100m and 250m radius, the highest mean reach is found in Dar El Salam indicating that an agricultural grid can increase the density of the settlement. However, the lowest mean reach is in Ard EL Lewa, which could indicate that the very long, straight streets that are influenced by the agricultural grid could impede walkability at a low radius.

In contrast, the mean reach at 100m in planned neighbourhoods is between 290.14m - 560.49m, and 1451.3m - 3082.4m at 250m which indicates a lesser distance that can be reached on foot. This indicates that planned areas are less walkable than informal areas (a pedestrian can walk for a long distance and still remain on the same segment/street). An exception to this is in New Cairo, where a high co-efficient of variation (70.1% at 100m and 66% at 250m) indicates that there are some areas in the neighbourhood that have a much higher reach than others. This can be attributed to the Third Settlement, a smaller area in the south of New Cairo that is designed on a much smaller grid, so is therefore denser with a higher reach.

The mean reach for mixed neighbourhoods tends to lie between the mean for planned and informal neighbourhoods. The mean reach at 100m is 391.93m - 450.43m and 2355.0m - 2064.5m at 250m. This is slightly higher than planned neighbourhoods but not as high as informal neighbourhoods. In mixed neighbourhoods the reach measure with radius 100m or 250m starts to highlight the individual cores of each type (informal or planned). The informal cores tend to have a higher reach at this level because they are denser, so this measure can highlight the differences between the planned and informal sections of the mixed neighbourhood.

500m – 1000m radius

At 500m and 1000m radius (10min-20min walk) the results of the reach analysis follow the previous trend of the informal-infill neighbourhoods having the highest reach, with informal-organic neighbourhoods being slightly lower, and planned neighbourhoods having the lowest mean reach. However, at this higher radius, the overall spatial structure is highlighted more than the small cores of dense urban fabric. The visualisations are similar to those of the angular integration measure, which implies that the streets that have high reach at a high radius are also well integrated.

Using 1000m radius was found to be not as suitable for smaller settlements, since the radius may be larger than the whole settlement. When this is the case, the visualisation has been omitted because it may be less informative than other radii. For informal settlements, the results at 500m radius are analysed, and for planned and mixed settlements, the results at 500m and 1000m are analysed.

The 500m radius is suitable for use in informal settlements and highlights the overall centre of the neighbourhood and some of the main roads. The trends are similar to the previous radii; the mean reach at 500m is between 4159m and 18,072m for all informal areas. In informal-infill neighbourhoods, the mean reach at 500m is 4159m to 18,072m, which is

slightly higher than the mean reach in informal organic/desert neighbourhoods (9968.6m – 13188m). This reinforces the idea of higher walkability in informal neighbourhoods.

In planned and mixed neighbourhoods, the reach at 500m and 1000m starts to highlight the core of the neighbourhoods and the main streets, which are often the main vehicular roads. The implication is that a pedestrian would have to walk 500m-1000m to reach a main road. The mean reach in planned neighbourhoods is still lower than that of informal neighbourhoods, 4796.4m – 11310m at 500m radius and 13320m – 32541m at 1000m radius. In mixed neighbourhoods, the mean reach is slightly higher than in planned neighbourhoods, 7476.3m - 8548.7m at 500m radius and 26269m – 27256m at 1000m radius. This is still lower than most informal neighbourhoods.

To summarise, the metric reach measure can highlight the density and walkability of a neighbourhood at a lower radius, and the spatial structure and main roads at a higher radius. At all radii, informal settlements have higher mean reach, due to their increased density and shorter streets. This indicates an increased walkability in informal neighbourhoods. Generally, informal infill has the highest mean reach, which can be linked to emergence on the agricultural grid which leads to well-connected, straight streets. Planned neighbourhoods have the lowest mean reach, which can be attributed to having a less dense street network with longer streets. At the high radius, the cores and main roads highlighted are similar to those highlighted by the angular integration measure, which indicates that streets with high metric reach are also well integrated.

Table 39: Summary of mean reach by type

Type	n	MR1,000m	MR500m	MR250m	MR100m
Informal	7	43,149	13,240	3,501	623
Informal – Infill	3	55,543	15,292	3,761	645
Informal - Aggregate	4	33,853	11,701	3,306	606
Planned	4	23,258	7,193	2,013	403
Mixed	2	26,763	8,013	2,210	421

Table 39 shows the summary of the mean reach by type. There is not much difference in terms of classification when the radius is changed, however there starts to emerge differences between informal, mixed and planned neighbourhoods. The densest neighbourhoods are informal, followed by mixed then by planned neighbourhoods. Within the informal classification, the informal-infill are denser than the informal-aggregate neighbourhoods. There are not a lot of differences between the density of the planned and mixed neighbourhoods.

7.3. Cluster Analysis and Categorisation of Streets into Types

As mentioned previously in Chapter 3.2, k-means cluster analysis is used to organise data into meaningful groups when the number and parameters of the clusters is unknown. This is used to find categories in large datasets that may not be apparent using traditional statistical analysis. The following section sets out the process for finding the optimum number of clusters (k) and then the analysis of the output clusters in order to define them into meaningful categories. This definition is found by studying their spatial configuration and distribution within neighbourhoods and the cluster parameters and ranges of values. The result is the categorisation of streets in the whole sample and the organisation of them into types.

7.3.3. Clustering process

The clustering process was split into two phases, initial data clean-up and organisation and determining the number of clusters. To prepare the data for input, firstly all the data was compiled using global ID to match variables to segments. Secondly, the input values were standardised as they have different units or no units, in order to avoid one variable dominating the cluster definition. The resulting dataset consisted of 56,532 street segments with 8 variable values assigned to each segment. The street segment clustering concentrates on the syntactic properties of the settlements. The eight variables used for the clustering were: Angular integration, NACH, two radii of directional reach and four radii of metric reach presented and detailed in the section above.

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 73. This number of clusters allowed differentiation between clusters without becoming too granular.

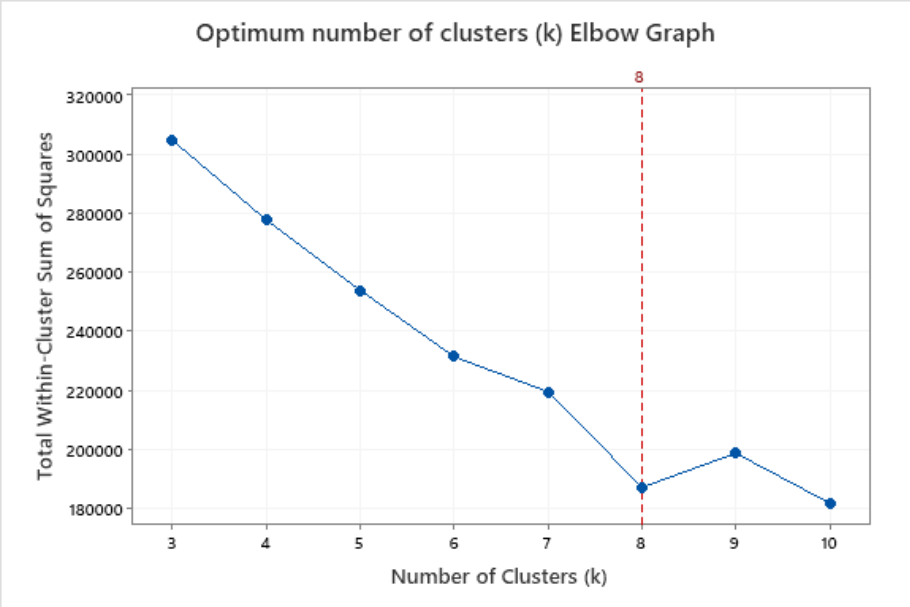


Figure 73: Elbow Graph for Street Segment Clusters

After the clustering process was complete, each segment was assigned its cluster, which was then mapped back onto the vector models of the neighbourhoods, which allows for the study of spatial configuration and location in the neighbourhoods. Descriptive statistics and distribution of each cluster was also extracted, which allows for the definition of clusters using the value ranges and distribution in neighbourhoods.

7.3.4. 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. The

cluster value ranges (Table 40) can be used to define the cluster, and to potentially be used to classify other street systems.

Table 40: Cluster Values Ranges (min-max)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Angular Integration	0 - 0.62	0.02 – 0.52	0.05-0.42	0-0.73	0.08-1.71	0.12-3.40	0-0.33	0-0.34
NACH	0 - 0.85	0.47 – 1.62	0.35-1.62	0-0.64	0-2.045	0-2.8	0-1.59	0-1.64
Directional Reach 0D (m)	0 - 1405	0 – 1748	0-2557	0-2671	0-2873	1291-6966	0-934	5.7-2557
Directional Reach 2D (m)	0 – 39,939	0-32,457	0-45,616	0-40,553	0-62,060	1865 – 113,492	0-26,515	789 – 59,656
Metric Reach 100m (m)	0 - 1536	0- 1045	142-1214	0-1004	0-823	0-1007	275-2244	202 – 1501
Metric Reach 250m (m)	0 – 7261	0-3562	0-5269	0-4534	0-4479	0-4740	0-7888	1968-7385
Metric Reach 500m (m)	0 – 25,921	0-21,465	4584 – 25,377	0-21,883	0-25,132	0-20,107	8071 – 24,607	9577-27,461
Metric Reach 1000m (m)	0 - 101,243	0-64,740	0-97,244	0-73,692	0-92,117	1056-70,200	21,715-98,174	38,677-104,245

7.3.5. Description of Each Cluster

Table 41: 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 41),

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 42: 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 42), 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 43: 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 43) 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 44: 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 44). 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 45: 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 45). 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 46: 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 46). 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 47: 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 47). 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 48: 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 48). 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.

7.3.6. Cluster Spatial Configuration and Location in Neighbourhood

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. This provides insight into whether there are unique spatial structures present in informal areas. Figure 74 and Figure 75 show the location of the clusters within the neighbourhoods and the spatial configurations they may form.

Figure 74: Cluster Spatial Configuration

Figure 75: Cluster Spatial Configurations

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 3.

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.

7.3.7. 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.

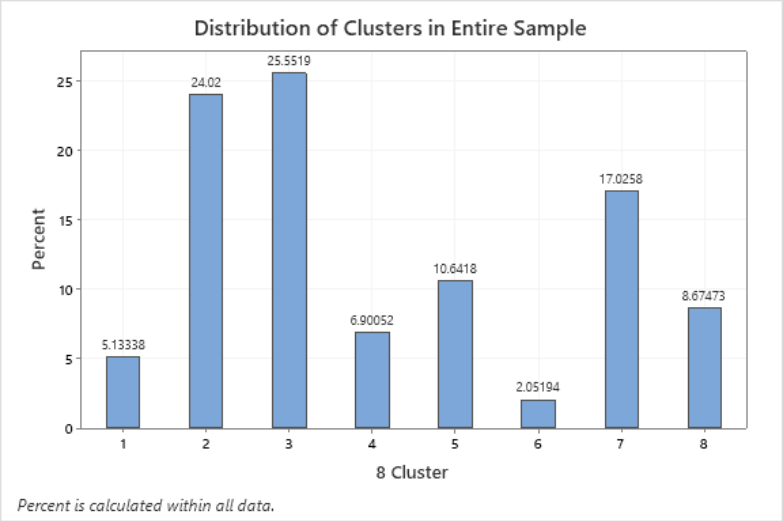


Figure 76: Cluster distribution in Entire Sample (by number of streets)

Figure 76 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 offers a different perspective and accurate summary, as some streets may be few but high in length and vice versa. Table 49 shows the cluster distribution as percentage of total street segment number. Table 50 shows Cluster distribution as percentage of total Road Length and Figure 77 illustrates both distributions.

Table 49: 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 50: 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

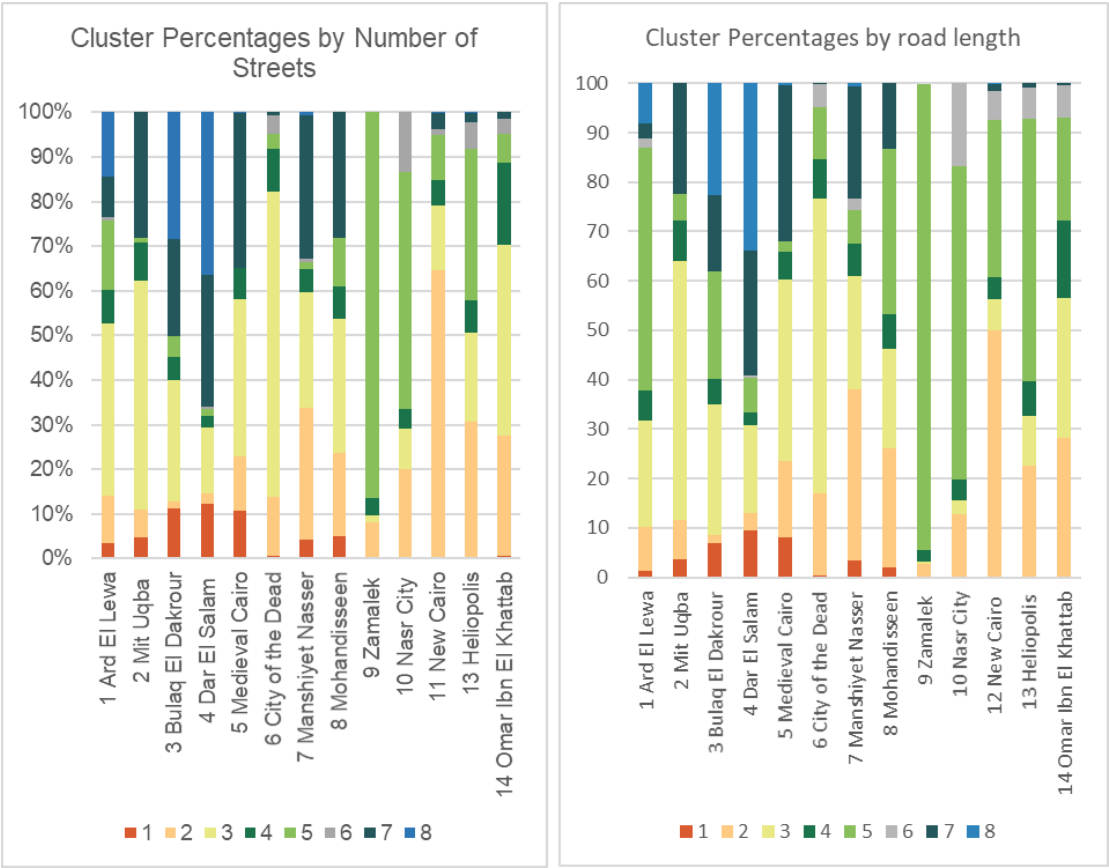


Figure 77: Cluster Distribution in the neighbourhoods

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 (organic desert) type. 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.

7.3.8. Categorisation of Streets based on Results

The following 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.

Street Types from Literature

These classifications are based on the study by Soliman (2012) in Matariya:

- Inter-settlement arteries
- Narrow streets bounding residential block
- Intra block access (hara, darb, alley)

A further category was added to highlight the transport infrastructure that informal settlements may or may not be connected to

- Highways (with or without access)

The street network in Jeddah was also categorised into three types by Karimi (2007):

- primary boulevards
- secondary boulevards
- locally important routes

Cluster Definitions and Grouping

Following on from the results, clusters can be grouped together into four main categories based on, 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

7.4. Conclusions

The analysis shows that a distinction starts to emerge between types of settlement in terms of integration, choice and reach. Planned neighbourhoods tend to be slightly more integrated than informal neighbourhoods, with mixed neighbourhoods in between. Within informal neighbourhoods, the informal infill type generally has a higher integration value. The most integrated street segments include the main roads within informal settlements and highways within planned settlements. When the highway runs through a planned

neighbourhood, it is generally the most integrated street. When it runs through an informal neighbourhood without access, it is not integrated. The most integrated streets are either the highway or the main vehicular routes that lead to the highway. This consistency also highlights the presence of a highway super-grid, which can be picked up by the analysis even when each neighbourhood is analysed individually.

The NACH highlights the main spatial structure of the neighbourhoods. In Ard El Lewa, Mit Uqba and Dar El Salam the high NACH values clearly highlight the agricultural grid as influence on the spatial structure of the neighbourhood, with the irrigation canals and paths between plots as the shortest paths in the neighbourhoods. In Mit Uqba and Medieval Cairo the historic core is highlighted, which are not necessarily the most integrated streets, rather the first ones to have emerged (most direct routes). In planned areas the main vehicular streets are highlighted. There is a very clear street hierarchy visible using NACH in all neighbourhoods.

The directional reach can also highlight the structure of the neighbourhood. With two directional change, the analysis starts to highlight the spatial structure of the neighbourhoods. In the planned neighbourhoods, the vehicular paths that were shown to be the main roads are highlighted as having high reach. The analysis also highlights the ex-canal system in neighbourhoods that have emerged on an agricultural grid, as well as the neighbourhood core in neighbourhoods that have emerged organically on desert land. Again, the highway is highlighted as an important part of the structure. In planned neighbourhoods the streets with the highest reach tend to be the highways. When the highway is accessible in informal areas, such as in City of the Dead and Manshiyet Nasser, it tends to have the highest directional reach in the neighbourhoods. In contrast, when the highway is not accessible from the neighbourhood, such as Ard El Lewa, Dar El Salam and Medieval Cairo, it has very low reach.

The metric reach can highlight the density and walkability of the neighbourhoods. At all radii, informal settlements have higher mean reach, due to their increased density and shorter

streets. This indicates an increased walkability in informal neighbourhoods. Generally, informal infill settlements have the highest mean reach, which can be linked to emergence on the agricultural grid, which leads to well-connected, straight streets. Planned neighbourhoods have the lowest mean reach, which can be attributed to having a less dense street network with longer streets. At the high radius, the cores and main roads highlighted are similar to those highlighted by the angular integration measure, which indicates that streets with high metric reach are also well integrated.

Street Types

Table 51: Summary of Street Types

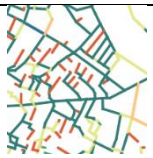
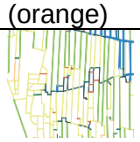
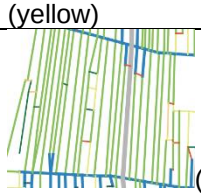
Cluster Group	Definition	Visualisation	Present in
1 Intra-block Access	**Small, singular roads that are considered private access to blocks**		
Cluster 1	High Reach 'Hara'	 (red)	Informal settlements only
Cluster 4	Low Reach 'Alley'	 (dark green)	Mostly Planned settlements
2 Secondary Boulevards	**forms the local grid between superstructures**		
Cluster 2	Low integration, Low Reach Angular Local Street Grid	 (orange)	Mostly planned
Cluster 3	Integrated, High Reach Angular Local Street Grid	 (yellow)	Mostly informal
Cluster 5	Long Straight Local Street	 (green)	Both planned and informal

Table 51 (continued): Summary of Street Types

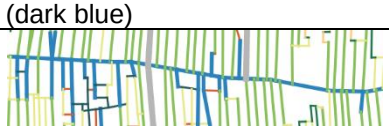
3 Super-Grid	**main highway super-grid**		
Cluster 6	High Choice, high integration Highway/Main Vehicular Road	 (grey)	Planned
4 Integrated Social Core	**always forms a configuration in informal areas that often aligns with the neighbourhood core**		
Cluster 7	High Reach Deformed dense organic grid	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

Table 51 shows the resultant street descriptions of the cluster analysis. The cluster analysis based on the previous variables resulted in 8 clusters, which were then organised into three groups based on the literature review in chapter 2, 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 two clusters that seem to be unique to informal settlements, which can also be differentiated by the emergence of the settlement – if it was infill on agricultural land or aggregated on desert land. These clusters can be used to aid in classification of the entire sample, and the cluster definition and ranges could potentially be used to classify outside the sample.

The relationship and interface of the local street network to the highway can also be used as a classifying factor. 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. This relationship can also

potentially be used in urban interventions, to reconnect the local street networks of informal settlements to the highway.

The main findings are:

- There are clusters that exist only in informal settlements and can be differentiated based on emergence.
- There is a quantitative way to differentiate between settlements without having to rely on previously known emergence and history.
- The highway super-grid is always highlighted as an important route and has its own cluster.

CHAPTER 8: SOCIAL LANDSCAPE OF INFORMAL SETTLEMENTS

This chapter outlines the results of the pilot social studies that were undertaken. The overall aim is to investigate the link between the social norms and spatial structure. The first study provides insight into how the community functions within an informal settlement, and the second study shows how the rest of the city interacts with informal settlements to fulfil their daily needs. While the studies are limited in scope due to methodological challenges, they fulfil the aim of contextualising the research and providing justification for proposed urban intervention. Chapter 8.1 presents a short study conducted in the appropriated informal settlement in Cairo, the City of the Dead. This settlement was part of the case studies of the quantitative analysis. This study aimed to show how the spatial structure of the settlement could support the community in their everyday living. It aimed to provide a case for using the quantitative analysis to uncover the spatial structure, and then tie that to the social observations in the field. The study shows that the spatial structure supports the community in their everyday living by providing access to job opportunities and social interaction. More importantly, the areas highlighted by the spatial analysis align with important areas in the neighbourhood, which provides some validation for analysing informal settlements using the quantitative methods.

Chapter 8.2 presents the results of an online questionnaire undertaken to show how the residents of Cairo travel across the city to fulfil their daily needs. The study quantified the questionnaire responses through movement maps. The results show that informal settlements are considered like any other neighbourhood in terms of moving, work and accessing services. The participant use of the transport network also indicates the presence of an informal transport network, which arose to fulfil the need to access different parts of the city. This indicates that informal settlements would benefit from urban upgrading and reintegration into the main city form, as they are not socially isolated.

8.1. CREATING COMMUNITY IN THE CITY OF THE DEAD

8.1.1. Introduction

The primary purpose of this pilot study was to explore how spatial structure can support the creation and maintaining of social links and daily activities in an urban fabric that was not designed to maintain community's everyday living. It is important to link the community's daily activities with the spatial structure in order to emphasise the effect that spatial structure has on supporting a community, and to assess the suitability of the quantitative approach to studying informal settlements.

This study uses space syntax and urban morphology analysis for two purposes: firstly, to analyse the spatial structure and secondly, to find out specific areas for investigation for the fieldwork. Fieldwork is informed by ANT (Actor Network Theory) where buildings are embedded in the social networks and users have their own spatial stories of everyday living (Latour 2005). The fieldwork investigates how the spaces highlighted by the spatial analysis are used, and the sense of community in the neighbourhood.

8.1.2. Neighbourhood Background

The City of the Dead is located in the Eastern Cemetery (also called the Northern Cemetery), which is one of a series of cemeteries located near Medieval Cairo. In this settlement, people live amongst the tombs due to eviction from central Cairo and rural migration (Rodenbeck 1998). In current estimates, its population exceeds half a million citizens (Ansah 2010) who started living there around the 1960s, initially as tomb guardians (Hamza 2001). The main typology of building is the Single Storey courtyard house built in Egyptian Funerary Tradition – "Hawsh" – which is usually a grave owned by one family. There has been additional informal building as more people have moved to the neighbourhood. Water is supplied via street taps, there is sewage piping on the periphery but not in centre, and electricity is provided in most areas (Nedoroscik 1997). People living in the City of the Dead maintain strong social links and have a sense of community, despite

living in an urban area that, on the surface, does not accommodate public spaces, community areas and space for everyday living (Hamza 2001).

8.1.3. Research Process Narrative

This section provides a brief overview of the research process, which has been explained in depth in chapter 3.2. Firstly, space syntax and urban morphology analysis was carried out to describe the neighbourhood quantitatively and to find potential areas of investigation. After that, the two questionnaires, some guidance for the interviews, as well as ethical approval and fieldwork plan, were prepared. The fieldwork visit was then carried out by Reem Saad in Cairo. This was done by direct observation, questionnaires, and key interviews with the residents. After the fieldwork was completed, the questionnaire and interviews were analysed and related to the spatial analysis.

8.1.4. Results

8.1.4.1. Syntactic and Morphological Description of the Site

The space syntax and urban morphology analysis produced a numerical description of the site and highlighted areas of interest for observations (Figure 78)

The syntactic description uncovered a regionalised integration core structure with two sub cores. There is a main spine connecting the two sub-cores and edge movement near the highway, which allows vehicular access. There are also access points into the centre of the neighbourhood which link the core with the edges. The neighbourhood also has comparable integration values to organically generated medieval settlements, and low standard deviation so there are no areas of major segregation from the rest of the neighbourhood (Table 52)

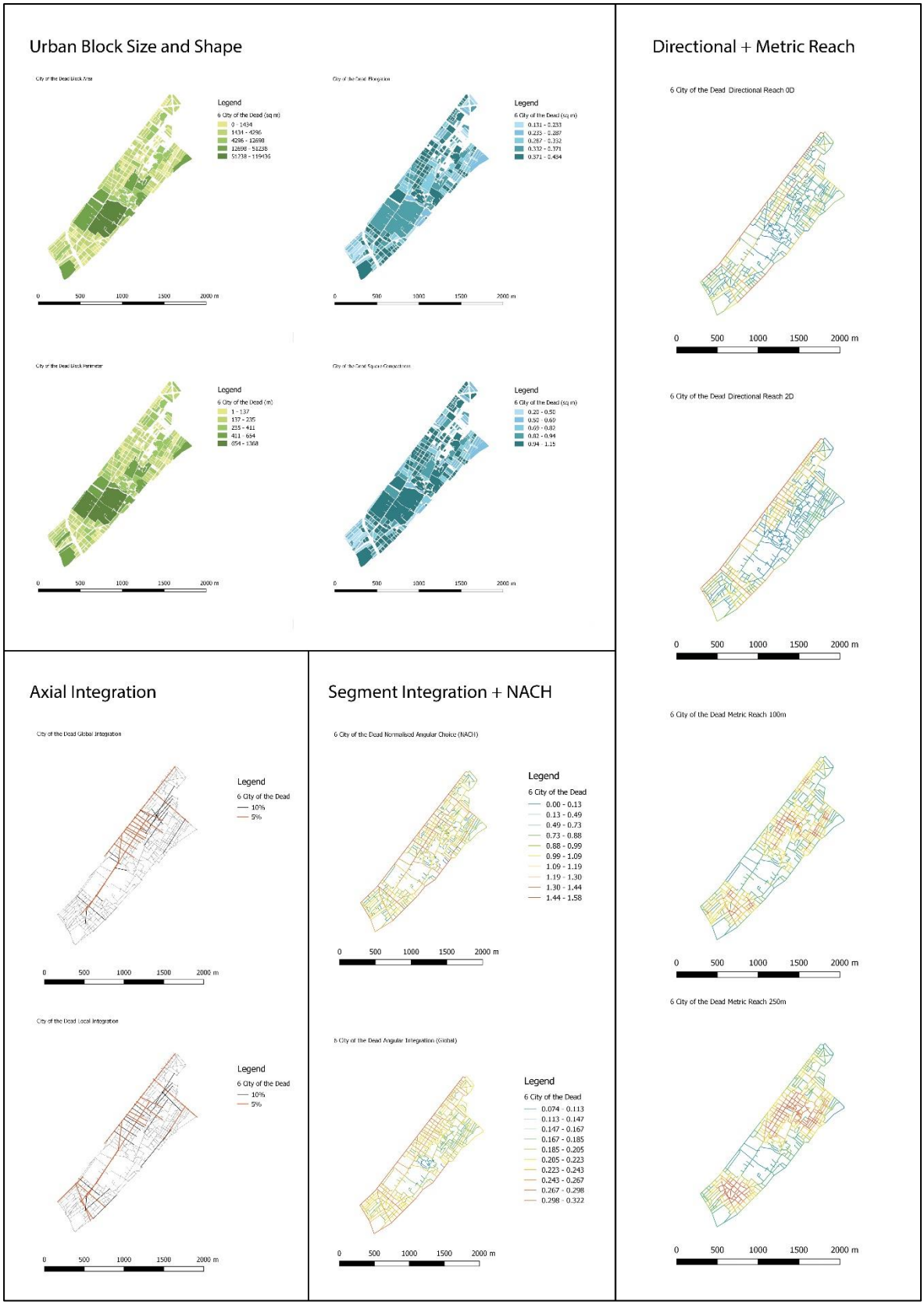


Figure 78: City of the Dead Syntactic and Morphological Analysis

The segment map results are similar to the axial map. NACH highlights the primary structure (shortest routes) of the neighbourhood which shows consistent edge movement, a clear core and streets connecting the two. The northern part of the neighbourhood also has several local streets intersecting the long straight street, which can be considered an emergent live centre. This indicates that the neighbourhood has potential to support community interactions and is accessible for residents and visitors.

Table 52: City of the Dead Axial Descriptive Statistics

Variable	Mean	StDev	CoefVar	Minimum	Maximum
Int_Global	1.47	0.28	19.00	0.81	2.34
Int_R3	2.29	0.55	24.06	0.42	3.95

Table 53: City of the Dead Urban Block Descriptive Statistics

Variable	**N**	**Mean**	**StDev**	**CoefVar %**	**Minimum**	**Maximum**
Average Block Face length (m)	467	45.7	30	65.7	3.85	342.3
Block_Area (ha)	467	0.25	0.66	268.8	0.0006	11.94
Sq_Comp	467	0.85	0.17	20.3	0.19	1.15
Elongation	467	0.34	0.057	16.9	0.13	0.43

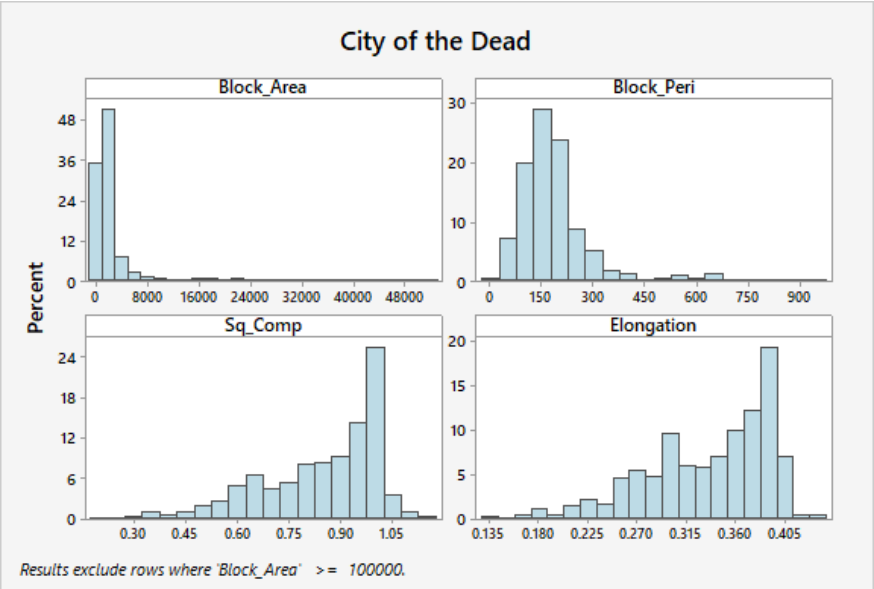


Figure 79: City of the Dead Distribution Graphs

The urban block analysis shows a straight grid pattern that has existed since inception, which retains plots that were designed previously to accommodate tombs. There are 467 blocks in this neighbourhood. Low standard deviation across the values shows little variation in the size and shape of blocks. Blocks have high elongation and square compactness, which shows their tendency toward regular rectangles, as originally designed (Table 53). The distribution graphs (Figure 79) show that 36% of the blocks are smaller than 0.2 ha and 85% are smaller than 0.4 ha with a few large outliers. Square compactness ranges from 0.3 to 1.05, with half the blocks between 0.9 and 1. The majority of blocks have an elongation value of 0.3-0.405. Both of these variables indicate that blocks are mostly medium and regular.

Through the analysis the following areas of investigation for observation are selected:

- Straight central streets (core/live centre)
- Straight streets in north-west corner (live centre/vehicular access)
- Two areas of density in north and south as shown by the reach
- Four large blocks in the middle

8.1.4.2. Key Observations

This section provides an overview of the observations undertaken in the fieldwork. It is split into two sections: the observations in the areas of investigation as identified in the previous analysis, and general observations of people's everyday living.

Observations in Areas of Investigation

- **Straight central streets** – these streets have been present since inception and it was observed that this is the main central route of the neighbourhood, which has shops, access to residences, etc. This aligns with the prediction from the syntactic analysis that these **streets are the core of the neighbourhood**.

- **Straight streets in north-west corner**- these streets **provide vehicular access** from Salah Salem highway and **provide space for cord spinning job opportunity.** This also aligns with the prediction from the syntactic analysis that they are important streets.

- **Two areas of density in north and south** – the neighbourhood is split into two zones; each area of density aligns with the centre of the neighbourhood parts where more intense building has taken place.

- **Four large blocks in the middle** - Very dense area in the centre comprise single graves/small plots that have merged together rather than separate courtyard houses. This highlights the difficulty in defining what is a block in an informal context since what may appear to be one entity can be composed of many smaller ones merged together.

Observations of People, Home and Work

These observations were conducted through walks through the cemetery and 1 month of family visits and studied how the residents used the space to fulfil their daily activities. The observations range from where the residents live, how they use the streets for access and what job opportunities are available.

Home

The main typology of housing in the City of the Dead is the single storey courtyard house, where residents co-exist with those buried there. The observations uncovered that funerary activities were normalised and unnoticed by the residents e.g., sharing living space within the tomb and using tomb as furniture. Tomb spaces were also appropriated by adding

wallpaper, tiling, furniture and using the burial courtyard for living space (Figure 80 and Figure 81)

Figure 80: examples of living spaces in the tombs and a sleeping space by a burial casket
Source: Saad, Reem. “Space and Everyday Life in Cairo’s City of the Dead.” Arab Academy for Science, Technology and Maritime Transport, 2019.

Figure 81: Example of appropriated courtyard space with addition of plants and seating.

Source: Saad, Reem. “Space and Everyday Life in Cairo’s City of the Dead.” Arab Academy for Science, Technology and Maritime Transport, 2019.

Public/Private Access and Job Opportunities

Figure 82: examples of the public streets with vehicular access

Source: Saad, Reem. “Space and Everyday Life in Cairo’s City of the Dead.” Arab Academy for Science, Technology and Maritime Transport, 2019.

Figure 83: example of the ‘hara’ semiprivate space in between two tombs

Source: Saad, Reem. “Space and Everyday Life in Cairo’s City of the Dead.” Arab Academy for Science, Technology and Maritime Transport, 2019.

Observation indicates that there is a clear public/private distinction in both the street network and the opportunities it offers. There is a differentiation between public roads and private streets/alleys. The main difference is that public roads are accessible by vehicles and private roads are not. This aligns with the assumption made in the syntactic analysis that there exist two movement networks, one for vehicles and one for pedestrians.

The private alley spaces are used as an extension of the home space, creating a ‘semiprivate’ area (Figure 83). This is also seen in other informal areas by usage of the ‘hara’ as an extension of the private sphere. The differentiation between public and private

Figure 84: Examples of the cord spinning profession carried out on the longest, straightest streets.

Source: Saad, Reem. "Space and Everyday Life in Cairo's City of the Dead." Arab Academy for Science, Technology and Maritime Transport, 2019.

streets affects the job opportunities that are available for both genders. Women tend work out of the home spaces by selling confectionary through the windows overlooking the semiprivate and public roads, and men usually work as car mechanics on the publicly accessible roads, tomb guards or silk spinners (Figure 82). The silk/cord spinning profession is directly related to the spatial structure of the streets, as it requires long, straight streets to effectively carry out the silk spinning (Figure 84).

8.1.4.3. Key Interviews and Questionnaire Responses

This section summarises the information from the key interviews and Sense of Community questionnaire. Interviews were carried out in people's homes and on the street where they worked. 6 respondents allowed photos to be taken and quotes used and completed the 'Sense of Community Questionnaire'. All the dialogues with residents were conducted in Arabic and have been translated to English by the researchers.

Interviews

The responses from the interviews provide insight into the social bonds of the residents, the local perception of the spatial aspects of the neighbourhood, their sense of community and attitudes towards the funerary tradition. The following section provides a summary with selected anonymous quotes from the interviews.

Responses indicate that residents have lived in the neighbourhood for multiple generations. In some cases, they have had the opportunity to move to satellite cities and chose not to.

> *"I've lived here for 50 years; this is our family's graveyard. Our house was in Gamaleyya, but it fell down, so our family set up tents in Masjid el Muizz. The government keeps promising to house us, but they do not do anything. My grandfather decided to split the graveyard in two, half for the living and half for the dead. We saved up enough to buy a flat in 15th May City (satellite city) but it's too far for us to travel to work, so we didn't move, and I thought I'd save up this money for my children's education."*
>
> *"If they told me to go to New Cairo I'd say never! I have everything I need here within walking distance."*

These responses also indicate that one of the reasons for not moving is the spatial structure of the neighbourhood and the opportunities this affords – residents said that moving outside of the neighbourhood would be too far away for commuting to work and that they had everything they needed within walking distance.

The community seems to be tight knit, with everyone knowing everyone else nearby. People also take a community approach to problem solving. Generally, residents responded that others were helpful and co-operative, and that everyone had a similar socio-economic background, so they all know each other and have the same daily concerns. One resident noted that community bonds are generally not present in Egyptian society, but that they were more present in this neighbourhood. This aligns with previous literature about higher community bonds in informal settlements (Ansah 2010; Eldefrawi 2015).

> *"Problems? We do not have any problems here. Everyone knows each other but we don't have any hierarchy or snobbery, we're all poor here."*
>
> *"We don't have a boss, we're all poor here. If we have a problem, we will solve it together."*
>
> *"I know everyone who lives here, I haven't spent a single Eid in my house alone."*
>
> *"All our neighbours know each other and have grown up together, we don't let strangers in among us."*
>
> *"If there's a problem between us we have a neighbourhood meeting and solve it together."*

The spatial structure is also used as landmarks - the graves and other markers are used to direct people to where they want to go. Residents also state that it is easy to find where they want to go using these markers and would be able to describe these routes to a stranger.

> *"It's really easy to describe where to go, everyone is neighbours."*
>
> *"Yes, we know where we are and can describe our routes using the graves."*
>
> *"People are really co-operative and helpful here; they would direct a stranger to wherever they need to go."*

However, there are issues arising from living in an informal neighbourhood. The children are usually educated outside of the settlement due to a lack of schools. There is also no sewage system except on the periphery of the neighbourhood and water is supplied through street taps. Residents also face issues when dealing with the owners of the mausoleums and the family of the dead, which can treat them poorly and threaten their residency in the tombs.

> *"The schools that are here are not good, so the kids go to the school that's in the Hussein. They walk over there then get the bus."*
>
> *"All our problems are with the owners of the mausoleums not our neighbours. The girl [mausoleum owner] thinks that it is their right to be rude to us about cleanliness and such because we are living here for free, but I think not, they do not realise that this is our home, we paint and do the tiling and clean using our own money. If they come here one day and find a slipper lying about or washing hung up, they will argue with us. They treat us very badly; she won't come in if she finds our washing hung up."*
>
> *"We have telephones, water and electricity but no sewage system. The government do sometimes put in services; they say it's enough we're living with the dead."*

Death and funerary tradition are normalised and accepted as part of life while living in the city of the dead. There are many rumours and verbal stories about what goes on in the tombs.

"The weirdest story I know was told to me by my aunt. There was a pregnant woman who died and was buried here, and later on they opened up her grave and found her son in there just playing. They called him the dead boy."

"I always say to my friends that my neighbours are princes and pashas."

"There's famous mausoleums here. The kids say they have seen Sheikhs. Of course, the dead rise up."

To conclude, these interviews paint a picture of a neighbourhood that has appropriated the space of the city of the dead in order to fulfil their need for housing. There is also a sense of community present. Residents recognise the difficulty in living in such a neighbourhood, but in most cases do not want to leave. The spatial structure is also legible and contributes to their ability to carry out daily tasks – everything is in walking distance, and they know where to go by using landmarks.

Results of Sense of Community Questionnaire

The 'Sense of Community Questionnaire' was filled in by six respondents, and as a result, it does not allow for generalisation of the attitudes of residents. However, it provides a good insight into attitudes and a point of comparison for the interviews.

The questionnaire was graded out of 72 points. The highest score was 42 and the lowest 22, with most scores falling between 30-32. This indicates that most respondents felt that there was not a sense of community in the area. These scores contrast with what was said in the interviews, where residents felt that there was a sense of community in their neighbourhood. The reason for this discrepancy is unknown, so we may need to re-evaluate how we formulate questions and which scales/questionnaires are used.

8.1.5. Overall Findings and Conclusions

The main findings of this study fall into two categories – influence of the spatial structure and attitudes of the residents towards their neighbourhood. Findings indicate that the spatial structure contributes to job opportunities, for example, the long alleys allow the cord/silk spinner occupation, and the funerary houses act as housing for residents. From the

interviews it seems that there is a sense of community in this neighbourhood - residents have lived there for several generations and some have been offered the opportunity to move but do not want to. However, scores on the community questionnaires are low.

8.1.5.1. Spatial Elements Influence on the Community

Results indicate that the spatial elements (urban fabric and architectural style) support the community here by providing housing (people do not need to build their own houses) and providing access points from the highway. There are also different types of streets such as public access (car) vs private access (hara). These streets also allow for different activities and job opportunities, such as the cord spinners that need a long straight street and the confectioners that sell out of the tombs on the 'main' streets. The spatial structure is fairly legible and residents report having a sense of direction and being able to find their way and direct others using landmarks.

8.1.5.2. Conclusions

This study shows that there is a link between the spatial structure and the daily activities of the community. The areas highlighted by the spatial analysis align with important areas in the community such as the main street, access to the neighbourhood and the two neighbourhood cores. The urban fabric provides opportunities, housing, etc. unique to this location.

The study also contributes to the classification of informal settlements – this settlement can be classified as 'exformal' (Soliman 2004), which indicates a neighbourhood that was planned in some way, then was changed, and used differently to its initial purpose. There is also a further differentiation in the streets, reinforcing the 'hara' type and differentiating between public and private access. This aligns with streets found in the previous clustering in chapter 7.3.

8.1.5.3. Limitations

This study faced some limitations and highlighted the difficulties in fieldwork in Cairo. Data collection was limited due to having limited access to the field and not being able to re-evaluate the questions after the first set of results. Since only one neighbourhood was studied, it means the results of this study cannot be generalised. However, these limitations led to a creative social data collection through online questionnaire. It also reinforced the importance of the spatial analysis and its validity in this context.

8.2. DAILY ACTIVITIES OF CAIRENES QUESTIONNAIRE

8.2.1. Introduction

The questionnaire's primary purpose was to investigate whether people travel outside their neighbourhood to carry out their daily activities, with a focus on travel from planned areas to informal areas. This can provide insight into whether informal areas are socially integrated into the city and whether they provide services to the residents in order to justify physical reintegration. It also aimed to map the movement patterns of participants that travel from their neighbourhoods to work, school, or for other reasons.

In this questionnaire, the three categories of settlement used the broad legal categorisation of planned and informal. Informal areas include all emergences and morphologies and hybrid/exformal/sha'abi areas which may have become informal over time. Satellite cities are included as a subset of planned settlements as they emerged much later than those settlements within the main city form. This distinction is necessary as the separation of satellite towns from the main city form may influence transport, access to amenities etc. Satellite cities are also a relatively recent phenomenon in Cairo (2000s) so are distinct from planned areas that have been developing alongside informal areas. In all graphs and visualisations orange represents planned areas, yellow represents informal areas and green represents satellite cities, except were indicated otherwise.

Movement Maps Based on the Questions

One of the purposes of this questionnaire was to provide data points which would be mapped to visualise the participants' movements from their residential neighbourhood to their daily activities. The data produced was less than expected, but nevertheless it produced some data points that could be mapped. Two base maps were created, one of the participants' childhood home and one of their adult home. These were then cross referenced with work and school data to create movement maps. In total, three movement maps were created: showing the move from the childhood to adulthood residence, travel

from childhood home to school and travel from adulthood home to work. The rest of the questions about shopping for necessities and leisure did not produce enough data points to make a meaningful movement map.

Each line on the map represents one participant's journey. The number of movement lines varies as it represents each question's answers. Each map is presented alongside the relevant questions.

8.2.2. Questionnaire Part 1: Basic Demography and Filtering Questions

Questions:

- Gender (Male/Female)
- Age (Under 18, 18-24, 25-34, 35-44, 45-55, 55)
- Original Family Governorate

Filtering Questions:

- "Do you have children? (Yes/No)"
- "Do you own a car? (Yes/No")

8.2.2.1. Age and Gender of Participants

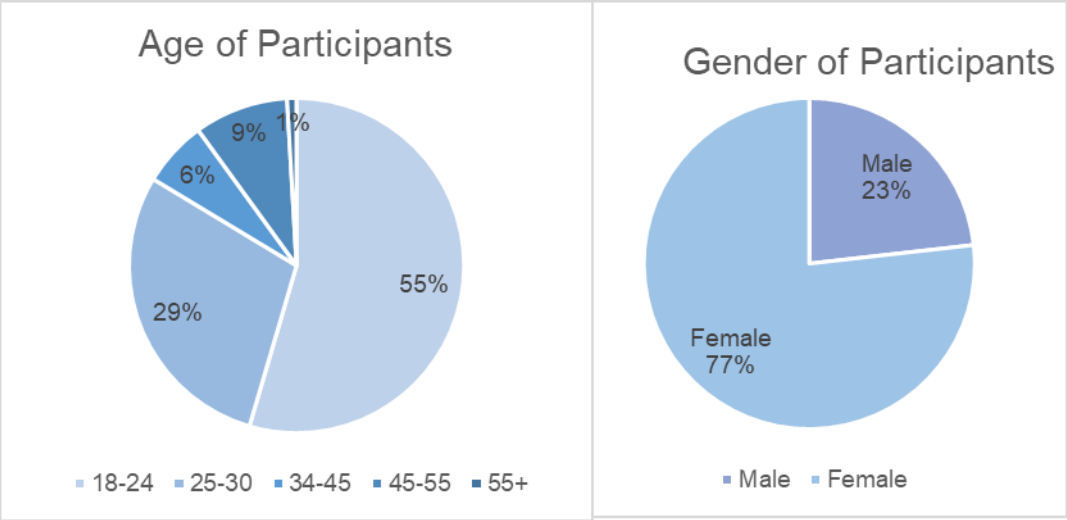


Figure 85: Pie chart showing age and gender of participants

The above pie charts (Figure 85) show the percentage of answers for each demography question. The main bulk of the participants (55%) belonged to the 18-24 age range, over a third (29%) belonged to the age range 25-30, and the rest of the participants were over 45 years old. Two participants were under 18 and their responses have been filtered out. Such distribution can be explained by the nature of the dissemination method. The sample size is skewed towards younger participants, since they are more likely to use Facebook. However, this age distribution remains reflective of Egypt's population where there is a significant 'youth bulge'; the median age is 24.6 years in 2020 and 56.4% of the population is between 15 and 54 years (CAPMAS, 2019b).

Regarding gender, the majority of participants were women (77%). The gender of participants is not indicative of population split, which is 48.9% female and 51.1% male (CAPMAS, 2019b). The potential explanation for this unequal split is that the questionnaire was disseminated through the researcher's own network and initially through women only Facebook groups. Therefore, it is important to bear in mind that the questionnaire results will be more reflective of a woman's point of view of life in Cairo.

8.2.2.2. Original Family Governorate

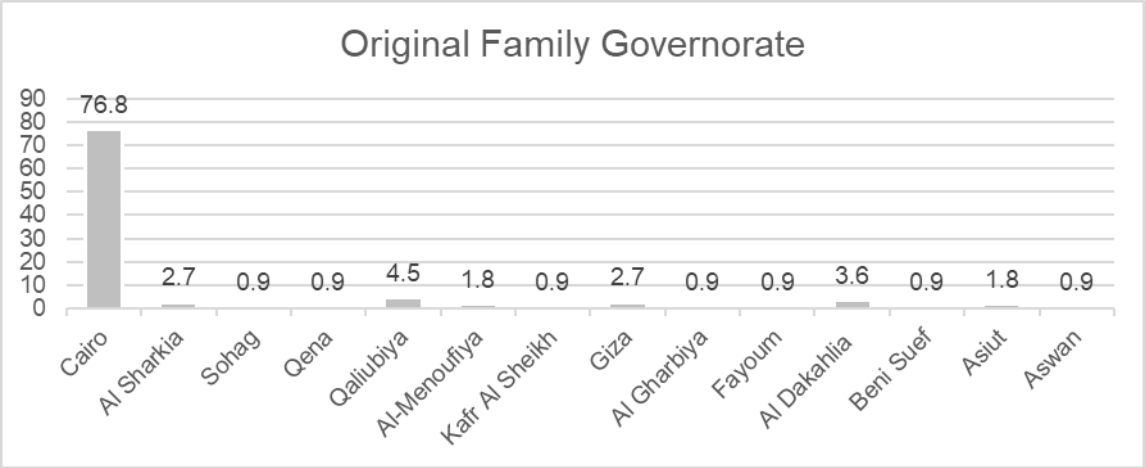


Figure 86: Chart showing responses to the original family governorate question

This question aimed to record the potential internal migration that may have occurred in the life of the participants from other governorates to Cairo. It provided an important insight into how participants identify themselves – as belonging to the city of Cairo or somewhere else. The majority (2/3rd) of the participants answered that they were born in Cairo (77%), while the remaining participants originated from 13 other governorates (out of 27). The provenance was fairly distributed across all these other governorates (1-2%), with Qalubiya, Giza, Al Sharkia and Al Dakahlia slightly more cited (3-4%) (Figure 86). These are Cairo's neighbouring governorates, so it is expected that they would have the highest migration rates. These results are reflective of the general trend of internal migration (David et al. 2019).

However, since most migration from the countryside took place in the 1950's (Nagi 1974), most participants must have been second generation Cairenes, if their grandparents migrated from the countryside. This question should have specified the date/era of migration for more accuracy.

8.2.2.3. Children and car ownership

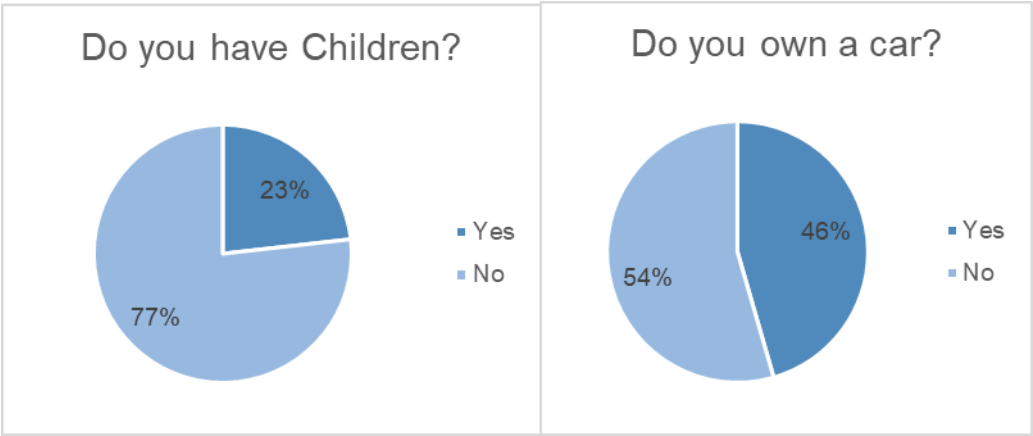


Figure 87: Pie chart indicating if participants have children or own a car

The majority (77%) of participants did not have children (Figure 87). This can be attributed to the relatively young age of the participants. In hindsight the questionnaire should have included a question about marital status as well as having children, as the daily activities and movements of a married couple could be different from those of a single person.

Just under half (46%) of participants owned a car (**Error! Reference source not found.**). This is much higher than the average car ownership in the Greater Cairo Region which is among the lowest worldwide, 90 cars per 1000 inhabitants (9%), (CAPMAS 2015; El-Dorghamy 2018). It would have been useful to have a further question asking if the participants personally owned their car or just had access to a family-owned car. However, the question fulfilled its purpose of directing participants to further questions about transport usage and car maintenance which produced mappable data.

8.2.3. Questionnaire Part 2: Childhood Lifestyle Questions

Questions:

- “Where did you live as a child?”
- “Where was your school?”
- “Where did you play?”
- “Where did you buy food and sweets?”

The Childhood Lifestyle Questions asked about where the participants lived as children, where they went to school, where they played and where they bought snacks and sweets. These questions can provide insight both into the history of residence areas in Cairo (since it was smaller and satellite cities had not been built when the participants were children), and the internal movements to school and leisure compared to the present. It also provided insight into where the family home was situated compared to the participants' current residence and how the urban conditions changed over time.

The questions were deliberately kept simple since for many participants this era would have been a long time ago and details could be lost in memory. The answers from these questions were mapped. Movement between activities was also mapped and compared to the participants' living situation and movement as adults.

8.2.3.1. Residence as Children

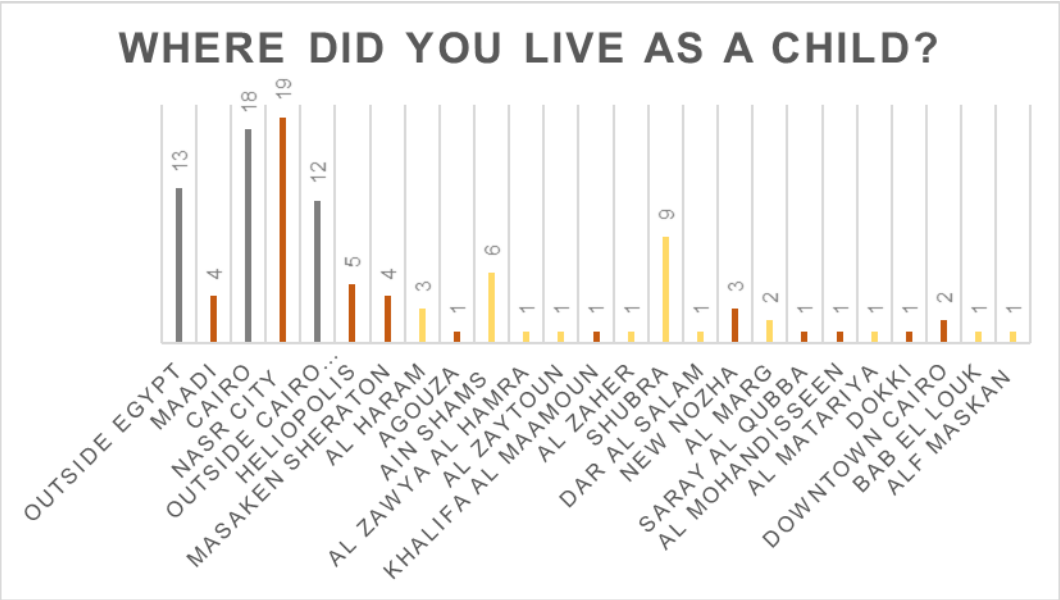


Figure 88: Chart showing the childhood residence neighbourhoods of the participants

This question was designed to find out where participants lived as children in order to provide a starting point for movement maps. A short form text box was provided to allow participants to write in their answer rather than try and predict all possible answers. The answers were mostly districts in the Greater Cairo region (Figure 88). All answers outside Egypt and outside Cairo were grouped together in the results, as well as answers that were

just ‘Cairo’. These groups were disregarded in the mapping diagram that follows. This filtration resulted in 22 different areas of Cairo as answers. 11 of those areas are planned and 11 are informal.

13 participants lived outside Egypt and 12 participants lived outside Cairo during their childhoods. 18 participants answered ‘Cairo’ without specifying the district. This leaves 67 participants that specified a district. Overall, 24 participants lived in informal or ‘sha’abi’ (popular) areas, and 43 lived in planned neighbourhoods. The highest recorded answer was Nasr City. 19 participants grew up in Nasr City which can be explained by it being the most populous planned district in Cairo (CAPMAS 2019b). The second highest recorded answers were Shubra with 9 participants and Ain Shams with 6 participants. Both of these areas are considered ‘sha’abi and have grown informally (Sims 2012). The rest of the districts had 5 responses or less.

Childhood Home Base Map

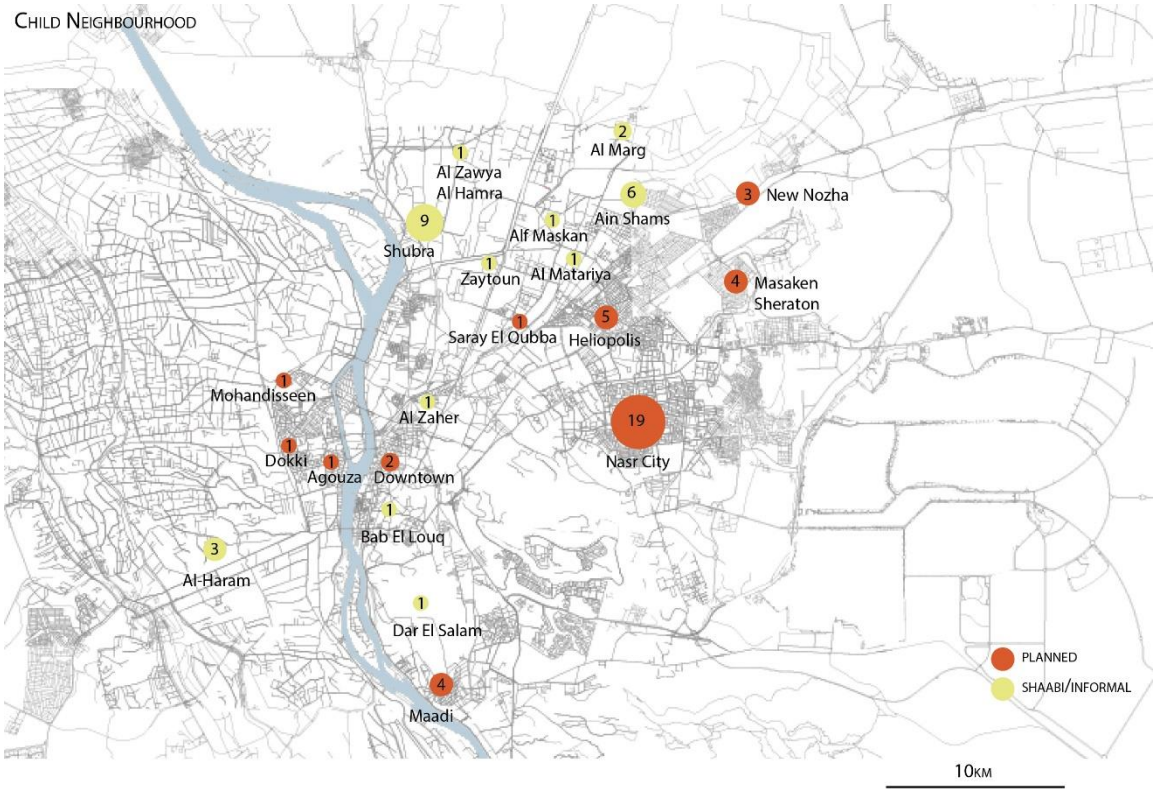


Figure 89: Childhood neighbourhood base map

The base map shows the geographical spread of neighbourhoods where the participants lived as children (Figure 89). It also categorises each neighbourhood and shows the number of participants that live there. The map that was used as a background to this mapped data is from 1999; since that is the year where the majority of participants would be between 6 and 18 years old. At the time, there were no satellite cities, as their construction had just begun, and the city itself was much smaller than it is presently.

8.2.3.2. Location of School as a Child

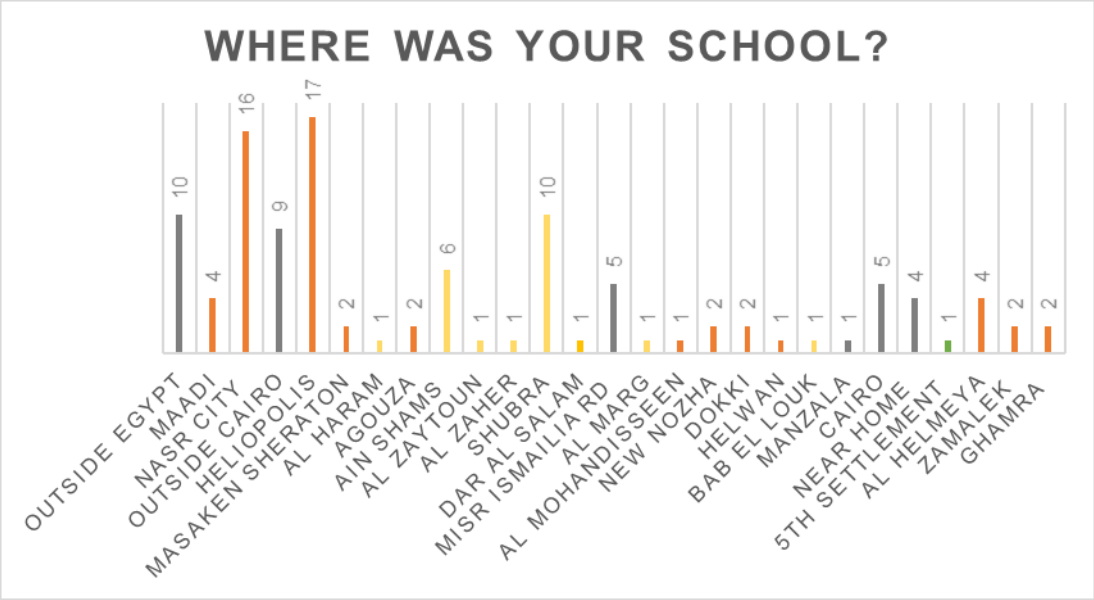


Figure 90: Chart showing location of schools of participants

This question asked where the participants went to school. Its purpose was to explore if they went to school in the same district as they lived or if they needed to travel to attend school. Similar to the previous question, ‘Cairo’ ‘Outside Cairo’ ‘Near Home’ and ‘Outside Egypt’ answers were grouped together and disregarded from the movement maps. There were some participants who answered ‘Cairo’ to the question about where they lived even though they knew which neighbourhood their school was in. This may be because they did not know or remember the exact area where they lived then.

Figure 90 shows the results of this question. 10 participants went to school outside Egypt, 9 outside Cairo, 5 in Cairo and 4 ‘near home’. Overall, 82 participants provided mappable data over 11 planned and 11 informal districts. It is important to note that Misr Ismailia Rd

is not a district, rather it is a road on the outskirts of Cairo that provides access to many schools around it. Nasr City and Heliopolis were the top answers with 16 and 17 participants respectively attending school there. Shubra and Ain Shams were the second most popular answers with 10 and 6 participants attending school there. The rest of the answers had 5 responses or less.

Movement from childhood neighbourhood to school

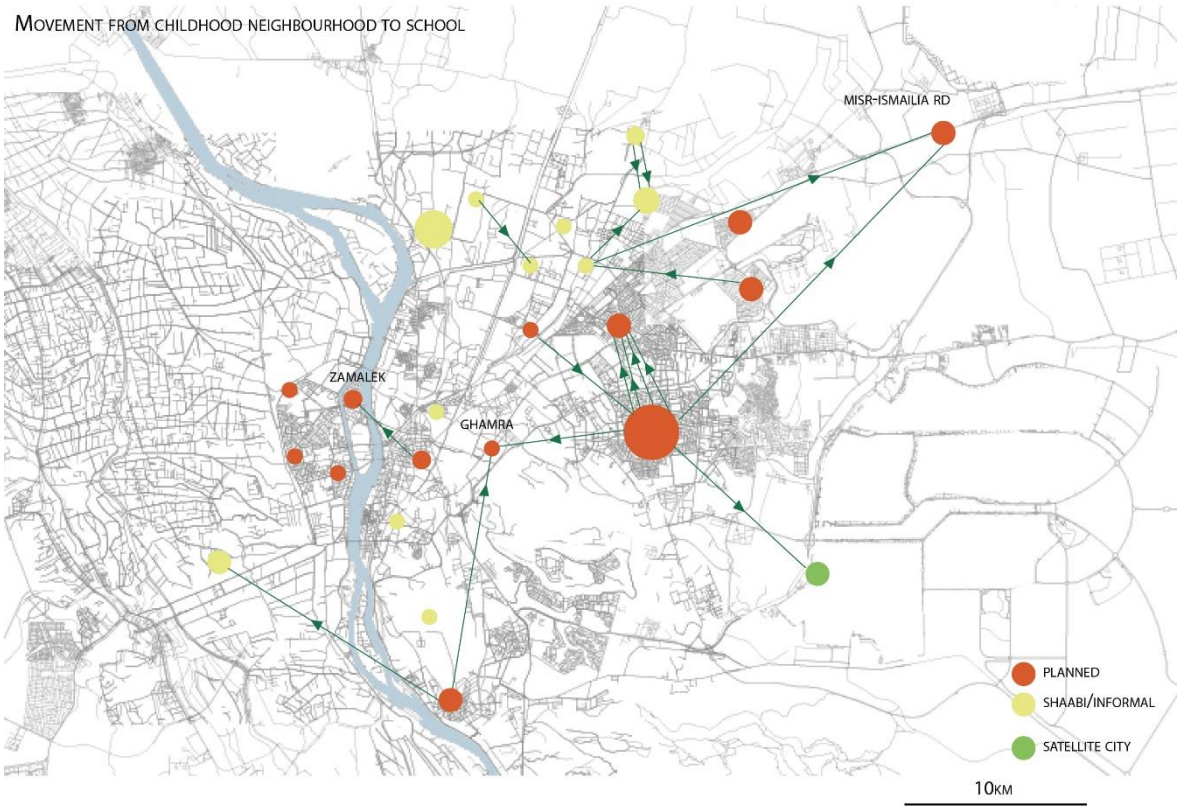


Figure 91: Movement map showing movement from childhood neighbourhood to school

Figure 91 shows the travel by pupils from their home neighbourhood to attend their schools. Where no line is connecting two neighbourhoods it means that the pupils who attend school in that neighbourhood also live there. The map and previous graph show that children who live in informal areas are more likely to attend school there, and pupils who live in planned settlements attend schools outside their neighbourhood more often than not. This could be due to pupils in planned settlements being more affluent and able to afford transportation to better schools. Pupils who live in an informal settlement that is near to a planned

settlement also attend school in the planned settlement over school in their informal settlement.

8.2.3.3. Play and leisure as a child

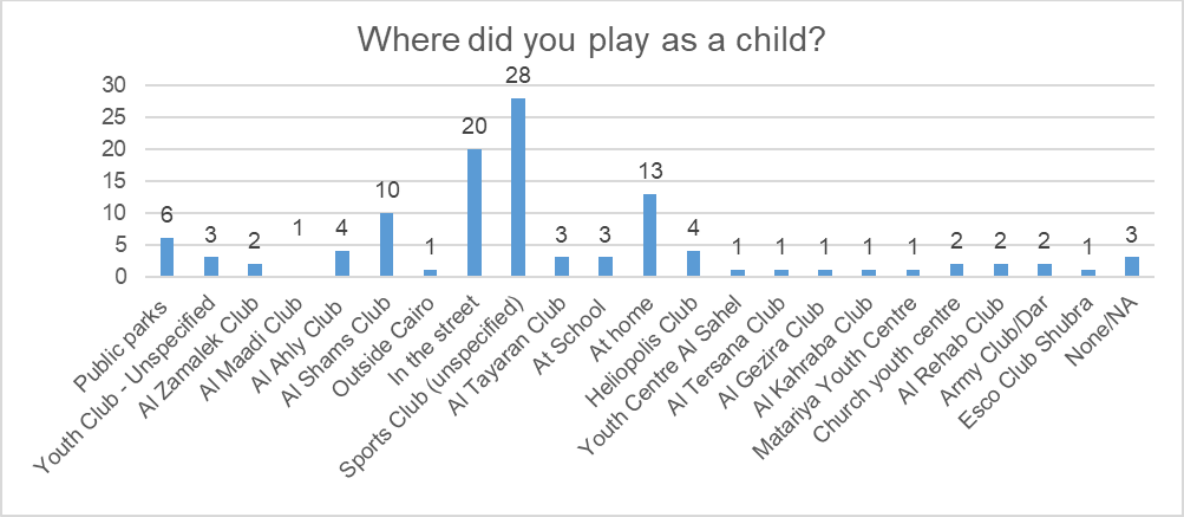


Figure 92: Chart showing where participants played as children

This question asks how the participant spent free time as a child. It intended to examine if children played within their neighbourhood or they travelled outside of it to spent leisure time. It also highlighted differences in leisure time between participants who lived in planned neighbourhoods and those who lived in informal/sha'abi neighbourhoods. A short form text box was provided where participants could write in their answer, or multiple answers. This question was optional, as a result some participants chose not to answer. Figure 92 shows the results of this question. Overall, there are 113 responses to this question, with some participants writing in multiple answers. Unfortunately, this question did not yield much mappable data as many responses did not specify a location, but it still provided insight into the daily movements of the participants as children when cross referenced with where they lived.

The primary answer categories were public parks, sports clubs, youth centres or at home, in the local street or at school. The first distinction to be made is free and paid activities. Public parks, youth centres, playing in the street, at school and at home were all classified

as free, while sports clubs were paid. There is a distinction to be made between sports clubs and youth centres; while they offer similar activities, youth centres are free, and government funded, while sports clubs are privately run, and families pay an annual membership fee. Another type of club is the *'dar'* which is only available for use by army officers and their families.

The participants were split evenly between paid and free activities. In total, 60 participants (55%) answered they spent their leisure time in sports clubs. Just over half of those participants specified which sports club it was, with Al Shams Club being the most popular with 10 responses. 7 participants answered that they spent their leisure time at youth centres. The rest of the answers were split between playing in parks, local street, home, or school. 6 participants spent their leisure time at parks, 20 in their local street, 3 at school and 13 at home.

When cross referenced with the residential neighbourhood data, there was no correlation between free activities such as playing at home, in the street, at school or in public parks, and where the participants lived, indicating that these activities at the time were not split between income classes. The main difference was that participants who lived in informal and sha'abi areas would use youth centres, which are usually located in their neighbourhoods. However, participants who lived in planned settlements exclusively used paid sports clubs in their neighbourhood or in one nearby.

8.2.3.4. Shopping for snacks and sweets

This question asked participants where they spent pocket money on food as a child. A short form text box was provided where participants could write their answer. In total, 76 participants answered some form of unnamed supermarket and the rest named the supermarket or location. This did not yield mappable data, and in hindsight it would have been useful to provide a choice of answers such as 'near school' or 'near home' which could then be cross referenced with previous answers.

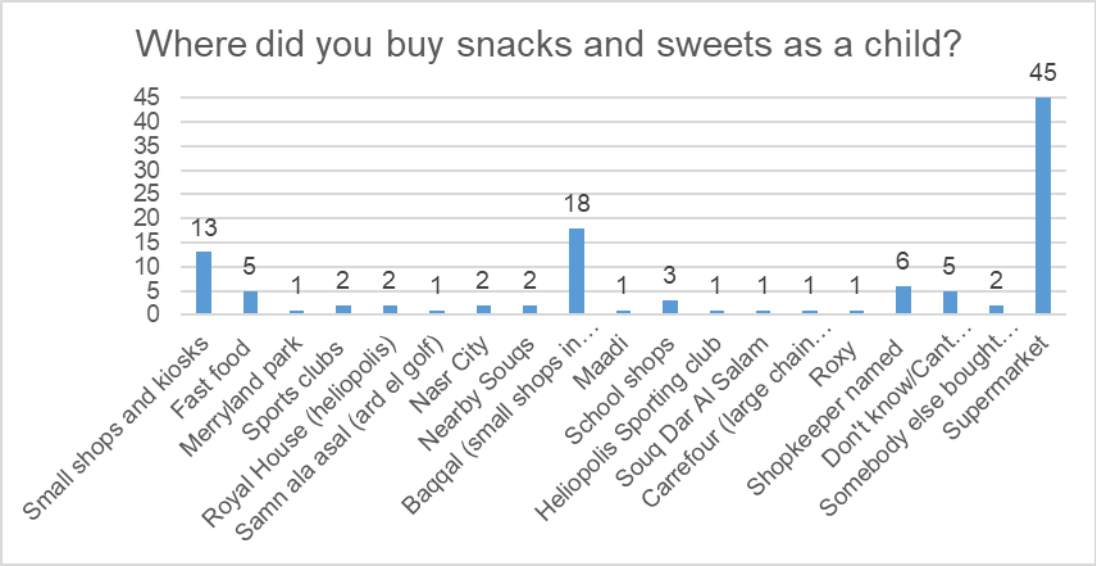


Figure 93: Chart showing where participants bought snacks as a child

Figure 93 shows the results of this question. While this question did not yield much location data, it helped bring to light some linguistic differences in the answers from participants in informal, sha'abi and planned neighbourhoods. The first is the usage of the words *mahal, baqqal*, kiosk and supermarket to refer to small corner shops. The majority of participants that referred to the corner shop as 'supermarket' lived in planned settlements. Those who referred to it as *mahal* had no correlation to where they lived, since *mahal* is a general Arabic word that means 'shop'. Those who used *baqqal,* a word that is also used in Turkish and Greek, mostly lived in sha'abi or informal areas. *Baqqal* is considered a very old way of saying grocery or shop. As well as this, all participants who answered with a named shopkeeper e.g., Uncle Joseph, Uncle Alaa, Om Reda, lived in informal or sha'abi areas. This could indicate that informal areas have stronger community bonds as they know the shopkeeper by name and have also retained an older Egyptian dialect.

8.2.4. Questionnaire Part 3: Adult Lifestyle Questions

Questions:

- "Where do you live now?"
- "Do you have children? (Yes/No)"
    - "If yes, where is their school?"

- “Where do you go to spend time with your friends?”
- “Where do you work?”
- “Do you own a car? (Yes/No”)
    - “If you own a car, where do you get it fixed?”
- “Where do you buy clothes?”
- “Where do you buy food? From which area, shop or marketplace?”

These questions were similar to the questions asked in the childhood lifestyle section. They cover where the participants live now as adults, where they send their children to school, where they work, where they spend their leisure time, where they get their car fixed, where they buy clothes and food and their usage of public and private transportation.

The participants’ residential areas could be mapped to show movement from their childhood neighbourhoods. The other questions represented everyday activities such as going to work, spending time with family and friends and shopping, the intention of which was to show how participants moved around the city to fulfil their everyday activities, and to show in which neighbourhoods (planned, informal or sha’abi) these activities took place. Services such as hospitals, police, fire stations etc., were not included in these questions since they are not considered a daily activity for most people. These data can be found elsewhere on the CAPMAS GIS platform or in census data.

8.2.4.1. Residence neighbourhood as adults

This question asks about the neighbourhoods where the participants live now as adults. A short form text box was provided where participants could write their answer. ‘Outside Egypt’ ‘Outside Cairo’ and ‘Cairo’ and the ‘did not move’ answers were grouped together. In total there are 82 mappable responses over 18 planned areas and 4 sha’abi/informal areas. The first thing to note is the increased number of planned neighbourhoods, which is due to the expansion of Cairo and the addition of several satellite towns such as 5th Settlement, 6th of October and Al Obour. This new class of settlement emerged in the early 2000’s and was designed to provide housing for the expanding population of Cairo.

Nowadays only 3-5% of Cairo's residents live in satellite towns and they have a vacancy rate of about 75% (Sims 2015).

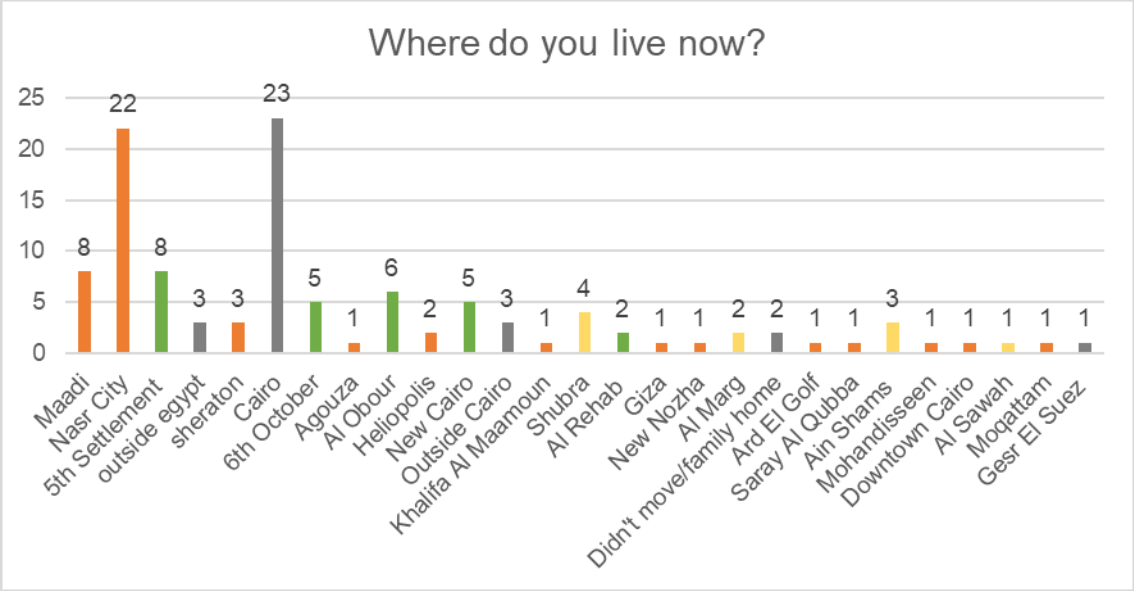


Figure 94: Chart showing where the participants live as adults

Figure 94 shows the results of this question. Overall, 71 participants answered that they live in planned neighbourhoods and 11 in informal/sha'abi neighbourhoods. The most popular answer is still Nasr City with 22 responses. This is followed by the planned settlements Maadi and 5th Settlement with 8 responses. The informal settlements with the most answers are still Ain Shams with 3 responses and Shubra with 4 responses.

When compared with the childhood residency question this shows a decrease in those living in informal areas and an increase of those living in planned areas. However, it is important to note that all but 2 participants have moved from their childhood areas, so it is probable that those who lived in informal areas to have moved in planned areas.

Adult Home Base Map and Movement from Childhood Neighbourhoods

Figure 95 shows a map of the home neighbourhood of participants as adults. The neighbourhoods are categorised with 'satellite city' being a new category of neighbourhood. The base map itself shows Cairo as it was in 2018, which is much larger than in 1999, with the addition of satellite cities.

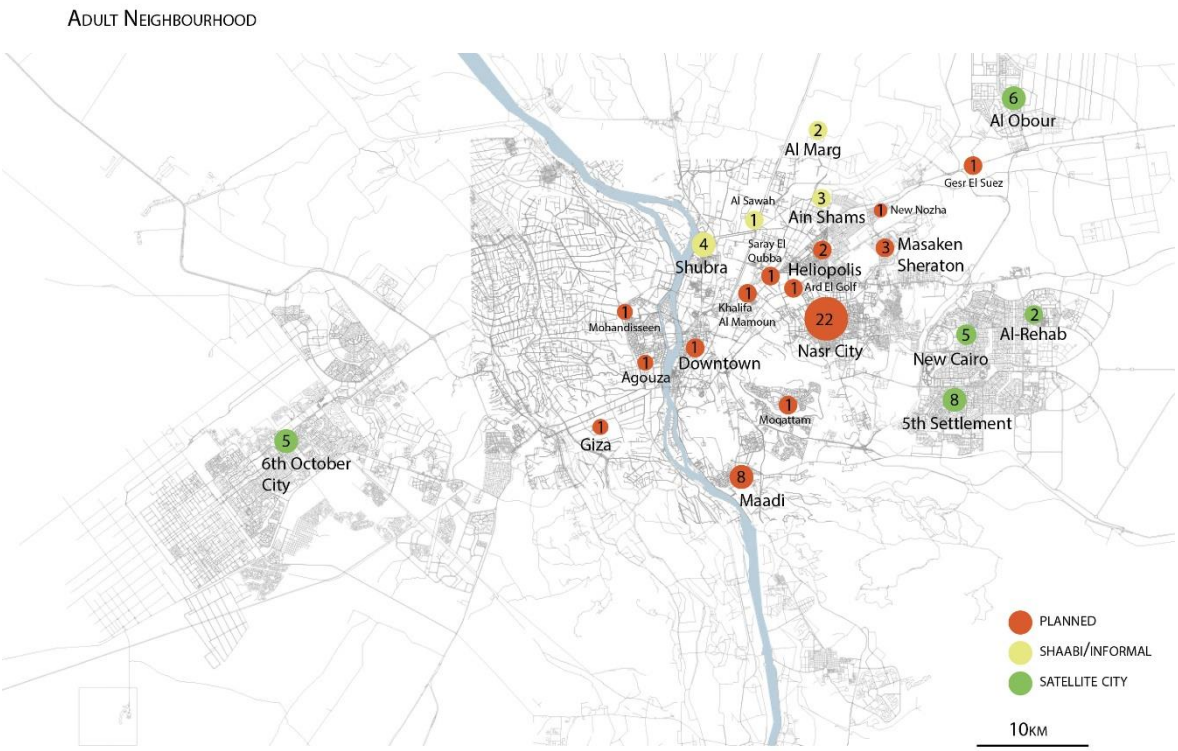


Figure 95: Base Map for Adult Neighbourhood

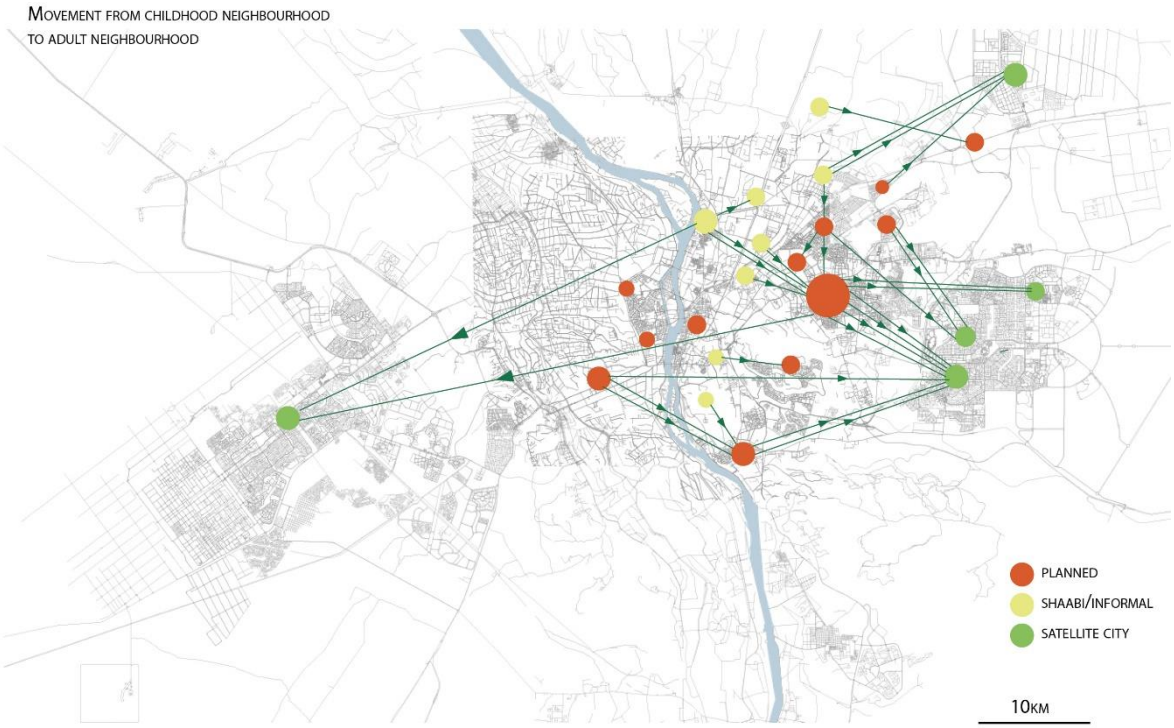


Figure 96: Map showing movement from childhood neighbourhood to adult neighbourhood

There is still a significant percentage of the participants living in Nasr City, but studying the movement from child to adult neighbourhoods shows that it is not necessarily the same participants living there as adults, that lived there as children. Figure 96 shows the movement from childhood neighbourhood to adult neighbourhood. There has been significant migration towards the east of Cairo, with participants that used to live in informal or sha'abi areas moving to Nasr City, and participants who lived in Nasr City (the affluent neighbourhood of the time) as children, moving to the 5th Settlement and other satellite towns. The movement lines show a clear tendency for those who lived in planned areas as children to move to satellite cities as adults (13 participants, 43% of data points). 8 participants (26%) who lived in informal areas moved to planned areas and only 3 participants who lived in informal areas moved to a satellite city.

Of 24 participants who lived in informal areas as children, 12 remained where they were, 11 relocated to Nasr City or other planned settlements, with one participant relocating to a different informal area. Of 43 participants who lived in planned areas, 14 remained where they were, 20 relocated to a satellite town and 9 relocated to another planned area. To generalise, 32% of residents in a planned area have lived there since childhood while 50% of residents in an informal area have lived there since childhood. Participants who lived in informal and sha'abi areas were less likely to move, indicating that there could be a stronger community or familial bond in informal areas. However, it is just as likely that it is too expensive for participants who lived in informal areas to move out of them.

8.2.4.2. Location of Children's schools.

This question was the most unsuccessful of all the questions. Some participants went on to respond even after indicating they did not have any children- these responses were disregarded. Of the ones that did have children, the majority of them were not yet school age due to the younger age of the participants, so there was no significant data gathered.

8.2.4.3. Location of Leisure Activities

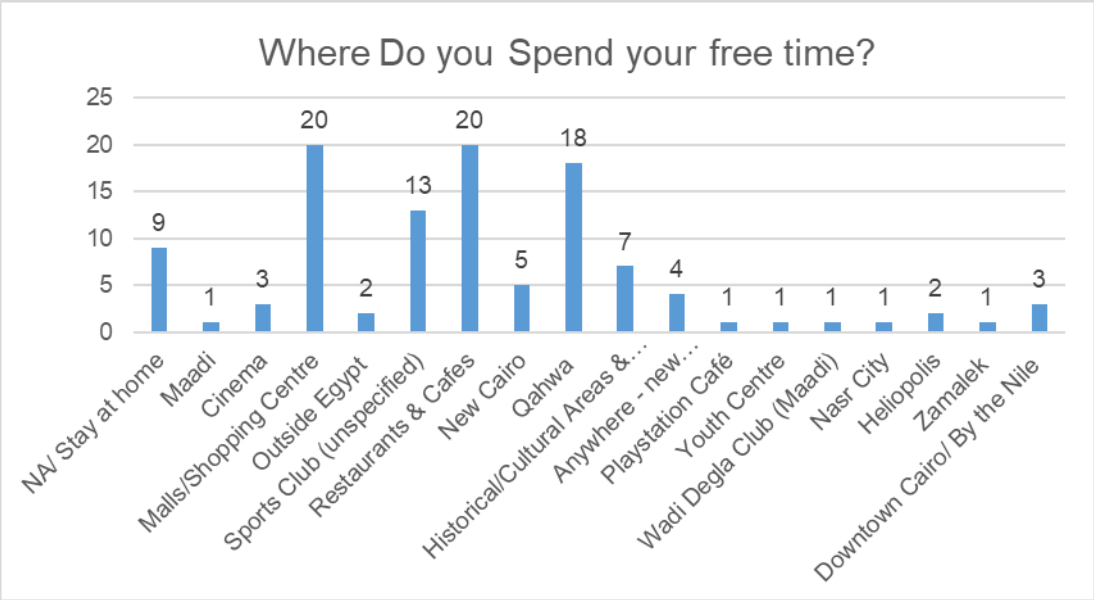


Figure 97: Chart showing where participants spend their free time

This question asked the participants where they spend their leisure time. The intent was to mirror the childhood lifestyle question about play. A short form text box was provided where participants could write their answer and allowed multiple answers to be written in. Figure 97 shows the results of this question. The most popular answers were Malls/Shopping Centres and Restaurants/Cafes with 20 responses each. The second most popular answer was the Qahwa with 18 responses. Sports clubs were also popular with 13 responses. The rest of the answers got 7 responses or less.

This question was also difficult to map since many participants gave an example of the type of leisure activities, they take part in but did not specify the location. However, it showed some more linguistic and cultural differences between participants which was related to where they live. The word ‘Qahwa’ means café in Arabic, but it is used to refer to a certain type of male dominated café that often serves coffee and shisha, the Egyptian tobacco water pipe. These are often informal and found in almost all neighbourhoods regardless of whether they are planned or informal. All the participants that answered ‘Qahwa’ were male, living in both planned and informal neighbourhoods. Most participants that responded ‘malls

and shopping centres' were from planned settlements, which is where malls are usually located.

8.2.4.4. Location of Workplace

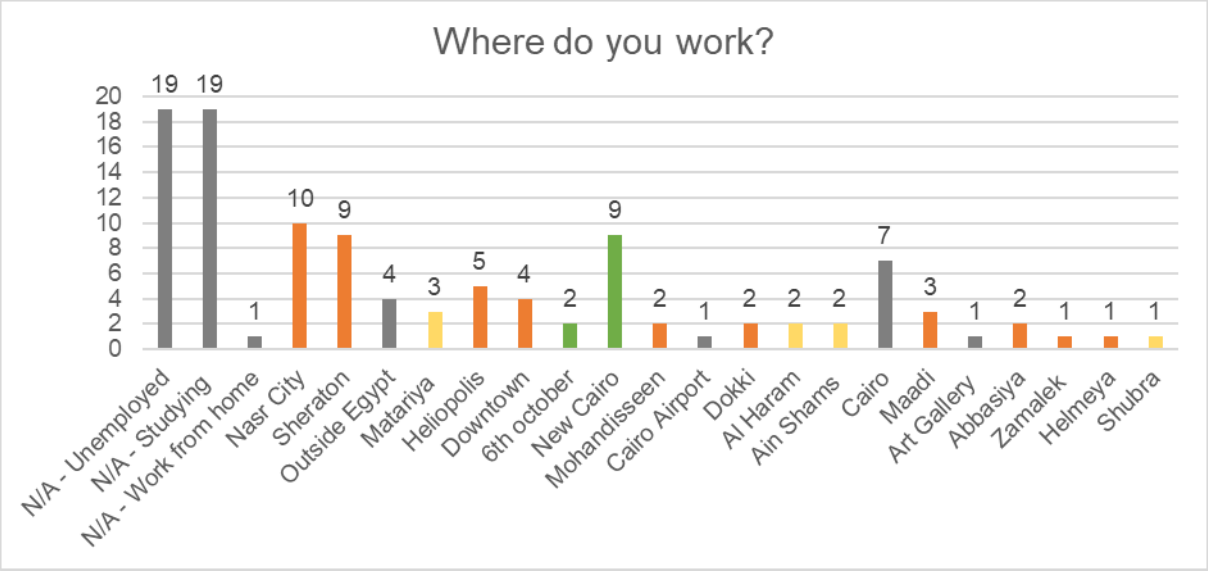


Figure 98: Chart showing where participants work

This question was designed to ask where the participants work in order to compare it to their residence neighbourhood and map journeys from home to work. A short form text box was provided where participants could write their work neighbourhood. Figure 98 shows the results of this question. In total, there were 110 responses with the majority of respondents either unemployed (17%) or studying (17%) and the rest employed (66%). The high number of participants in education can be attributed to the relatively young age of the participants, however the unemployment rate is higher than the national average of 8.9% (CAPMAS 2019). This can be explained by the fact that the majority of participants were female, since unemployment for women age 15-29 in Egypt is at 30.7% (CAPMAS 2019). In hindsight, this question should have also had an option for working in the home as a housewife.

Of the 72 of those who were employed, 4 responded that they work outside Cairo, 7 responded with just 'Cairo', and one worked in an art gallery and one in Cairo Airport. The

other 59 responses included a neighbourhood name which could be mapped. In total 16 neighbourhoods are mentioned, with 13 planned and 3 sha'abi/informal. The most popular work neighbourhoods are all classified as planned areas; Nasr City has 10 responses and Masaken Sheraton and Heliopolis have 9 each. Only 6 participants total work in sha'abi/informal areas. This could indicate that planned areas have more job opportunities.

Figure 99: Movement map showing how residents travel from their home neighbourhood to their workplace

This data was cross referenced with the participants' residence neighbourhood and the results are presented in Figure 99.

Figure 98 shows that there is a fairly even distribution of places where participants work, with the majority of them in planned settlements – Nasr City, Sheraton, and New Cairo. When the work locations are mapped with the residential locations of participants, it becomes evident that the majority do not live in the same area where they work, even if there is employment available in those areas. Participants are willing to travel very long

distances to reach their workplace, and with less than half owning cars, this means that there is a strain on the public transport systems in place. There does not seem to be a pattern between where people live and where they work.

8.2.4.5. Car Mechanic Location

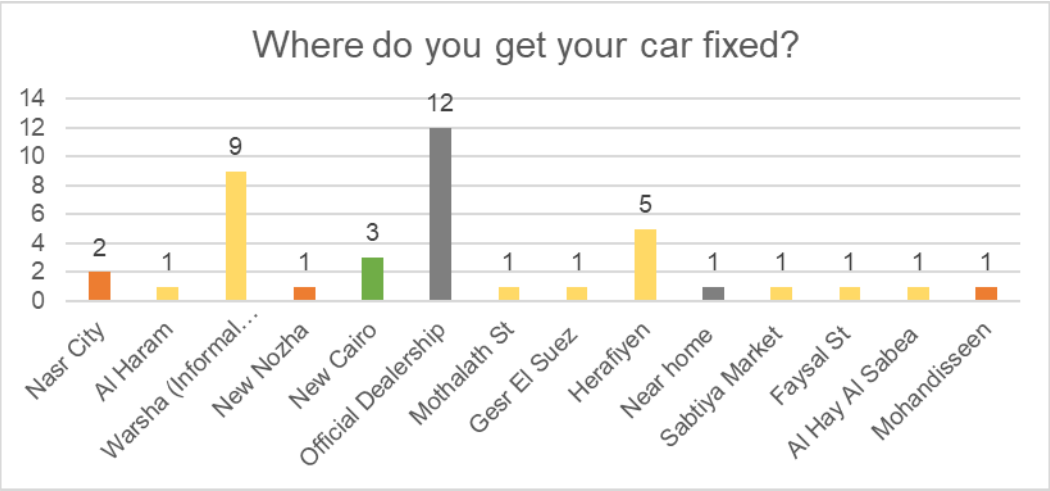


Figure 100: Chart showing where participants got their cars fixed

This question aimed to find out where the participants who own a car get maintenance and repairs done. Informal areas often contain car repair workshops, which are operated by the residents. There workshops are often better value for money than the official dealership (Sims 2010). This question investigated whether those who own cars travelled to an informal area to get car maintenance. A short form text box was provided where participants could write their answer.

Figure 100 shows the results of this question. Overall, there were 40 responses to this question, which correlated with the number of participants who previously answered that they use a car. The answers were spread over 14 locations which have been grouped by informal workshop or official dealership. 19 participants responded that they went to an informal workshop to get their car fixed (*Warsha*, Herafiyeen, Sabtiiya Market, Al Hay al Sabea', Mothalath St, Gesr El Suez) and 12 responded that they use the official dealership. 9 responses that named a planned area were not counted as informal workshops. The fact

that the majority of participants (47.5%) use informal workshops can indicate that people who live outside of informal areas will travel there if a service is offered.

8.2.4.6. Shopping for Essentials (Food and Clothing)

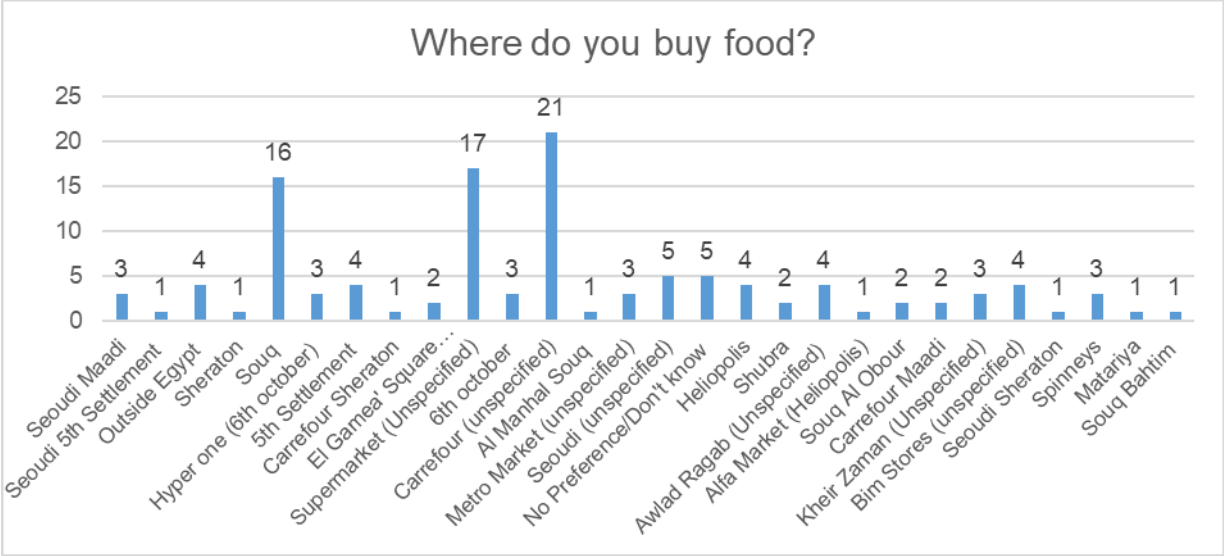


Figure 101: Chart showing where participants buy their essentials

The purpose of this question was to find where participants purchase essentials such as clothing and food, and whether they tend to leave their neighbourhood to do so. A short form text box was provided, and participants could write in multiple answers. Figure 101 shows the answers to that question. There were 118 responses to where participants buy food and 151 responses to where participants buy clothes, which evidences that they did mention multiple locations. While there were some named locations for shops, cross

referencing with residential data did not provide many journey data points, so no movement map was created for this question. However, this question provides some insight into how far some participants travel and informal market use.

The two most popular answers for where participants buy food were unnamed supermarkets with 17 responses and Carrefour, a popular supermarket chain, with 21 responses. Informal Souq had 16 responses making it the third most popular answer. The rest of the answers had 5 or less responses and were categorised as either named supermarkets or small souqs. The most popular answers for purchasing clothes were unnamed shops with 21 responses and shops in Nasr City with 34 responses. Nasr City is the largest planned area in Cairo, so it is expected that it has a high concentration of shopping areas.

Even though there were not enough data points to create a meaningful movement map, the data shows some trends about where the participants shop. Participants tended to shop near where they live when buying food and go to malls or well-known planned areas (Roxy square, Downtown, Nasr City) when buying clothes. Participants also shopped in souqs (informal open-air marketplaces) regardless of where they lived, and there was no noticeable difference between shoppers from planned and informal settlements. This could indicate that participants would travel to an informal area for food shopping, and that residents from both planned and informal areas would travel to access services in the other.

8.2.4.7. Use of Public Transport

Questions:

- “Do you use any of these? (Uber/Careem/Taxi/I don’t use any of these)”
- “Do you use public transport? (Yes/No/Sometimes)”
    - “If yes, what type do you use? (Bus, microbus, metro, tuk-tuk, tram, train, other)”

- “Which lines or stops do you use?”

This section was comprised of four questions designed to investigate the participants’ use of public transport and alternative transport methods. Due to the relatively low vehicle ownership rate, it was expected that most participants would use public transport in some form. The questions asked whether the participants use public transport, which types, and lines they use and if they use any alternative transport methods. The first answer about public transport usage was in Yes/No/Sometimes format, the second answer listed types of alternative transport such as Uber/Careem/Taxi (car sharing services). The third and fourth answers to the type and line questions listed some examples such as bus, metro and were followed with a short form text format to allow participants to type in multiple answers.

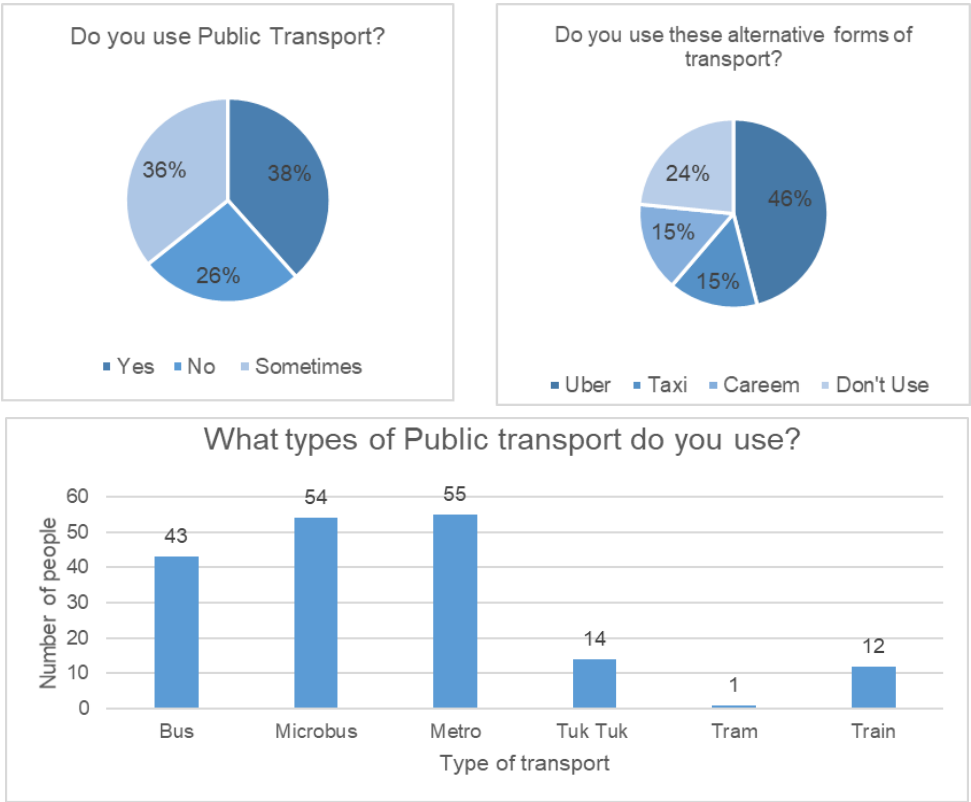


Figure 102: Chart showing which type of public transport participants used

Table 54: Transport Lines used by participants

Transport Line	Number	Percentage (%)	
Metro line 1 (Helwan - Marg)	4	12.1	
Metro Line 2 (Shubra - Monib)	1	3	
Metro Line 3 (Al Ahram - Attaba)	3	9.1	
Gesr El Suez (microbus)	3	9.1	
Sheraton - Ramesis (bus)	3	9.1	
Sheraton - Shubra	1	3	
Sheraton - Nasr City	4	12.1	
Heliopolis - Ramesis	4	12.1	
Nasr City - 10th Ramadan	3	9.1	
Roxy Square - Alf Maskan	1	3	
Cairo - Alexandria train	1	3	
Giza bus	1	3	
Ramesis Train Station	1	3	
Nasr City internal microbus	1	3	
Al Wayli	1	3	**Total Formal: 19**
Ain Shams - Ezbet Al Nakhl	1	3	**Total Informal: 14**

Figure 102 shows the results of the questions. The majority of participants use public transport at least sometimes (74%) with over a third (38%) using public transport as their primary method of transport. Only 26% of participants answered that they never use public transport. It would have been useful to include a time frame (e.g., within a week, month, etc) with the 'sometimes' response, to better visualise the public transport usage. There are both formal and informal types of public transport in Cairo. The formal transport systems include most buses, the Metro lines, the tram system in Heliopolis and the train linking Cairo with other governorates. Informal public transport includes Microbuses and tuk-tuks.

76% of participants answered that they use a car sharing service such as Uber and taxis some of the time. On demand car ride services such as Uber and Careem are more commonly used than standard licensed white taxis. Set fares (often cheaper than a standard white taxi), tracking and accountability often means that Uber and Careem are an attractive option which is reflected in the participants' responses, where only 15% use standard taxis as opposed to 61% using on demand car services.

There were 179 responses to the type of public transport used, due to the participants being able to write in multiple answers. The most popular method of public transport used was the

Metro with 55 responses (30.7%), an expected answer as it spans most of Cairo (Cairo Metro 2018) and can be more reliable than road based transport systems such as buses. The second most popular method of public transport was informal Microbuses, which tend to have informal set lines and informal stops. 43 participants responded that they also use buses which tend to have formal stops and are usually owned by a company such as the Cairo Transport Authority (CTA). 14 responded that they use the tuk-tuk (auto rickshaw - small 3 wheeled vehicles for short journeys) and 12 responded they use the train, which only runs between cities rather than within Cairo.

Fewer participants indicated the route they use, with only 33 responses to this question. In Table 54, informal public transport systems are highlighted in green. There were 9 formal transport routes and 7 informal transport routes mentioned, with 19 responses saying they use formal transport and 14 answering they use informal transport. The top 3 answers are the formal Metro line 1, the informal Sheraton-Nasr City microbus and the formal Heliopolis-Ramesis bus route, with four responses each. This shows that informal transport is used almost as much as formal transport in Cairo.

The metro lines mainly follow the north-south axis of Cairo and cover the central area, but more lines are planned in the future. This means that the east and west of the city are not yet serviced by the metro, so informal transport routes have evolved to connect these areas to the nearest metro stop and other places that are not covered by the formal public transport system. It is indicated in the questionnaire that they are used almost as much as the metro system but there are no official rider statistics of informal transport links to back this up.

It is interesting to note that the users of microbuses are from all over Cairo, and microbus and tuk-tuk usage do not indicate where the participant is from (a formal or informal area). This shows that even if someone lives in a planned area, they still participate in informal activities every time they use the informal public transport system.

8.2.5. Conclusions

This questionnaire shed light on the daily activities of the participants and how they fulfil those daily needs by travelling within the city. There were also some unexpected linguistic and social insights into the differences between planned and informal areas. The summary of results, significance, limitations, and some reflections on the study are set out below.

The participants of this study were mostly under 30 and female, so the answers may be biased toward a younger female perspective. The majority did not have children or a car, they used public transport and lived within planned settlements. About two thirds were employed, mostly in planned areas. While the job opportunities are concentrated in planned areas, participants still travelled to informal areas for shopping in souqs, car maintenance and other activities. Those who lived in informal areas travelled to planned areas for work, school, and shopping for necessities.

Even though the participants lived in different types of neighbourhoods, the majority travelled to both planned and informal areas to fulfil their daily needs. People who lived in planned areas participated in informal activities such as informal transport and informal markets (souqs) and vice versa. The distances that people travel to work every day also creates a need for an informal transportation system and improved streets and circulation systems.

The significance of this is that these results can indicate that informal settlements are not self-contained or isolated, but already socially integrated into the city. This can provide justification for further physical consolidation and development in informal areas since they are already socially and functionally integrated into the city and can provide services to non-residents.

The questionnaire also provided insight into some social and linguistic differences present in informal areas. Those who lived in informal areas tended to use older Arabic words such as *mahal* and *Qahwa* to refer to shops and cafes. Residents of informal areas also tended

to live there since childhood (50% vs 32% of planned settlement residents). They also knew the name of the shopkeepers which can indicate stronger community bonds. While interesting, these results are incidental and should not be generalised.

The main limitation of this study is the small and random sample size as the dissemination method did not allow to choose participants with specific characteristics. The sample could have been a better representation of the population by including older people, more males and more people who live in informal settlements. The sample size of 110 is also small compared to the population of Cairo, so it would have been better to recruit more participants. However, this was not possible as the questionnaire had to be taken down due to some negative comments from Facebook users.

Overall, the questionnaire provided the required information into the daily activities of Cairenes. From this point of view, this questionnaire was a success. It is important to bear the limitations in mind when interpreting results such as the small sample size and having to halt participant recruitment before reaching saturation. Even with those limitations however, the results of this questionnaire can inform the further quantitative analysis of the spatial aspects of informal areas.

DISCUSSION AND CONCLUSIONS

The following chapters discuss the results of the quantitative analysis and how it can be related back to the existing classification system and developed further to create a refined classification framework. In chapter 9, the refined classification is presented as a taxonomy diagram, along with a summary of the classifying parameters from the previous chapters. The classification resulted in four types of settlement being identified: infill, aggregate, mixed, and planned. How the classifications were determined is discussed, with a focus on the role of emergence conditions, urban configurations and street types. The different spatial structures present in the city are discussed, highlighting the role of configurations that are conducive to social interaction, and the role of the highway in both spatial fragmentation and potential reconnection. Avenues of urban intervention are presented, focusing on three main approaches from literature: block consolidation, street network normalisation and reconnection to the rest of the city. Finally, some urban interventions are designed based on the quantitative analysis and justifications from the social studies, as a proof of concept that minor urban intervention could be used to alleviate socio-spatial issues highlighted previously.

Chapter 10 presents the conclusions of the study, the main findings and original contributions. Some limitations, considerations for policy and avenues of future work are also presented.

CHAPTER 9: DISCUSSION

9.1. Classification of Settlements

The main aim of this work has been to review, build upon and challenge the existing classification systems of informal settlements in order to provide a more comprehensive framework that includes focus on the physical characteristics, history, syntactic structure and morphology of the settlement. A first step was to consolidate existing classification of neighbourhoods mainly based on emergence processes from the literature review and consolidation of existing classification of streets. Based on the previous literature review, two classification parameters are set: Emergence and Subdivision. Based on the quantitative analysis and clustering, four more classification parameters are set; Relationship to Supergrid, Urban Block Type, Axial Configuration and Street Type. Finally, all six parameters are brought together to create four types, namely, Infill, Aggregate, Planned and Mixed.

9.1.1. Consolidation of Existing Classification Criteria

The classification frameworks presented in chapter 2.1 highlighted the role of location, emergence and boundary in developing classifications. In chapter 2.2, the classifications specific to Cairo included two types of informal neighbourhoods based on emergence on either agricultural land or desert land, which were split into further typologies. Planned settlements were defined as those that have evidence of subdivision, and the mixed type was introduced.

The cases were initially classified in Chapter 4 based on the following categories, taken from Chapter 2.1.:

- Informal
    - Agricultural (urban fringe infill)
    - Agricultural (historic village extension – pre 1950s)
    - Desert (aggregate)
- Planned – evidence of subdivision.
- Mixed – also referred to as exformal or hybrid and can consist of:

    - Planned and informal fabric together within one neighbourhood
    - Historically planned but appropriated informally

In Chapter 2.2., different street types were highlighted both in Cairo and in other parts of the world, with some similarities between the types found in different studies. These different classifications were consolidated into the following categories in Chapter 7, Section 7.3.8 :

- 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)

The neighbourhood and street level classifications were then developed and refined through the quantitative analysis.

9.1.2. Development of Existing Classifications through Defining the Classification Parameters

To develop the refined classification framework, two classification parameters were included from the literature review, and four additional parameters extracted from the quantitative analysis.

Parameters from Literature Review

Based on the classifications of Cairo and other places around the world, these two classification parameters are used:

- **Emergence and history**

  This parameter refers to the type of land that the settlement emerged on at its conception. This is based on the classifications of Cairo's urban fabric presented in Chapter 2.2, and the three categories are **Agricultural Land, Historic or Desert Land.**

- **Evidence of subdivision**

  This parameter is similar to the emergence but focuses on the physical aspects of the land before building takes place. It indicates whether there is existing land

subdivision before building takes place. There can be **no subdivision**, non-urban or urban subdivision. **Non-urban subdivision** refers to the agricultural subdivision of fields and canals. **Urban subdivision** refers to streets and blocks that are decided upon conception of the city.

Even though they are similar, both parameters are included because the categories are not mutually exclusive, for example, desert land could have no subdivision, or an urban subdivision.

Parameters from Quantitative Analysis

Through the quantitative analysis, four more classification parameters are added onto the classification framework:

- **Urban Block Type**

  This parameter results from the morphological clustering of the urban blocks in Chapter 5, based on their size and shape. There is one size outlier cluster and five defined clusters, presented in Figure 104.

- **Axial Configuration**

  This parameter represents the potential for movement in open space, which is aligned with the pedestrian experience, as analysed in Chapter 6. There are different configurations which illustrate access in that neighbourhood, some of which are conducive to social interaction, shown in Figure 104.

- **Street Type**

  This parameter is the result of the clustering analysis undertaken in Chapter 7, which is based on the Integration, Choice and Reach measures of the street segments. The 8 resulting clusters have been grouped into 4 categories, the initial classification of three groups outlined above, with a fourth Group added from the cluster analysis (Group 4 – Integrated Social Core). The groups can be found in Figure 104.

- **Relationship to the Supergrid**

  This parameter refers to the relationship of the settlement with the highway supergrid, primarily whether it is connected or disconnected. Types of highway and potential relationships are explained in Chapter 4, section 4.6. The highways have also been included in the street network analysis and form their own syntactic clustered street type due to their importance.

9.1.3. Resulting Classification Framework of the Urban Fabric

Based on the quantitative analysis undertaken in chapters 5-7, four types of urban fabric in Greater Cairo were assigned. The types were based on the resultant urban form and street network configuration instead of legality and history and were drawn from which parameter category is dominant or significant in each type. Figure 103 shows the parameters, the categories within the parameters, the resulting types and the relationships between the categories and types. The legends for the axial configuration, the urban block type and the street type are in Figure 104 and the summary for the types is in Figure 105.

The resulting types are:

1. **Infill** (on pre-existing grid – agricultural post 1950s) [1,3,4]
2. **Aggregate** (combined on desert land and historical emergences (pre 1950s) as they converge to the organic form) [2,5,7]
3. **Hybrid/Exformal** (mixed planned/informal development OR previously planned then appropriated informally) [6,12,13]
4. **Planned** (evidence of subdivision) [8,9,10,11]

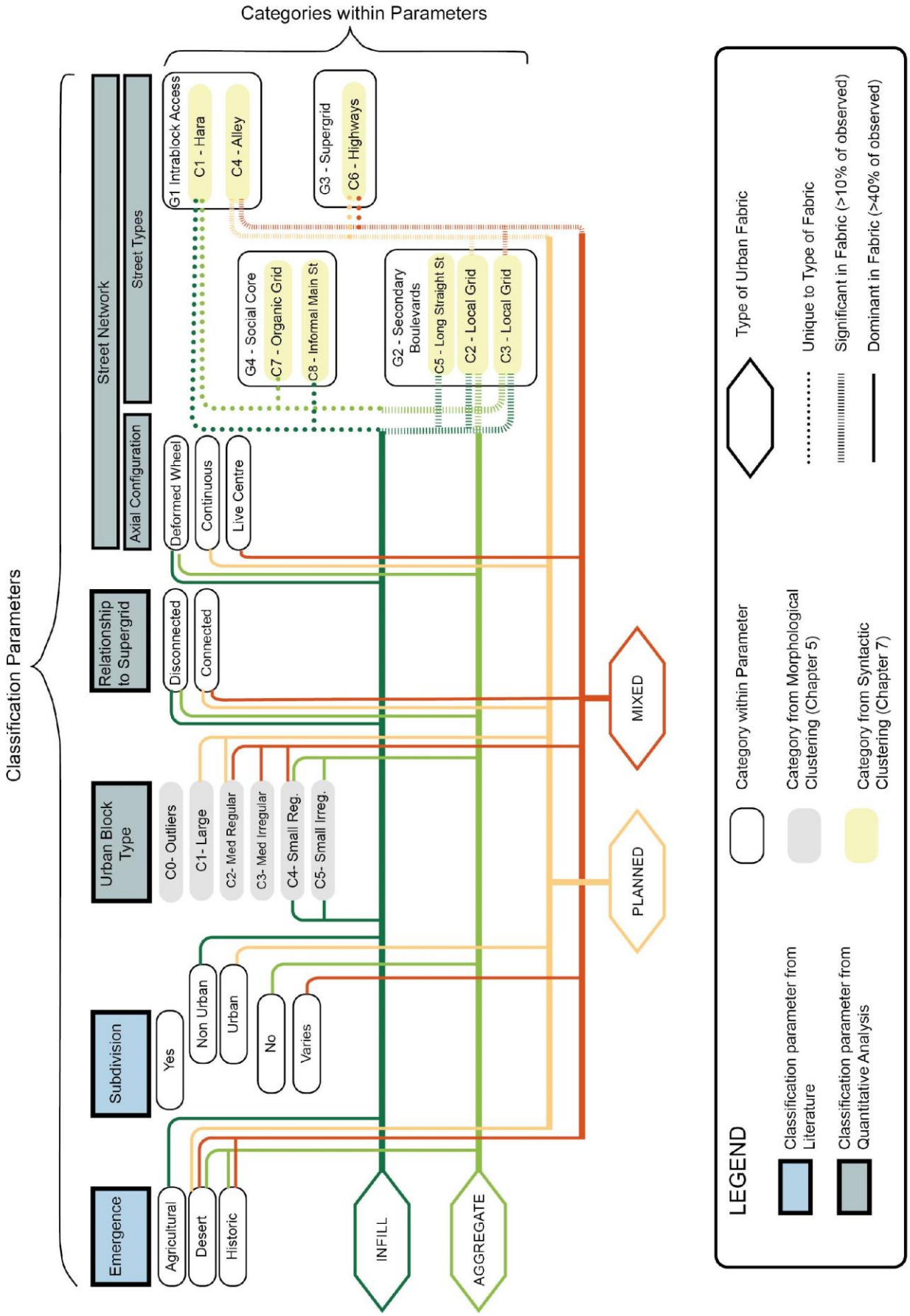


Figure 103: Diagram showing the different parameters, how they relate together, and the typologies developed

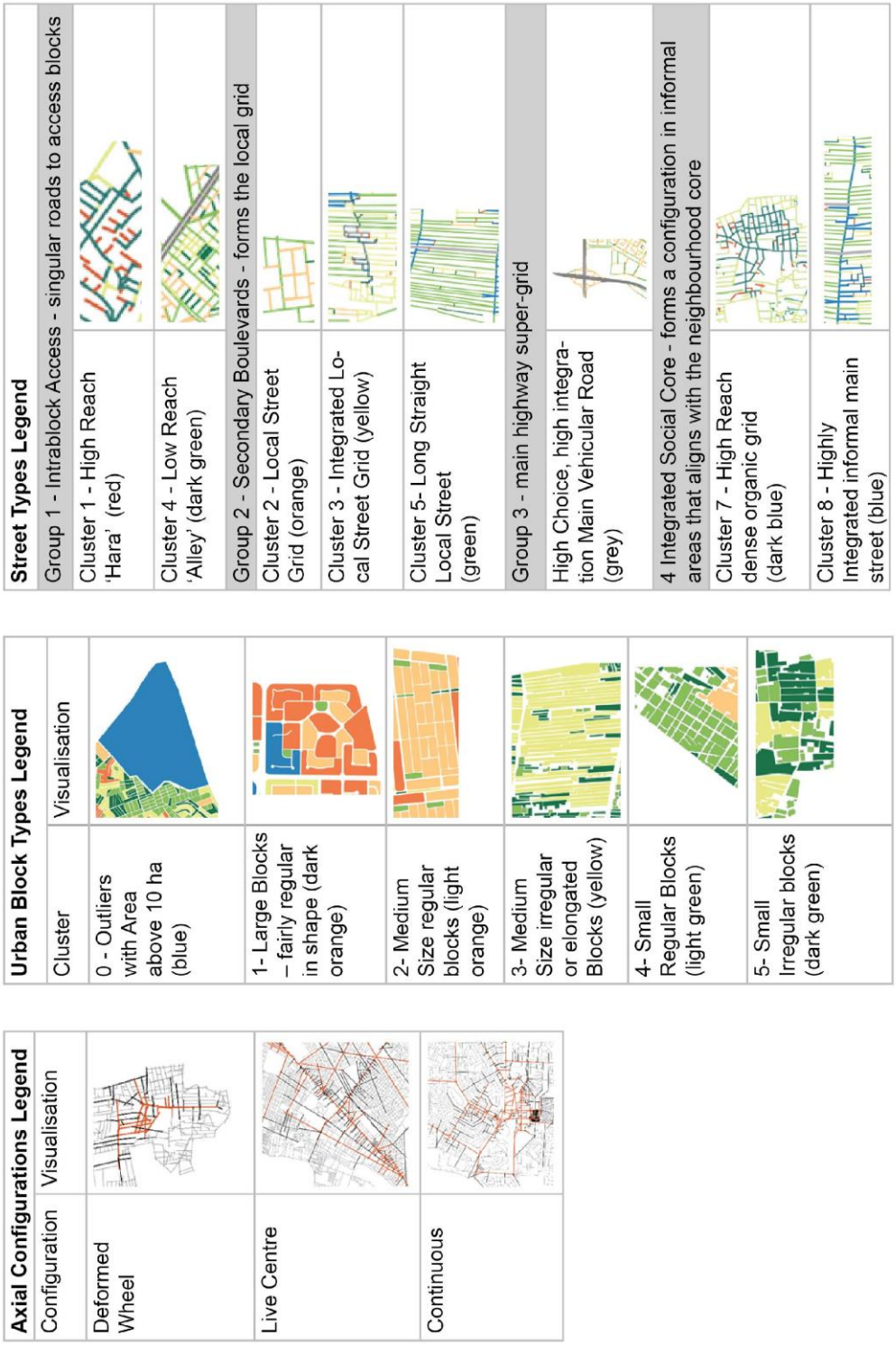


Figure 104: Legends for Axial Configurations, Urban Block Types and Street Types

Summary of Types

TYPE	Example Neighbourhoods	Emergence	Subdivison	Urban Block Type	Relationship to Supergrid	Axial Configuration	Street Type
INFILL	Ard El Lewa, Bulaq El Dakrour, Dar El Salam	Post-1950s on agricultural land	Yes – agricultural plot subdivision	Small – medium Regular and irregular elongated Cluster 4 and 5	Street network is generally not connected to the highway which cuts through pedestrian paths	Partial De-formed Wheel — often follows the ex-canal pattern	Cluster 1 – Hara Cluster 2, 3 - Infill UNIQUE Cluster 8: Highly Integrat-ed informal main street
AGGREGATE	Mit Uqba, Medieval Cairo, Manshiyet Nasser	Desert Land or Historic Area	Little	Small – medium Irregular blocks with dead ends Cluster 4 and 5	Street network is generally not connected to the highway which cuts through pedestrian paths	Clear De-formed Wheel – sometimes with edge movement	Cluster 1 – Hara Cluster 2, 3 – Infill UNIQUE Cluster 7: High Reach Deformed dense organic grid
PLANNED	Zamalek, Mohan-disseen, Nasr City, New Cairo	planned streets and blocks at the same time, no informal appropri-ation	Yes	Medium – Large Regular Cluster 1, 2 and 3	Highway accessible and forms part of the spatial structure	Dispersed/ continuous vehicular Core	Cluster 2 and 4 Cluster 6 – Highway mostly found in planned neighbourhoods
MIXED	Heliopolis, Omar Ibn El Khattab, City of the Dead	Varies – planned and informal development or previously planned then appropriated informally	Varies	Small – Medium – Large Mostly regular blocks Cluster 2,3 and 4	Generally, highway is accessible – can form a live centre if certain conditions met	Live Centre where different street networks meet	Cluster 3,4, 5, 6

Figure 105: Summary of Types and their Characteristics

9.2. Determining the Classifications

This section outlines how each type was determined. The figures above and the discussion in this section addresses the following research questions:

1. Physical Aspects
    a. How does the **physical topography** and **manmade grids and boundaries** affect informal settlements' urban form?
    b. How do the resulting settlements compare to each other and planned settlements in terms of:
        i. Urban morphology?
        ii. Street network?
        iii. Relationship to the main city form and regional transport network?
        iv. Mechanism of growth?
    c. How does the emergence, growth, street network and urban morphology influence the classification of informal settlements into types?
        i. Are there **unique spatial structures** present in informal settlements?

Infill

This type of settlement emerges on land that has a pre-existing grid, or non-urban land subdivision. In the case of Cairo, it is the agricultural grid. The resulting blocks and street network are clearly influenced by the subdivision grid, where buildings have infilled the pre-existing grid. The urban blocks are usually small to medium and tend to be more elongated, based on the pre-existing grid. The pedestrian network tends to be well developed and supportive of the community. The highway can act as both a boundary to the settlement and a disconnector, interrupting the pedestrian network. There is a unique street structure present in this type of settlement, the informal main street, which is usually found as a main road influenced by the ex-irrigation canals.

Aggregate

This type of settlement emerges on land where there is no pre-existing subdivision. In this case, buildings aggregate over time to form urban blocks, and the leftover space is the streets. This type also includes historic settlements since they existed before planning

codes and followed the same settlement processes as informal settlements post-1950s. The resultant urban fabric consists of small, irregular blocks with dead ends. The pedestrian network is well-developed with access to the neighbourhood core and connection to the edges, in some cases. The highway can disrupt the pedestrian network by cutting through the settlement. There is a unique street structure present in this type of settlement, the high reach dense organic grid, which is usually found in the centre of the settlement.

Hybrid - Exformal

This type of settlement generally has a mixed urban fabric, and generally consists of simultaneous planned and informal development or previously planned development which was then appropriated informally. The resultant blocks and street network can vary and are usually a mixture of planned and informal characteristics. What is common to the settlements of this type is the different street networks being accessible to all residents. The highways in this case are usually accessible and may form a live centre where people can mix and access different parts of the neighbourhood. This may be what characterises the settlement and contributes to their continued coexistence.

Planned

Planned settlements are those that have clear evidence of subdivision and are generally purpose built on land with no previous non-urban subdivision. These settlements tend to have fewer, larger urban blocks that can accommodate modern building footprints, but may impede walkability due to their size. The street network is usually designed for vehicular use. The pedestrian street network is not well developed and tends to follow the main vehicular routes. The highways are always accessible from this type of neighbourhood and they form the main spatial structure.

9.2.1. The Role of Emergence Conditions and Processes in Determining Type

The main determinant of type of informal settlement was found to be the process of emergence and the type of land that the settlement occurred on, mainly whether the land

has existing subdivision system (irrigation system, agricultural plots) or has no previous subdivision. This section discusses the role of the informal settlement process in determining the type and how the specific emergence in Greater Cairo on agricultural land or desert land affects the resulting urban fabric. The differentiation between street types and public vs private open space is also discussed. This addresses the research question "How does the existing physical topography and manmade grids and boundaries affect informal settlements' urban form?".

There is an important distinction to be made between settlements that emerge on land without subdivision and land with subdivision. In the case of Cairo, this corresponds to desert land and agricultural land. Desert land can be considered a blank canvas for urban settling as it rarely has a pre-existing structure, except in the case of topography such as slopes and cliffs. However, agricultural land has a pre-existing structure of the subdivision of fields and irrigation canals, which may influence urban settling. This distinction can be seen in the settlement Dar El Salam, where it has emerged on both desert and agricultural land (partially with or without subdivision) within the same timeframe and the same social processes and context. However, the two urban fabrics are very different, which suggests that the influence of the pre-existing subdivision is greater than the social processes and context.

On agricultural land, there is a pre-existing man-made grid of agricultural fields and irrigation canals. As outlined in the literature review, this grid consists of long strips of fields (ahwad) and irrigation canals (missa'). These long fields are then split further into smaller fields and may be owned by different individuals. The settlement process starts by individuals building housing on the field they own, which then infills the existing grid until the long strip of fields is built up. The canals are no longer used as irrigation, rather they become the street network. This results in an urban fabric with very long blocks, and the intersection of ex-irrigation canal main street with the residential streets results in a well-connected main street. This main street presents as well connected, where social interactions are increased

and access to the residential areas is straightforward. This presents a unique street configuration that is conducive to community living and should be preserved in urban intervention. The issue in this settlement is the very long, narrow blocks that impede walkability and may not accommodate larger building footprints. Another issue is that the highway often disrupts the pedestrian network. This type of settlement could benefit from re-blocking/block consolidation and reconnection to the highway/main transport network. This is an example where a subdivision system defined for a different purpose can only partially accommodate a new land use. It raises the question of the need for intervention to allow for a more diverse urban form.

The settlements that emerge on land without any pre-existing subdivision tend to result in a small-grain, organic urban fabric, which share similar characteristics with the historical fabric. The settlement process is fuelled by aggregation of buildings over time, which results in those buildings forming urban blocks, and the leftover open space considered as streets. This resultant fabric was observed regardless of the social conditions and history of the settlement emergence, whether the neighbourhood emerged informally on desert land or as part of the historical agglomeration. This seems to reinforce the idea that it is the physical topography and boundary that influences the urban fabric, rather than the social conditions and the history of the settlement. This type of settlement also has a unique street structure, the high reach dense organic core, which is a configuration that is conducive to community encounters. Because of similarities with historical settlements, similar urban interventions can be applied to preserve the dense core while allowing for new streets to link the core to the wider street network.

9.2.2. The Mixed Type

The mixed type is one that is more difficult to define than the two informal types. This type encompasses a wide variety of social conditions, histories, and urban fabric. There are different types of mixture, ranging from planned and informal fabric side by side to planned fabric that has expanded informally. What they have in common is the co-existence of

different urban fabrics within one neighbourhood. The connection between the two fabrics is what makes this type of neighbourhood unique: there exists a 'live centre', which is usually located between the different fabrics, and which allows access to all parts of the neighbourhood. This live centre can be a ground level highway, or an access street. This type of connection could be applied to other neighbourhoods in order to improve connection and address spatial fragmentation.

9.2.3. Street Types and Their Role in Classification

The results highlighted eight different types of streets that are present within the sample. Some of these types are used to inform classification. 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 differentiating between settlements.

9.2.4 Private vs Public Open Space

The classification of the neighbourhoods through the morphological characteristics of their urban blocks showed commonalities and differences between planned and informal open space. As a whole, the city does not have enough open space as suggested by Perry (1929). Across all settlements, open space ranges from 43.9% in Manshiyet Nasser to only 3.9% in New Cairo. This may be because of the way open space is calculated in this thesis. In informal settlements, all open space is considered public. In contrast, planned settlement

subdivision allows for creating private open spaces within blocks that are not accessible by the public. A suggestion for increasing open space would be to investigate the space that is accessible in the city (within blocks), especially in planned settlements. It is suggested that the 'hara' is more easily accessible due to it branching off the main neighbourhood core, but the alley could lead to a more private open space within a block. It is difficult to differentiate due to the nature of the analysis methods, and this warrants further investigation into the nature of open space and how it is accessed.

9.3. The Spatial Structure and Its Role in The City

This section outlines the differences between the two spatial structures present in the city, the pedestrian network, and the vehicular network. The pedestrian network can be tied to the social structure of space within a neighbourhood, and the vehicular network connects different neighbourhoods together across the region. This section addresses the two questions "Does the spatial structure of informal settlements support the community in their everyday living?" and "Are informal settlements accessed and used by non-residents or are they socially and spatially segregated from the rest of the city?".

9.3.1. Social Structure of Space

Previous literature in chapter 3 suggests that the social and spatial properties of the city are inextricably linked. There exist two main spatial configurations conducive to social interaction within a neighbourhood, the deformed wheel, and the live centre. Both of these configurations have been shown to support the community by enabling social encounters, access to the neighbourhood and to the surrounding street networks. The findings show that these configurations are present in both types of informal settlement and in some cases of mixed settlement.

The spatial analysis of the City of the Dead highlighted the core of the neighbourhood and a live centre configuration. The importance of this street configuration was verified by observation in the field, which shows that the spatial structure supports community

activities. These streets also allow for different activities and job opportunities, such as the cord spinners that need a long straight street and the confectioners that sell out of the tombs on the ‘main’ streets. The spatial structure is fairly legible and residents report having a sense of direction and being able to find their way and direct others using landmarks. This shows that the urban fabric provides opportunities and housing unique to this location, and that the spatial structure can support the community in its activities.

These two configurations are also present in other informal areas, which presents another avenue of investigation in the field. In Mit Uqba, the deformed wheel highlighted by the spatial analysis corresponds with the centre of the neighbourhood that contains a marketplace and sporting club. These configurations are also highlighted by the cluster analysis and form the unique spatial structures that differentiate between types. These structures may be tied to the social motivations in informal settlement and should be preserved in intervention since they potentially support the community in its everyday living.

9.3.2. Spatial Fragmentation by Highway Super-Grid

As presented in the literature review in chapter 2, spatial fragmentation is a pressing issue in cities with a high percentage of informal areas. The highways play an important role in the city by forming the regional transport network and enabling movement between different neighbourhoods. Spatial fragmentation can increase when informal areas do not have access to the highways or the regional transport network.

The previous spatial analysis shows that the highway can interrupt the pedestrian network by cutting through it and can limit the growth of a neighbourhood by acting as a boundary. This is highlighted in the axial analysis, where the highway is not part of the main pedestrian network in informal settlements. The highway is also categorised as its own street type by the clustering analysis, and it is generally only present in planned areas. This indicates that in informal settlements, the highway tends to cut through or act as a boundary. In planned settlements, the highway often forms part of the main spatial structure of the neighbourhood.

However, despite spatial segregation due to the highways in Greater Cairo, it appears that social segregation is less present. The Daily Activities Questionnaire results indicate that there is still movement to and from informal neighbourhoods, despite being cut off or bound by the highway. Even though the participants lived in different types of neighbourhoods, the majority travelled to both planned and informal areas to fulfil their daily needs. People who lived in planned areas participated in informal activities such as informal transport and informal markets (souqs) and vice versa. The distances that people travel to work every day also creates a need for an informal transportation system and improved streets and circulation systems.

The significance of this is that these results can indicate that informal settlements are not self-contained but already socially integrated into the city. This can provide justification for further physical consolidation and development in informal areas since they are already socially and functionally integrated into the city and can provide services to non-residents. An avenue of physical intervention could be reconnecting informal settlements to the highway network.

9.4. Avenues of Urban Intervention

This section outlines some avenues for urban intervention that were first developed in three papers published as part of this research: *'Syntactic Stitching: Towards a Better Integration of Cairo's Urban Fabric' (Zied and Vialard 2017), 'Syntactic Stitching II: Testing the Rationalisation of the Urban Fabric as an Intervention Method in Cairo, Egypt'. (Zied, Vialard and Dalton 2019) and 'Reintegrating Informal Settlements into the Greater Cairo Region of Egypt through the Regional Highway Network'. (Zied and Vialard 2020).*

The above results can be used to inform urban intervention in a number of ways. Uncovering the logics and processes of informal settlement and the resulting street structures/morphologies can be used to apply physical in-situ upgrading policies that have been trialled previously but can now be more nuanced and informed.

These physical intervention methods are suggested in the literature to be used for in-situ upgrading:

- Upgrading can be undertaken by **preserving existing important structures (buildings, blocks, and streets)** but removing dilapidated housing and **increasing access to the rest of the city** (Batty 2013; Batty and Marshall 2009; Geddes 1915).
- **Re-blocking of plots, plot reallocation and road network normalisation** (Choguill et al. 1994; Mitlin 2016)

This provides three avenues of intervention, block consolidation, street network normalisation and increasing access to the rest of the city.

9.4.1. Avenues of Block Consolidation

The results highlighted a main issue with the blocks in Greater Cairo. There is generally a lack of diversity in block sizes, as highlighted by the distribution of block sizes. Informal settlements tend to have many, small blocks but lack larger blocks. Planned settlements tend to have fewer, larger blocks, that can accommodate modern building footprints but may decrease walkability. This results in limitations caused by the lack of one or two types of block associated with specific functions, for example, not many large blocks for civic or institutional buildings, or small blocks in planned settlements to increase walkability and social interaction. This issue can be addressed re-blocking based on configurational and morphological analysis.

There are two avenues to achieving a diversity of block sizes: firstly, consolidating smaller blocks together in informal settlements, and secondly, splitting larger blocks in planned settlements to increase walkability. The first approach is illustrated here, first published in *'Syntactic Stitching II: Testing the Rationalisation of the Urban Fabric as an Intervention Method in Cairo, Egypt'. (Zied, Vialard and Dalton 2019):*

The case study taken was Ard El Lewa. The intervention proposal is illustrated in Figure 106. Firstly, an axial analysis was conducted to highlight the important paths in the

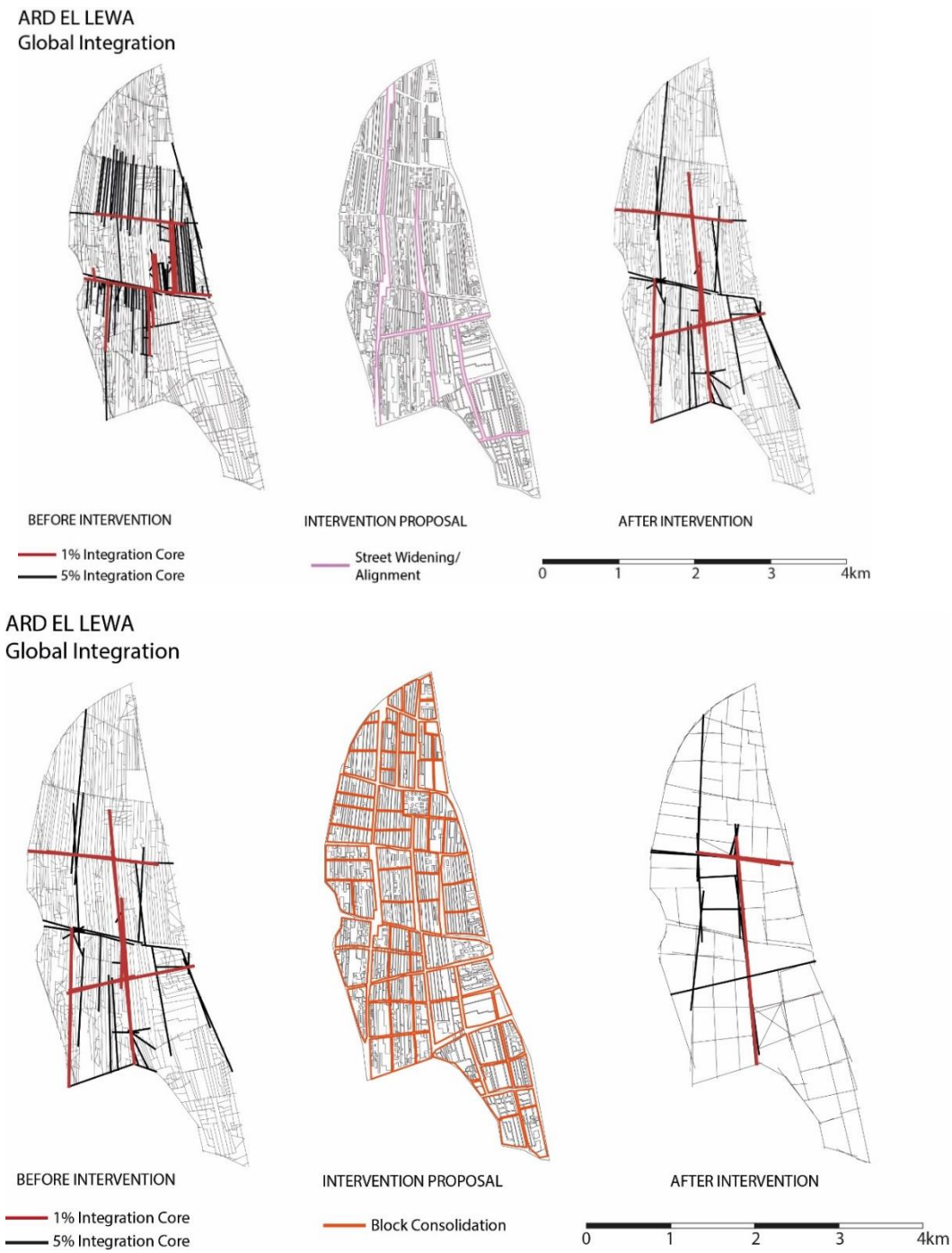


Figure 106: Ard El Lewa Intervention Proposal. Source: *'Syntactic Stitching II: Testing the Rationalisation of the Urban Fabric as an Intervention Method in Cairo, Egypt'. (Zied, Vialard and Dalton 2019)*

neighbourhood. These paths were reinforced using 'creative destruction' of the urban fabric – the removal of some small blocks and buildings in order to create points of access to the neighbourhood. The aim was to strengthen the existing street network rather than add in new streets, and to reinforce the existing north-south and east-west axes. Then, the blocks

were consolidated into larger blocks instead of the long, narrow blocks that were the result of the influence of the agricultural grid. The block consolidation was based on preserving the points of access, reducing the number of blocks, and increasing their area.

The result of this intervention proposal was the creation of two cores in the neighbourhood with a north-south axis linking them, as well as the creation of east-west axis, further optimising the street network. The urban blocks are fewer in number and higher in area, with a more regular shape. This means that they can accommodate modern building footprints and allow for further interventions such as adding in services and public buildings and improving infrastructure.

The second approach, splitting larger blocks in planned settlements, presents an avenue for future work. It can be undertaken by using the clustering analysis to highlight larger blocks that can be split and using the street network analysis to highlight access points into the larger blocks.

9.4.2. Street Network Normalisation – Improving the Spatial Structure Within the Neighbourhood

The second avenue of potential urban intervention is to improve the spatial structure within the neighbourhood through street network normalisation. This study was first published in 'Syntactic Stitching II: Testing the Rationalisation of the Urban Fabric as an Intervention Method in Cairo, Egypt'. (Zied, Vialard and Dalton 2019). It involved undertaking street network analysis to find out existing issues, then proposing the widening and alignment of streets in order to improve and reinforce the internal spatial structure.

The two neighbourhoods studied were Medieval Cairo, a UNESCO World Heritage Site, and Dar El Salam, an informal settlement built on agricultural land. Firstly, an axial analysis was undertaken to highlight the main pedestrian street network. Based on this analysis, certain streets were chosen to be slightly widened and aligned in order to improve the spatial structure and enable more community encounters.

Figure 107: Dar El Salam Intervention Proposal. Source: *'Syntactic Stitching II: Testing the Rationalisation of the Urban Fabric as an Intervention Method in Cairo, Egypt'. (Zied, Vialard and Dalton 2019)*

In Dar El Salam (Figure 107), some selected streets were widened and aligned together, which resulted in a reinforced pedestrian network. The integration core now reached the segregated part of the settlement in the north, and now consisted of clear north-south and east-west axes. This allowed further access to the neighbourhood.

In medieval Cairo (Figure 108), the street widening resulted in the integration core being aligned with Al-Muizz Street, which is the historic street that contains most attractions in the area. This means that the street is now easier to access for visitors and residents. The highway barrier was also removed, which allowed access into the northern part of the neighbourhood. This shows that it is possible to create minor interventions that have a large impact on the accessibility of the neighbourhood.

The significance of this is that proposing a strategic minor intervention could be easier for practitioners to undertake and for policymakers to support. Using the analysis of the existing urban fabric means that interventions are research

Figure 108: Medieval Cairo Intervention Proposal.

Source: *'Syntactic Stitching II: Testing the Rationalisation of the Urban Fabric as an Intervention Method in Cairo, Egypt'. (Zied, Vialard and Dalton 2019)*

based and specific to the informal settlement, rather than creating overarching intervention policies for all informal areas.

This limited set of interventions shows that it is possible to strategically widen and align internal neighbourhood streets, based on the spatial analysis, in order to reinforce the internal spatial structure and therefore improve community encounters.

9.4.3. Addressing Spatial Fragmentation in the City as a Whole using the Regional Highway Network

Another issue highlighted in this study is the role of the highways in connecting or segregating the urban fabric, depending on access to the highway from the local street network. This is studied in more detail in 'Reintegrating Informal Settlements into the Greater Cairo Region of Egypt through the Regional Highway Network' (Zied and Vialard 2020) and 'Syntactic Stitching: Towards a Better Integration of Cairo's Urban Fabric' (Zied and Vialard 2017).

The Highway as a Connector

The highways in Greater Cairo are the main travel corridors between neighbourhoods, however, often informal settlements do not have access to them, which can increase spatial fragmentation. The importance of this access is highlighted when residents in Ard El Lewa built their own access ramp to the highway. When highways cut through or act as a boundary to informal settlements, they act as a segregator, preventing access to the rest of the city. Nevertheless, when highways have certain characteristics such as being ground

Figure 109: Heliopolis Axial Analysis. Source: 'Reintegrating Informal Settlements into the Greater Cairo Region of Egypt through the Regional Highway Network'. (Zied and Vialard 2020)

level and crossable by pedestrians, they can act as integrators for the region. An example of the highway acting as an integrator can be found in the mixed neighbourhood of Heliopolis (Figure 109), where the ground-level, crossable highway links together different street networks. When analysed separately, the two sides of the neighbourhood both display a well-developed internal spatial structure. When analysed together, this structure is improved by the highway acting as a connector to both sides of the neighbourhood.

This shows that highways can become live centres if they have certain characteristics, such as being levelled and crossable. It is also important that the different street networks intersect the highway at many different points, which allows the creation of the live centre.

The Influence of the Agricultural Land Subdivision on the Highway Super-Grid

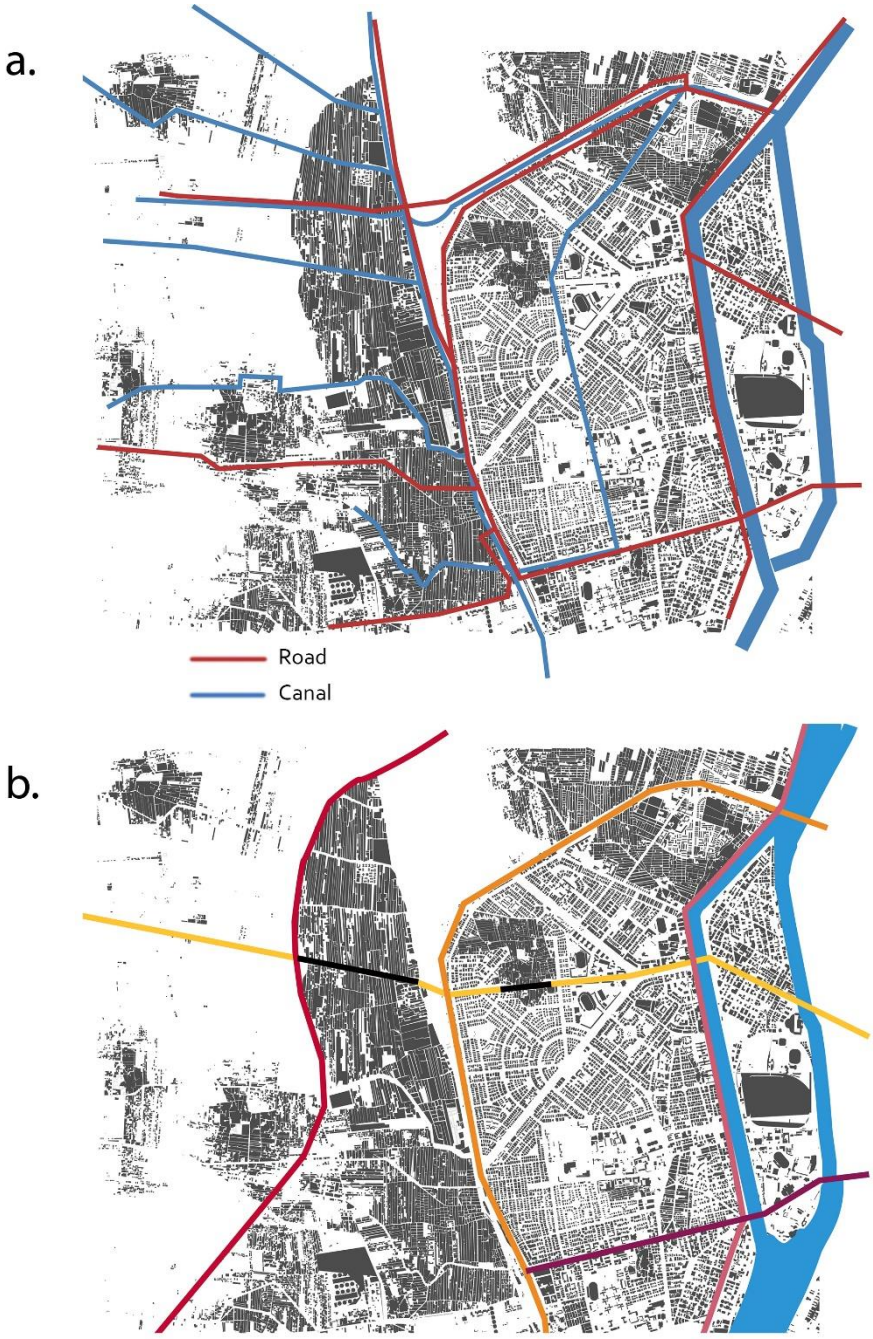


Figure 110: Influence of the Canal System on the Highway Network. A) map with the historical canals, b) current highway network. Source: 'Syntactic Stitching: Towards a Better Integration of Cairo's Urban Fabric' (Zied and Vialard 2017)

An analysis of a case study on the western bank of the Nile (Figure 110) indicates that the highways that run through it are influenced by the pre-existing agricultural grid. The agricultural grid also influences the main streets in informal settlements. Since the

agricultural grid is partly made up of canals and tributaries of the Nile, it means that it can be used as a framework for reconnection, by following the ex-canals.

These two studies show that there is potential for the highways to become a regional integrator with minimal intervention. The highway can be used to connect different street networks together by creating a live centre, which can link different spatial communities. The highway can also be used to connect the planned transport network with the informal main roads, which all align with the ex-canal system. The highways need to fulfil certain criteria such as being crossable and at ground level, so it is not a one-size fits all solution. This highlights the highways' potential role as a connector which may reduce spatial fragmentation in the region.

9.5. Conclusions and Summary of Intervention Approaches

The discussion sets out the refined classification system and presents how each category is determined. The main determinants are the type of land the settlement emerged upon and whether the land has a pre-existing subdivision grid. The street network configuration also plays a role in classification, with some street types seeming to be unique to informal areas. The importance of the social structures of space and the highway super-grid were highlighted. From these discussion points, some intervention criteria were presented, which primarily focused on urban block consolidation, street network normalisation and the reconnection of internal street network to the main highway super-grid. Table 55 summarises the approaches that could be taken to develop urban interventions. The approaches are split by type and some considerations and effects are presented.

Table 55: Summary of Intervention Proposals

Type	Intervention proposals	Potential Effects	Considerations
Informal – Infill	Block Consolidation – reduce **length** of blocks and increasing block size	Increased walkability and improved accommodation of functions	Should be done with residents' co-operation to know which blocks can be consolidated
	Highway reconnection – core connection to the super-grid	Increased access to the rest of the city	Preservation of social structures **(live centre)** Highways should have suitable characteristics to aid intervention
	Street Widening and Alignment	Improved spatial structure	Preservation of social structures **(informal main street)**
Informal- Aggregate	Street Widening and Alignment	Improved spatial structure	Preservation of social structures **(dense organic grid)** Preservation of historical areas
	Block Consolidation – reducing number of small blocks and creating additional larger blocks	Improved accommodation of functions	Should be done with residents' co-operation to know which blocks can be consolidated. Preservation of historical areas
	Access points for the highway network	Increased access to the rest of the city	Conservation of pedestrian networks that support the community
Planned	Block Splitting – create access through blocks or smaller blocks	Increased walkability, improved block diversity	Community and stakeholder consultation on which blocks to develop
	Increase open public space and Pedestrianisation	Increased walkability, general improvements that come with additional open space	Implementation of a new pedestrian network that is independent of vehicular network
Mixed	Increase open public space	general improvements that come with additional open space	Preservation of the informal main street, making sure all can access the new open space

CHAPTER 10: CONCLUSIONS

This chapter summarises the main aim of the thesis, how the research was carried out and the main findings of the study. It also highlights the original contribution of the study, applicability for policy, some limitations, and avenues for future work.

This thesis argued that studying the spatial characteristics of informal settlements can create a more nuanced classification based on the urban block morphology and street network configuration of neighbourhoods. This further classification can be used to develop urban interventions based on the spatial form and social needs of neighbourhoods, rather than the ‘planned/informal’ binary classification. This could help in alleviating the socio-spatial segregation present in the region.

10.1. Main Findings: A Refined Classification

Globally, there exists a binary, legal versus illegal, classification system for informal settlements which affects how urban interventions are carried out. In Cairo, some efforts have been made to create a further classification system, as informal settlements make up a large part of the city's urban fabric and house a large part of the population. However, informal settlements physical characteristics (street network and blocks) have not been meaningfully quantified within this classification system.

Methodology literature suggests that informal settlements have implicit rules that direct urban growth and the resultant urban fabric. Studying the informal fabric quantitatively can uncover such implicit rules. Methods such as space syntax and urban morphology have been applied to other informal settlements and have the potential to be used to find unique spatial structures to inform classification.

Results of the social studies indicate that the spatial structure supports everyday living in one appropriated informal settlement with regard to access to the city, housing in the neighbourhood and job opportunities. The questionnaire indicated that informal settlements

are at least somewhat socially and economically integrated into the city, which supported the approach for physical integration/urban intervention methods.

Quantitative study of the urban blocks and street network indicate that there are some features in urban blocks and axial configurations that are more common to informal settlement, and pre-existing land subdivision and topography is the main driver of the resultant urban form rather than social processes. More importantly, **some street network configurations seem to be unique to informal settlements and do not exist in planned settlements.** These results are used to refine and develop existing classification framework and present a classification that builds upon the existing from literature and adds on quantitative evidence.

The categories are based on the resultant urban form and street network configuration instead of legality/history.

Classifications:

1. **Infill** (on pre-existing grid – agricultural post 1950s)
2. **Aggregate** (combined on desert land and historical emergences (pre 1950s) as they converge to the organic form)
3. **Hybrid/Exformal** (mixed planned/informal development OR previously planned then appropriated informally)
4. **Planned** (evidence of subdivision)

This research also presents several avenues of urban intervention that builds upon existing literature about re-blocking and increasing access to the city. Knowing which parts of the street network have the highest potential to support the community and have emerged due to their needs can be used to inform urban intervention and create more nuanced intervention methods. This in turn can address the negative issues of informal settlement such as spatial fragmentation and lack of connection to main transport networks.

The key takeaways are:

- The pre-existing land subdivision (or lack of it) and topography is the main influence on the resultant urban form rather than social processes. Existing subdivision results in a distinct urban fabric based on that subdivision, while a lack of subdivision tends to result in an organic urban fabric.
- The physical topography and manmade grids affect the resultant urban fabric and can be used as a classifying attribute - This is a quantitative way to differentiate between settlements without having to rely on incomplete historical or demographic information.
- There are street structures 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 structures can be preserved in urban interventions.
- The highway super-grid is always highlighted as an important route and forms its own street structures. 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.

10.2. Original Contributions: Going Beyond the Binary

This thesis provides quantitative evidence for a classification system that goes beyond the planned/informal binary and develops further the classifications suggested by other researchers. Primarily, the existing classification system is built upon and refined, by adding on more classification parameters and highlighting different features that are present in informal and planned settlements. The results show potentially unique spatial (street) structures that are present in informal areas, which can be used to inform classification. The results also highlight the influence of existing topography and land subdivision on the resultant urban form, which was observed regardless of the social and historical processes that led to the neighbourhood emergence.

This thesis also highlights some important points about tying the spatial structure to the community's everyday living through social research. For example, in the City of the Dead the social activities are directly linked with the spatial structure, which support the

community's everyday living. The questionnaire also highlights the movement of people to other parts of the city, which shows that the city suffers from spatial fragmentation but not necessarily social fragmentation. The social research is also quantified, by representing the qualitative data gathered as movement maps and cartograms. The unique spatial structures present in informal areas often align with the potential social core of the neighbourhood.

The contribution is not just the developed classifications but the usage of quantitative methods to describe the informal urban fabric. These methods can be applied to other informal settlements worldwide. This research also adds a large amount of data to the body of knowledge by mapping informal settlements that were not previously mapped and creating vector models of these settlements so spatial analysis can take place.

10.3. Applicability in Policy: Informing Urban Intervention

These results can be used to inform urban upgrading. Based on these conclusions, practitioners should consider the use of the highlighted clusters to inform intervention, the potential of block consolidation and street network normalisation, and the role of the highways. There are different recommendations to be made for urban intervention in planned or informal settlements.

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. The mixed informal neighbourhoods provide relevant examples on how the urban fabric can evolve, and how different fabrics can co-exist through a connected street network. In planned neighbourhoods, the clusters can be used to assess the diversity, or lack of diversity, of the urban fabric. It can also inform the selection of streets and blocks for intervention. The clustering process can also be

applied to other informal settlements that are outside the sample, in order to develop interventions for them.

In both planned and informal settlements, interventions can be designed that improve the diversity of block sizes. In informal settlements, block consolidation can help accommodate modern building footprints such as schools and public buildings. In planned settlements, blocks can have additional access points and crossing to improve permeability and walkability of the urban fabric. Street network normalisation based on the previous analysis can improve the internal spatial structure of informal settlements and allow for more community encounters and opportunities.

Reconnecting informal settlements to the highway can also play a role in reducing spatial fragmentation. This can be undertaken by reconnecting the internal spatial structure of informal settlements to the nearest highway or removing barriers for access. This allows for easier access into and out of the informal settlement, which in turn will increase access to opportunities and services in the rest of the city.

Overall, these results and analysis methods could be to inform interventions and add nuance, as well as develop specific interventions based on individual settlements' needs. It is important to bear in mind that physical intervention is the first step in a holistic urban upgrading plan. These interventions can pave the way for further upgrading such as additional public buildings and community support, more infrastructure and more suitable housing within the neighbourhood.

10.4. Limitations

The main limitation of this study was the availability of data. Informal settlement map data was scarce, so a variety of data sources were used and a map upgrading procedure was developed. The maps created are also valid between 2017 – 2019, since informal settlements grow very quickly. The research could have included more informal neighbourhoods if data availability was not a concern. More historical analysis could have

been carried out for certain older neighbourhoods such as Medieval Cairo, to include different phases of urban development such as the addition of 19th century boulevards and changes of access streets in the neighbourhoods.

Fieldwork for social studies was also difficult to carry out, so more creative data collection methods were used, including collaboration with other researchers and online questionnaires. There were some issues with combining quantitative and qualitative data streams, so the qualitative data was quantified, and themes are found within both types of data to inform the classification.

There were also some methodological considerations, which could be a limitation. The definitions of street and block that were taken to inform the mapping procedure resulted in the urban blocks in informal areas not having any open space within them, but there may have been open space within the planned blocks. This is something to be considered in future work. The variables chosen for the cluster analysis can also be reconsidered, since it may not be necessary to include all of the variables for each measure. This also presents an avenue of future work.

Finally, as with any classification system that uses multiple data types and analysis methods, there is some subjectivity and researcher bias within the categories that were decided. However, the use of quantitative analysis methods allows for the replication of results, and so strengthens the classifications. The subjectivity of the categories also allows them to be further discussed and challenged, which could result in more refinement.

10.5. Avenues of Future Work

In order to address some limitations and to better understand the implications of these results, future studies could address the following. The resultant classifications and clusters could be applied to other neighbourhoods, by applying the cluster parameters after spatial analysis. This could be used to find whether the results are applicable to other neighbourhoods outside of the sample and in other countries. The mapping methods used

in this study could also be developed further, with more investigation into the definitions of streets and blocks, different emergence processes and the automation of mapping rather than doing it manually. More research-based intervention approaches can also be developed, in order to further integrate the results into urban policy.

10.6. Conclusion

This research set out to consolidate, quantify and refine the existing classification of informal settlements, in order to contribute to more nuanced and specific urban interventions. The study used a mixed method approach to combine quantitative and qualitative data streams to inform classification. The results indicated that there exist four main types of urban fabric in Greater Cairo, mostly influenced by the existing topography and land subdivision. Results also indicate that there are unique spatial structures found in informal settlements that are similar to the ones found in organically generated historical settlements. These structures often represent the social core of informal neighbourhoods and can be preserved in urban intervention. The role of the highway super-grid is also highlighted, which shows that while the highways may contribute to spatial fragmentation, they can also act as a connector, which presents another avenue for urban intervention. This research contributes to the existing body of literature by refining the existing classification, using quantitative methods to describe the urban fabric, and proposing some avenues of urban intervention that could be developed further by practitioners.

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APPENDIX A – SOCIAL RESEARCH MATERIALS

This is a translated version of the questionnaire; the actual questionnaire will be in Arabic. The black text indicates the questions, and the blue indicates researcher notes on purpose of the question. If a question has options then they will be indicated in brackets, otherwise it is a short form text answer.

Research into the Daily Lives of Egyptians

Description: This research is for my PhD project on how people use spaces in their daily lives and how they move in their neighbourhood and their city. You can fill in this form or use this link https://www.zeemaps.com/map?group=2796768# to answer the questions. Please do not write your name or address, just indicate in which neighbourhood or street your answer is. To contact the researcher with any questions please email: eman.abozied@northumbria.ac.uk. By continuing with the questionnaire, you consent to your answers being used in the final PhD project.

1. Gender (Male/Female)
2. Age (Under 18, 18-24, 25-34, 35-44, 45-55, 55)

Section 1: This Section is to do with your childhood

3. Which Governorate is your family from? (A list of all 27 governorates in Egypt) This question was to see the levels of migration from the countryside into the capital
4. Where did you live as a child?
5. Where was your school?
6. Where did you play?
7. Where did you buy food and sweets?
   All these questions were to see if people remained in their neighbourhood to carry out their daily activities or if they went outside their neighbourhood. It also shows where services are in relation to residential areas. It also indicates the temporal changes that occur in the transition from childhood to adulthood and how they can be compared.

Section 2: This Section is to do with your life now

8. Where do you live now? Shows migration from initial neighbourhood – do people generally try and stay near their families? Does it depend on if it is a planned or informal area?
9. Do you have children (Yes/No)?
10. If yes, where is their school? Do people send their children to school in their neighbourhood or elsewhere?
11. Where do you go to spend time with your friends?

12. Where do you work? Both of these questions are to show if people leave their neighbourhood for daily activities, are services and work available there?
13. Do you own a car? (Yes/No)
14. If you own a car, where do you get it fixed? Informal areas often have workshops and car repair shops – it would have been interesting to see if people who lived in planned settlements go to informal settlements for a service
15. Do you use public transport? (Yes/No/Sometimes)
16. If yes, what type do you use? (Bus, microbus, metro, tuk-tuk, tram, train, other) microbuses and tuk-tuks are informal methods of transportation that run on lines set by demand rather than by a company or through government. This would show that even if people lived in planned settlements they still participate in informal activities.
17. Which lines or stops do you use? The informal modes of transport would usually run all over Cairo, including the informal areas, and it is interesting to see which modes and lines people use to create a holistic map of movement.
18. Do you use any of these? (Uber/Careem/Taxi/I don't use any of these) this is the third way of transportation around Cairo, a privately hired vehicle.
19. Where do you buy clothes?
20. Where do you buy food? From which area, shop or marketplace? Informal souqs often operate in both planned and informal neighbourhoods, I am interested to see which are more commonly used – large supermarkets or the souqs
21. If you wish to be contacted by the researcher for further questions, please leave your email or Facebook link below.

البحث عن الأنشطة اليومية للمصريين

يمكنك ملء هذا النموذج أو استخدام الخريطة: https://www.zeemaps.com/map?group=2796768#
لا تحتاج إلى وضع عنوانك، يرجى كتابة المنطقة أو الشارع

* Required

1. النوع *

Mark only one oval.

- أنثى
- ذكر

2. العمر *

Mark only one oval.

- تحت 18
- 18-24
- 25-34
- 34-45
- 45-55
- 55+

الجزء الاول
هذا الجزء متعلق بفترة طفولتكم

C

3. عائلتك من أي محافظة؟ *

Mark only one oval.

- القاهرة
- الإسكندرية
- أسوان
- أسيوط
- البحيرة
- بني سويف
- الدقهلية
- دمياط
- الفيوم
- الغربية
- الجيزة
- الاسماعيلية
- كفر الشيخ
- الأقصر
- مطروح
- المنيا
- المنوفية
- الوادي الجديد
- شمال سيناء
- بورسعيد
- القليوبية
- قنا
- البحر الأحمر
- الشرقية
- سوهاج
- جنوب سيناء
- السويس

D

4. أين كنت تسكن عندما كنت طفلا؟ *

5. أين كانت مدرستك؟ *

6. (أين كنت تلعب؟ (ملعب، نادي ... الخ *

7. أين كنت تشتري الطعام والحلويات عندما كنت طفلا؟ *

الجزء الثاني

هذا الجزء متعلق بحياتك الآن. إذا كنت تعيش خارج مصر الرجاء الإجابة عندما كنت في مصر

8. أين تسكن الآن؟ *

9. هل لديك أطفال؟ *

Mark only one oval.

- نعم
- لا

10. إذا كان لديك أطفال، أين هي مدرستهم؟

E

11. أين تذهب لقضاء وقت الفراغ مع أصدقائك؟ *

12. أين هو مكان عملك؟ *

13. هل تملك سيارة؟ *

Mark only one oval.

- نعم
- لا

14. أين تذهب لإصلاح سيارتك؟

15. هل تستخدم وسائل النقل العام؟ *

Mark only one oval.

- نعم
- لا
- أحيانا

F

16. إذا كنت تستخدم وسائل النقل العام، ما هي الأنواع التي تستخدمها؟

Check all that apply.

- [ ] أتوبيس
- [ ] ميكروباص
- [ ] المترو
- [ ] توك توك
- [ ] ترام
- [ ] قطار

Other: [ ] _____

17. ما هي خطوط النقل العام و محطات النقل التي تستخدمها؟

_____
_____
_____
_____
_____

18. هل تستخدم أي مما يلي *

Mark only one oval.

- ( ) Uber - اوبر
- ( ) Careem - كريم
- ( ) Taxi - تاكسي
- ( ) لا تستخدم أي من هذه

19. من أين تشتري ملابسك؟ من أي منطقة أو محل؟ *

_____

20. من أين تشتري المواد الغذائية؟ من أي منطقة أو محل أو سوق؟ *

_____

G

21. إذا كنت تريد أن يتم الاتصال بك من الباحث لمزيد من الأسئلة أو المعلومات يرجى ترك البريد الإلكتروني الخاص بك أو رابط الفيسبوك

شكرا لمشاركتكم :)

H

SENSE OF COMMUNITY INDEX II

The following questions about community refer to: City of the Dead.
الأسئلة التالية حول المجتمع تشير إلى:

How important is it to you to feel a sense of community with other community members?
ما مدى أهمية شعورك بالمجتمع مع أفراد المجتمع الآخرين؟

1	2	3	4	5	6
Prefer Not to be Part of This Community	Not Important at All ليس مهما على الإطلاق	Not Very Important ليس مهما جدا	Somewhat Important مهم نوعا ما	Important مهم	Very Important مهم جدا

أفضل ان لا يكون جزءا من هذا المجتمع

How well do each of the following statements represent how you *feel* about this community?
إلى أي مدى تمثل كل عبارة من العبارات التالية كيف تشعر حيال هذا المجتمع؟

		Not at All لا	Somewhat قليلا	Mostly نوعاً ما	Completely تماما
1.	I get important needs of mine met because I am part of this community. أحصل على تلبية الاحتياجات الهامة لأنني جزء من هذا المجتمع.	❍	❍	❍	❍
2.	Community members and I value the same things. أعضاء المجتمع ولدي نفس القيم	❍	❍	❍	❍
3.	This community has been successful in getting the needs of its members met. هذا المجتمع هو ناجح في الحصول على احتياجات أعضائها	❍	❍	❍	❍
4.	Being a member of this community makes me feel good. كونه عضوا في هذا المجتمع يجعلني أشعر أنني بحالة جيدة.	❍	❍	❍	❍
5.	When I have a problem, I can talk about it with members of this community. عندما يكون لدي مشكلة، يمكنني الحديث عن ذلك مع أعضاء هذا المجتمع.	❍	❍	❍	❍
6.	People in this community have similar needs, priorities, and goals. الناس في هذا المجتمع لديهم احتياجات وأولويات وأهداف مماثلة.	❍	❍	❍	❍
7.	I can trust people in this community. أستطيع أن أثق في الناس في هذا المجتمع.	❍	❍	❍	❍

	Not at All لا	Somewhat قليلا	Mostly نوعاً ما	Completely تماما
8. I can recognize most of the members of this community. يمكنني التعرف على معظم أعضاء هذا المجتمع.	❍	❍	❍	❍
9. Most of the community knows me معظم المجتمع يعرفني	❍	❍	❍	❍
10. This community has symbols and expressions of membership such as clothes, signs, art, architecture, logos, landmarks, and flags that people can recognize. هذا المجتمع لديه رموز وعبارات العضوية مثل الملابس، وعلامات، والفن، والهندسة المعمارية، والشعارات، والمعالم، والأعلام التي يمكن للناس الاعتراف بها.	❍	❍	❍	❍
11. I put a lot of time and effort into being part of this community. لقد وضعت الكثير من الوقت والجهد في أن تكون جزءا من هذا المجتمع.	❍	❍	❍	❍
12. Being a member of this community is a part of my identity. من المهم أن تكون عضوا في هذا المجتمع	❍	❍	❍	❍
13. Fitting into this community is important to me. الاندماج في هذا المجتمع مهم بالنسبة لي.	❍	❍	❍	❍
14. This community can influence other communities. ويمكن لهذا المجتمع أن يؤثر على المجتمعات الأخرى.	❍	❍	❍	❍
15. I care about what other community members think of me. أهتم بما يعتقده أعضاء المجتمع الآخرون مني.	❍	❍	❍	❍
16. I have influence over what this community is like. لدي تأثير على ما هذا المجتمع	❍	❍	❍	❍
17. If there is a problem in this community, members can get it solved. إذا كان هناك مشكلة في هذا المجتمع، يمكن للأعضاء حلها	❍	❍	❍	❍
18. This community has good leaders. هذا المجتمع لديه قادة جيدة.	❍	❍	❍	❍
19. It is very important to me to be a part of this community. من المهم جدا أن أكون جزءا من هذا المجتمع.	❍	❍	❍	❍
20. I am with other community members a lot and enjoy being with them. أقضي الكثير من الوقت مع الآخرين أفراد هذة مجتمع استمتع بهذا الوقت	❍	❍	❍	❍
21. I expect to be a part of this community for a long time. أتوقع أن أكون جزءا من هذا المجتمع لفترة طويلة.	❍	❍	❍	❍
22. Members of this community have shared important events together such as holidays, celebrations, or disasters. قد شارك أعضاء هذا المجتمع الأحداث الهامة معا، مثل الأعياد، والاحتفالات، أو الكوارث	❍	❍	❍	❍
23. I feel hopeful about the future of this community. أشعر بالأمل في مستقبل هذا المجتمع	❍	❍	❍	❍
24. Members of this community care about each other أعضاء هذا المجتمع يهتمون ببعضهم البعض	❍	❍	❍	❍

Date:
Time
Observations: