

# A configurational morphogenesis of incremental urbanism: A comparative study of the access network transformations in informal settlements

Aminreza Iranmanesh<sup>a</sup>, Hesam Kamalipour<sup>b,\*</sup>

<sup>a</sup> Faculty of Architecture and Fine Arts, Final International University, Girne, TRNC, Via Mersin 10, Turkey

<sup>b</sup> School of Geography and Planning, Cardiff University, Cardiff CF10 3WA, UK

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## ABSTRACT

The morphologies of informal settlements constantly change as they undergo processes of incremental adaptations and transformations in relation to emerging circumstances. One of the ways to explore the underlying morphogenic processes governing such adaptations and transformations is to study the morphogenesis of informal settlement. Informal settlements can tell the story of how access networks evolve through incremental processes of change as they generally emerge and where possible become consolidated through forms of adaptations and transformations. Adopting a comparative case study research design approach, this paper explores the incremental transformations of access networks across three emerging settlements located in proximity to Abuja in Nigeria. These settlements are comparatively mapped using historic satellite images illustrating eight temporal stages between 2007 and 2021. Space Syntax is used as an analytical method to study the configurational morphogenesis of the access network with a focus on the measures of connectivity, betweenness, closeness, and intelligibility. The study shows how the flexibility of the early stages of development provides opportunities for the formation of what might be considered irregular elements in the access network. The research findings also suggest that the access network becomes less intelligible as it evolves. The locations of the main local cores of the access networks are found to remain relatively unchanged and somewhat fixed as emerging local cores come about in the newly developed areas. The spatial circumstances of the studied settlements are also found to have impacts on how the incremental adaptations and transformations generate new elements as part of the access networks. The findings of this study can inform the ways the built environment professions can engage with processes of incremental transformation by providing a better understanding of configurational morphogenesis in the context of informal urbanism.

## 1. Introduction

Informal settlements are home to roughly one billion inhabitants and the number is estimated to rise in the coming decades (UN-Habitat, 2020). The rapid growth of informal settlements as well as the critical and complex role they play in forming future cities have been highlighted in the related UN-Habitat reports (UN-Habitat, 2006, 2016, 2020, 2022). These settlements are not generally included as part of the official maps, and they often remain invisible (Dovey & Kamalipour, 2018; Kamalipour & Dovey, 2019; Robinson, 2002). How these settlements are perceived can have impacts on the related policies and actions as some may view them as an “aesthetic accomplishment” while others may consider them to be “eyesores” that are fit for demolition (Pugh, 2000: 332). The lack of official data has been the side effect of this

exclusion, making research on the topic a challenging endeavour (Myers, 2021). Informal settlements are one of the key contemporary urban challenges around the globe (see: Davis, 2006). Kellett and Napier (1995) shed light on why and how our view of informal settlements must be revised. Informal settlements can be explored as architectural productions that include examples of the creativity of underprivileged classes in adapting to modern living experiences (see: Elleh, 2014). Developing nuanced approaches to critically engage with the capacities and challenges of informal settlements and the ways they can become integrated into the broader urban environments and structures relies on a sophisticated understanding of how these settlements emerge and undergo processes of incremental transformations over time.

Informal settlements are not anomalies; they are rather settlements in the process of becoming. These settlements significantly contribute to

\* Corresponding author.

E-mail addresses: [aminreza.iranmanesh@final.edu.tr](mailto:aminreza.iranmanesh@final.edu.tr) (A. Iranmanesh), [kamalipourh@cardiff.ac.uk](mailto:kamalipourh@cardiff.ac.uk) (H. Kamalipour).

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the larger city structures (Dovey & King, 2011; Wurm & Taubenböck, 2018). The existing literature suggests that many informal settlements operate very similar to well-established urban spaces (Dovey, 2015). As such, analysing their evolution can open up new horizons in our understanding of the genesis of the urban form in the context of informal settlements. There is an emerging body of knowledge exploring the morphologies of informal settlements (Dovey & Kamalipour, 2018; Dovey & King, 2011; Jones, 2021; Kamalipour, 2016, 2017; Kamalipour & Dovey, 2018; Samper et al., 2020). There are also a number of recent studies in the existing literature that primarily focus on exploring the morphogenesis of informal settlements (Alegría & Dovey, 2022; Dovey et al., 2020; Kamalipour & Iranmanesh, 2021) and the related spatial patterns and/or rules (Jones, 2019; Kamalipour & Dovey, 2020; Suhartini & Jones, 2020). Scholars have also explored how informal settlements are being shaped by the people. The longitudinal study by Perlman (2010) in the context of *favelas* in Rio de Janeiro is one of the most notable contributions that draws on direct observation, in-depth interviews, survey questionnaires, longitudinal comparisons, and ethnographic insights. De La Hoz (2013) explores the evolution of *favela* as an architectural typology. Drawing on a case study in Brasília, Ribeiro (1997) elaborates on the relations between movement patterns and spatial layouts. Hernández García (2013) investigates how public spaces work in the context of informal settlements in Bogotá with a focus on their production, transformation, meaning, and the relationship between people and place. In a recent study, Pojani (2021) deploys a framework, which takes into account the context, settlement, house, dwellers, and the process of formation and transformation to explore informal settlements in the context of the Western Balkans. Drawing on semi-structured interviews and historical urban mappings, Samper (2017) explores the growth of informal settlements in relation to governance structures and social networks in the context of Medellín, Colombia. The systematic spatio-temporal documentation of the Earth's surface within the past two decades coupled with the ever-increasing growth of informal settlements in the Global South provides an unprecedented opportunity to explore the underlying patterns that generate urban spaces across different contexts. Providing a better understanding of the underlying structures of complexities inherent in urban forms would help to approach urban design and planning strategies to become more adaptive and human-centric (Alexander et al., 1977).

This study is an early attempt to explore the configurational morphogenesis of emerging settlements. The significance of the study lies in its potential contributions to the relevant planning and policy-making processes that are often ignorant of the generative capacity of informal urban forms (Lombard, 2014). The study first explores the existing literature concerning forms of urban informality with a focus on the morphology and morphogenesis of informal settlements. It will then analyse the configurational development of three case studies within a time span of about 14 years (2007–2021) at two-year intervals. The availability of satellite images for the selected case studies at regular intervals has provided an opportunity for exploring the genesis of the urban form starting with actual tangible evidence illustrating the step-by-step evolution of the access network in the context of emerging settlements. A systematic spatio-temporal mapping using Geographic Information System (GIS) via the QGIS platform and Space Syntax analysis is used to explore the morphogenesis of incremental urbanism. The primary focus of this study is on investigating the access network transformations across multiple case studies as the patterns of access networks can spatially establish the framework for a range of other aspects or dimensions of urban design (Marshall, 2005: 251). This paper aims to contribute to the relevant body of knowledge and inform the ways the built environment professions can engage with informal settlements by providing a better understanding of the configurational patterns of incremental development and how the access network transformations play out in informal settlements. The key objectives of this paper include tracking the change of certain Space Syntax measures

(i.e., connectivity, closeness, betweenness, and intelligibility), mapping the development of the local cores of the studied settlements over time, and exploring the predictability of the latest stages of the access network by the features of the early stages.

It is important to note that the study has certain limitations regarding its methodology and scope. The configurational approach used for the analysis might be rather limited in reflecting the actual space as experienced by people. The limited availability of data in the studied region further restricts the extent of the analysis. While the study adopts a comparative approach, it only explores three case studies. It is therefore critical to avoid overgeneralisation of the related findings to other cases and contexts beyond the studied settlements. The intrinsic complexities of the concept of urban informality make any analytical exploration challenging. Ground truthing and deploying other methods, such as direct field observations and qualitative interviews with local residents and/or practitioners, are among the key research limitations. While the study adopts a consistent analytical approach that primarily focuses on exploring the access network transformations, it is also important to note that there might be other influential variables, such as topography, resources, and land ownership, influencing the formation and transformation of the access network. Exploring the underlying socio-political and socio-cultural contexts remains a limitation of this study and a task for future research.

## 2. Urban informality and forms of informal settlement

The transformational processes of urban physical form have traditionally been explored in the field of urban morphology (Conzen, 1960; Kostof et al., 1999). Forms of informal settlement, including their morphologies and incremental adaptations, have not been sufficiently addressed in the related literature although they are home to about one billion people worldwide (UN-Habitat, 2020). Urban informality is a complex concept that is rather difficult to define. AlSayyad (2004) refers to urban informality as a way of life and Roy (2015) presents it as a mode of space regulation and production. For Simone (2009), it incorporates a capacity to enable interaction beyond regulatory frameworks. Forms of urban informality can be broadly understood as a range of activities that generally take place beyond, yet in relation to, state control (Dovey, 2012; Kamalipour, 2022). In this context, the term “informal” can incorporate the bottom-up, generative, and self-organised production of urban space. This process might render various outcomes depending on the contextual circumstances (such as slums) (Dovey, 2019). These incremental processes blur the boundaries between formal and informal, generating functional parts of urban form in the process (Hernández García, 2013; Martin, 2015).

Many cities of the Global South have been facing the challenges of rapid expansion and the integration of informal settlements into urban areas (UN-Habitat, 2016). Much of the existing literature on informal settlements has focused on governance (Amin & Cirolia, 2018; Suhartini & Jones, 2019) and policy and political economy (Pugh, 2000; Zhang, 2011), among others, mainly engaging with larger planning issues (Roy, 2005). Valorising the macro scale over the micro has left the creative generative processes that form and transform the morphologies of informal settlements understudied (Kamalipour, 2022). Despite limited resources, the architecture of underprivileged inhabitants can be considered spontaneous and dynamic (Elleh, 2011: 73). While most informal settlements are considered permanent, little is known about their emergence and incremental transformations (Kamalipour & Dovey, 2020). There is only an emerging body of knowledge that goes beyond addressing the living conditions, segregation, and inequity to investigate the incremental adaptations of informal settlements and/or the associated generative codes or rules (Alegría & Dovey, 2022; Dovey et al., 2020; Jones, 2019; Kamalipour, 2020, 2023; Kamalipour & Dovey, 2020; Kamalipour & Iranmanesh, 2021; Samper et al., 2020; Suhartini & Jones, 2020). Any intervention, planning, or policy concerning the improvement of informal settlements can be most effective

when it is in balance with the self-organising nature of development that shapes them in the first place (Pugh, 2000; Silva & Farrall, 2016). The bottom-up and generative processes shaping urban forms are often the result of a range of micro-scale incremental transformations. Exploring the ways these incremental adaptations work provides insight into how urban space is being generated through informal processes.

Informal settlements initially come about out of necessities related to safety and shelter (Habraken, 1998) through incremental and generative self-organising processes (Kamalipour, 2016; Silva & Farrall, 2016). At the core of most urban structures exists an underlying historic informality resulting from a series of micro-scale adaptations (Dovey, 2012). Somewhat similar processes are at play today, forming what would become the future of many cities in the Global South (AlSaiyad, 2004). Nevertheless, it is important to note that forms of informality are not necessarily limited to what is considered the Global South (Arefi & Kickert, 2019; Kamalipour & Peimani, 2021; Roy, 2005). Even the most formal settlements are subject to incremental processes of change that incorporate a degree of informality. This paper primarily engages with exploring the spatiality of what Bayat (1997: 33) refers to as “the quiet encroachment of the ordinary” with a focus on the incremental adaptations and transformations of emerging settlements in the context of the Global South.

Informal settlements are composed of a multitude of complex and interconnected layers, enabling a range of incremental adaptations that can transform the built environment in relation to emerging circumstances. While exploring complexity and self-organisation has been a central theme in urban studies (Alexander, 1965; Batty, 2005; Jacobs, 1961; Portugali, 2000; Portugali et al., 2012), the emergence of informal settlements, their incremental transformations, and the associated generative rules and processes could benefit from more investigations. As Pojani (2019) argues, there is a need for more studies to draw a more comprehensive image of the generative capacities of informal settlements. This study aims to provide a better understanding of the spatial complexities of the ways urban forms emerge and change in informal settlements. This is not to advocate for the existence of a universal pattern, but rather, an advancement of the current understanding of the morphogenesis of informal settlements. This is an emerging approach due to the availability of regular scanning of the Earth’s surface within the past two decades, which has coincided with the rapid expansion of informal settlements in the Global South cities.

### 3. Space syntax as a configurational approach

The study uses Space Syntax analysis to explore the configurational morphogenesis of informal settlement across multiple case studies. Space Syntax is a set of configurational analytical methods and theories that explore spatial structures based on how their fundamental components interact with each other and in relation to the whole network (Hillier, 1996b; Hillier & Hanson, 1984). These fundamental components are based on the function of perception and movement in what Gibson (1979) calls the “field of affordance”. In urban studies, this field is represented on an axial map derived from all convex spaces using the longest line of sight where movement is possible (Liu & Jiang, 2012). The method, in general, is an analytical approach that explores the relationship between social and spatial structures using the fundamental properties of space and network. Space Syntax explores the spatial manifestation of the collective interaction between people and space (Karimi, 2012). In this perspective, the spatial configuration of cities is not a mere outcome – or a background – of social processes, but rather a continuous feedback loop between society and space, each reflecting the other (Hillier, 2014). So far, the use of Space Syntax in exploring the configurational aspects of Nigerian cities has been limited. The most notable examples are related to the distribution of land use in Abuja by Ahmed (2019) and neighbourhood walking behaviour in Akure by Alabi (2021).

Space Syntax analyses come in different variations such as

topological (Hillier, 1999b), angular (Hillier, 2012), and Euclidian metric centralities (Wang et al., 2014), all of which, have shown promising results in exploring socio-spatial and socio-economic aspects of urban form. Among them, the Space Syntax measures of angular integration (closeness) and angular choice (betweenness) have shown the strongest results in predicting the collective movement of people (Sharmin & Kamruzzaman, 2018). It must be noted that these processes are not bidirectional, they represent an ongoing feedback cycle between the social content and the spatial grid that forms, reforms, adapts, and evolves new spatialities over time as an ongoing process (Hillier, 2012; Kim & Sohn, 2002; Penn & Turner, 2004). This is one of the main propositions of Space Syntax indicating that space is not a background for human activities but rather an intrinsic aspect of it (Hillier & Vaughan, 2007). Moreover, this approach explores how the spatial structure works as a whole, indicating that network elements cannot be explored in isolation and must be seen within the framework of their interconnected relations (Karimi, 2012).

#### 3.1. Space syntax and incremental urbanism

For this study, Space Syntax provides a systematic analysis of the fundamental properties of the network of spaces and their connections to one another as a whole. Longitudinal studies using Space Syntax analysis has precedent in the related literature in cases such as Santiago by Greene (2003), Limassol by Geddes (2020), informal settlements of Manila by Cutini et al. (2019), urban transformation of Dhaka by Ahmed et al. (2014), configurational characteristics of informal settlements in Cairo (Mohamed, 2016; Mohamed et al., 2022; Mohamed & van Ham, 2022), and the growth of Manhattan and Barcelona by Al-Sayed et al. (2012), to name a few. Mills (1992) highlights the effectiveness of this method in revealing the emerging socio-spatial patterns in informal residential spaces in Cape Town. According to Karimi and Parham (2012), Space Syntax methodology offers objective analytical insights into the exploration of informal settlements, which can effectively inform planning and policymaking aimed at addressing the challenges posed by the burgeoning informal settlements. Vasku (2013) argues that analysing the street access network through configurational exploration can serve as a valuable approach for effectively integrating informal settlements into the larger urban context. A notable example is a study by Hillier et al. (2000) on the incremental development of informal settlements that grow in relation to the larger urban network of Santiago. Their analysis indicates the influence of the city on the evolution of emerging informal settlements. It has been argued that the spatial layouts and locations of informal settlements can play a significant role in their consolidation (Hillier et al., 2000). Nevertheless, the generative processes that have formed cities from the very original core to the larger complex spatial structure remain understudied in the literature. This is often due to a lack of reliable data that can effectively represent the incremental adaptations of the access network. The integration of Space Syntax into this study is particularly significant because many of the original propositions of Space Syntax are based on the bottom-up incremental local processes that form the eventual larger grids of cities (Griffiths, 2012; Hillier, 1996b; Hillier et al., 2000). Space Syntax considers the network of spaces as an interconnected entity, rejecting the idea that parts of the grid can be understood in isolation (Hillier & Vaughan, 2007; Karimi, 2012). This presupposition makes the method suitable for exploring the incremental evolution of the access network as a whole.

### 4. Research design and methods

This study undertakes a systematic mapping of emerging settlements at various stages of their formation and transformation by drawing on three case studies in Nigeria. Fig. 1 illustrates the research design, including the methodological process of the study. The data collection was conducted using historic satellite images from the Google Earth

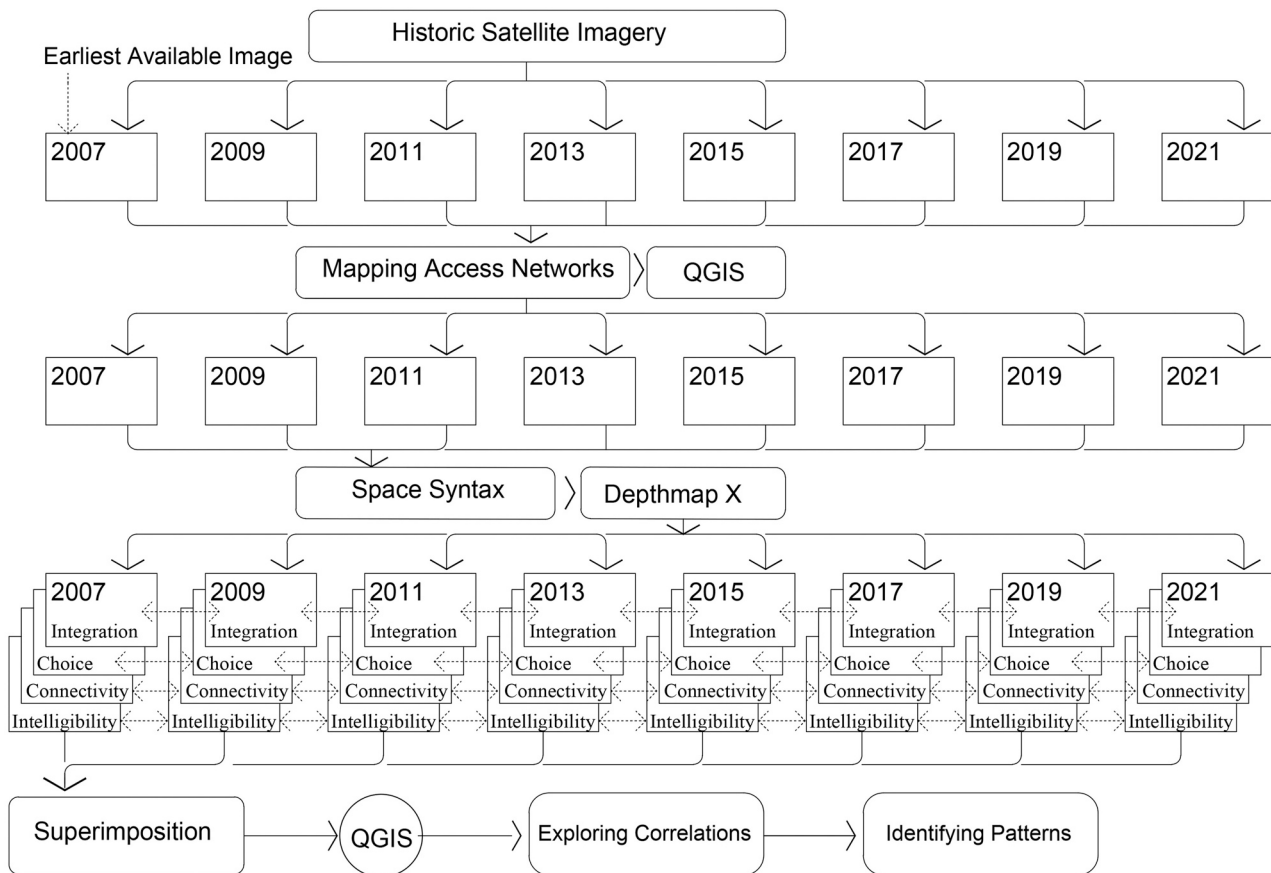


Fig. 1. The research design, including the methodological process of the study.

database. A multi-layered database of superimposed satellite images with consistent time intervals was produced and further analysed through mapping within the Geographic Information System (GIS) environment. Urban mapping techniques include the documentation of the incremental transformations of access networks in the selected settlements (see: [Pinho & Oliveira, 2009](#)). Mapping informal settlements using historic satellite images has shown promising results in relation to reading, classifying, and systematically analysing informal settlements ([Dovey & Kamalipour, 2018](#); [Kuffer et al., 2016](#); [Samper et al., 2020](#)). Urban mapping is used to generate spatial knowledge by analysing morphological patterns and emerging typologies ([Dovey et al., 2018](#); [Kamalipour, 2017](#); [Kamalipour & Iranmanesh, 2021](#)).

Space Syntax analyses were conducted using the Depthmap X application ([DepthmapX development team, 2017](#)). The study uses the original axial map proposed by [Hillier and Hanson \(1984\)](#) for three reasons. First, the majority of paths that emerged in the initial nuclei of the studied settlements are extant as footpaths and informal connections that are flexible in nature. Here, it is not possible to conceptualise a road-centre line. Second, no sidewalks or spatial restrictions (including topography) were observed, accordingly, the longest lines of sight – with the possibility of movement – were mapped. Third, due to the small scale of the network, the mean axial length remains relatively low and permeable (mean segment length = 27.4 m, mean axial length = 114.2 m).

4.1. Case studies

Nigeria has faced a rapid process of urbanisation in the past few decades. As a result, its urban centres have faced an overflow of population from rural areas ([Obi-Ani & Isiani, 2020](#)). To achieve future sustainable urban development in the region, it is critical to integrate

informal settlements into planning, as noted by [Awuah and Booth \(2020\)](#). The area around Abuja, the planned capital of Nigeria, is home to numerous settlements that have exploded in size during the past 20 years. The result of this rapid expansion has created many emerging satellite nuclei around the city which used to be predominantly small rural settlements ([Gumel et al., 2020](#); [Zubair et al., 2015](#)). The initial plan of the city covered “845 pre-existing indigenous settlements”, many of which were completely eradicated, and a few remain amalgamated within the new urban fabric ([Myers, 2011](#): 63). However, the rapid movement flows toward the new capital have been associated with an influx of informal development. Since the construction of residential units – as designed in the related masterplan – could not keep up with the rate at which people moved to the city, large informal dwellings have emerged in the periphery and over time extended to small villages in the outskirts of the city ([Abubakar, 2014](#); [Myers, 2011](#)). Exploring the emerging settlements around Abuja can provide insights into how the related access networks have emerged and evolved over time.

In line with the aim and scope of this study, multiple locations were considered in the process of case study selection. Among the myriad of settlements around Abuja, 12 potential settlements were initially selected as they met the related case study selection criteria, which primarily included the availability of clear satellite images (from 2007 to 2021 at two-year intervals) and the sequential detectability of spatial transformations (from an initial core to an evolved settlement within the timeframe of the study). We then narrowed down these potential cases to a total of three settlements using a deductive approach. The aim was to minimise the impacts of other influential factors so that the focus of the study would be more on the configurational dimension. As such, other cases were excluded due to their topography, close proximity to other consolidated large urban settlements, and/or limited growth during the study timeframe (2007–2021). Finally, the villages of Gbessa



(Case 1: 8°55'55.47"N, 7°15'19.54"E), Iddo Sabo (Case 2: 8°57'40.64"N, 7°13'46.28"E), and Waru (Case 3: 8°55'35.87"N, 7°29'17.61"E) were selected. Fig. 2 shows the location of the selected case studies. The three selected settlements show different relations to the main roads nearby: Case 1 is relatively far away, case 2 is relatively close, and case 3 envelopes the road over time. All three settlements initially emerged as relatively small local cores in 2007 and have significantly expanded thereafter (Fig. 3).

## 5. Analysis and results

Adopting a comparative approach, this section presents the key results of the study in relation to the analysis of connectivity, integration, choice, the configurational evolution of the core, and intelligibility across the selected case studies.

### 5.1. Connectivity

The study analyses connectivity based on axial and angular measures. The axial connectivity represents the number of associated spaces with each line of movement. Angular connectivity, first introduced by Turner (2001), measures the value of a connection according to its relative angle with an intersecting axis. Fig. 4 shows the mean value for both measures 2007–2021. Overall, a gradual increase in angular connectivity is observable in all cases. This indicates two points: first, the average number of paths intersecting with each junction has slightly increased over time, and second, there is a slight decline in the number of irregular wide-angle intersections in the access network. This trend is more visible in case 2, which is the smallest settlement and has undergone the most significant expansion relative to its initial size. In case 3, which is located near the main road, there is less fluctuation in angular connectivity although a slight, gradual increase can still be identified. Case 1 shows a significant increase in the earlier periods when rapid expansion of the network takes place. The axial connectivity seems to be associated with the expansion of the settlements. For instance, case 1 shows a significant expansion between 2009 and 2011, which indicates

the emergence of long axes of movement at the stage before they are broken into smaller segments.

### 5.2. Integration

Integration (also known as “to-movement”) is a measure of closeness, representing the potential accessibility of each space from all other parts of the grid (origin-destinations). Integration is interlinked with fundamental Space Syntax ideas such as the notions of “natural movement” (Hillier et al., 1993) and cities as “movement economies” (Hillier, 1996a). Integration is reported to be closely associated with potential co-presence in urban spaces, thereby generating spaces that are pedestrian destinations (Baran et al., 2008; Law et al., 2012; Read, 1999). Spaces with a relatively higher degree of integration tend to become more frequently used and develop a central role in the network over time.

The analysis of integration is comparatively undertaken on the related axial maps across the selected case studies (Fig. 5). Regarding the integration value of the studied settlements over time, it is evident that the overall location of the core remains relatively unchanged, but its form changes and evolves. Case 1 is the most established settlement among the three in 2007. Its distance from the main road and other settlements makes its growth relatively uninterrupted by external access elements and closer to what Hillier (1996b) described as the “deformed wheel”. In this case, the approximate location of the centre of the integration core remains relatively unchanged as it branches out making connections with emerging parts of the network. Case 2 is the smallest in 2007 and faces a slight shift in its integration core. The introduction of a new connection to the main road in 2017 has changed the configuration of the network, this change becomes more dominant in the following stages as the new connection finds a more central role (2019–2021). Case 3 evolves with the road. As a result, the integration core slowly shifts toward the main road as the network makes more connections with the main road.

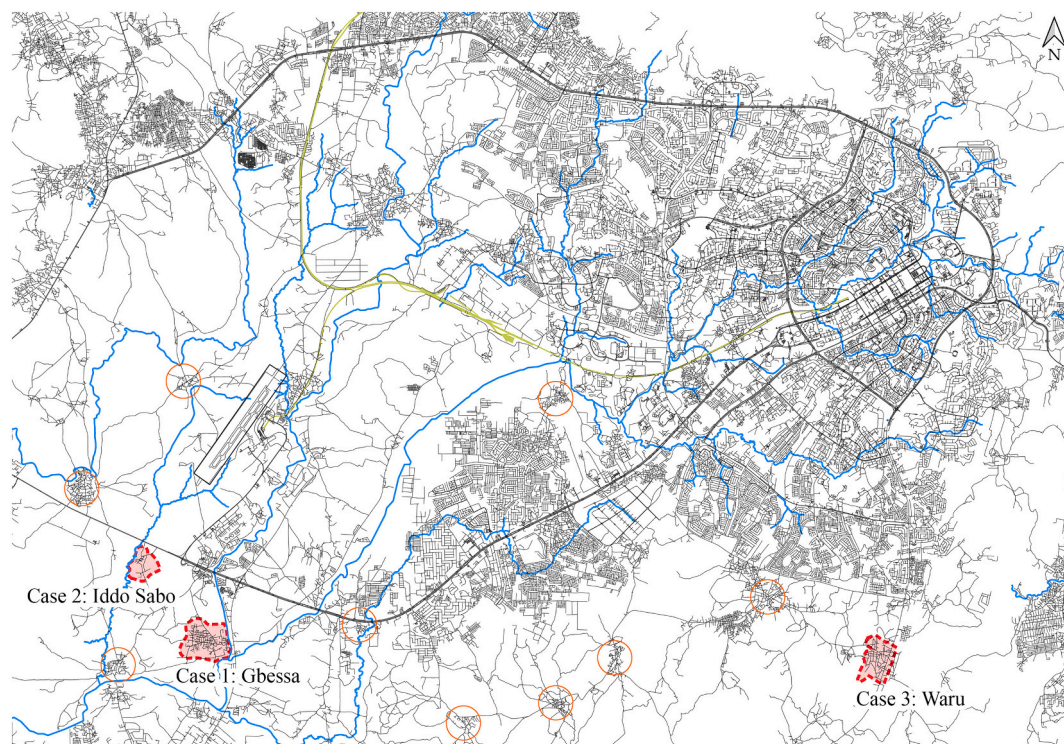


Fig. 2. The location of the selected case studies near Abuja. GIS data sourced from OpenStreetMap.

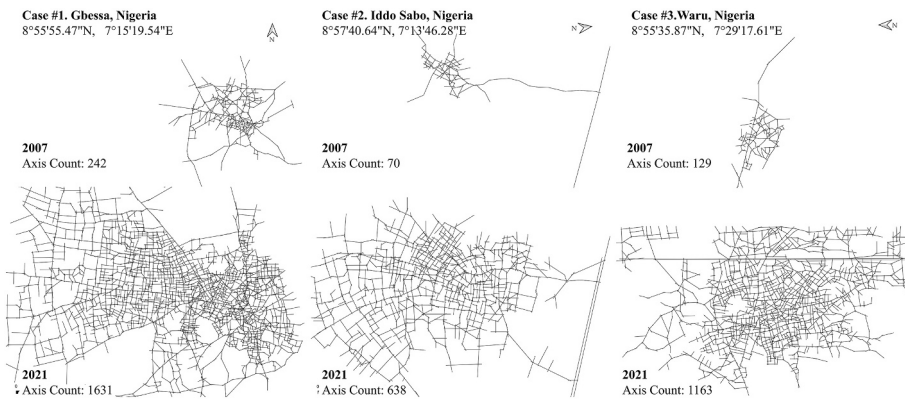


Fig. 3. The axial maps of the selected case studies 2007–2021.

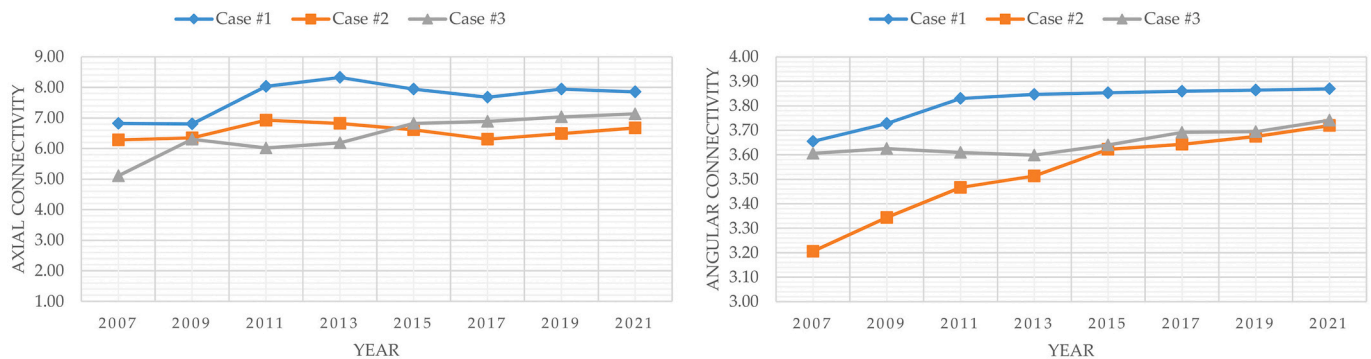


Fig. 4. The axial connectivity (left) and angular connectivity (right) 2007–2021.

5.3. Choice

Choice (also known as “through-movement”) is an analytical representation of betweenness in a spatial network. Considering all possible movements within a network, the choice is the rate of recurrence of each space as a passage. Choice indicates the efficiency of each space as a vessel of movement (Hillier, 2012). It is also shown to be a better predictor of longer movement (Hillier & Iida, 2005).

The evolution of the core is further analysed in terms of the choice value. The study made the assumption that the initial axis with a high choice value might provide clues into the structural direction toward which the network core would expand over time (see: Hillier et al., 2012). The betweenness core (axes with the highest choice value) often highlights the foreground spaces. These lines can provide insight into the expansion direction of the integration core. The choice core remains the same in cases 1 and 3 over the analysed period, but in case 2, the addition of a further access to the main road changes the betweenness dynamic (Fig. 6).

5.4. The configurational evolution of the core

The evolution of the network core was analysed in two steps. First, the highest values of integration and choice were isolated for each step, following the method proposed by Hillier (1999a), as shown in Fig. 7. Second, linear correlation analysis was performed between all temporal stages (Tables 1 & 2).

The first step of the analysis shows the evolution of integration and choice cores over time. These outcomes are in line with the original observations made by Hillier (1999a) where the global integration (in 2021) starts to resemble the “deformed wheel” and “spiked potato” (Fig. 7). It is evident that the global core has maintained its central spatial location but has expanded toward lines with higher choice

values. The analysis shows a significant correlation between the original integration properties in 2007 and 2021 even though the networks had grown approximately 300 % in size.

The relationship between the network and the main road seems to be highly influential in how the network evolves. The formation of the “deformed wheel” is most notable in case 1 where the settlement is not highly influenced by the road. The transformation of the core in cases 2 and 3 is significantly oriented toward the main road. In case 3, the development of the settlement seems to be more dependent on the main road as an access network element. It is noticeable in Fig. 7 that only in case 3 the main road becomes a significant part of both the integration and the choice core of the settlement after 2013.

In the second stage of the analysis of the network core, and in order to explore the progression of Space Syntax over the eight temporal stages, a heat map was created for each stage. All heat maps were superimposed, and a linear correlation was performed using QGIS. The objective of this analysis is to determine to what extent each stage can be predicted by the properties of its predecessor (Tables 1 & 2).

Among all the correlations shown in Tables 1 and 2, local integration at radius-2 shows the highest relative stability as the network expands. The analysis indicates that the local cores are less likely to change — notwithstanding the formation of new local cores, which is probably associated with the decline in correlations. This phenomenon is also present for local choice measures at relatively similar strength. Most stages show high degree of similarity with their immediate following stages. The exception is in the earliest stages where the paths are more flexible (e.g., more footpaths and shortcuts) and the correlation between consecutive stages is relatively weaker. For instance, the correlation between 2007 and 2009 is the lowest among all cases (considering consecutive stages), but it gradually increases approaching 2017, 2019, and 2021.



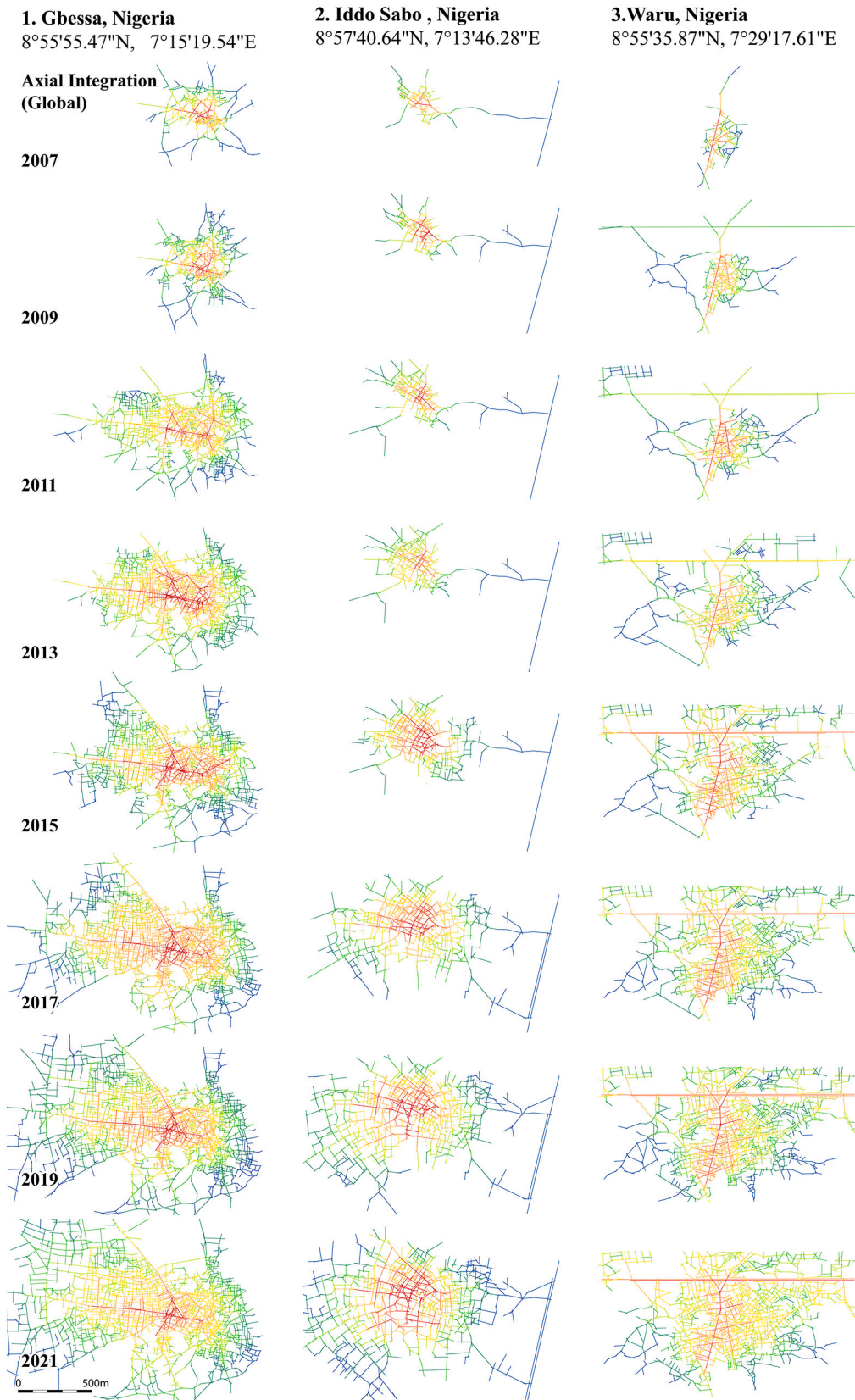


Fig. 5. The global integration on the axial maps (radius-n) 2007–2021.

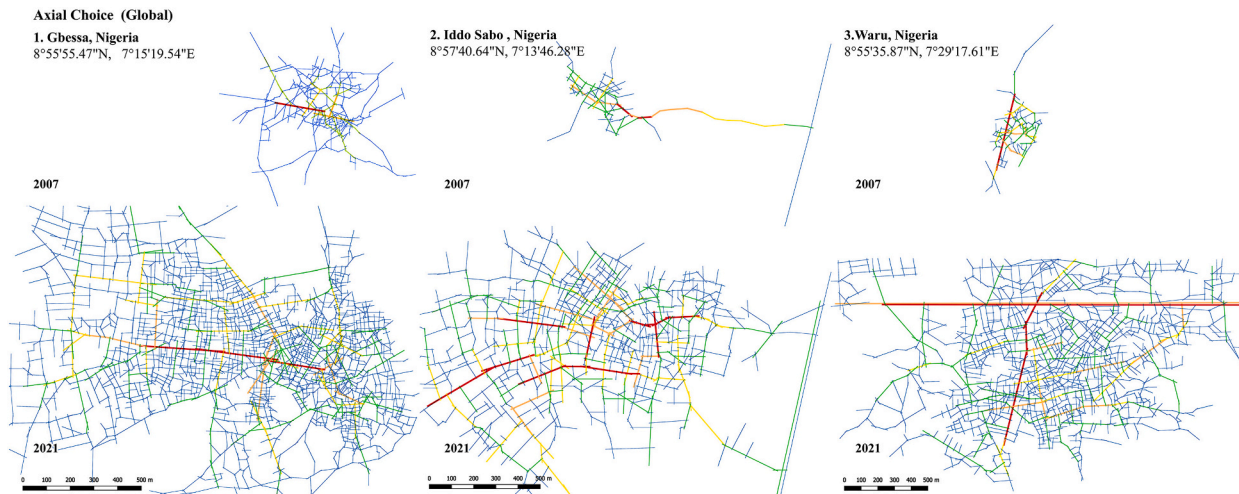


Fig. 6. The axial global choice (global at radius-n) 2007–2021.

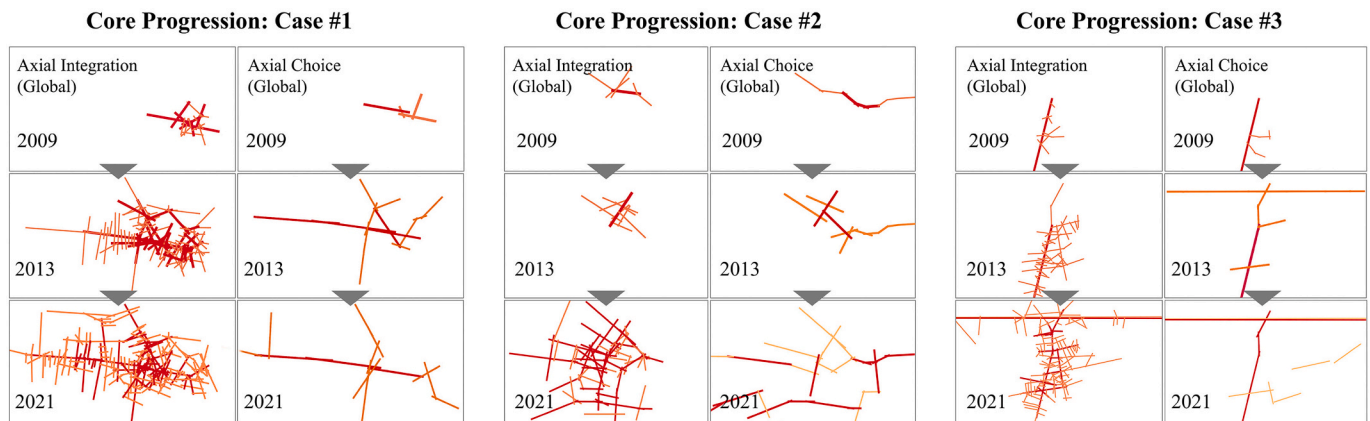


Fig. 7. The evolution of the integration and choice cores.

### 5.5. Intelligibility

Intelligibility in Space Syntax literature is regarded as the statistical correlation between global integration and connectivity of the axial element (Bafna, 2003). Intelligibility expresses the degree to which the network as a whole can be understood from the visible attributes of local elements (Hillier et al., 1986; Hillier et al., 1993). Here, intelligibility is represented as the correlation coefficient between axial integration and connectivity, which describes how much the larger network can be understood from its local component. The results indicate that as the network grows, intelligibility decreases (Fig. 8). The natural side effect of rapid expansion is the introduction of long lines of movement. Hence, in each iteration, there exist axes with high connectivity that are not yet a part of the integration core.

The incremental changes in the correlation between local and global cores are further analysed (Fig. 9). This step in the analysis follows the guideline set by Hillier (1999a). The analysis tries to show the potential formation of additional local cores outside the main core as the network expands. The local measurement here has been conducted on the axial map (radius-2) for both integration and choice. In all three cases, the similarity between local and global cores is high in the initial stages of development, but it is evident that the correlation between local and global cores gradually declines (Fig. 9). This is in line with intelligibility results (Fig. 8). The decline is present both for integration and choice, but it is more prominent for choice, and it highlights the contextual differences between the cases (see: Hillier et al., 2012). Case 3, which is

divided by the main road, shows the most rapid decline, it is evident that having an additional long axis cutting through the network has made that line a strong central line (particularly as an in-between space). It must be noted that the global core often remains a local core too, the decline here can be associated with the emergence of new local cores.

### 6. Discussion

This study has primarily explored the configurational morphogenesis of the access network with a focus on the measures of connectivity, betweenness, closeness, and intelligibility across three settlements located in proximity to Abuja in Nigeria. In comparison with traditional vernacular settlements, informal settlements have generally emerged and grown in the context of significant uncertainty and rapid change (Kellett, 2011; Kellett & Napier, 1995). When planning for the future of informal settlements, it is important to take into consideration the formation and transformation of these settlements. This study contributes to an emerging body of knowledge exploring the morphogenesis of informal settlements. The aim has been to provide a better understanding of how emerging settlements are being shaped by adopting a comparative approach and using Space Syntax as an analytical method. One of the main premises of Space Syntax in this regard is the fact that it considers all spaces as a whole and in relationship with other spaces. As such, no parts of the access network can be fully understood in isolation in this approach (Hillier & Vaughan, 2007).

The outcome of this study indicates that in the earliest stages of



**Table 1**  
Correlation coefficient between periodical global integration (left) and global choice (right).

		Correlation coefficient between global integration at different periods								Correlation coefficient between global choice at different periods.								
		Years	2009	2011	2013	2015	2017	2019	2021	Years	2009	2011	2013	2015	2017	2019	2021	
Case #1	2007		0.81	0.63	0.56	0.59	0.56	0.56	0.55	2007		0.79	0.66	0.55	0.47	0.39	0.4	0.4
	2009			0.75	0.65	0.67	0.64	0.63	0.63	2009			0.72	0.58	0.53	0.44	0.43	0.43
	2011				0.93	0.87	0.77	0.72	0.71	2011				0.95	0.86	0.73	0.6	0.59
	2013					0.92	0.83	0.78	0.76	2013					0.88	0.8	0.69	0.66
	2015						0.92	0.87	0.85	2015						0.9	0.74	0.79
	2017							0.93	0.9	2017							0.82	0.86
	2019								0.95	2019								0.9
	2021									2021								
Case #2	2007		0.84	0.81	0.72	0.57	0.45	0.35	0.37	2007		0.75	0.83	0.79	0.63	0.36	0.22	0.25
	2009			0.89	0.81	0.68	0.53	0.42	0.4	2009			0.9	0.84	0.74	0.37	0.24	0.29
	2011				0.9	0.71	0.51	0.37	0.38	2011				0.94	0.75	0.35	0.2	0.36
	2013					0.85	0.64	0.48	0.44	2013					0.82	0.44	0.26	0.43
	2015						0.85	0.68	0.67	2015						0.61	0.41	0.58
	2017							0.87	0.86	2017							0.86	0.81
	2019								0.96	2019								0.9
	2021									2021								
Case #3	2007		0.79	0.7	0.6	0.51	0.44	0.34	0.32	2007		0.72	0.65	0.56	0.34	0.37	0.32	0.43
	2009			0.85	0.72	0.55	0.49	0.39	0.41	2009			0.84	0.73	0.56	0.54	0.46	0.46
	2011				0.88	0.71	0.65	0.54	0.54	2011				0.86	0.68	0.67	0.59	0.57
	2013					0.84	0.77	0.66	0.67	2013					0.85	0.84	0.75	0.67
	2015						0.94	0.84	0.85	2015						0.98	0.91	0.79
	2017							0.92	0.93	2017							0.94	0.81
	2019								0.97	2019								0.88
	2021									2021								

**Table 2**  
Correlation coefficient between periodical local integration (left) and local choice (right).

		Correlation coefficient between local integration (r2) at different periods.								Correlation coefficient between local choice (r2) at different periods.								
		Years	2009	2011	2013	2015	2017	2019	2021	Years	2009	2011	2013	2015	2017	2019	2021	
Case #1	2007		0.83	0.66	0.58	0.65	0.62	0.63	0.62	2007		0.83	0.66	0.59	0.66	0.64	0.62	0.51
	2009			0.81	0.68	0.76	0.74	0.74	0.7	2009			0.81	0.67	0.76	0.76	0.75	0.74
	2011				0.93	0.93	0.87	0.83	0.78	2011				0.92	0.93	0.9	0.86	0.84
	2013					0.92	0.9	0.86	0.83	2013					0.92	0.92	0.88	0.85
	2015						0.95	0.94	0.88	2015						0.95	0.94	0.92
	2017							0.96	0.91	2017							0.96	0.95
	2019								0.92	2019								0.96
	2021									2021								
Case #2	2007		0.84	0.83	0.79	0.67	0.57	0.44	0.53	2007		0.8	0.83	0.78	0.66	0.55	0.43	0.47
	2009			0.87	0.81	0.74	0.64	0.55	0.6	2009			0.85	0.78	0.71	0.62	0.54	0.59
	2011				0.94	0.79	0.62	0.46	0.58	2011				0.96	0.79	0.63	0.47	0.61
	2013					0.9	0.74	0.57	0.63	2013					0.88	0.71	0.55	0.58
	2015						0.91	0.76	0.75	2015						0.91	0.77	0.78
	2017							0.91	0.85	2017							0.93	0.84
	2019								0.91	2019								0.86
	2021									2021								
Case #3	2007		0.86	0.82	0.79	0.71	0.61	0.5	0.39	2007		0.83	0.79	0.76	0.64	0.53	0.42	0.29
	2009			0.93	0.84	0.71	0.58	0.47	0.44	2009			0.94	0.84	0.76	0.58	0.43	0.33
	2011				0.94	0.84	0.73	0.62	0.6	2011				0.93	0.86	0.7	0.56	0.41
	2013					0.93	0.85	0.73	0.74	2013					0.94	0.83	0.67	0.51
	2015						0.94	0.85	0.86	2015						0.9	0.76	0.62
	2017							0.93	0.91	2017							0.91	0.7
	2019								0.97	2019								0.88
	2021									2021								

settlement, the primary movements are often shortcuts connecting various points. As the settlements become more consolidated, the spatial affordances for the emergence of shortcuts become less. Consequently, the formality of the grid overpowers the informal qualities of the initial structure. This can be considered as an incremental striation of the access network where hierarchical structures become more established, and the initial spatial flexibilities become less pronounced. Drawing on

Alexander (1965), this can also be considered as a process through which the access network becomes less of a semi-lattice and more of a tree-like structure. The range of spatial possibilities for the emergence of new elements is likely to become limited as the access network evolves and becomes more consolidated. This is further supported by the gradual increase in angular connectivity as the settlements expand. The slight gradual increase in angular connectivity is in line with the findings of

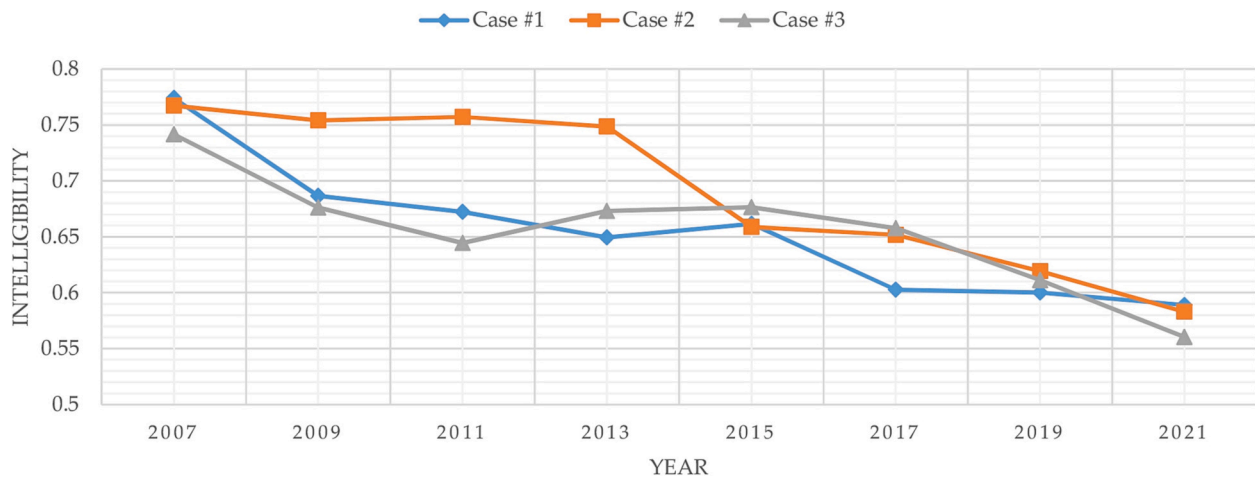


Fig. 8. Intelligibility is represented as the correlation coefficient between axial integration and connectivity.

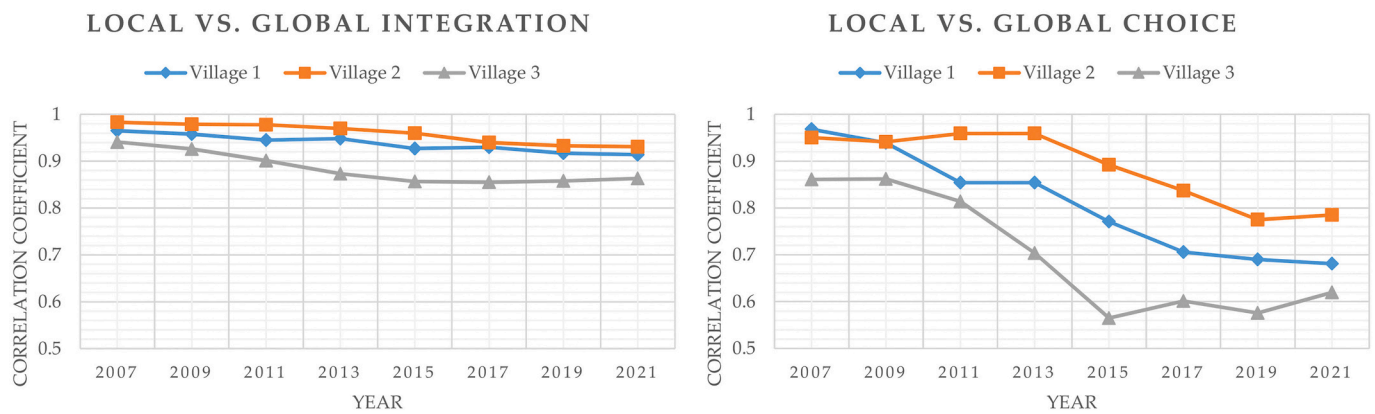


Fig. 9. The incremental changes in the correlation between local and global measures.

Kamalipour and Iranmanesh (2021), which show a decrease in the number of Y-shaped junctions as the network grows. By cross-referencing the related stages to provide insight into these transformations (Tables 1 and 2), it can be argued that in the earlier stages of settlement, the network is more flexible than its successors. This is most likely enabled by the flexibility provided by empty spaces that facilitated the possibility of emerging elements, which slowly declines over time.

These findings are also supported by the analysis regarding the intelligibility of the network. The readability of the larger structures through local measures declines as the network grows and becomes more regular. The intelligibility of the network significantly declines over time. This was further tested by exploring the correlation between local and global analysis for each stage, showing a slow decline as new local cores emerge over time. These phenomena can be annotated in the relational approach between what Hillier (2012: 26) calls “the dual city” consisting of a set of foreground and background access network elements. The foreground spaces are progressive; they are the vessels of the micro-economy and the engines of urban development. These spaces are highly integrated with other areas and are often central to the network (Mohamed & van Ham, 2022). This is a phenomenon also noted in studies on informal settlements (see: Mohamed, 2016; Mohamed & van Ham, 2022). On the other hand, the background spaces mainly consist of residential life (see: Hillier, 2012). This is further supported here when comparing the integration and choice core. Choice core highlighting the foreground spaces indicates the directional transformation of the core and is changed by the introduction of new axes more than the integration core. As shown in this paper, Space Syntax can provide an informed reading of bottom-up processes that generate urban spaces (also see:

Mohamed et al., 2022). A study by Al-Sayed et al. (2012) has shown the “choice” to be the best predictor of urban growth direction. It has also been argued that axes with relatively higher choice values are more resilient and less prone to removal/alteration. This study shows similar findings in cases 1 and 3 where the through-movement core remains almost the same throughout the selected timeframe, albeit new axes – with high choice value – slowly branch out of the core over time. Case 2, however, shows a rupture in the urban core. This becomes very strong when a new connection to the main road becomes highly influential. Case 2 showcases an example in which the network core transforms and splits into smaller nuclei. These findings are in line with a study by Hillier et al. (2012) showing that choice cores vary from case to case, and choice cores are often the indicators of change whereas integration cores of most cases show more similarity and relative locational stability over time.

The two centrality measures that were employed as part of this study illustrate a few significant points. Closeness, as measured by integration, revealed a gradual expansion of the core, where the location of the centre remains stationary, but the shape and direction were gradually transformed. The direction of this transformation seems to be highly influenced by the direction of lines with the highest betweenness values (as measured by choice). This influence is not merely limited to the transformations of the integration core, but also the overall expansion of the settlement. It can be argued that integration is more associated with general stability and choice is more related to development potentials in the access network (see Fig. 9). The analyses illustrate that the measure of Space Syntax choice is more subject to change whereas the relative spatial position of integration cores is less susceptible to change by the

introduction of new access network elements. This is more evident when considering the relationship between the settlement and the main road. In case 2 for instance, a new connection to the main road creates a rupture in the core and influences the orientation of new access network elements. In case 3, the road directly cuts through the network and quickly generates new access network elements alongside it. Furthermore, different rate of decline in the correlation between local and global measures reveals the fact that the integration core is more resilient compared to the choice core, which is quickly influenced by the introduction of new axes.

The processes that govern the degree of flexibility seem to be among the key forces of network evolution. A system with restrictions (a grid for instance) might be considered somewhat regular in terms of its physical form, yet more difficult to read when walking on the actual ground of the city. This can be further interpreted by drawing on the concept of “affordance” (Gibson, 1979). The emergence of a line of movement is highly associated with the spatial possibilities that the setting provides (also see: Hillier et al., 2000). The availability of more possibilities can enable the emergence of more alternatives. The presence of a myriad of empty spaces in the earlier stages of settlement sets the ground for the emergence of more access network elements. Introducing change, as Gouverneur (2016: 171) points out, is generally more challenging in informal settlements that are more consolidated. The outcome of this study suggests that networks in their earliest stages are more flexible, showing higher degrees of randomness embedded in their generative processes. Therefore, change can be more feasible. In a sense, the scope for transformational change becomes more constrained as settlements become more consolidated over time. This sheds light on why and the extent to which certain urban design interventions and practices of upgrading can become quite challenging in consolidated settlements.

## 7. Conclusion

While generative and bottom-up processes play a key role in the formation and transformation of the spatial structure of cities, the details of many of these processes and the ways they play out have remained underexplored often due to data limitations and uncertainties associated with reading historic layers of development in established urban forms. The spatio-temporal documentation of the Earth’s surface over the past two decades has made it possible to look deeper into the spatiality of these processes with more tangible evidence. This article has examined the incremental development of three case studies in Nigeria over about 14 years (2007–2021) by adopting a comparative approach and using Space Syntax as an analytical method. The study traces the evolution of access networks in these settlements from the emergence of initial cores in 2007. A configurational analysis using Space Syntax has been undertaken every two years since 2007 to detect patterns that may provide insight into the morphogenesis of emerging settlements. The key findings of the current study can be summarised in the following points.

First is the encroachment of regularity into the access network. In the earliest core of settlements, the movement between points is irregular and there are shortcuts connecting them. As the settlement becomes more developed, these shortcuts become less common, and the network structure becomes more formal. This leads to the emergence of a somewhat hierarchical structure with less flexibility than the initial settlement. While traces of initial irregularities can be observed in the early stages of access network evolution, the emergence of irregular access becomes less prevalent over time. This may be attributed to the increase in the density of building footprints, which leaves less spatial potential for irregular movement patterns. Second, the results indicate that the overall intelligibility of access networks declines as they expand, suggesting that the larger urban network becomes less readable from its local elements as new local cores emerge. Third, the expansion of settlements and their associated cores is highly influenced by the orientation of elements with a higher betweenness value, though contextual differences among cases are significant. In this case, the

relationship with the main road was shown to be highly influential in the progression of betweenness cores, and consequently, the entire settlement. Accordingly, it can be argued that radical interventions, if imposed, might create ruptures in the network and disturb the centrality of the core. Fourth, the integration cores demonstrate more stability and resilience over time. This is evident in both local and global cores; although the core expands, their approximate locations remain relatively unchanged.

Providing a better understanding of how forms of incremental urbanism work by exploring their generative patterns and configurational morphogenesis can inform the development of more human-centric settlements. The findings of this study contribute to how the built environment professions can effectively engage with the capacities and challenges of emerging settlements across cities of the Global South with a focus on developing spatially grounded and contextually responsive design strategies that are aligned with how the ordinary urban spaces and structures are being shaped. The study outcomes can also be useful in devising appropriate planning strategies regarding the development of emerging access networks. Taking into account the configurational qualities that are associated with the morphogenesis of the settlement can be a starting point in this regard. For instance, observing the choice metrics of the evolving network can provide clues about the direction of its growth. Similarly, tracking intelligibility can provide insights into the local legibility of the network, which might decline when facing over-regulation in top-down planning approaches. Finally, the emergence of new local cores is associated with network expansion, and design strategies could benefit from identifying these cores to aim for the development of more human-scale approaches. Future studies can build upon the configurational morphogenesis presented here to further explore these elements across different contexts. The selected case studies can also be revisited at some point in the future to further explore the access network transformations over time.

## CRedit authorship contribution statement

**Aminreza Iranmanesh:** Conceptualization, Methodology, Software, Formal analysis, Data curation, Visualization, Writing – original draft.  
**Hesam Kamalipour:** Conceptualization, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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