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Research Article

Beyond streets: The role of alleys in Abu Dhabi's and Dubai's network systems

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A R T I C L E I N F O

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A B S T R A C T

The network system is defined as the combination of streets and alleys. Although the potential of alleys in complementing street networks is acknowledged, the topic has not received a considerable attention in urban planning practice and scholarship. This paper evaluates alleys' role in the combined street-alley networks by calculating Information Centrality, a metric in Multiple Centrality Assessment (MCA). The combined network of streets and alleys in thirteen neighborhoods of Abu Dhabi and Dubai have been studied. Findings indicate that alleys may or may not contribute to increment of network efficiency. Generally, the contribution of alleys to efficiency is more significant if the corresponding street network has low efficiency.

1. Introduction

The centrality and efficiency of street networks impose great effects on sustainable urban form. Efficiency is defined as an indicator of how well the intersections communicate over the network. The efficiency between any two nodes in a network is inversely proportional to the shortest path length between them. It is well-established in the literature that central locations serve as attractors to businesses and services (Newman & Kenworthy, 1999; Wang et al., 2011), and also as social nodes (Amen, 2022). Furthermore, central places have location advantage (Zhang et al., 2019) and often bring in real estate investments and services which consequently benefit the economy (Jordaan et al., 2004). Bavelas (1948) first coined the term "centrality" in his research of social networks. He recognized that certain people at the center of the social network have more power and control over others. Therefore, they gain greater influence on other members in the same network. The concept of centrality and efficiency was adopted in several disciplines including economics (Cai et al., 2023), transportation studies (Chakrabarti et al., 2022), land use planning (Porta et al., 2009; Wang et al., 2014), and finance (Chen et al., 2022). The network of streets resembles the complex networks of socio-economic systems in terms of properties like distance and clustering between nodes in their respective networks. Linton Freeman, Roeder, and Mulholland (1979) defined closeness, degree, and betweenness centrality, the three first centrality indicators. These indicators were later revised by various scholars like Bonacich (1987) and Stephenson and Zelen (1989), and subsequently adopted by scholars in the field of geography, transportation planning and urban studies. More recently, Straightness, Reach, Gravity, and Betweenness have been developed as centrality indicators

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by different scholars (Porta et al., 2006; Sevtsuk & Mekonnen, 2012).

In general, network systems are considered to be a combination of two elements in the built environment– streets and alleys (Alawadi et al., 2023; Marshall et al., 2014). Despite being an important component in the network system, alleys have received little attention from researchers (Helderop & Grubesic, 2019). For instance, various scholars have categorized streets based on their image (Mehta, 2013), function (Dover & Massengale, 2013), and morphology (Wheeler, 2008; Marshall & Garrick, 2011), but a similar classification of alleys is relatively scarce (Jones, 2019; Martin, 2002; Yoshii, 2018). In particular, only a few studies have studied alleys by using quantitative approaches. Sadeghi, Kharaghani, Tam, Gaerlan, and Loáiciga (2019) quantified the area occupied by alleys in Los Angeles and showed that it is greater than the area of New York's Central Park. Vialard (2012) showed that alleys have an impact on both the built form (e.g., shortening block lengths) and the circulation pattern (e.g., providing through access between streets) by reducing the number of blocks in Savannah, Atlanta. However, the contribution of alleys towards network efficiency in the combined network of streets and alleys has not been quantified yet. In other words, it has not been explored whether alleys can play a more critical role than streets to achieve greater efficiency of the combined network.

The functions and patterns of alleys differ from a place to another. Some alleys are only used by pedestrians, others accommodate vehicular traffic as well, and some are deemed unsafe and abandoned. Data related to streets like GIS layers, and other physical attributes is readily available from a variety of sources, but the alleys data is scarcely available. For instance, in commonly used mapping platforms like OpenStreetMaps (OSM), layers of street segments can be found for various cities; on the contrary, alley segments are seldom mapped, or do not exist. This research quantitatively assesses whether or not alleys can contribute more than streets towards the efficiency of the combined network. This research considers alleys to be more critical than streets if the addition of alleys results to significant changes in the network efficiency. Morphological analysis is used to discern one alley typology from another. Likewise, one of the Multiple Centrality Assessment (MCA) metrics, Information centrality is utilized to determine the contribution of alleys. Information Centrality metric is proposed by Latora and Marchiori (2007) and determines the contribution of alleys by calculating the change in the network efficiency when the nodes of alleys are added. This paper aims to contribute to both urban planning scholarship and practice. In our strive toward sustainable, walkable and neighbourhood-based cities, it is necessary to understand and utilize the potential of alleys to make our cities more efficient.

This paper takes Abu Dhabi's and Dubai's neighborhoods as case studies. Thirteen neighborhoods in total, six in Abu Dhabi and seven in Dubai have been studied— namely Al Falah, Al Bahya, Baniyas, Khalifa City, Mohamed Bin Zayed (MBZ) City, and West Island in Abu Dhabi; Creek, Al Barsha, Al Badaa, Al Satwa, Al Warqa, Al Quoz, and Al Rashidiya in Dubai. From these case studies, thirty-six samples (sized 800 m × 800 m) have been selected for analysis. Twenty-one samples are located in Abu Dhabi and fifteen samples are taken from Dubai's neighborhoods. In both cities, alleys provide access to pedestrians and play a role in the network. To understand the actual contribution of alleys and their role in promoting efficiency, this study asks three questions: 1) What are the different patterns of alleys found in Abu Dhabi and Dubai? 2) Can alleys contribute more than streets towards the network efficiency in the combined network of streets and alleys? Or Under what conditions do alleys take subordinate or more important roles as compared to streets in terms of contributing to network efficiency? 3) How does the contribution of alleys towards network efficiency differ between Abu Dhabi and Dubai?

2. Literature review

This section commences by emphasizing the utmost significance of streets as a fundamental element of the built environment, providing an overview of its extensive presence, various functions, and subsequent categories in cities. Then, the alleys are explored– despite their considerable presence and variety of functions, they are scarcely studied when compared to streets and other elements of the built environment. Afterward, various efforts at reclaiming alleys to increase connectivity, walkability, and social cohesion are discussed in the backdrop of urban revitalization, walkability and placemaking discourses. Following this, we pinpoint a significant research gap, namely, the lack of quantitative investigations into the role of alleys in the existing literature. Finally, Information Centrality, the metric that calculates the contribution of alleys in the combined network of streets and alleys, is discussed.

2.1. Definitions: streets & alleys

Streets are an essential element of the built environment. As the first element laid out during the planning process, streets shape city form and direct its growth (Dover & Massengale, 2013). Streets also occupy a large swath of land, sometimes up to 55% of developed land (Ben-Joseph, 1997). Streets take multiple roles such as circulation spaces, public spaces, as well as access to building frontages (Marshall & Garrick, 2011). The varied functions of streets have led different authors to categorize streets in different ways. For instance, streets have been classified based on their perceived pedestrian level of service (Skoufas et al., 2023), their feel and image (Mehta, 2013), and their morphology and patterns (Southworth & Ben-Joseph, 2013). This paper focuses on one understudied topic in urban morphology: the alley. The term alley comes from multiple lingual origins like Latin word '***ambulare***' (Ratzlaff, 2020), Arabic word '***sikkak***' (Ruggles, 2012), and French word '***allee***' (Blazy, 2019). Alleys are unique for two main reasons: (1) alleys are transitional spaces between the public and private realms which make their ownership and maintenance responsibility ambiguous (Hage, 2008); (2) they are hidden spaces utilized for everyday uses or for informal cultural expression (Martin, 1996; Abdelmonem, 2017; Cho & Križnik, 2020).

In the context of the Middle East, alleys have served both utilitarian and cultural functions. In old Islamic neighborhoods, alleys have played a major role in maintaining Quranic principles such as privacy and gender segregation (Abu-Lughod, 1987). Islamic alleys served as connections between clusters of buildings and individuals of similar backgrounds, ethnicities, or professions. This principle of Islamic alleys has eventually fused with the utilitarian functional approach of the Western alleys. For example, in the UAE, alleys are used both as a place for social interaction among neighbors (Alawadi et al., 2020), and as efficient walkways to access daily destinations like grocery stores, schools, and mosques (Alawadi et al., 2022). Moreover, one of the primary functions of these alleys is to provide a sense of privacy and seclusion for neighboring families. At the heart of the alley's purpose lies the preservation of privacy and the nurturing of neighborly connections. Another distinctive feature of alleys in the UAE is their restriction to pedestrian use only. Automobile traffic is prohibited in these narrow passageways. This limitation not only adds to the tranquility of the environment but also enhances safety for pedestrians, particularly children and the elderly. By excluding vehicles, these pathways become safe spaces for leisurely strolls, playtime, and casual gatherings. In this paper, streets are characterized as thoroughfares mainly utilized by motorized traffic and public usage, whereas alleys are described as passageways primarily intended for non-motorized traffic and semi-public usage. Although the process of suburbanization has gradually changed the function of alleys from being primarily social spaces to utilitarian ones (Abdelmonem, 2017), the semi-public nature of alleys in contrast to the streets is still visible in some areas of Abu Dhabi and Dubai.

In a recent study, Alawadi et al. (2023) have conducted a morphological classification of alleys into ten alley typologies— organic, square grid, rectangular grid, linear, semi-linear, semi-grid, looping grid, discontinuous grid, fragmented, and radially fragmented. This study also uses these typologies to compare the network efficiencies between different samples. Organic alleys are defined by irregular, dense, and meandering layouts, punctuated by frequent twists and turns. Square grid alleys have an orthogonal layout that forms a grid of perfect squares. Similarly, rectangular grid alleys have a layout consisting of perfect rectangles. Linear alleys are defined by a seamless, unidirectional, and rectilinear arrangement, exhibiting either a lack of intersections or minimal presence thereof. Semi-linear alleys have layouts that are continuous and one-directional but include some distortions and interruptions. Semi-grid alleys exhibit a layout that approximates a near-perfect grid, yet consists of distortions and restricted alignment between alleys in adjacent blocks. Looping grid alleys are distinguished by a notable abundance of T-junctions, which serve to enable a looping pattern of movement within their layout. Discontinuous grid alleys display an incomplete rendition of a grid or semi-grid pattern, marked by multiple interruptions and a lack of a definitive structure. Fragmented alleys feature scattered fragments and disjointed segments, lacking any discernible pattern. Radially fragmented alleys are characterized by their fragmented and dispersed nature, arranged in a radial pattern with minimal interconnection between them.

2.2. Inclusion of alleys in network studies

There are three possible justifications as to why researchers tend to overlook alleys when studying streets or network systems. First, all alleys are not multimodal, some of them only accommodate pedestrians while others can accommodate both pedestrians and vehicles (Hage, 2008). This justifies why traffic flow studies would simply isolate the street network from the combined network of streets and alleys while analyzing vehicular network performance. Second, alleys are sometimes stigmatized as unsafe, abandoned paths that pedestrians avoid (Wolch et al., 2010). Such stigmas stem from years of criticism as alleys were historically used for slave housing, storing wood for fuel, disposing of trash, housing immigrants, as well as parking cars (Ratzlaff, 2020). Third, the exclusion of alleys in network studies can be attributed to the unavailability of geospatial data and the required computation power. In fact, studying the simplified street network alone has only been recently popularized as it was initially too computationally demanding (Sevtsuk & Mekonnen, 2012).

Recent studies and advocates of urban planning ideals have offered new insights into the potential of alleys to increase connectivity, walkability, and social cohesion in an urban setting (Blazy, 2019; Gehl, 2011). Alleys are also considered to be avenues where microclimatic issues like the urban heat island can be addressed (Kleerekoper et al., 2012). The potential role of alleys as public spaces was realized notably during and after the COVID-19 pandemic (Honey-Rosés et al., 2021). Alleys possess qualities that make them conducive to three types of outdoor activities— necessary activities, optional activities, and social activities. Alleys provide opportunities for individuals to spontaneously connect, encounter, and engage with others in a "relaxed and undemanding way" (Gehl, 2011, p. 17). Consequently, numerous studies have been directed toward investigating the different ways to reclaim alleys in an urban setting. Bain et al. (2012) exemplified the scope of revitalizing alleys through eight case studies from various American cities. Blazy (2019) studied alleys in Mexico City and Warsaw, and highlighted the socio-cultural significance of alleys. Machado-León et al., 2020 studied the potential of alleys to be used as a dynamic space for both pedestrians and freight services by taking Seattle as a case study. The studies mentioned earlier are predominantly qualitative in nature, focusing on the functional and social aspects of alleys. In contrast, this paper adopts a quantitative approach, specifically examining a critical physical design element of alleys—namely, their morphological typology. In simpler terms, our research aims to calculate the impact of various alley typologies on network efficiency.

2.3. Information centrality

Network centrality is used synonymously with accessibility, proximity, connectivity, and efficiency (Porta et al., 2006). Centrality was first studied by Bavelas (1948) for human communication. In sociology, good locations in a network equal authority, impacts, and control over the others. The centrality concept was developed further by Freeman et al. (1979) for the study of social networks. Freeman defined degree, closeness, and betweenness centrality. In urban planning, Porta et al. (2006) employed these concepts in studying centrality of street networks. Porta et al. (2006) defined a family of centrality indices named Degree, Closeness, Betweenness, Straightness, Efficiency, and Information Centrality. These centrality indices are determined by network analysis, which is a process of spatially analyzing the network systems in cities.

Network analysis is developed based on the graph theory which simplifies any network into a set of nodes and edges of various configurations and characteristics. Graph representation could either be primal or dual. Dual representation such as that used in Space

Syntax is a topological representation that considers streets as nodes and junctions as edges (Hillier & Hanson, 1989). In contrast to the dual approach, primal representation considers streets as edges or links and junctions as nodes reflecting a more realistic structure of street networks (Porta et al., 2006). Primal representation also takes actual network lengths into consideration as opposed to the Euclidean distances. Primal representation was used and developed into an approach named Multiple Centrality Assessment (MCA) which captures the multifaceted concept of network centrality more holistically. MCA takes metric distances into consideration and assesses the network by calculating four different centrality metrics namely Closeness, Betweenness, Straightness, Gravity, and Information Centrality (Porta et al., 2006). Sevtsuk and Mekonnen (2012) further enhanced the assessment of primal graphs by adding buildings or blocks with specific attributes (defined as weights) using the Urban Network Analysis (UNA) toolbox[1]. These features allow for fine-tuning evaluation of network centrality and efficiency.

MCA measures have been used in multiple studies. Previous studies have used MCA metrics to explore the importance of different public transportation nodes (Tu, 2013; Wang & Fu, 2017); to assess the factors that influence traffic volume at particular traffic nodes (Akbarzadeh et al., 2019); and to study the redistribution of metro passenger flow (Derrible, 2012). In addition, MCA has been utilized to investigate the relation between street centrality and the densities and types of economic, commercial, and service activities (Ozuduru et al., 2020; Porta et al., 2009, 2012).

While some MCA metrics like Reach and Gravity capture concepts such as network accessibility and metrics such as Straightness calculate route directness, Information Centrality is a measure of how important a node (or a group of nodes) is to the functionality of the combined network (Porta et al., 2008). The importance of a node is quantitatively measured as the gain in network efficiency upon the addition of the node or a group of nodes. Information centrality has several advantages over the other centrality metrics. First, it combines the conceptual approaches of metrics like Closeness and Betweenness. Closeness is a type of centrality metric that considers proximity to other nodes to be the primary property of central nodes, while the Betweenness metric considers central nodes to be the ones that lie between numerous other nodes. Unlike other centrality metrics, Information Centrality applies to groups as well as single nodes, and it considers the new shortest path when activating or deactivating nodes or edges. It also clearly differentiates between planned and organic cities (Porta et al., 2006; Latora & Marchiori, 2007). These properties of Information Centrality helped to answer research questions 2 and 3, where the removal or the deactivation of nodes, and topological comparison were required. Thus, this study uses the Information Centrality metric over the other MCA metrics. This study offers perspectives on how alleys contribute to enhancing the efficiency of the combined network. It employs quantitative methods to systematically investigate the significance of alleys. This quantitative approach serves as a valuable complement to the existing literature, which has predominantly employed qualitative techniques in alley-related research. The importance of alleys in the combined network can be determined by recording the change in network efficiency when alleys are included.

3. Evolution of streets and alleys in the UAE

The patterns of streets and alleys have evolved alongside urban form. The evolution of street network morphology, without alleys, has been heavily investigated in the literature. It is well-established that streets evolve according to the type of urban growth (Southworth & Ben-Joseph, 2013). According to Southworth and Owens (1993), streets shifted from organic to gridlock, to interrupted parallels, then to loops and lollipops. While this transformation created streets that are perceived by inhabitants as safer, disjointed street patterns resulted in urban fragmentation, increased trip lengths, and reduced intersection density, number of blocks, and route options (Southworth & Owens, 1993).

In the United Arab Emirates (UAE), both Abu Dhabi and Dubai have experienced similar transformations in urban growth and hence also in street and alley morphology. Abu Dhabi has gone through three growth phases namely Inception, Dispersion and Redemption (See Fig. 1). The Inception Period (1961–1975) consisted of small-scale, gridded blocks with gridiron street networks. This was followed by the Dispersion Phase (1975–2007) which responded to the oil boom by rapid urbanization and automobile dependency, highly resembling the North American suburban model. Streets during this phase took the form of fragmented parallels. However, from 2007 to 2017, Abu Dhabi incorporated traditional design ideals such as walkability, density, and mixed-use in the development of its new suburbs. After 2017, the Dispersion Period has resumed in Abu Dhabi.

Dubai has also undergone similar periods of urban growth namely Inception (1950–1975), Pre-Dispersion (1968–1977) and Dispersion (1976–present) (See Fig. 2). However, unlike Abu Dhabi, Dubai started organically between 1900 and 1955 as reflected in the fine urban grain and organic streets. This organic phase was followed by the Pre-dispersion phase (1956–1970) which highly resembles the compact orthogonal grids of Abu Dhabi's Inception phase (Elsheshtawy, 2004; Pacione, 2005). Similar to the Dispersion phase in Abu Dhabi, Dubai's Dispersion phase (1971–1993) followed the model of post-WWII North American suburbs with interrupted parallel, fragmented, and looping street layouts. However, Dubai did not shift to the Redemption Phase and instead amplified the effect of Dispersion into Bigness (1994–2007), followed by Recession phase (2008–2013), and finally Post-Expo Bid (2014–present).

This study utilizes Abu Dhabi and Dubai as case studies, specifically chosen for their contrasting development patterns. Dubai exhibits an organic and subdivided evolution without a distinct modular planning system, while Abu Dhabi showcases a systematic, modular, planned design. While the governmental and planning processes in Abu Dhabi and Dubai share similarities, their

[1] Urban Network Analysis (UNA) is a toolbox created by the City Form Lab at the Singapore University of Technology and Design in collaboration with MIT. This toolbox is used as a plug into either GIS or Rhino to conduct graphical and mathematical network analysis in order to describe the spatial patterns of urban areas (Sevtsuk & Mekonnen, 2012). UNA toolbox is an open-source software that can be downloaded from the website of City Form Lab: https://cityform.mit.edu/projects/una-rhino-toolbox.

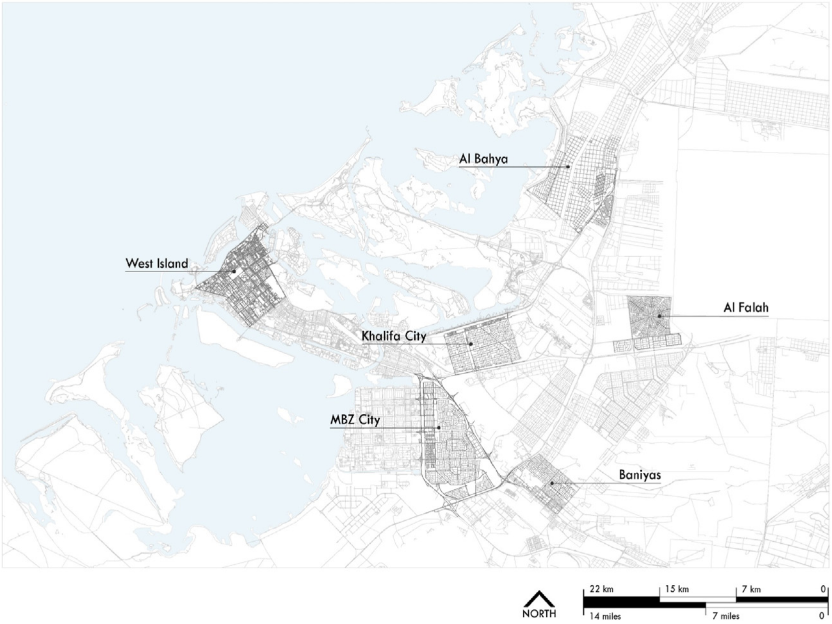


Fig. 1. The location of case study neighborhoods in Abu Dhabi: West Island, Baniyas, Al Bahya, Khalifa City, MBZ City, and Al Falah.

Fig. 2. The location of case study neighborhoods in Dubai: Creek, Al Satwa, Al Badaa, Al Rashidiya, Al Quoz, Al Warqa, and Al Barsha.

neighborhoods exhibit distinct morphological layouts. Nonetheless, these layouts in both cities bear a resemblance to common neighborhood typologies found in Western urban areas. The patterns of urbanization, suburbanization, and subsequent development of various neighborhood forms in the United Arab Emirates (UAE) have been influenced by Western countries. This Western influence has deeply permeated the urban development practices of both Abu Dhabi and Dubai. Both cities have a history of engaging North American and European consulting firms, as well as foreign architects educated in Western countries. For instance, companies like Halcrow, Arup International, and W.S. Atkins, and architects such as John Elliott, Katsuhiko Takahashi, Abdul Makhlouf, and Larry Beasley have contributed to various masterplans for Abu Dhabi (Hashim, 2018; Khrifan & Jaffer, 2013). In Dubai, firms like Parsons, AECOM, and Halcrow, along with architects like John Harris, have played pivotal roles in its urban growth and development (Pacione, 2005). The suburban growth in both Dubai and Abu Dhabi has followed the post-World War II suburbanization model of the United States. This model is characterized by segregated communities primarily consisting of single-family detached housing units connected via fragmented networks of streets and multi-lane highways (Elsheshtawy, 2009). Abu Dhabi and Dubai constantly attract attention, whether through admiration, criticism, emulation, or research, owing to their global ambitions, unprecedented urban growth rates, strategies for attracting investment, iconic architecture, and status as popular tourist destinations (Ponzini, 2011; 2022). Moreover, the diverse range of neighborhood examples from Abu Dhabi and Dubai represents grid and fragmented layouts that are widely applied in urban planning worldwide. Therefore, the case studies presented in this paper bear international relevance in terms of urban form, making the findings valuable for urban planners in various contexts.

Similar to streets, alleys have evolved during different aforementioned growth phases in Abu Dhabi and Dubai. Nevertheless, a notable presence of alleys in the combined network of streets and alleys is consistent across all growth phases (See Fig. 3). Older, densely populated areas like Dubai Creek featured narrow alleys bounded by midrise commercial buildings. As modern utilities became prevalent, alleys in places like AD West and Al Satwa evolved into service corridors, with utilities lining midrise buildings. However, with the introduction of more concealed utilities, a shift towards low-rise private villas in Emirati housing, and segregated commercial spaces, alleys became more private. These alleys serve as play areas or personal storage. In modern suburban areas, alleys, now wider and often unpaved, emphasize privacy. This design has led to many alleys seeming deserted and not pedestrian-friendly, undermining their role as efficient walking routes.

Another notable variation in alleyways, which is key to this study, is their morphology. For instance, in Dubai Creek of Inception period, the layout of alleys is organic, alongside the organic street network. In other cases, alleys can be some form of a grid such as

Fig. 3. Evolution and the variable usage of Alleys (top left to bottom right): Dubai Creek, AD West, Al Satwa, BaniYas, Khalifa City, Al Falah, Al Warqa.

square grid in old parts of Al Satwa and Al Badaa in Dubai which belong to Pre-Dispersion period; and rectangular grid in parts of Baniyas in Abu Dhabi from Dispersion period. If a layout closely resembles a grid but has dead ends, and multiple T-intersections, forming some disconnections in the network, it is identified as a semi-grid network. Alley networks can also be in the form of fragmented alleys such as those observed in Al Warqa from Dispersion period. The fragmented layouts have sporadic presence of alley segments with minimal continuity (See Fig. 4). In this paper, continuity has been defined as the extension of the existing street segments that occurs when the alley segments are added to the network. Given that alleyways are primarily a walking infrastructure, this study investigates the role of different alley morphologies in enhancing the network efficiency by computing the information centrality of different samples.

4. Methodology

This section commences by discussing the selection process of neighborhood samples and the edge effect. The edge effect determines the search radius of the analysis. Then, the efficiency and information centrality are introduced and described in detail. Finally, the scenarios for calculating Information Centrality are mentioned (Fig. 5).

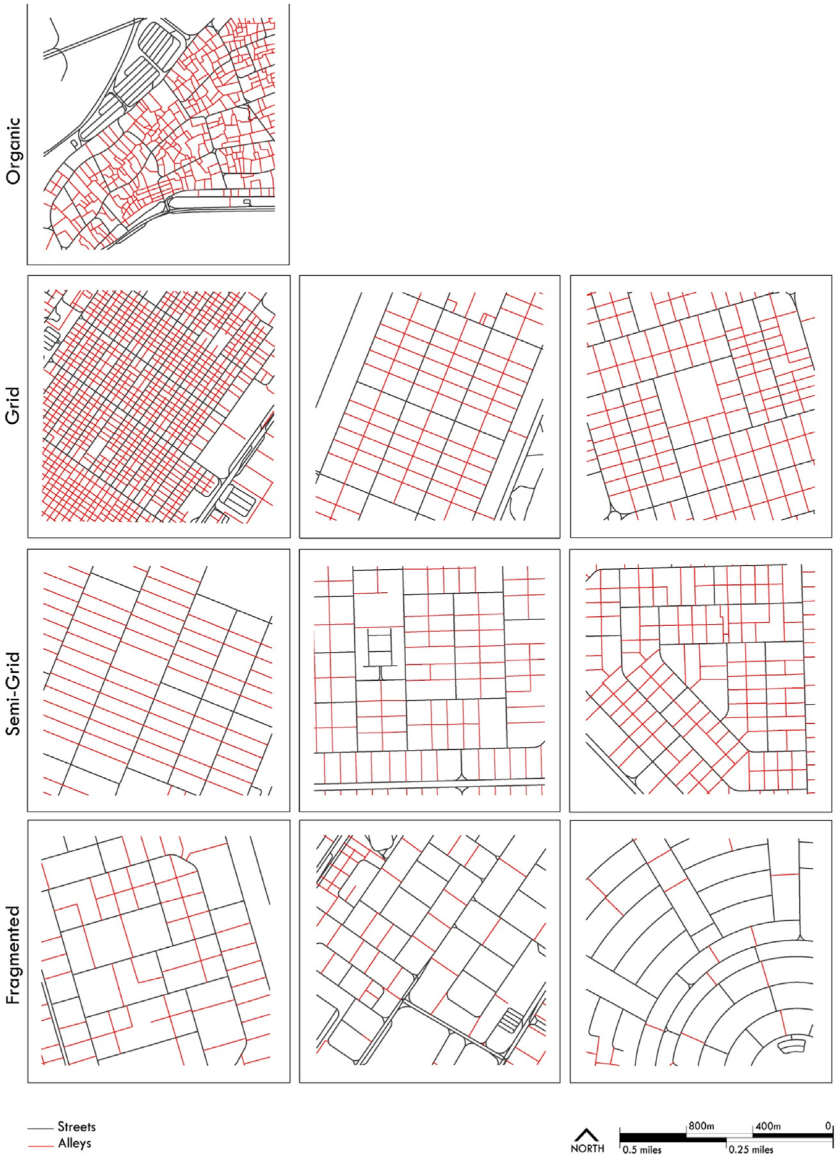


Fig. 4. Alleys typologies (from top row to bottom row): Organic, Grids, Semi-grids, and Fragmented. Organic alleys are usually found in old settlements that evolved without any formal planning interventions. Grid alleys resemble the grid network of streets with a high number of four-way intersections. If a layout closely resembles a grid but has dead ends and multiple T-intersections forming some disconnections in the network, it is identified as a semi-grid network. Fragmented layouts have sporadic presence of alley segments with minimal continuity.

4.1. Selection of neighborhoods & edge effect

The identification of street layouts and alley typologies was carried out by analyzing aerial photographs and geospatial data obtained from Dubai Municipality and Abu Dhabi's Department of Municipalities and Transport. The ArcGIS platform was used to retrieve the data for the selected neighborhoods. Since the alleyway network was not available in the data set, manual mapping was carried out for all chosen cases. Thirteen neighborhoods in Abu Dhabi and Dubai were taken as case studies. These case study neighborhoods represent the diversity of urban morphology and evolution in both cities. The six neighborhoods of Abu Dhabi include Al Falah, Al Bahya, Baniyas, Khalifa City, Mohamed Bin Zayed (MBZ) City, and the West Island. The seven neighborhoods of Dubai include Dubai Creek, Al Barsha, Al Warqa, Al Badaa, Al Satwa, Al Quoz, and Al Rashidiya. From each neighborhood, two to six samples, each with a dimension of 800 m by 800 m were selected (See Fig. 6a and b). There are thirty-six samples in total– twenty-one samples were taken from Abu Dhabi and fifteen samples were taken from Dubai's neighborhoods (See Fig. 7a and b).

Street networks are continuous in reality, and when analyses are carried out within an artificially bounded study area, network elements and events that occur beyond the boundary are ignored (Gil, 2017). This ignorance leads to a bias called edge effect, because the analytic algorithms are fundamentally relational. Edge effect influences the nodes on or adjacent to the study area's boundary and all other nodes in the network (Barthélemy, 2011). The reliability of any network analysis is deemed questionable if the edge effect is not considered (Ratti, 2004). In this study, each sample was calculated with a large search radius of 10,000 m to avoid the edge effect. The use of a 10,000 m radius guaranteed that all nodes had an equal opportunity to reach all other nodes within a sample rather than clipping away opportunity nodes. Although the sample size is 800 m × 800 m, to avoid edge effect, theoretically the radius should equal to infinity; but since the maximum radius in Rhino is 10,000 m, it is chosen as the search radius. In other words, the search radius should be much greater than the maximum possible network segment length within the sample area. For example, within the sample size of 800 m × 800 m, from one corner to another diagonally-opposite corner, a network segment can be longer than 3000 m, which makes a radius of 3000 m or less vulnerable to the edge effect. In this study, the streets that intersect the edges of samples were included up to the end of their natural edge (i.e., the next point of intersection) during the analysis.

4.2. Efficiency and information centrality

Porta et al. (2006) first proposed Multiple Centrality Assessment (MCA) to evaluate centrality and efficiency of street networks. The MCA includes metrics like Closeness, Straightness, Betweenness, Information Centrality, and Gravity. As compared to other MCA

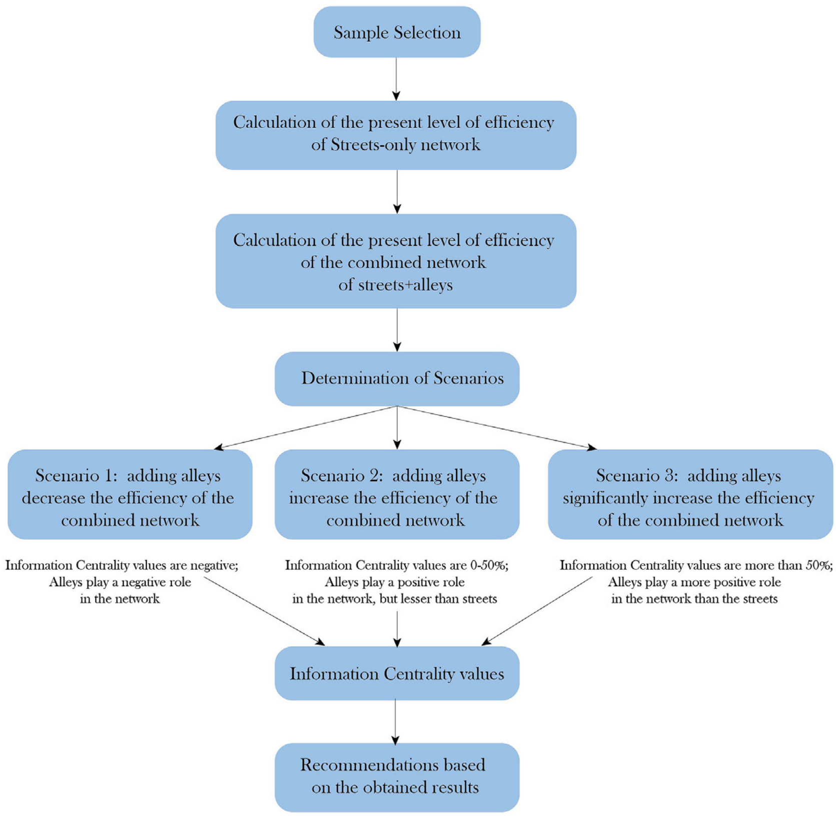


Fig. 5. A step by step process of inquiry.

Fig. 6a. Location of samples in Abu Dhabi.

Fig. 6b. Location of samples in Dubai.

metrics, Information Centrality has been scarcely used by urban and transport planning scholars. Information Centrality is a measure of how important a node is to the operationality of the network (Porta et al., 2008). According to Crucitti et al. (2006), removing a node (or a group of nodes) from the network will exclude edges (or streets) that connect to that node (or the particular group of nodes). Therefore, the removal impacts the efficiency of the combined network of streets and alleys. Consequently, the network efficiency can either increase or decrease. If it increases, the Information Centrality receives a positive value and if it decreases, the value of Information Centrality receives a negative value. This study calculates Information Centrality to assess the contribution of alleys towards network efficiency. The level of contribution is determined by the change in network efficiency when alleys are included in the analysis. The formula of Information Centrality proposed by Latora and Marchiori (2007) was utilized.

$$E(G) = \frac{1}{N(N-1)} \sum \frac{d_{ij}^{Eucl}}{d_{ij}} \quad (1)$$

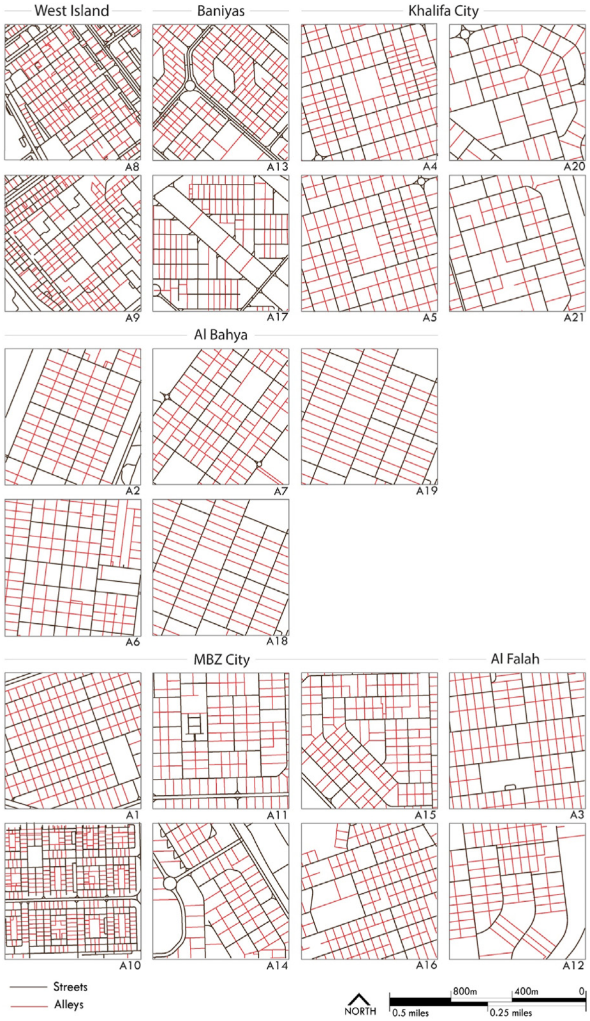


Fig. 7a. Studied samples in Abu Dhabi's neighborhoods: A8 and A9 in West Island; A13 and A17 in Baniyas; A3 and A12 in Al Falah; A4, A5, A20 and A21 in Khalifa City; A2, A6, A7, A18 and A19 in Al Bahya; and A1, A10, A11, A14, A15, and A16 in MBZ City.

$$C^I = \frac{\Delta E}{E(G')} = \frac{E(G') - E(G)}{E(G')} \tag{2}$$

In Equations (1) and (2) shown above, G is the graph of links that connect N nodes. This represents the street network without alleys. Similarly, G′ is the graph of N′ nodes obtained by adding alleys to G. Also, in the equations, E(G) is the efficiency of Graph G which only contains streets, E (G′) is the efficiency of Graph G' which consists both streets and alleys, and C^I is Information Centrality. In addition, d_{ij} is the geodesic path and d_{ij}^{Eucl} is the Euclidean straight-line path. The efficiencies for studied neighborhood samples were calculated in Rhino by using the Urban Network Analysis (UNA) toolbox. The obtained values of efficiencies were then used as inputs for the calculation of Information Centrality by using Equation (2) shown above. In this study, the efficiency values were categorized into high, mid-level, and low efficiencies according to the quartiles of the obtained efficiency values. Low efficiency is represented by the values up to the first quartile ranging from 0.59 to 0.71. Similarly, mid-level efficiency is represented by the values between the first and the third quartile ranging from 0.71 to 0.80. The values lying beyond the third quartile (from 0.80 to 0.89) are considered high efficiency.

4.3. Scenarios for calculating information centrality

First, a street network without alleys (Graph G) was taken. After adding alleys, the network G' is obtained. This changes the efficiency of the combined network of streets and alleys, and the Information Centrality changes accordingly. In general, it might be wrongly assumed that the addition of alleys to the network always increases the network efficiency. However, this is not always the case. Thus, this paper investigated both cases-when the inclusion of alleys increases and decreases network efficiency.

There are three probable scenarios when alleys are added to the network. In Scenario 1, the efficiency of the combined network

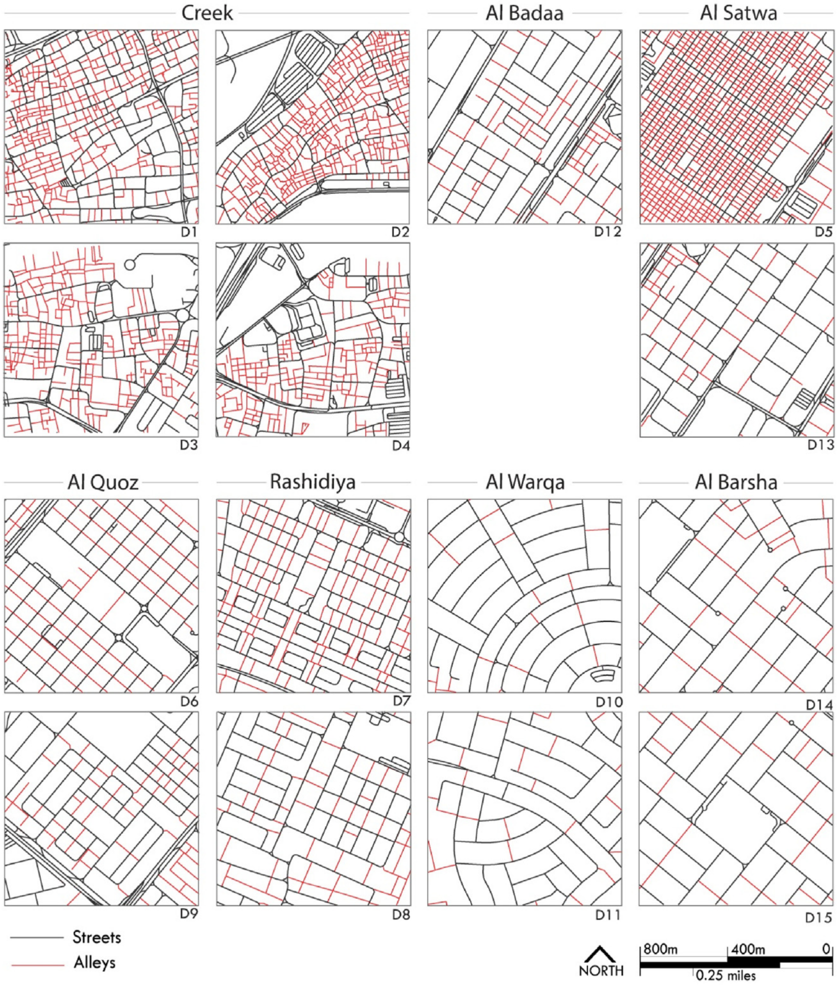


Fig. 7b. Studied samples in Dubai's neighborhoods: D1, D2, D3 and D4 in Creek; D12 in Al Badaa; D5 and D13 in Al Satwa; D6 and D9 in Al Quoz; D7 and D8 in Rashidiya; D10 and D11 in Al Warqa; and D14 and D15 in Al Barsha.

would decrease after the addition of alleys which would correspond to the negative value of Information Centrality (C^I) obtained from the calculation of Equations (1) and (2). In Scenario 2, the efficiency of the network would increase but not significantly after the addition of alleys. This would be indicated by the positive values of Information Centrality, less than or equal to 50%. In Scenario 3, the efficiency of the combined network would increase significantly when alleys are added, and would correspond to Information Centrality (C^I) values higher than 50%. The Information Centrality value higher than 50% means that the increase in efficiency obtained after the addition of alleys surpasses the previous network efficiency. In this case, alleys networks play a more crucial role than streets in the combined network. If the network efficiency increases by less than 100%, then alley networks play a supplementary role in the combined network. If E(G) is the efficiency of the streets-only network and E (G′) is the efficiency of the network after adding alleys, then let $\Delta E = E(G') - E(G)$. Thus, the three probable scenarios can be mathematically written as follows.

- Scenario 1: If $E(G') < E(G)$, then adding alleys decrease the efficiency of the combined network. Consequently, from formula (2), $C^I < 0\%$
- Scenario 2: If $E(G') > E(G)$ and $\Delta E < E(G)$, then adding alleys increase the efficiency of the combined network. Consequently, from formula (2), $0 < C^I \leq 50\%$
- Scenario 3: If $E(G') > E(G)$ and $\Delta E > E(G)$, then adding alleys significantly increase the efficiency of the combined network. Consequently, from formula (2), $C^I > 50\%$.

5. Results

This section highlights several key observations pertaining to network efficiency. Grid street patterns consistently exhibit high efficiency values, typically ranging from 0.80 to 0.89, with the exception of one sample. For instance, the highest efficiency score of 0.89 is achieved by sample A2 in Al Bahya, which features a gridiron street pattern. Organic streets, on the other hand, demonstrate mid-range efficiency values spanning from 0.71 to 0.80. All four samples in Dubai Creek with organic street layouts fall within this middle range. Fragmented street patterns exhibit a more varied range of network efficiencies, encompassing all three categories. For example, D15 in Al Barsha demonstrates a high efficiency value of 0.80, while D12 in Al Badaa exhibits a lower efficiency value below 0.71, specifically 0.59. When organic alleys are introduced to organic street layouts (e.g., samples D1, D2, D3, and D4), it results in positive Information Centrality values. In contrast, when grid alleys are added to a gridiron street network (e.g., samples A2 and D5), the outcomes can either be positive or negative Information Centrality values. When fragmented alleys are introduced to fragmented street layouts (e.g., samples D12 and D13), the results are similar to grid-grid street-alley combinations where Information Centrality has both positive and negative values. This variance is attributed to differences in network attributes such as typology and average street segment length.

5.1. *Efficiency*

Only eight out of the total thirty-six samples obtain high efficiency values (0.80–0.89) in both cases (i.e., when only the street network is considered, and when the combined network of streets and alleys is taken into consideration). Among the eight samples with highly efficient networks, seven are located in Abu Dhabi— Khalifa (2 samples), Al Bahya (2 samples), Baniyas (1 sample), Al Falah (1 sample), and MBZ (1 sample); while one sample is from Dubai— Al Quoz. For instance, Samples A2 Al Bahya, A7 Al Bahya, A13 Baniyas, A20 Khalifa, A21 Khalifa, D6 Al Quoz, A1 MBZ, and A12 Al Falah have efficiency values of 0.89, 0.88, 0.84, 0.82, 0.81, 0.80, 0.80 and 0.80 respectively when only street network (Graph G) is considered. It is observed that except Al Falah, Quoz, and MBZ, all samples with the highest efficiency also have negative Information Centrality ranging from −0.71% to −10.11%. On the contrary, all samples with low efficiency (0.59–0.71) have positive Information Centrality ranging from 2.33% to 16.49%. Among nine samples with low efficiency values, four from Abu Dhabi and five from Dubai have positive Information Centrality. This means that regardless of the street typologies and alleys topologies of the samples, the introduction of alleys increases the efficiency of street networks with low efficiency more significantly as compared to networks that already have high efficiency.

The efficiency values for Graph G (Streets only network) indicate that gridiron street pattern (for example, Al Bahya in Abu Dhabi) is

Table 1
Information centrality values for all samples.

SAMPLE ID	NEIGHBORHOOD	ALLEY TYPOLOGY	Street/ Alley ratio	EFFICIENCY OF STREETS ONLY NETWORK G	EFFICIENCY OF COMBINED STREETS + ALLEYS NETWORK G′	INFORMATION CENTRALITY (CI)
A3	Al Falah	Grid	0.39	0.71	0.80	11.41%
A13	Baniyas	Grid	0.55	0.84	0.80	7.62%
A12	Al Falah	Semi-Grid	0.44	0.80	0.81	7.09%
A9	West Island	Fragmented	1.11	0.75	0.79	6.52%
A19	Al Bahya	Semi-Grid	0.58	0.77	0.82	6.18%
A15	MBZ City	Semi-Grid	1.18	0.76	0.81	5.50%
A11	MBZ City	Grid	1.00	0.76	0.80	5.33%
A16	MBZ City	Grid	0.47	0.75	0.80	5.30%
A17	Baniyas	Semi-Grid	1.11	0.75	0.79	5.02%
A18	Al Bahya	Semi-Grid	1.59	0.68	0.71	4.82%
A1	MBZ City	Grid	0.49	0.80	0.80	3.09%
A10	MBZ City	Semi-Grid	0.72	0.68	0.70	2.33%
A8	West Island	Fragmented	1.41	0.74	0.75	2.32%
A4	Khalifa City	Grid	0.45	0.79	0.80	0.96%
A21	Khalifa City	Fragmented	1.09	0.81	0.80	−0.71%
A20	Khalifa City	Fragmented	1.12	0.82	0.81	−0.82%
A5	Khalifa City	Grid	0.46	0.80	0.79	−0.99%
A14	MBZ City	Grid	0.57	0.77	0.75	−2.32%
A6	Al Bahya	Grid	0.49	0.84	0.78	−7.30%
A7	Al Bahya	Grid	0.57	0.88	0.80	−9.80%
A2	Al Bahya	Grid	0.71	0.89	0.81	−10.11%
D10	Al Warqa	Fragmented	6.91	0.65	0.78	16.49%
D12	Al Badaa	Fragmented	2.85	0.59	0.68	13.17%
D11	Al Warqa	Fragmented	4.45	0.66	0.75	12.99%
D8	Al Rashidiya	Semi-Grid	2.17	0.64	0.73	12.09%
D5	Al Satwa	Grid	0.48	0.73	0.79	11.20%
D13	Al Satwa	Fragmented	3.34	0.71	0.76	6.84%
D4	Creek	Organic	1.53	0.71	0.75	5.50%
D2	Creek	Organic	0.88	0.77	0.81	4.88%
D3	Creek	Organic	0.84	0.73	0.75	4.79%
D1	Creek	Organic	0.99	0.77	0.79	3.31%
D9	Al Quoz	Fragmented	3.22	0.73	0.76	3.29%
D14	Al Barsha	Fragmented	2.29	0.78	0.79	0.65%
D6	Al Quoz	Semi-Grid	1.87	0.80	0.80	0.38%
D15	Al Barsha	Fragmented	2.83	0.80	0.79	−1.42%
D7	Al Rashidiya	Semi-Grid	1.54	0.74	0.67	−9.96%

the most efficient typology. Except for Al Satwa (mid-range efficiency of 0.73), all other samples with gridiron street patterns have the high efficiency values ranging from 0.84 to 0.89. The fragmented parallel patterns of Al Barsha and Khalifa City have efficiency in the middle and high categories. On the other hand, the organic street pattern (Dubai Creek) also has mid-range efficiency (0.71–0.80). Fragmented parallel is the most common street typology, found in ten out of thirty-six samples, which have low to high efficiencies from case-to-case basis.

5.2. Information centrality

Graph G' is obtained by adding alleys to Graph G. The addition of semi-grid, and fragmented alleys to the existing network can result to either positive or negative Information Centrality, which corresponds to an increase or decrease of the network efficiency. For instance, both samples− A3 and A7 have gridded alleys but their Information centrality values are 11.41% and −9.8% respectively (See Table 1). However, among the studied samples, the network efficiency has always increased when organic alleys and semi-grid alleys are added to the network. For example, samples D1, D2, D3 and D4 in Dubai Creek have organic alleys resulting to positive Information Centrality values of 3.31%, 4.88%, 4.79%, and 5.50% respectively. Likewise, A10 in MBZ, A12 in Al Falah and A15 in MBZ have semi-grid alleys with numerous T-intersections, and consequently have positive Information Centrality values of 2.33%, 7.09% and 5.50% respectively. It should be noted that the linkage of Information Centrality values and alley typologies are observations only, a more conclusive and generalized findings could be determined by studying a larger set of samples.

The grid type alleys can also have either positive or negative impact on the network efficiency corresponding to positive or negative Information Centrality values. For instance, Sample A2 in Al Bahya has Information Centrality value of −10.11% while Sample A13 in Baniyas has a corresponding value of 7.62%. The varying effect of the same alley typology can be attributable to the difference between the street networks − Sample A2 in Al Bahya has gridiron street layout, while Sample A13 in Baniyas has fragmented parallel street network. Moreover, in case of sample A2, the network efficiency at 0.89 is already very high before the introduction of alleys. Conversely, the samples that have low efficiency values before adding alleys result to high Information Centrality values. For example, before adding alleys, Samples D12 in Al Badaa, D8 in Rashidiya and D10 in Al Warqa have network efficiency values of 0.59, 0.64 and 0.65 respectively. These are the three lowest network efficiency values among all thirty-six samples when only streets are taken. When alleys are added to the network, some of the highest Information Centrality values are obtained by Samples D12, D8 and D10 at 13.17%, 12.09% and 16.49% respectively.

The results obtained after the calculation of Information Centrality correspond to the aforementioned Scenarios 1 and 2, and Scenario 3 is not achieved by any sample. Among the thirteen neighborhoods, the highest increase in network efficiency is found in Sample D10 of Al Warqa (Dubai) with Information Centrality of 16.49% while the highest decrease is obtained by Sample A2 in Al Bahya (Abu Dhabi) with −10.11%. Sample D10 also has the highest street-alley ratio among all samples at 6.91 (See Table 1). On the contrary, Sample A3 (Al Falah) has the lowest street-alley ratio at 0.39, but both samples have high positive Information Centrality values (i.e., 11.49% for A3 and 16.49% for D10). Thus, for the studied samples there is no correlation between Information Centrality and the ratio of the lengths of streets and alleys.

Twenty-seven out of thirty-six samples have positive Information Centrality while only nine samples have negative values. Eleven samples have Information Centrality of less than 5%. Thus, in majority of the samples, efficiency increases with the introduction of alleys. There are several samples that have a higher increase in efficiency among the studied samples (i.e., where the Information Centrality is more than 10 percent). For instance, two samples in Al Warqa (16.49% and 12.99%), one sample each in neighborhoods like Al Badaa (13.17%), Al Rashidiya (12.09%), Al Satwa (11.2%), and Al Falah (11.41%). All the relatively high scoring samples are located in Dubai except for Sample A3 of Al Falah, Abu Dhabi. On the other hand, the majority of samples with negative Information Centrality values are located in Abu Dhabi. For example, except for the two samples from Al Barsha and Al Rashidiya in Dubai with −1.42% and −9.96% respectively, the remaining seven samples with negative Information Centrality values are found in Abu Dhabi. The network efficiency decreases slightly in three samples— A21, A20 and A5 of Khalifa City with Information Centrality values of −0.71%, −0.82%, and −0.99% respectively. However, for other samples like A14 of MBZ (−2.32%) and three samples of Al Bahya— A6 (−7.3%), A7 (−9.8%) and A2 (−10.11%), the decrease is significant.

6. Discussion

6.1. Roles of alleys in the combined network

Results have shown that alleys can contribute positively or negatively to the network efficiency. The highest contribution of alleys to the network is 16.49% in Sample D10 in Al Warqa, Dubai. Thus, Information Centrality in all samples is much smaller than the threshold of 50% defined in Scenario 3. This threshold is needed for alleys to be considered as a more important infrastructure element than streets in the combined network. However, alleys still exist massively in the network of Abu Dhabi and Dubai, and contribute towards the increment of network efficiency in a majority of the studied samples. In twenty-seven out of thirty-six samples, alleys have a positive contribution to the network efficiency; six among these positive cases have Information Centrality values higher than 10%. Thus, in Abu Dhabi and Dubai, alleys contribute positively to the network efficiency, but the contribution is not more critical than the contribution of streets.

The Information Centrality value higher than 50% can only be obtained if the network efficiency after the addition of alleys increases drastically. This is because 50% value of Information Centrality corresponds to an increase in the network efficiency by 100%. In other words, 50% Information Centrality refers to a scenario when the initial network efficiency doubles after the addition of alleys. Among the studied samples, the highest efficiency of 0.82 is obtained by Sample A19 in Al Bahya, Abu Dhabi. In order to become more significant contributor to efficiency than streets in the combined network, the initial efficiency before adding alleys should be low. For example, if A19 sample had the initial efficiency of 0.40, then alleys would have contributed more towards efficiency than streets in that particular network because the efficiency after the inclusion of alleys would be 0.82. This would have resulted to an increase in network efficiency by 0.42 corresponding to an Information Centrality value greater than 50% at 51.22%. However, this level of increment in efficiencies does not occur in any of the studied samples. The lowest efficiency is 0.59 in Sample D12 of Al Badaa, which is still much higher than the hypothetical initial efficiency of 0.40. In twenty-one out of thirty-six, or 58% of the studied samples, network efficiency after adding alleys ranges from 0.79 to 0.81.

6.2. Comparison: Abu Dhabi & Dubai

The average efficiency of the network without alleys in Abu Dhabi is 0.78, while the corresponding value in Dubai is 0.72. Likewise, the average efficiency of the combined network in Abu Dhabi is 0.79 as compared to 0.76 in Dubai. This indicates that both the street and combined networks in Abu Dhabi are more efficient than those in Dubai (See Fig. 8a and b). Among the twenty-one samples in Abu Dhabi, seven samples, or one-third of the samples, have negative Information Centrality. In contrast, Dubai only has two out of fifteen samples with negative Information Centrality. In addition, Dubai's combined network also has a higher average of positive Information Centrality value (7.35%) as compared to Abu Dhabi (5.25%). Therefore, the addition of alleys as an additional infrastructure increases the efficiency of the combined networks of Dubai's samples more than those of Abu Dhabi. It also means that street networks in Dubai are less efficient and thus alleys can contribute to notable increments in the network efficiency values. This could be attributable to the fact that, unlike Abu Dhabi, there has been no stop to the suburban dispersion in Dubai. Instead, various megaprojects are being developed where large swaths of land, each with their own masterplan, are controlled by different companies (Alawadi, Khanal, & Almulla, 2018). Similar megraprojects are active in Abu Dhabi but it went through a growth period of Redemption (2007 - 2017) when traditional design ideals such as walkability, density, and mixed-use were promoted within a holistic urban vision barring some island developments.

6.3. Typologies of the combined networks

Results of the combined street-alley network typologies have also revealed new insights (See Table 2). For example, the gridiron street pattern and grid alleys in Sample D5 of Al Satwa generate a positive Information Centrality of 11.2%. However, the same grid-grid combination of streets and alleys, in Sample A2 of Al Bahya produces a negative Information Centrality of −10.11%. The difference between the two samples of D5 at 11.2% and A2 at −10.11% is attributable to their average street segment lengths and network morphologies. Sample D5 has a smaller average street segment length of 107.5 m and its streets are more continuous as compared to Sample A2 with an average street segment length of 262.5 m. Likewise, samples D12, D13, and D9 have looping fragmented parallel layouts combined with fragmented alleys, but they result in various levels of Information Centrality (from 13.17% to 6.84%, and 3.29% respectively). For instance, Sample D12 has the lowest efficiency at 0.59, and when alleys are added, its street continuity is improved. Large blocks are shortened significantly (from 190 m × 65 m–80 m × 32 m), leading to an increased efficiency of 0.68. Likewise, samples of D13 and D9 (with initial efficiencies at 0.71 and 0.73 respectively) also benefit when alleys are added to the network. However, the

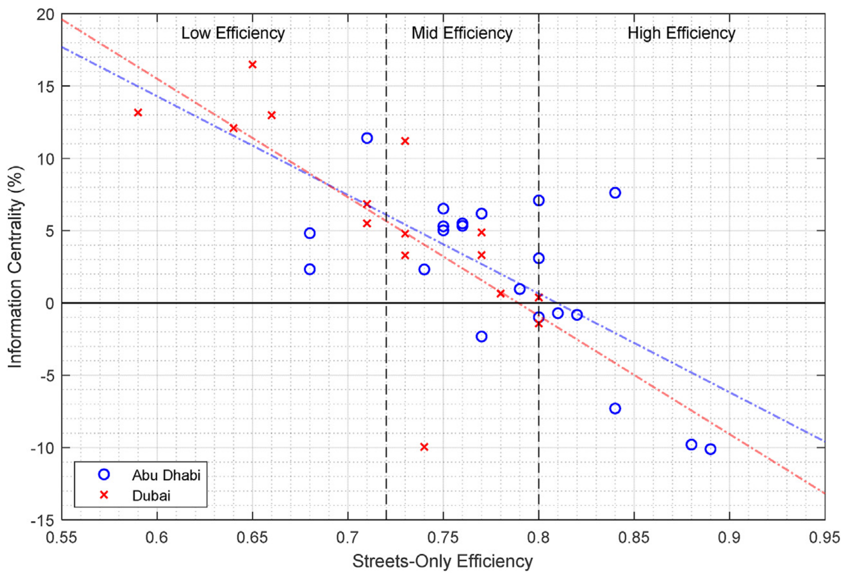


Fig. 8a. The correlation between street-only efficiency and information centrality in Abu Dhabi and Dubai. Dubai streets are generally less efficient than Abu Dhabi streets.

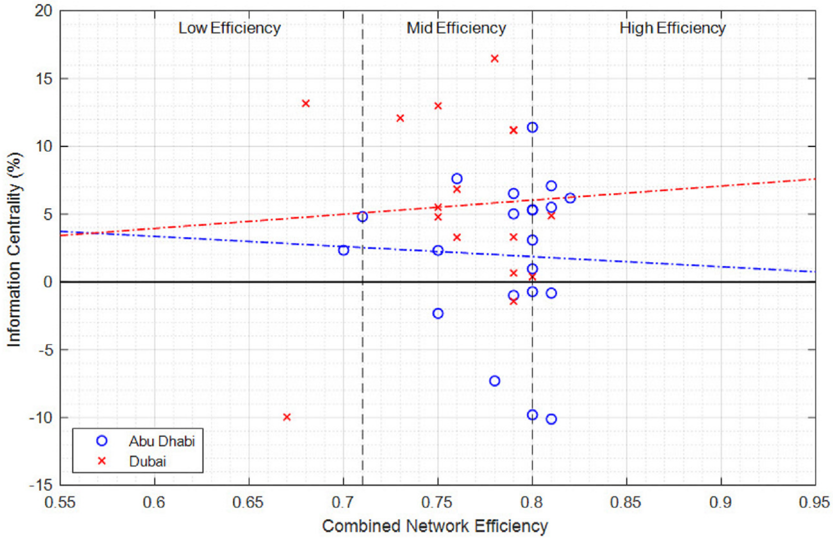


Fig. 8b. The correlation between the efficiency of the combined network (streets and alleys) and information centrality in Abu Dhabi and Dubai.

effect is diminished because these samples already have high street efficiencies. Other samples such as A2 and A18 of Al Bahya, as well as Sample A9 of West Island with varied levels of street continuity reveal that continuity is one of the factors that determine the level of Information Centrality. Nevertheless, continuity alone is not the single determinant of Information Centrality.

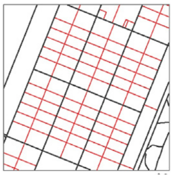
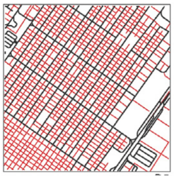
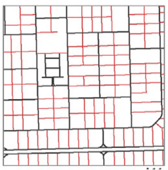
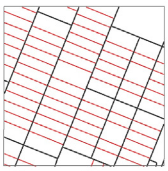
The second factor that determines the efficiency of the street network is the average segment lengths. In cases when the initial networks are already continuous, adding alleys can maintain continuity while also reducing block size and hence increasing the network efficiency. For instance, in Dubai Creek's Sample D4, introducing organic alleys leads to the division of large blocks into small blocks, thereby reducing the distance between intersections. Subsequently, the average segment length decreases while the network efficiency increases, as evident in Sample D4 (from 0.71 to 0.75). Other examples are neighborhoods such as Al Warqa (D11), Al Rashidiya (D8), Al Badaa South (D12), and Al Satwa South (D5) that have large block sizes (ranging from 120 m × 40 m–205 m × 75 m) and hence benefit the most by introducing alleys. This is because the alleys pass through the big blocks and facilitate easy movement across the blocks. For instance, in Al Badaa South (Sample D12), a high Information Centrality at 13.17% represents a notable increase in network efficiency. This finding corroborates previous research which has shown that compact layouts with smaller block sizes have higher connectivity efficiencies (Randall & Baetz, 2001). In addition, results have hinted that Information Centrality does not correlate with some physical attributes like the ratio of total street length and alley length in a sample.

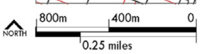
6.4. *Implications for practice*

There is a prominent presence of collector streets in almost all samples. The findings of this study indicate that if a collector street is present in a sample with minimal connections between the areas separated by the collector street, the network efficiency decreases significantly. In particular, when a collector street lies between two areas with high street and alley densities, it acts as a separating element and reinforces the discontinuity in the network. This leads to a condition where a higher number of nodes are unreachable. On the other hand, samples with shorter segments of collector streets (i.e., less than 1000 m) and frequent intersections have higher efficiency as compared to samples with segregating collector streets (i.e., more than 2500 m in length). For instance, Sample D6 in Al Quoz has a shorter collector street (i.e., 800 m compared to 2400 m in D10 Al Warqa) that provides more connections to areas located on both sides. This sample with a high network efficiency of 0.80 exemplifies that higher efficiency can be achieved by providing frequent connections with adjacent areas. On the contrary, Sample D10 in Al Warqa features a longer collector street segment, spanning 2400 m, in contrast to the 800 m found in D6 Al Quoz. This longer segment has fewer intersections, resulting in a lower network efficiency of 0.65. However, after the addition of alleys, the network efficiency increases to 0.78. Nonetheless, this figure remains lower than the initial efficiency of Sample D6 in Al Quoz, which focused solely on streets.

The network efficiency does not only depend on network morphology but also on the way local scale urban fabrics are integrated into their surrounding networks, creating a greater connection from local (400–1600 m) to global scales (more than 2000 m). The network acquires higher efficiency when there is higher interconnection to the surrounding urban fabric. In other words, if adjacent neighborhood blocks have seams instead of border vacuums, higher efficiency values are likely to be obtained due to the continuity of network segments. Seams are created when efficient pedestrian movement occurs between adjoining city blocks as opposed to the existence of abrupt edges that restrict or hamper the movement (i.e., when border vacuums exist) (Jacobs, 1961). Thus, Information Centrality values are also related to the integration between blocks or neighborhoods, which is scarcely explored in the existing literature by using quantitative measures. The integration between neighborhoods can reduce border vacuums and create a continuous network of walkable communities with a variety of route choices. The concept of neighborhood integration that was first raised by

Table 2
Various factors impact Information Centrality values, and the integration of alleys can lead to diverse contributions to network efficiency, contingent on factors such as continuity and the average length of street segments. Notably, not all grid layouts exhibit perfection, as illustrated in the case of Sample A2 in Al Bahya. However, there is evidence that fragmented street networks can be enhanced, as exemplified by the cases of Samples A11 in MBZ City and A18 in Al Bahya.

SAMPLE NAME		STREET & ALLEY TYPOLOGY	INFORMATION CENTRALITY	Initial Efficiency (Streets only network)	Efficiency of the combined network of streets and alleys	FACTORS INFLUENCING INFORMATION CENTRALITY VALUE
A2 AL BAHYA		Grid-grid combination of streets and alleys	Negative: −10.11%	0.89	0.81	Higher average street segment length at 262.5 m, and less continuous streets as compared to Sample D5 which also has grid streets with grid alleys.
D5 AL SATWA		Grid-grid combination of streets and alleys	Positive: 11.20%	0.73	0.79	Lower average street segment length at 107.5 m, and a presence of more continuous streets when compared to Sample A2, which has a similar grid layout but with larger length at 262.5
D9 AL QUOZ		Looping fragmented parallel street layout with fragmented alleys	Positive: 3.29%	0.73	0.76	The continuity of streets segments is increased when alleys are added to the network, resulting to an increased efficiency.
D12 AL BADAA		Looping fragmented parallel street layout with fragmented alleys	Positive: 13.17%	0.59	0.68	When alleys are added to the network, its streets continuity are improved and the large blocks are shortened significantly, leading to an increased efficiency.
D13 AL SATWA		Looping fragmented parallel street layout with fragmented alleys	Positive: 6.84%	0.71	0.76	The continuity of streets segments is increased when alleys are added, resulting to an increased efficiency.
A11 MBZ CITY		Fragmented parallel street layout with grid alleys	Positive: 5.33%	0.76	0.80	The continuity of streets segments is increased when alleys are added to the network, resulting to an increased efficiency.
A18 AL BAHYA		Fragmented parallel street layout with semi-grid alleys	Positive: 4.82%	0.68	0.71	The continuity of streets segments is increased when alleys are added to the network, resulting to an increased efficiency.



Jacobs in the 60s has been revisited by the principles of New Regionalism. New Regionalism emphasizes environmental and equity aspects of post-modern urban development, often highlighting the need to manage uncontrolled growth of city regions (Wheeler, 2002). The role of neighborhood design in integrating various parts of city fabrics and preventing leapfrogging disjointed developments has been emphasized (Wheeler, 2002).

The sample size used in this study (800 m × 800 m) is big enough to fit one superblock in the case of Abu Dhabi, and a couple of blocks that represent a particular urban typology in Dubai's case. Thus, the Information Centrality values of the samples also indicate the interconnection between adjacent blocks. Findings have revealed that network efficiency increases if the continuity of the network is improved. In addition, the reduction of the average block lengths also assists in enhancing efficiency. Finally, the application of alleys will be most helpful if the street network before the addition of alleys has low efficiency. This is evident from Samples 7H, 7I, and 7 E in Al Badaa, Al Satwa, and Al Quoz respectively (Refer to Table 1).

The results of this study also provide evidence that adding a great number of alleys does not always translate to high network efficiency. In other words, an adequate number of alleys need to be strategically placed to mitigate the drawbacks of the street layouts by enhancing street continuity and shortening the block lengths. For example, in Sample A10 of MBZ and Sample A18 of Al Bahya, 40% and 56% of the total network segments are alleys respectively. However, these samples have one of the lowest increments in network efficiency values at 0.02 in MBZ and 0.03 in Al Bahya when alleys are added. A proper utilization of the alley network can solve the deficiencies of the street network. If the initial efficiency is low, the network efficiency can be improved by strategic placement of alleys. In other words, in a neighborhood with high initial efficiency when only streets are taken, alleys have minimal scope to improve the existing network efficiency. For instance, Sample A2 in Al Bahya has an efficiency of 0.89 when only streets are considered, and there is no room for alleys to contribute notably.

7. Conclusion

This paper has evaluated the role of alleys in the combined network of streets and alleys. Results have proven the potential of alley networks to improve efficiency in most of the network morphologies. This study contributes to the conceptual as well as methodological understanding of the combination of street and alley networks. Information Centrality metric of the Multiple Centrality Assessment (MCA) has been utilized to re-examine the role of alleys and shed light on the scarcely explored topic of street-alley relationships. More specifically, the efficiency of networks before (i.e., street network) and after adding alleys (i.e., the combined network of streets and alleys) has been assessed by calculating Information Centrality in sample areas of Abu Dhabi and Dubai. Findings have shown that alleys can contribute positively or negatively to the network efficiency. The alleys in Abu Dhabi and Dubai cannot be considered as more important components than streets in the network as indicated by the Information Centrality values. Alleys can become the major component of the combined network only if the Information Centrality value of greater than 50% is obtained. However, none of the studied samples obtain Information Centrality values that cross the 50% threshold.

While the combined networks of streets and alleys in Abu Dhabi and Dubai do not meet the condition of being more important than streets, alleys in both cities still contribute to the network efficiency of the combined network. The contribution of alleys in terms of improving network efficiency is more significant if the street network has low efficiency. This study has also revealed that the strategic addition of alleys to the existing street network has a greater impact on Information Centrality rather than random inclusion of alley segments. In particular, the continuity or the extension of the existing street segments by alleys is one of the factors that determine the level of Information Centrality. If the addition of alleys maintains or enhances the combined network's continuity, then the network efficiency increases. Consequently, the increment of network efficiency results to a positive Information Centrality value.

Nevertheless, continuity alone is not the single factor that influences Information Centrality value. When large blocks are permeated by alley segments, smaller block lengths are obtained. Subsequently, the efficiency of the combined network increases because shorter blocks provide quicker access to all intersections in the network. This study repositions alleys as an important urban form element by providing insights about the contribution of alleys towards network efficiency. The study of alleys' efficiency and their role in the combined network of streets and alleys has an important implication for the planning and design of neighborhoods. Future studies can study integration between neighborhoods by calculating Information Centrality, or other MCA metrics to assess the neighborhood characteristics advocated by movements like New Regionalism that emphasize integration between neighborhoods, and other movements such as Transit-oriented development, Smart cities, Smart growth, Liveable Cities and New Urbanism that focus on neigbhorhood-scale elements like alleys. Future research can also focus on observing the real usage of alleys where the users are categorized by age, gender, nationality, and activity types. The correlation between alley typologies and how they promote or discourage specific uses can also be investigated. The mapping and categorization of alleys based on their cultural function, utilitarian function, or both can also be explored. Furthermore, an examination of the influence of physical attributes of alleys and streets, such as block size, network density, and intersection density, on network efficiency can be undertaken. Investigating the evolving dynamics, physical conditions and parameters, and functional uses of alleys stands as a critical pursuit, shedding light on the criticality of alleys and providing guidance for informed urban planning and design practices.

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CRediT authorship contribution statement

Asim Khanal: Formal Analysis, Data Curation, Methods Development, Writing – Review & Editing, Visualization, Development of Subsequent Drafts. Rawan Sohdy: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing First Draft–;

Review, Visualization. Khaled Alawadi: Conceptualization, Writing – Review & Editing, Supervision, Methods Development, Development of Subsequent Drafts, Project Administration. Ngoc Hong Nguyen: Conceptualization, Methodology, Validation, Writing First Draft.

Declaration of competing interest

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