Syntactic Stitching II

Testing the rationalisation of the urban fabric as an intervention method in Cairo, Egypt

EMAN ZIED[1], ALICE VIALARD[1], RUTH CONROY DALTON[1]

[1]Northumbria University, Newcastle-upon-Tyne, United Kingdom

ABSTRACT

Self-generated informal settlements in Cairo are the product of incremental decisions which lead to a gradual aggregation of buildings that form urban blocks (Sioufi, 1981). The resulting block shapes and sizes may be suitable for meeting an individual's needs for housing but may not meet the community's needs for amenities that have a larger area. The street network is partially the product of building aggregation and therefore is unplanned and may not meet the community's needs. This paper argues that minor urban interventions can be used to alleviate some of the issues that informal settlements face such as over-crowdedness and lack of access to the city.

Based on previous work by Zied and Vialard in Cairo (2017) this study uses a two-pronged approach to develop a holistic intervention plan for informal settlements in Cairo, rationalizing the urban fabric by consolidating urban blocks to increase their resilience and optimizing the street network to improve connectivity and integration both within the settlement and to the wider urban fabric of Cairo. This type of informed intervention may improve community living standards and allow the settlement to develop into a functional neighbourhood that can be incorporated into the wider urban fabric.

Based on measures tested and developed in the work of Colaninno et al in Barcelona (2011) and Song and Knaap in Portland (2007) this study firstly analyses self-generated urban blocks in terms of their shape and size, then explores how self-generated blocks can be consolidated. This study will then analyse the street network (Hillier and Hanson, 1989) then improve the syntactic structure of settlements and reconnect it to the city super-grid (Peponis et al., 2015). Interventions are developed and tested then compared to the initial state of the settlement to establish which is most beneficial to the settlement.

The case studies selected are as follows:

1. Informal Growth on agricultural land -Ard El Lewa, Dar El Salam
2. Historic District –Mit Uqba and Medieval Cairo

The methodology of this study uses two urban morphology measures; square compactness (Maceachren, 1985; Steadman et al., 2000) which measures the block's deviation from a square, and elongation (Angel et al., 2010; Schumm, 1956) which uses the longest axis of the shape to measure its deviation from a circle. The urban block measures show the size and shape of blocks to assess their suitability and functionality in the urban fabric. The area and perimeter of the block will also be considered according to the proposed intervention. The axial analysis will be used to analyse the street network and visualise the integration core and syntactic structure of the settlement (Hillier, 1999; Hillier and Hanson, 1989) in order to rationalise the street network.

Results indicate that minor interventions cause an acceptable improvement in the syntactic structure and block measures of the settlement, and can be enough to improve the settlement and reconnect it to the wider urban fabric. Urban blocks can be consolidated to accept functions which require a large area, but since the existing blocks often contain housing and streets create crucial access points, a holistic intervention plan (Levy, 1999) should be developed that consolidates blocks and widens and reroutes streets to improve the urban fabric without disrupting the existing structure.

KEYWORDS

Space Syntax, Informal Settlements, Urban Planning, Rationalisation, Urban Morphology

1. INTRODUCTION

Informal settlements (also known as *ashwa'iyat* – meaning 'random built') is two-thirds of the urban fabric in Greater Cairo, making it the dominant urban fabric (Sims, 2010). Informal settlements suffer from issues such as overcrowding and lack of connection to the rest of the city. As informal settlements are the dominant urbanism, these issues need to be addressed to help improve the quality of life of their residents. This paper argues that minor urban interventions can be used to alleviate some of the issues that informal settlements face. Results indicate that minor interventions through street network optimisation and urban block consolidation can be enough to improve the settlement and reconnect it to the wider urban fabric

1.1. Informality in Egypt

It is estimated that over 15 million people in Egypt live in informal settlements, between 25% and 30% of Egypt's total population (Nawar and Al-Qattat, 2008). 63% of Cairo's population live in informal settlements - they contribute more units to the housing stock than any other source (Arandel and El Batran, 1997). However, due to their unplanned nature, informal settlements suffer from a variety of issues such as overcrowding, pollution, lack of compliance with building standards, lack of amenities and lack of access to the rest of the city. Current planning policy has exacerbated these issues by excluding informal settlements from large scale transportation projects such as the highway network and the metro, and by removal of the settlements and eviction of residents instead of designing urban interventions to improve quality of life (Hegazy, 2016).

Informal settlements as they are known now started to emerge in the early 1960s after the government reduced spending on its national housing projects. Rapid urbanisation and migration from rural areas caused a sharp rise in Cairo's population, and the formal sector could no longer provide suitable, affordable housing. An increase in planned housing prices also meant that many families could not afford housing, and by 1986 there were 523,000 vacant planned housing units and informal housing units had increased from an estimated 40,000 to 144,000 units. By the 1990s to early 2000s, the focus shifted to building new towns in the desert rather than increasing low-income housing stock so those who could not afford to buy a planned housing unit turned to building informal units illegally (Arandel and El Batran, 1997).

The government initially ignored informal settlements but after pressure from the international community, the government started to pay attention to informal areas. In the 1970s and '80s, some informal areas were recognised as legitimate but this process took an extremely long time and was eventually abandoned. By 1993 the government had abandoned its role as regulator for informal settlements and started to provide infrastructure to those who could afford it, rather than who needed it most. Settlements were chosen for intervention on the basis of needing to be controlled rather than being in poor condition (Deboulet, 1994). The current government policy is to sporadically intervene by demolishing informal housing and relocation of residents to satellite cities in the desert or to ignore informal areas entirely (Hegazy, 2016). Most interventions in informal areas are now carried out by research groups, NGOs or private urban planning firms at their own cost (Howeidy et al., 2009).

There are four main types of informal settlement:

1. Informal building on agricultural land – the people own the land but it is illegal to build on it
2. Informal building on state-owned desert land
3. Deteriorated historical areas with informal building
4. Previously planned *shaabi* (popular, low-income housing) settlements with informal extensions

The most common type of informal building is on privately owned agricultural land (Sioufi, 1981).
Informal areas are considered informal because of their illegality but the urban morphology of informal settlements follows formal rules – the building isn't random. Informal settlements are self-generated and different types of emergence lead to different morphological outcomes. Informal settlements that have emerged on agricultural land retain the agricultural grid as the urban grid, farming plots become building plots and irrigation routes as streets and roads (Zied and Vialard, 2017); this type of growth is labelled 'informal – infill'. Informal settlements on desert land tend to form by aggregation of building units over time, with the leftover space

designated as streets. This type of growth is labelled 'informal – organic'. *Shaabi* and historical settlements can grow in either of these ways but generally were planned before informal growth occurred.

1.2. Studies in Cairo and other Informal Settlements

There have been a number of relevant studies in informal settlements that use space syntax analysis. In 2014 a study was conducted in Cairo that showed that spatial segregation contributed to social segregation. The study also showed that planning policy did not allow highway access to informal areas. The highways also create a hard edge where pedestrians cannot cross, and limits settlement expansion (Mohamed et al., 2014). Interventions in the urban fabric can reconnect informal settlements to the highway super grid and reduce overall segregation.

A study conducted in Santiago, Chile, shows that the more spatially integrated the existing settlement is on its edge boundary with the surrounding urban fabric the more self-generated economic activity and community development. A neighbourhood's relation to the wider urban context and its internal spatial layout are a good predictor of future consolidation into the main urban form (Hillier et al., 2000). Interventions can be designed that encourage this kind of edge movement can be used to consolidate informal settlements into Cairo.

A study conducted in Jeddah in Saudi Arabia shows that minor physical interventions improve unplanned settlements in the historic core of Jeddah that have distinct local structure (Karimi et al., 2007). The principles of minor intervention have been used in this paper, but the settlements are in different areas of Cairo rather than exclusively at the core.

2. METHODS

2.1 Methodology

The methodology used in this study focuses on first analysing the settlements as they exist, then identifying pathologies in the urban fabric. After this, interventions are developed and then re-analysed to show what changes have occurred. This section outlines the theoretical background that informs this study's methodology. From space syntax, the concept of a superblock, super grid and deformed wheel are used. Measures originally used in geographic research are adapted for use in urban contexts. Square compactness, which was adapted by Steadman from MacEachren's index of compactness (Maceachren, 1985; Steadman et al., 2000), measures the block's tendency towards a square. Elongation, developed by Schumm to measure river drainage basins, measures the compactness of a block using the longest axis (Schumm, 1956). These measures are used to compare settlements to others to show the functionality and suitability of the settlement quantitatively.

The deformed wheel is a street configuration that is evident in many different cities and is considered a sign of a healthy city with good syntactic structure. It consists of a highly integrated core of spaces and a spatial rim of movement around the edge of the settlement. These two elements are connected by spokes that radiate from the central core to the edge rim (Hillier and Stoner, 2010). The deformed wheel is one type of integration core (Hillier and Hanson, 1989) that can be seen by highlighting the top 1%, 5% or 10% of spaces in a system. In this study, it is used as a benchmark to indicate when the syntactic settlement of the neighbourhood is improving. Axial analysis is used to measure the potential for movement in settlements and to identify the integration core and main thoroughfares (Hillier, 1999; Hillier and Hanson, 1989). As the settlements are large and complex systems and have high connectivity (Carpenter and Peponis, 2010) the top 1% and 5% of spaces have been designated as the integration core.

The super grid is a way of differentiating between scales in an urban system. Grids can be both regular and deformed and are usually made up of arterial roads or highways. The super grid in Cairo's case consists of planned highways (Zied and Vialard, 2017). These highways span the city, cross the Nile and encircle the city proper. They have an average length of 30-50km for highways that span the city and 80- 100km for the highways that encircle the city. In each neighbourhood, there exists a primary structure of main streets that provide access to the neighbourhood from outside and connects the most important parts inside the neighbourhood. Local streets are connected to the primary street structure, which then is connected to the super grid. This allows access from their neighbourhood to all other parts of the city. The blocks within the super grid are called superblocks and usually

contain four or more urban blocks (Peponis et al., 2017, 2015). In this study, the street network is used as an intervention tool, by reconnecting the settlements to the super grid or creating or consolidating a primary structure through thoroughfares.

Urban morphology measures are used to analyse the size and shape of blocks to measure the regularity and homogeneity of blocks. The area and perimeter of blocks are taken into consideration and used to calculate the square compactness (Maceachren, 1985; Steadman et al., 2000; Vialard, 2013) and elongation (Angel et al., 2010; Schumm, 1956) of blocks. Square compactness measures the block shape tendency towards a square and elongation is the ratio of the diameter of a circle of the same area as the block to the longest axis of a block. The formulae are as follows:

Square Compactness (level of deviation from a square) – adapted from MacEachren 1985, Steadman et al 2000:

- Extracted polygon perimeter and area from ArcGIS map
- Used formula $16 * \frac{Area}{Perimeter^2}$

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

Table 1: Values and Indication of Square Compactness measure

Elongation (compactness by longest axis (Schumm 1956)):

- Extracted polygon area from ArcGIS map
- Extracted longest axis of the polygon by using [minimum bounding geometry – convex hull – MBD_Length (the distance between the two furthest points)]
- Used formula $\frac{\sqrt{Area}/\pi}{Longest\ Axis}$

Value	**Indication**
0.9 - 1	Circular
0.8 – 0.9	Oval
0.7-0.8	Square
0.5 – 0.7	Tending towards rectangular
< 0.5	Elongated rectangle

Table 2: Values and Indication of Elongation Measure

The results of the urban block analysis are used to inform interventions by redesigning the block structure that occurred through aggregation or fragmentation (Vialard, 2012).

After the analysis is complete, the data is summarised using descriptive statistics (maximum value, minimum value, mean value, standard deviation) and represented in histograms to show distribution. The data summary is used to make decisions regarding interventions and to compare between the initial settlement analysis and the intervention.

2.1.2 Comparison to 'Best Practice' and Intervention Development

While there isn't yet a comprehensive list of best practice policies for blocks and streets, this study uses various principles on how a settlement can be improved and block measures from other successful cities around the world. To develop interventions, pathologies in the informal settlements' blocks and syntactic structure are identified and manually corrected as much as possible, then the consolidation principles outlined below are applied and the

settlement compared to the benchmarks outlined. Changes to the settlements are made based on this comparison and then the settlement is reanalysed. This is repeated until there is a positive change with an acceptable level of intervention. There isn't yet a measure for positive change and acceptable intervention so the author has used her judgement on when this has been achieved.

2.1.3 Consolidation Principles and Criteria

The following basic principles from the literature are applied in deciding where to intervene and what to change. These general criteria make a good starting point for analysis and intervention but are dependent on context. When comparing the existing urban form to these criteria it is important to have contextual awareness as some urban forms may work well within their specific context but do not fit the criteria; for example, small blocks in a small informal settlement – larger blocks would not be as functional in that context.

Generally, settlement blocks should not be too large or too small and regular in shape with few dead ends. The syntactic structure should be a deformed wheel configuration and correspond to real functions.

Urban Morphology

- Very large blocks impede walkability (Jacobs, 1993)
- Very long blocks reduce walkability and navigability as well as opportunities for encounters
- Very small blocks are less resilient over time and cannot accommodate different functions
- Very irregular shaped blocks impede navigability (Vialard, 2013)
- Dead ends reduce connectivity
- The settlement should be a maximum of 60% built area (Perry, 1929)

Syntactic Structure

- The settlement should have a distinct core and edge movement
- The syntactic structure needs to correspond to real functions
- The settlement should have deformed wheel structure (Hillier and Hanson, 1989)

The following table contains benchmarking data that the informal settlements are compared to. The table shows the total area of the study area, the mean area of a superblock (a large urban organisational unit surrounded by arterial roads) within the study area, the number of blocks and their mean area and the mean spacing between arterial roads.

Settlement	Total Area (ha)	Mean Area of Superblock (ha)	No. of Blocks	Mean Block Area (ha)	Mean Arterial Spacing (m)
Beijing	347.76	65.90	141	2.47	828.50
Chicago	263.03	65.76	128	2.05	810.50
Gangnam (Seoul)	138.66	69.50	272	0.51	837.50
Islamabad (G7)	295.19	68.14	556	0.53	865.50
Los Angeles	258.76	64.69	86	3.01	804.00
Perry Whitten (1929)	64.84	64.84	85	0.76	818.00
Baixa, Lisbon	-	-	-	0.25	-
Manhattan	-	-	-	1.48	-
Atlanta	-	-	-	1.49	-
Barcelona	-	-	-	1.27	-

Table 3: Benchmarking data from cities around the world (Peponis et al., 2017, 2015)

Since the mean area of superblocks and the mean arterial spacing values have little variation, they have been set as a benchmark for the informal settlements. The number of blocks and mean block area increases with the total area of the city, so informal settlements are compared to a city of similar size.

In the context of informal settlements in Cairo, the most important criteria to focus on are the syntactic structure, superblock sizes and arterial spacing, as this enables the reconnection to the super grid highway network. Reconnection is one of the more effective strategies for informal settlement intervention as the highway system was purposefully designed to exclude informal settlements from accessing it (Arandel and El Batran, 1997).

2.2 Case Studies

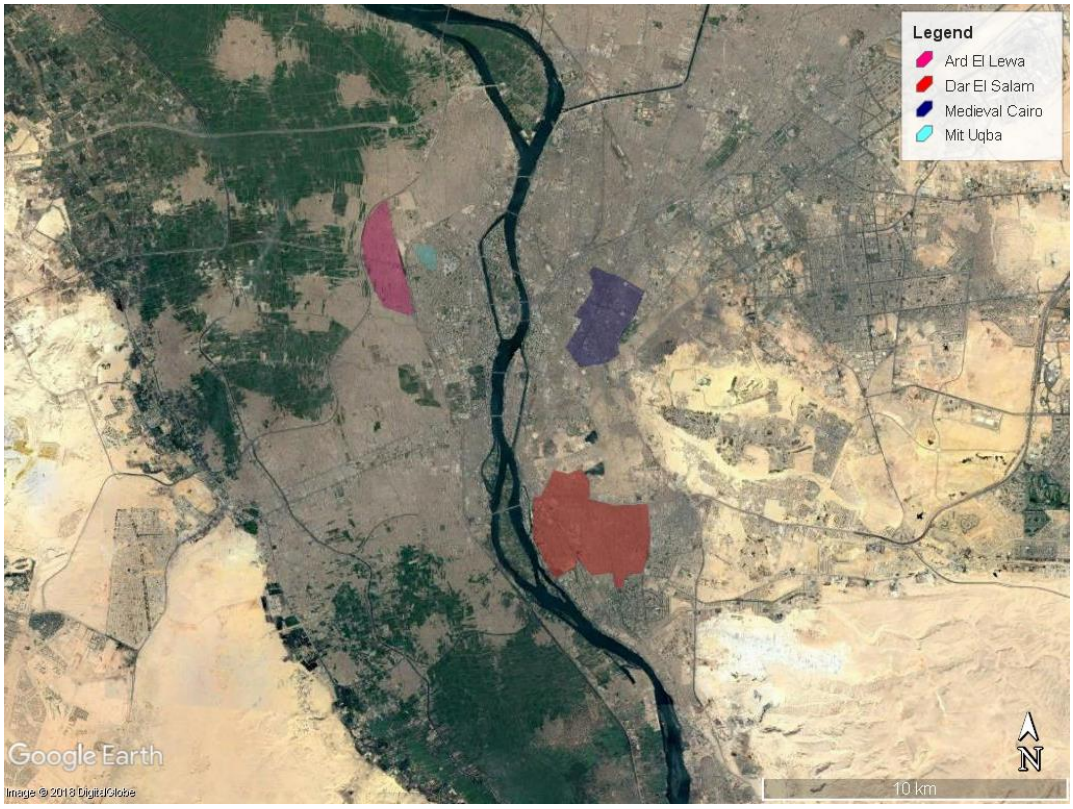

Figure 1: The four case studies in the Greater Cairo Area - Ard El Lewa (pink), Mit Uqba (blue), Medieval Cairo (purple) and Dar El Salam (red)

In this study, four case studies are analysed and intervention proposals created for them. This section provides information about the case studies history and any special considerations for intervention. The table below summarises the settlement typology, total area, population density and date of emergence of each settlement.

Settlement	**Typology**	**Area (hectare)**	**Population Density (people/hectare)**	**Date of Emergence**
Ard El Lewa	Informal – Infill	339	1157	1980's
Dar El Salam	Shaabi/Informal – Infill	939	1006	Early 1970's
Mit Uqba	Informal – Organic	46	2086	Approx. 1900's
Medieval Cairo	Historic – Organic	724	486	969 AD

Table 4: Summary of case study information

All settlements have some type of informal growth and a higher population density than the 464 people/hectare that is the mean for Cairo. While informal growth and high density alone are not necessarily pathological, the effects, such as narrow roads, small blocks, lack of public space and amenities are often detrimental.

2.2.1 Ard El Lewa

Ard El Lewa is an informal neighbourhood in north-western Cairo. It was built over time on agricultural land which gives it a distinctive urban fabric, characterised by long, thin blocks based on the agricultural grid and T-Junctions where roads meet. The street network is shaped by the old canal system and irrigation channels (Zied and Vialard, 2017) and the settlement is prevented from expanding by the Ring Road highway, which has led to increased density over time. This settlement was chosen because it is a good example of informal growth on agricultural land which is how the majority of informal settlements emerged in Cairo (Nagati and Elgendy, 2013; Sioufi, 1981)

2.2.2 Dar El Salam

Dar El Salam is a partially informal neighbourhood in south-eastern Cairo. There is little information about its history and emergence, but now it is one of the largest informal settlements in Cairo. Historical satellite imagery shows that the area was agricultural land in the 1970s and the informal settlement started to emerge in the 1980s. The area was recognised by the government and services such as electricity and waste removal are sporadically provided and there are a public hospital and schools (CAPMAS, 2016). It is adjacent to the affluent district *Al Maadi* and has the Ring Road highway cutting through it. This settlement was chosen because it is a good example of a *shaabi* neighbourhood, literally translated as 'popular', which is often informal but has been recognised by the government and some services provided.

2.2.3 Medieval Cairo

Medieval Cairo, also known as Islamic Cairo, Fatimid Cairo or Historic Cairo, is the historic core of the city. Originally built by the Fatimids in 969 AD after the Islamic conquest of Egypt, it contains many mosques, madrasas and other historic buildings. However, due to years of neglect and informal growth, it is now overcrowded and many residents live in poverty. The main thoroughfare is *Al Muizz* street, which runs from north to south of the settlement and is lined with heritage buildings (Abouseif, 2007). The area has been a protected UNESCO world heritage site since 1979 (UNESCO, 2017) which makes developing interventions a challenge – the intervention must address the issues that face Medieval Cairo such as overcrowding without harming the protected area. This makes it a good case study to test minor interventions.

2.2.4 Mit Uqba

Mit Uqba originated as a rural village in the 1900s, so is considered organic/historical rather than fully informal. The planned neighbourhood Al Mohandisseen was built adjacent to Mit Uqba in the 1950s but had fully surrounded Mit Uqba by the 1970s. The village contains a central marketplace and sporting club, but no health services. It also has little access to the 26th July Corridor highway that runs through the southern part of the neighbourhood (Tadamun, 2013). This case study was chosen because it is an organic area surrounded by a planned area, so it is a good opportunity to test reconnection to the rest of the city.

3. RESULTS

3.1 Initial Analysis

Initially, the block size and shape and the street network of settlements are analysed and the total area, mean superblock area, number of blocks, mean block area, mean arterial spacing and ratio of open space is calculated for each settlement.

The selected case studies cover a different range of areas and types of informal settlement. The initial block analysis for the settlements shows that generally, the settlements are very dense with a large number of small blocks. As they are unplanned, superblocks have been considered as the urban fabric between main arterial streets, and Mit Uqba, the smallest settlement, has been considered as one superblock.

3.1.1 Urban Morphology Analysis

Settlement	**Total Area (ha)**	**Mean Area of Superblock (ha)**	**No. of Blocks**	**Mean Block Area (ha)**	**Mean Arterial Spacing (m)**	**Ratio of open space (total area of blocks/total study area)**
Ard El Lewa	339	44.66	655	0.342	563.71	66% built
Dar El Salam	939	169.51	3474	0.168	875	68% built
Mit Uqba	46	46	246	0.141	307.33	75% built
Medieval Cairo	473	48.78	1490	0.175	807.75	55% built

Table 5: Initial block analysis of each settlement

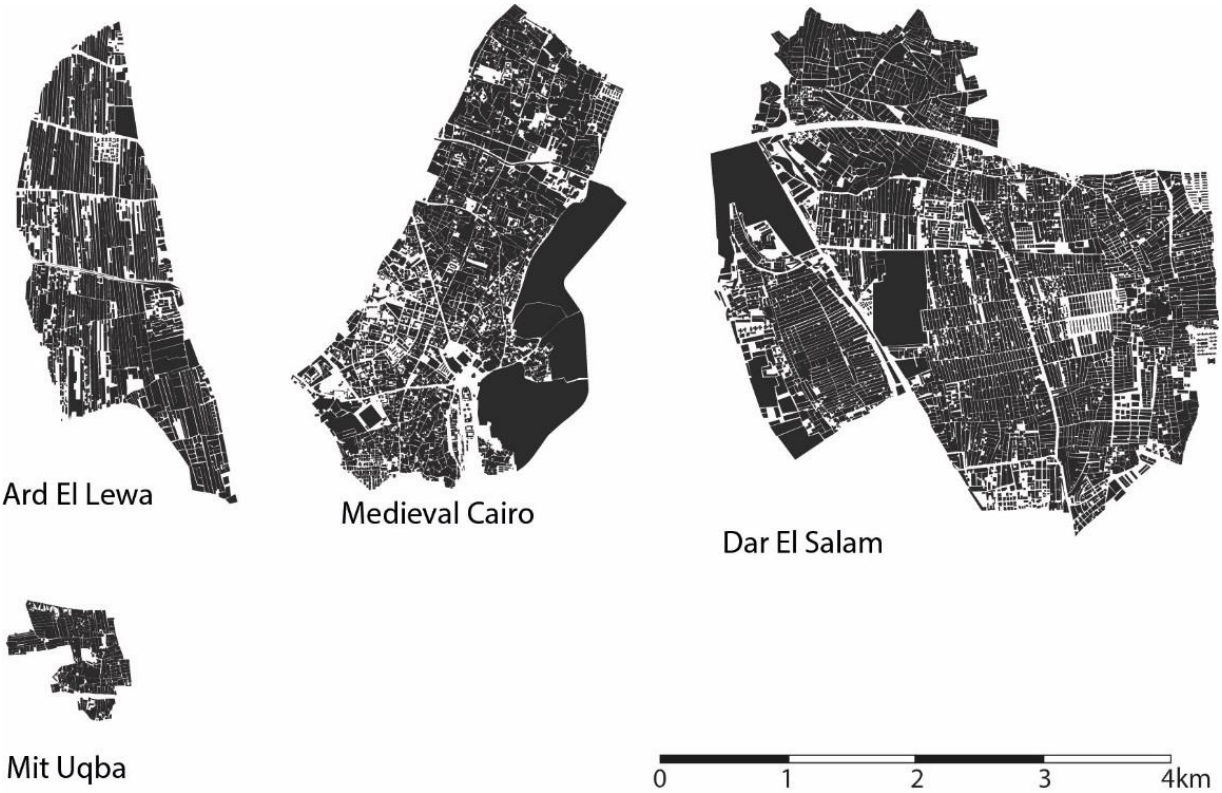

Figure 2: Figure-ground maps of the case studies

		Std Dev	**Mean**
Ard El Lewa	Square Compactness	0.274	0.514
	Elongation	0.088	0.241
Dar El Salam	Square Compactness	0.234	0.674
	Elongation	0.036	0.172
Mit Uqba (organic/historic)	Square Compactness	0.234	0.721
	Elongation	0.059	0.322
Medieval Cairo	Square Compactness	0.247	0.658
	Elongation	0.030	0.183

Table 6: Square Compactness and Elongation Measures of the blocks for each settlement

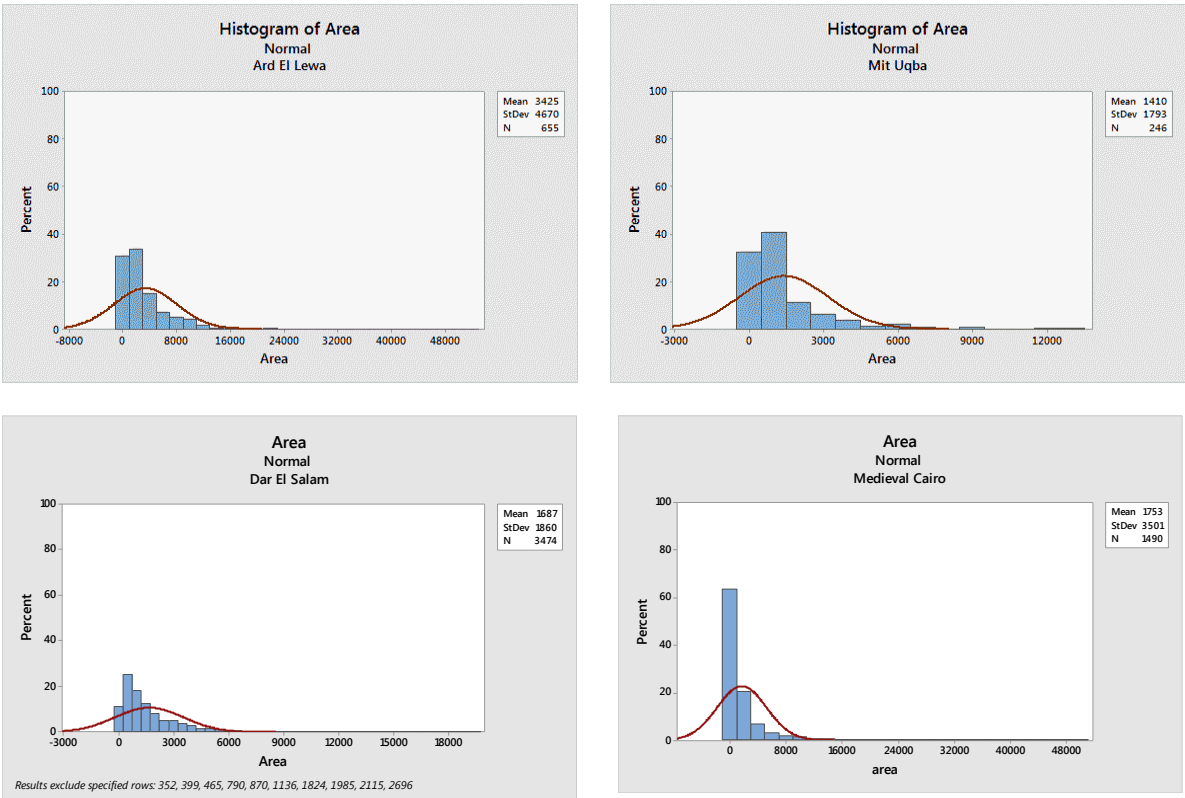

Figure 3: Histograms of block area distribution in case studies

The square compactness and elongation measures show that generally, blocks in Ard El Lewa and Dar El Salam are regular and homogenous, as they are influenced by the agricultural land grid. Mit Uqba and Medieval Cairo have similar values as they are both historical, organically generated settlements. Distribution histograms show that block areas are similar within each settlement (figure 3) with some outliers that can be attributed to large spaces such as the Citadel and Al Azhar Park in Medieval Cairo, industrial areas in Dar El Salam and agricultural fields in Ard El Lewa, which are visible on the figure-ground maps (figure 2).

The initial analysis shows that while the shape of blocks is acceptable, it is the size that may cause pathologies in the urban fabric. Small blocks may fulfil the need for housing but pose issues for larger amenities such as health services, schools etc. which need larger blocks. Small blocks also mean that there are a high number of unnecessary streets which increase maintenance costs. Compared to the benchmark cities (table 4) Ard El Lewa, Dar El Salam and Medieval Cairo would benefit from a reduction in the number of blocks by consolidating them into larger blocks. Ard El Lewa, Dar El Salam and Mit Uqba also have greater than 60% built-up area so would benefit from an increase in open space

3.1.2 Syntactic Analysis

The initial syntactic analysis shows some pathologies in the syntactic structure of the settlements. Ard El Lewa has little edge movement, and the core does not correspond with important settlement functions, as it is the highway that runs through the settlement. It also has little through movement and movement is too concentrated around the highway, leaving parts segregated. Medieval Cairo's core only partially aligns with the main thoroughfare of *Al Muizz* Street and the northern part of the settlement is segregated. Dar El Salam's northern part is also segregated due to the highway and there are few east-west movement axes. However, Mit Uqba has a good syntactic structure, with a clear core that corresponds to the marketplace and sporting clubs, spokes that reach the edge of the settlement and edge movement in the northern part.

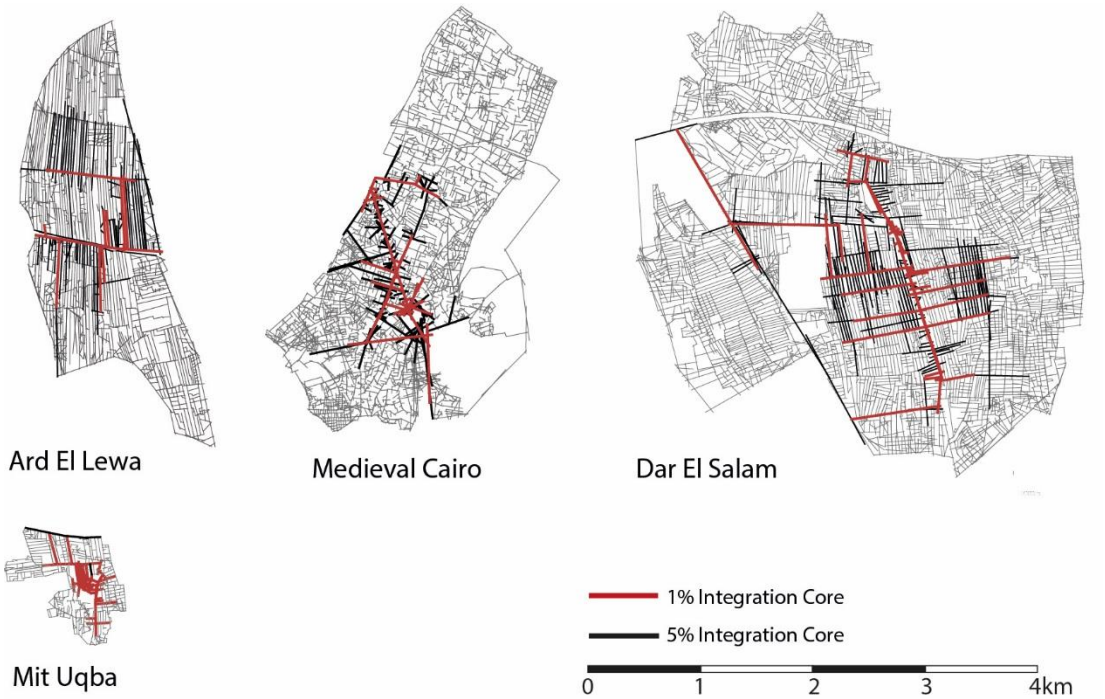

Figure 4: Initial Syntactic Structure (integration core) of the case studies

Integration Values		Avg	Min	Max	Std. Dev
Ard El Lewa	N	1.080	0.631	1.781	0.189
	N=3	2.151	0.682	4.374	0.612
Dar El Salam	N	1.067	0.545	1.721	0.198
	N=3	2.390	0.333	4.689	0.623
Mit Uqba	N	1.087	0.627	1.712	0.195
	N=3	1.951	0.333	3.194	0.477
Medieval Cairo	N	0.876	0.486	1.403	0.169
	N=3	2.032	0.333	4.480	0.684

Table 7: Global (n) and Local (n=3) values for each settlement

The integration values show that generally, the informal settlements have good local integration but low global integration, indicating that they function as a discrete settlement but are segregated from the rest of Cairo. The higher standard deviation in the local integration of Ard El Lewa, Dar El Salam and Medieval Cairo show that some areas within the settlement are more segregated than others and do not connect to the integration core, which can be seen in the syntactic structure (figure 5).

3.1.3. Intervention Recommendations

From the initial analysis, some intervention recommendations are proposed. Generally, interventions should aim to reduce the number of blocks, increase the block size and decrease the density of settlements. Further recommendations for individual settlements are outlined below. These intervention recommendations should be considered as a guideline for the specific settlement and their context.

Settlement	Recommendation
General	• Reduction of block number • Increase in block size • Decrease in density
Ard El Lewa	• Addition of through movement thoroughfares • Reduction of fragmentation in streets (widening and alignment) • Widening of highway crossing points
Dar El Salam	• Addition of the main thoroughfare to the northern part • Addition of arterial roads to decrease superblock sizes • Reinforcing street hierarchy
Medieval Cairo	• This is a UNESCO world heritage protected site so major intervention in blocks/buildings would not be allowed • Widening of the main thoroughfare to adjust the syntactic structure • Pedestrianisation of entire area
Mit Uqba	• Reconnect to the supergrid and surrounding settlement

Table 8: Intervention Recommendations for each settlement

3.2 Intervention Proposals

In this section, the final iteration reached of the intervention proposals is presented, along with the syntactic and morphological impact of interventions. It is important to note that proposals have been designed by the author and not computer generated, so they may not be the optimum intervention plan and can benefit from further development. The development of algorithms to measure the impact of interventions is out of the scope of this paper but has a high potential for future scholarship.

3.2.1 Types of Intervention

There are two main categories of intervention strategies; minor and drastic. Drastic interventions are considered to be those that fundamentally change the morphology and syntactic structure of the settlement, for example, cutting through the urban fabric to create highways, removal of large areas of housing or a major change of function e.g. removal of a marketplace. Drastic interventions may be beneficial in some cases where the settlements have a poor existing syntactic structure or very segregated areas, but minor interventions should be tested first before resorting to drastic interventions.

Intervention	Potential Impact
Increase block size by consolidation and pedestrianisation	• Can accommodate other functions in the future • Increased walkability • Potential loss of roads and additional disconnection
Addition/widening of arterial roads to increase the size of the super grid and regularise arterial spacing	• Improves navigability • Creates discrete neighbourhoods • Improves syntactic structure and integration • Improves access to neighbourhoods
Widening and consolidation of the existing road network	• Improved syntactic structure – improved navigability and integration • The improved connection between neighbourhoods
Core connection to the super grid	• Improved connection to segregated areas

Table 9: Potential Impact of individual intervention strategies

There are many potential types of minor interventions at different scales that can be applied to settlements, the ones selected to be used in this paper are as follows. They are able to be tested using space syntax and urban morphology methodologies and applied at the neighbourhood scale and achieve the recommendations above (table 9)

- Widening/Alignment of existing streets
- Addition of new streets (that are not significantly disruptive to the existing structure)
- Addition of open space and public squares
- Block consolidation (old streets can be retained as open space or private access within the blocks)

3.2.2 Evaluation Framework for Interventions

Interventions are evaluated by attaining or getting closer to the criteria set out in section 2.1.3. As stated above, each type of intervention can have a positive or negative change within this context. Some of the potential positive and negative outcomes of the whole intervention plan are outlined in table 10:

Positive change	**Negative Change**
• The emergence of deformed wheel syntactic structure • Increase in open space • Increase in block size (in order to accept amenities) • Regularity in superblock size and arterial spacing • Increased global integration	• Major disruption of existing syntactic structure e.g. removal of existing access points and main roads no longer corresponds to real functions • Destruction of >10% of the urban fabric

Table 10: Potential positive and negative outcomes of the entire intervention plan

In this context, the emergence of a deformed wheel structure and increased global integration is considered positive as informal settlements are disproportionately affected by segregated areas, lack of connectivity and lack of edge movement. Similarly, regularity in superblock size and arterial spacing mean that the informal settlements have increased the potential to be reconnected to the highway super grid. Increases in open space would mean that the settlements have become less dense, which is also considered positive as density in informal settlements is much higher than the rest of Cairo (table 4). Major disruption of the existing urban fabric and street network may have negative consequences such as lack of access to existing amenities and less opportunity to connect to the super grid.

3.2.3. Intervention Proposals

The intervention proposals presented below show the positive change made by minor interventions in the urban fabric (see table 9 for recommendations). The proposals have been developed by first optimising the street network then consolidating urban blocks when necessary. Pathologies are identified in the initial syntactic structure, then the street network is changed through widening and alignment of existing streets until the pathologies have been addressed. In some cases, additional streets may be created and local streets reconnected to the wider highway network. After the street network has been optimised, blocks can be left as they are if they are a suitable size and shape, or consolidated to increase the size and make the shape more regular. In this paper, intervention is considered complete when syntactic structure and urban block measures are close to the benchmarks outlined above (section 2.1.3) and achieved the recommendations. It is important to note that further intervention may be possible after this but may have diminishing returns.

Ard El Lewa

In the initial analysis, Ard El Lewa had a false syntactic core around the highway that cut through it. While it is likely that this is the area that sees most through movement, it is not beneficial to the settlement since there is only one access point to the highway from within the settlement. There were no continuous north-south axes in the neighbourhood and little edge movement. Blocks are narrow and elongated, following the agricultural grid.

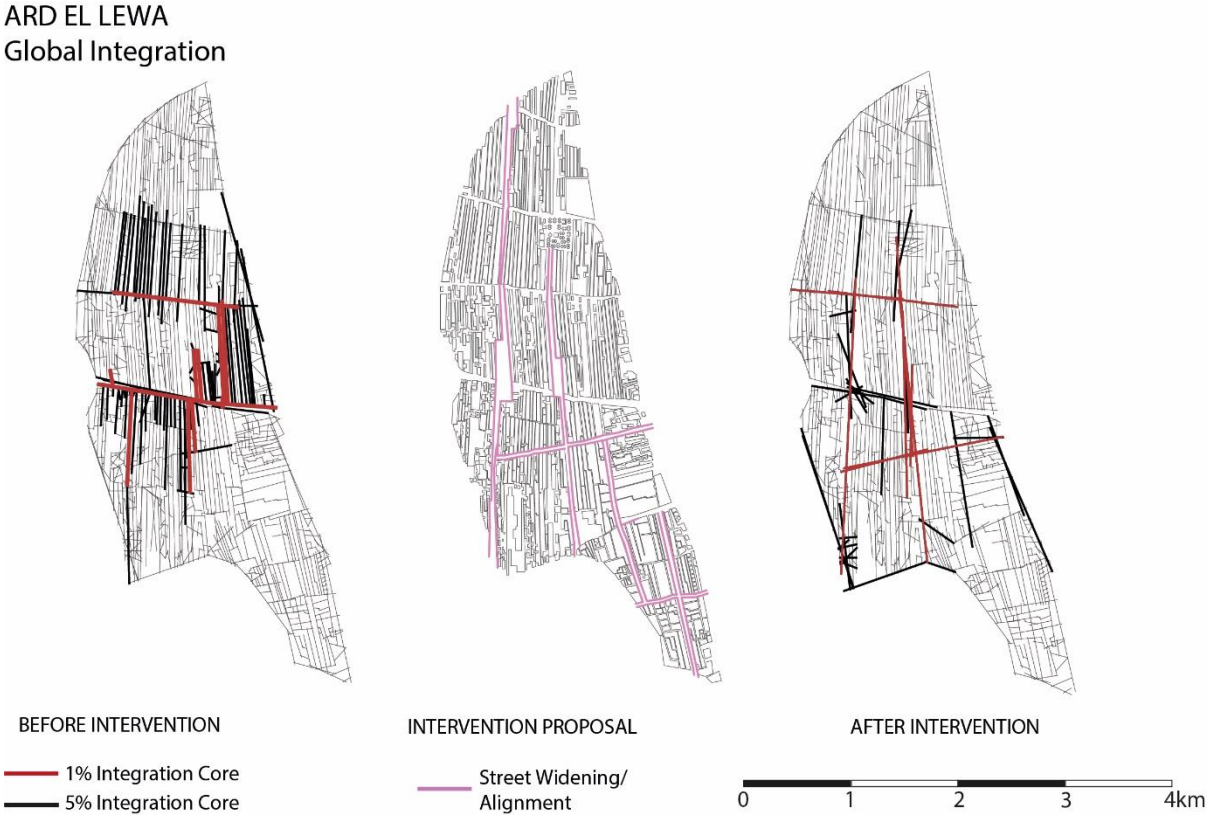

Figure 5: Street Network optimisation for Ard El Lewa

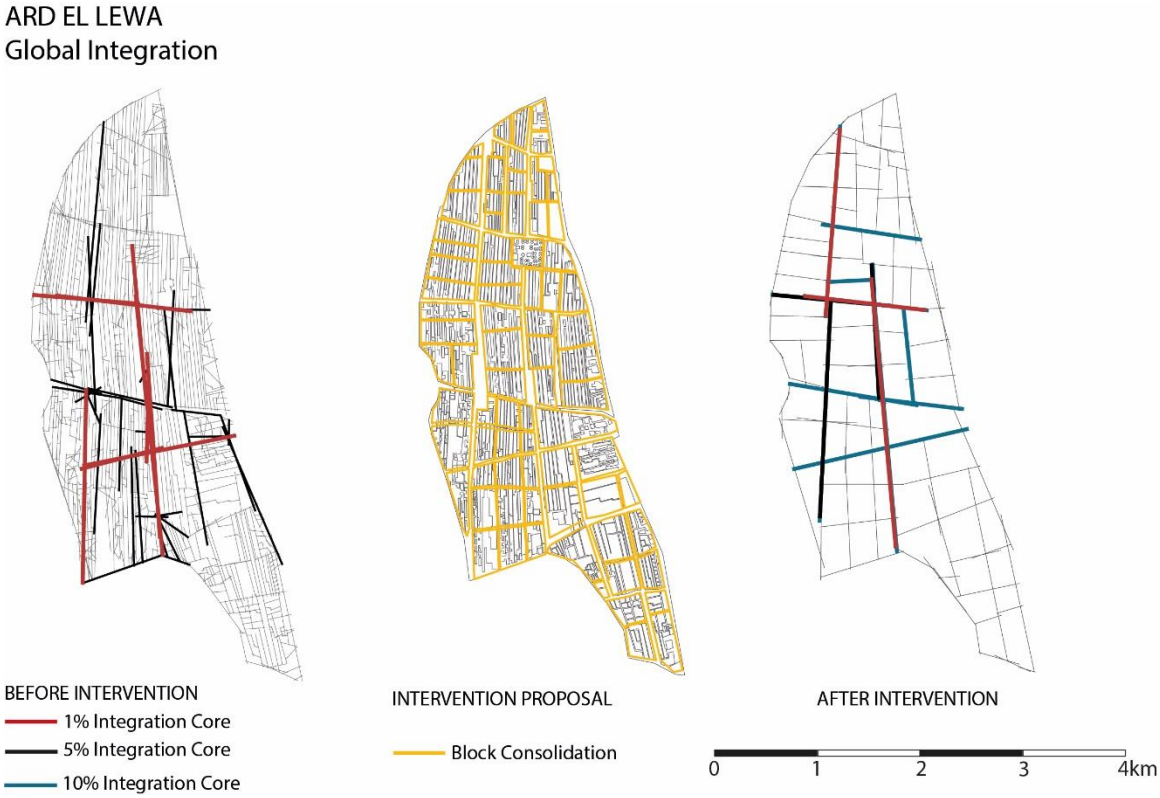

Figure 6: Block Consolidation for Ard El Lewa

Firstly, the street network was optimised by widening and aligning north-south streets selected from the most integrated streets to create north-south thoroughfares. After this, east-west thoroughfares were created by the same process. The aim was to strengthen the existing syntactic structure rather than add in new streets. After that, blocks were consolidated together based on the new strengthened syntactic structure and existing streets, with the aim of decreasing their number and reducing elongation, as well as maintaining as much of the urban fabric as possible. After block consolidation, the top 10% of spaces are also highlighted as the integration core, since the reduction of streets also occurred with block consolidation, so 5% would not highlight enough spaces to show the integration core.

After street network optimisation, the core of the settlement has moved away from the highway and the new north-south axis has been reinforced. New east-west axis has also been formed and more edge movement is noticeable. Consolidating blocks changed the syntactic structure further, so instead of a 'false' centre of the highway, there are two main east-west axes in both sides of the settlement and two North-South axes connecting both sides. The overall structure tends towards a deformed wheel with a core and spokes but would benefit from more edge movement.

Syntactic Analysis			
	Before Intervention	**After Street Network Optimisation**	**After Block Consolidation**
Min (n)	0.631	0.919	0.971
Avg (n)	1.080	1.731	1.557
Max (n)	1.781	3.201	2.692
Std. Dev (n)	0.189	0.354	0.367
Min (n=3)	0.682	0.849	1.195
Avg (n=3)	2.151	2.459	2.147
Max (n=3)	4.374	4.419	3.166
Std. Dev (n=3)	0.612	0.645	0.418

Block Analysis			
	Benchmark (Los Angeles)	**Before Intervention**	**After Intervention**
No. of blocks	86	655	77
Mean block area (ha)	3.01	0.342	3.39
Mean sq compactness	-	0.514	0.897
Std dev for square compactness	-	0.274	0.099
Mean elongation	-	0.241	0.328
Std dev for elongation	-	0.088	0.043

Table 11: Syntactic and Block analysis of Ard El Lewa before and after intervention

After the intervention, integration values increased, particularly the minimum integration values, meaning that the most segregated areas in the settlements became more integrated. Globally, the entire settlement has higher integration values, comparable to planned settlements (Zied and Vialard, 2017). The standard deviation for global integration has also increased, but that can be attributed to a major increase in the maximum integration value rather than parts of the settlement becoming more segregated. Minimum and average local integration have also increased, but paradoxically the maximum value has decreased after block consolidation. This can be explained by decreased connections to the most integrated path due to a reduction in streets.

Urban block measures have also improved. The number of blocks is greatly reduced and their size increased, increasing their potential for amenities and other functions. The square compactness measure has increased, meaning that block shape is now closer to a square; a regular shape with no dead ends. The standard deviation of square compactness has been reduced, meaning that blocks are more regular and homogenous. Elongation has also increased, meaning that blocks are less elongated. The standard deviation has also decreased, meaning blocks are now more regular

Medieval Cairo

Figure 7: Medieval Cairo before and after intervention

Medieval Cairo is a special case because as a UNESCO protected heritage site, it is more difficult to design interventions that fit the conservation criteria. The main goal of this intervention proposal is to align the integration core with the main thoroughfare and actual core of Medieval Cairo, *Al Muizz* Street. To achieve this, the informal building has been identified and removed from around *Al Muizz* Street to widen it, while preserving the historical buildings. Widening the street at the northern part of the settlement meant that it aligned with the existing integration core in the southern part of the settlement. The highway that ran through the settlement was also pedestrianised like the rest of the historical areas.

After this minor intervention, the integration core lines up with *Al Muizz* Street, meaning that the syntactic structure corresponds with real functions. Integration values have also increased, but not as much as other settlements due to this being a very minor intervention.

	Before		**After**	
	Global	Local	Global	Local
Avg	0.876	2.032	1.121	2.061
Min	0.486	0.333	0.506	0.333
Max	1.403	4.480	1.959	4.522
Std. Dev.	0.169	0.684	0.233	0.702

Table 12: Syntactic Analysis before and after intervention in Medieval Cairo

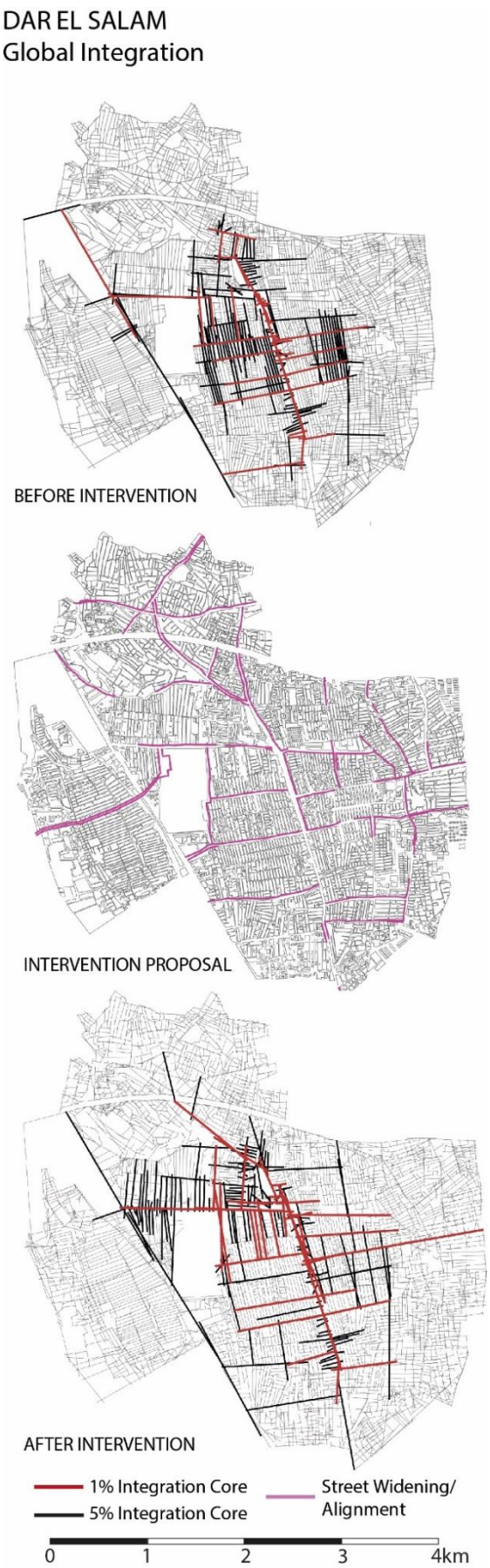

Figure 8: Dar El Salam before and after street network optimisation

Dar El Salam

	Before		**After**	
	Global	Local	Global	Local
Avg	1.067	2.390	1.336	2.475
Min	0.545	0.333	0.639	0.333
Max	1.721	4.689	2.297	4.822
Std. Dev.	0.198	0.623	0.250	0.656
Mean arterial spacing (m)	875		695.4	
Mean super block size (ha)	169.51		43.57	

Table 13: Syntactic and Block analysis for Dar El Salam before and after Intervention

In the initial analysis, Dar El Salam had a segregated northern part due to the highway that cuts through the settlement. The street hierarchy is also unclear, and superblock sizes are very large compared to the benchmarking data in table 4. There is also little east-west through movement except via the highway. To address these issues, it is recommended to reinforce the existing street hierarchy by alignment and widening streets, creating new arterial roads based on the existing syntactic structure.

After the intervention, part of the integration core now reaches across the highway at crossing points into the northern part of the settlement. Edge movement has been reinforced on the western side of the settlement and spokes radiate from the core of the settlement and create east-west movement separate from the highway. The main path in the centre of the neighbourhood now extends from the top to the bottom of the settlement instead of stopping part way through.

Integration values have increased across the entire settlement both locally and globally. Standard deviation has also increased but this can be attributed to the maximum integration increasing but the minimum integration staying the same. By designating existing streets with higher integration as arterial roads, the size of superblocks decreased to an acceptable size. This intervention can be improved by additional block consolidation but since the neighbourhood already has the amenities that require large blocks (such as schools and hospitals) it was considered unnecessarily disruptive.

Mit Uqba

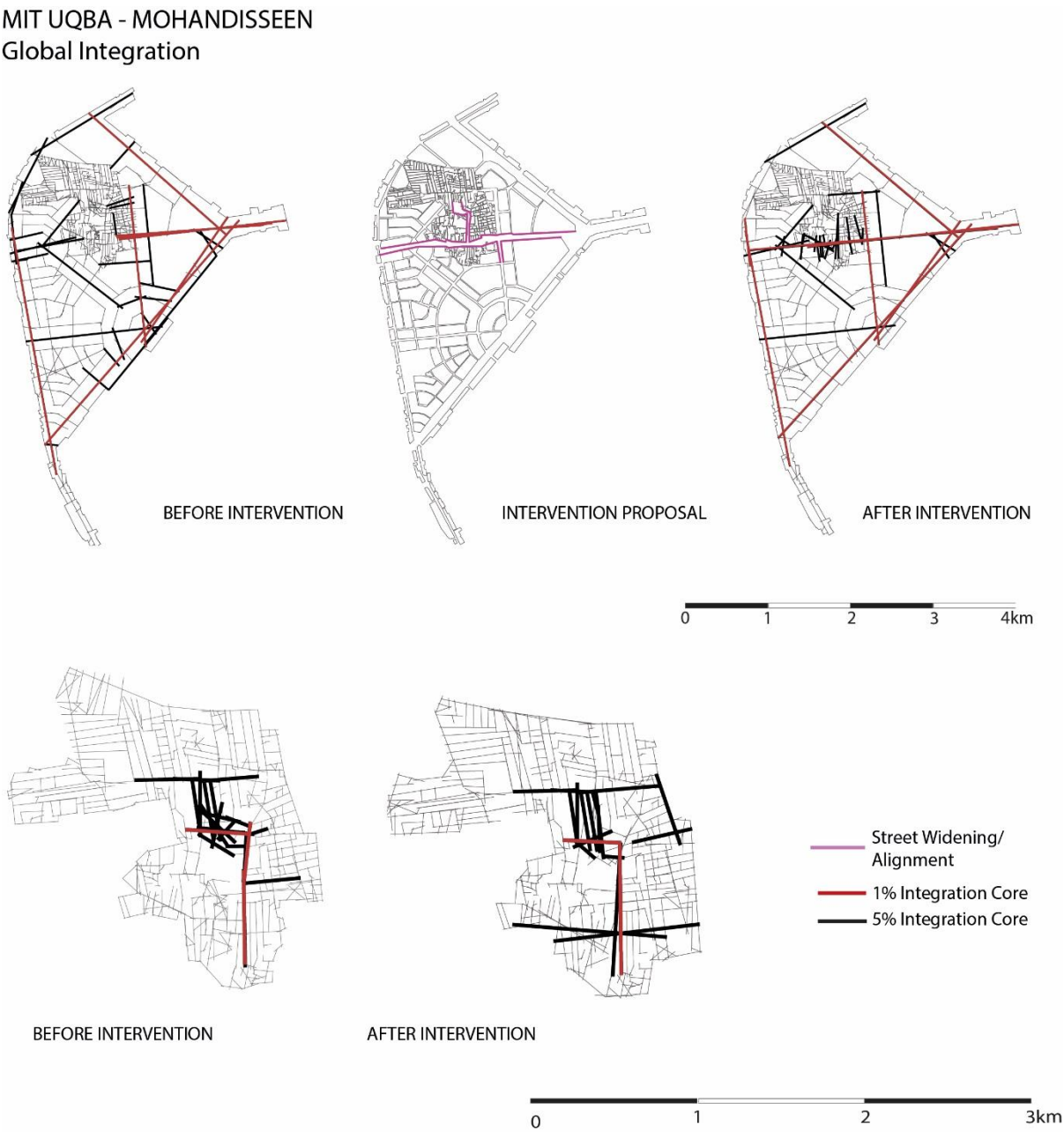

Figure 9: Mit Uqba and its surrounding planned settlement Mohandisseen before and after intervention (top) and Mit Uqba's syntactic structure before and after intervention (bottom)

As mentioned previously, Mit Uqba is a historic village that is surrounded by the planned settlement Mohandisseen. When analysed alone, Mit Uqba displays a deformed wheel syntactic structure that corresponds to real life functions. However, when analysed within the context of Mohandisseen, it is segregated from the planned settlement and has no access to the highway that could connect it to the rest of Cairo. This intervention is the most drastic out of all the proposals, it involves removing part of the settlement in order to create an access point to the highway by connecting the core of the settlement to the highway. Before the intervention, the integration core of Mohandisseen did not reach into Mit Uqba at all. After the intervention, the integration core is connected to the core of Mit Uqba, meaning that the settlement can now easily access the highway super grid that spans Cairo.

Integration values have increased slightly, but some areas of Mit Uqba remain segregated. Those areas have no direct access to the highway but they do have access to the core of Mit Uqba, and through that can access the

highway. As Mit Uqba is a very small settlement, further intervention would have resulted in the loss of too much of the urban fabric so this was considered an acceptable level of positive change.

This intervention shows the limitation of drastic interventions; while they are beneficial there is a limit to how much intervening is possible before the urban fabric starts to be negatively affected. It is more beneficial and cost effective to design a number of smaller interventions than one drastic intervention.

	Before		**After**	
	Global	Local	Global	Local
Avg	1.302	1.961	1.441	1.997
Min	0.643	0.333	0.675	0.333
Max	2.216	3.868	2.758	4.364
Std. Dev.	0.245	0.647	0.317	0.713

Table 14: Syntactic analysis for Mit Uqba before and after Intervention

4. CONCLUSIONS

4.1 Findings

This limited set of interventions has shown that in most cases, minor adjustments in the street layout can be a tool to consolidate or create the deformed wheel configuration. The creation of thoroughfares spanning from one side to the other of the settlement is the first step to create the relationship between the syntactic core of the settlement to its edges. The edges in Cairo are mainly the highway system that may require a different type of interventions: either a direct connection to the primary grid or the consolidation of the edge streets (edge rim) into boulevards acting as a transition space with the highway system. They will complete the deformed wheel configuration. It is recommended that to create the deformed wheel structure, interventions should be designed from the core outwards, first consolidating the primary street network within the neighbourhood then reconnection to the highway super grid.

Even though it has not been fully tested in this paper, block consolidation also shows promise as an intervention tool. Increasing block size is a way to make blocks more resilient over time by allowing them to accept different functions that may need a larger block area as the settlement grows. Consolidating blocks can reduce the number of streets in a system, making it less complex, potentially easier to navigate and potentially easier to reinforce the deformed wheel configuration. When using this tool, it is important to avoid making blocks too large or removing too many streets, as this will reduce connectivity and navigability and may increase pathologies in the urban fabric.

While pathologies exist in informal settlements, they can be improved through intervention plans that are based on the existing syntactic structure and urban morphology, presenting an alternative to the removal of informal settlements and the relocation of residents. Minor interventions cause an acceptable improvement in the syntactic structure and urban block measures of the settlements. It is recommended that minor interventions are developed first before resorting to more drastic interventions. Creative destruction of the urban fabric is an acceptable way to intervene in the urban fabric but further research is required to set parameters for intervention. This shows the value of space syntax and urban morphology analysis since many interventions can be tested before reaching a holistic intervention plan.

4.2 Discussion

The results above show that minor interventions are a valid way of improving urban fabric. The significance of this is that proposing a minor intervention such as widening a street may be easier for decision makers to accept, and more likely to become a reality than radically changing the urban fabric. Using the existing syntactic structure and urban block measures mean that interventions are based on the reality of the informal neighbourhood, rather than creating overarching intervention policies for all informal areas. As more data becomes available on informal settlements and classification of urban morphology becomes easier, there is more potential for interventions to be initially computer generated then developed further by designers.

There are some limitations to the methods used in this study. They have the disadvantage of not having set parameters for acceptable change, and thus designers are encouraged to use their own judgement in whether or not acceptable change has been achieved. Setting parameters could be a further avenue of research. Another limitation is that informal areas grow very quickly, so interventions may become less suitable in the time it takes for them to be implemented. The use of 2D analysis methods means that building height is not considered, but this was due to lack of data rather than a conscious methodological decision.

In this study, the proposed interventions are specific to the settlement they are designed for. Intervention strategies such as widening and alignment of roads and creating public space can be used in different contexts but must be tailored to address contextual needs. Minor physical interventions should be treated as a part of a holistic intervention plan, rather than a 'cure all' for the issues informal settlements face. The physical urban fabric forms the basis on which a holistic intervention plan is designed. Once issues in the urban fabric are addressed then other improvements can be added such as community amenities, improved infrastructure, and economic and social development programs.

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