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Article

A Grid Is Not a Tree: Toward a Reconciliation of Alexander's and Martin's Views of City Form

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Abstract

Christopher Alexander famously declared that "a city is not a tree," while Leslie Martin declared that "the grid is [a] generator." This article investigates how Alexander's call for overlap, adaptability, and order can indeed be manifested in grid networks, as Martin claimed. Order has been measured using the entropy of street orientation, while adaptability has been denoted by the streets' betweenness values. Through the analysis of Abu Dhabi's neighborhoods and global urban areas, the study reveals that overlap, order, and adaptability can coexist in gridded street network. A fine-grain scale of the grid plays a critical role in supporting the quality of urban space. To foster adaptation, planning policies should focus on adaptability providing room for informal and spontaneous growth. We conclude by noting that this approach represents a reconciliation between Christopher Alexander's views and those of Leslie Martin.

Keywords

Abu Dhabi; adaptability; betweenness; Christopher Alexander; grid; Leslie Martin; order; urban form

Issue

This article is part of the issue "Assessing the Complex Contributions of Christopher Alexander" edited by Michael W. Mehaffy (Sustasis Foundation) and Tigran Haas (KTH Royal Institute of Technology).

1. Introduction

Christopher Alexander is quoted as having said: "We both know what the appliance is. What we need to do now is to design the plugs to connect to the current power grid" (Alexander, 2004, as cited in Mehaffy, 2008, p. 69). He uses the power grid as a metaphor for the mass production process that is the substrate of modern civilization. Nevertheless, there are great concerns over issues of mass production. Koolhaas (1995, p. 28) laments that "this century has been a losing battle with the issue of quantity." Andres Duany compares the process of mass production with automated protocols in the real estate industry that enable residential and commercial buildings to be purchased and then developed in a single transaction (Mehaffy, 2008).

Alexander's metaphor equates the plug to a mechanism that takes advantage of mass production, making manufactured products more adaptable. The plug facilitates bottom-up and self-organized processes within a top-down system. Planners need to design a functional "plug": a mechanism or special modus operandi for generating bottom-up or self-organized processes.

To create a truly adaptable and vibrant built environment, planners must go beyond the traditional view of the grid as a mere generator of order. A grid network must be designed with qualities that promote efficiency while also fostering informal qualities and diversity. By doing so, planners can overcome the limitations of mass production in planning and allow for the free adaptation of built and non-built elements such as buildings, open spaces, and social activities.

The gridiron street network is ubiquitous in urban history; it has existed since the dawn of civilization to impose order and demonstrate control over nature (Mazza, 2009). From Hyppodamus of Miletus plan to China's Forbidden City (Kostof, 1991) and modern American cities, the grid has remained a fundamental planning language in building spaces. Its ability to facilitate rapid and efficient construction allows cities to expand at an unprecedented pace.

Leslie Martin (1972, p. 9) famously argued that the grid is not only a framework for urbanization but a tool for generating complexity in a city, associating that with "a net placed or thrown upon the ground." Meanwhile, Bettencourt (2015) recognizes that the grid, with its large number of possibilities, yields an endless array of social and economic arrangements in urban spaces. In his analysis of the gridiron network, Martin has argued that Alexander diminishes the value of such a system. However, this view seems to be at odds with Alexander's own position. In his seminal article "A City Is Not a Tree," Alexander (1965) referred to the gridiron as an exemplar of a system, which he later called a "semilattice." In fact, Alexander has used Manhattan—a gridiron urban environment—as a typical example of a grid that accommodates both order and complexity/adaptability. Thus, it is important to understand the nuances of Alexander's position on the gridiron network. Despite Martin's (1972) statement about "the grid as a generator," there is a dearth of research on the mechanism of this generator: the way a grid generates adaptability or its *modus operandi*. While several studies provide discourses about planned cities (Al Sayed et al., 2009), an analytic approach is needed to investigate the physical conditions that influence how well a grid can generate adaptability. This study attempts to explore how order and adaptability can *coexist* in a grid network and the physical conditions that facilitate these properties. Order has been measured from an analytical point of view. Boeing (2019) and Gudmundsson and Mohajeri (2013) have used entropies of street orientations to represent levels of order of a city. However, adaptability has not been measured explicitly in any research. This article devises a new approach for measuring adaptability, known as the quality of a semilattice system which in turn can be defined in terms of overlapping as stated by Alexander (1965). A semilattice, as defined by Alexander (1965), is a network of elements that are connected in a way where multiple paths between any two points are possible. This semilattice structure allows for redundancy and flexibility, as any element of this structure can be reached through multiple routes. In the context of this article, a semilattice concept is used to measure the adaptability of a grid network, as it allows for multiple connections and routes between elements whether they are nodes or edges, which can facilitate the emergence of bottom-up and self-organized processes within the top-down system.

The article examines betweenness values and entropies of street network orientations—proxies for the adaptability and order of grid networks. To categorize cities with diverse street patterns in terms of order and adaptability, the article assigns these proxies to the vertical and horizontal axes, respectively, to quantify order and adaptability for street networks. Specifically, using Abu Dhabi's street network as a case study, the article aims to answer the following questions:

1. How do adaptability and order operate and manifest in a grid network?
2. What morphological properties of a grid act as generators for adaptability and order? To what extent do adaptability and order perform in a grid network?
3. What strategies can be used to design street networks to accommodate both order and adaptability?

This article investigates seven neighborhoods in Abu Dhabi. In each neighborhood, three sample areas with the same size of one square mile are selected. To give a meaningful understanding of the way grid networks operate, Abu Dhabi's neighborhoods are compared with those of 60 other urban areas throughout the world. The cities are selected to represent diverse network types and are located in different geographical and cultural conditions. Through this comparison, a thorough understanding of the mechanism that makes a grid network become "great streets" emerges.

2. Literature Review

2.1. Virtues of a Grid Network

On the 50th anniversary of the publication of Alexander's article "A City Is Not a Tree," Porta et al. (2015) rediscovered the value of Martin's argument on gridiron networks. "The grid is a generator" is a provocative essay in which Martin (1972) pointed out that the grid is a tool to generate complexity in a city. According to Martin (1972, p. 75), a grid network is "a kind of playboard that sets out the rules of the game." The game's players are stakeholders who act according to the rules but have the freedom to use whatever initiatives and skills they have. This essay is Martin's refutation of Alexander's (1965) article. Martin criticized Alexander for diminishing the value of a gridiron network, an erroneous rejection. In fact, Alexander asserted that a gridiron is a typical example of a semilattice system and that it promotes the adaptability that is essential for "natural cities." Despite Martin's misjudgment, his support for a gridiron network was insightful: a grid is "an 'organic' growth and, without the structuring element of some kind of framework, is chaos" (Martin, 1972, p. 75). Furthermore, he stated that the grid sets a particular structure for a city but then allows a city to develop and grow in its own way. Martin's observation about the grid's merits in supporting organic growth is congruent with the quality of "the semilattice structure of natural cities" proposed by Alexander (1965, as cited in Porta et al., 2015, p. 121).

Martin recognized the grids' positive qualities. Yet, he admitted the grid's drawbacks, such as its monotony and rigidity. The way a grid accepts and responds to growth and change is conceptualized in this article as its adaptability. To understand "the interaction between the grid and the built form" (Martin, 1972, p. 76) or the "combinatorically large number of possibilities" (Bettencourt, 2015, p. 45), we use order and adaptability as the key performance indicators for the grid.

2.2. Urban Order

Order is usually perceived as good and disorder as evil. Nevertheless, this distinction is not always sharp. Aferi (2011, p. 54) states that it is "somewhat fuzzy," and Kostof (1991, p. 44) argues that the "irregularity of unplanned cities is also a matter of degree." He emphasizes that this kind of distinction is a matter of the "metamorphosis" of regularity/planned/order vs. irregularity/unplanned/disorder. It is not hard to see the comingling of order and disorder that is pervasive in traditional cities. Therefore, the cohabitation of irregular and planned street networks is not just a natural phenomenon but also an exemplar of a good city form.

In this article, the term order is used in line with Aferi's (2011, p. 44) explicit order—"the recognizable and explicit order in street layouts, consistent setbacks, and coherent physical and visual attributes." Recent works on assessing the order of street networks use street orientation entropy as an assessment measure (Boeing, 2019; Gudmundsson & Mohajeri, 2013). This article implements their method to quantify the level of order of a grid network. There are several other methods used in the literature for quantifying urban order. One example is the spatial autocorrelation analysis, which examines the degree of similarity in spatial patterns of different urban attributes. For instance, some researchers have proposed using fractal dimensions to measure urban order. For example, Frankhauser and Pumain (2022) applied fractal geometry for a better understanding of the hierarchical organization and spatial structure of urban order. Similarly, Jia et al. (2019) employed the correlation fractal method to explore place diversity at the neighbourhood scale in Brisbane, Australia. By measuring the spatial correlation between the density of buildings in a given area and its surrounding, the study found that Brisbane's urban form lacks place diversity and is influenced by modernist planning principles. These approaches demonstrate the diverse methods available for quantifying urban order and highlight the importance of using multiple measures to capture the complexity of urban form and its function. This article uses Boeing's (2019) and Gudmundsson and Mohajeri's (2013) methods to quantify the level of order in a grid network.

2.3. Adaptability

Thinkers such as Alexander and Jane Jacobs criticized the simplified tree pattern of a city, not order nor gridiron street patterns. Alexander particularly advocated for the semilattice structure, in which urban elements overlap and interact. Porta et al. (2015) explain further that the amalgamation of streets, block design, and placement of buildings should not separate activities from one another, but rather should promote integration between people and the built environment. The lesson here is that street patterns should "naturally overlap in space in unpredictable ways" (Porta et al., 2015, p. 123) and thereby build favorable conditions for overlapping activities to take place.

The general perception is that adaptation and self-organization happen in informal settlements (Kamalipour, 2016, p. 71), but incremental transformation also happens in a planned city, exemplified in its grid network. Adaptation is often perceived as transformation through time. To our best knowledge, adaptability has not been measured explicitly in any research. Thus, this article devises a new approach to measuring adaptability, the quality of a semilattice system which is in turn defined as overlapping (Alexander, 1965). The article finds that levels of movement on a street segment represent overlapping activities in a street network. This value of movement is known as betweenness centrality, a measurement of movement intensity a street segment through many shortest paths connecting different couples of nodes (Porta et al., 2006).

3. Methods

In this article, order and adaptability of street networks of Abu Dhabi and other international urban areas are quantified as entropies and betweenness centrality. These values are then plotted along vertical and horizontal axes.

3.1. Sample Selection

Seven neighborhoods in Abu Dhabi are selected as case studies. The selection includes West Island, Khalifa City, Al Bahya East, Al Bahya West, Mohamed Bin Zayed (MBZ), Al Falah, and Bani Yas (Figure 1). From each neighborhood, three sample areas of one square mile are selected, following the tradition of urban network study by Jacobs (2001). The neighborhood planning units (NPUs) are ordered chronologically from 1968 to 2015, representing the evolution of neighborhoods over 50 years. Each NPU is unique in terms of its street layout and level of grid-likeness. Moreover, the samples included street networks with different levels of grid-likeness, ranging from the perfect grid to high levels of fragmentation and cul-de-sacs.

To acquire a reasonable understanding of grid network structures, the study meticulously compares samples of Abu Dhabi's neighborhoods with other urban neighborhood samples taken from 60 cities worldwide (Figure 2). In order to ensure consistency, each city is represented by three sample areas measuring one

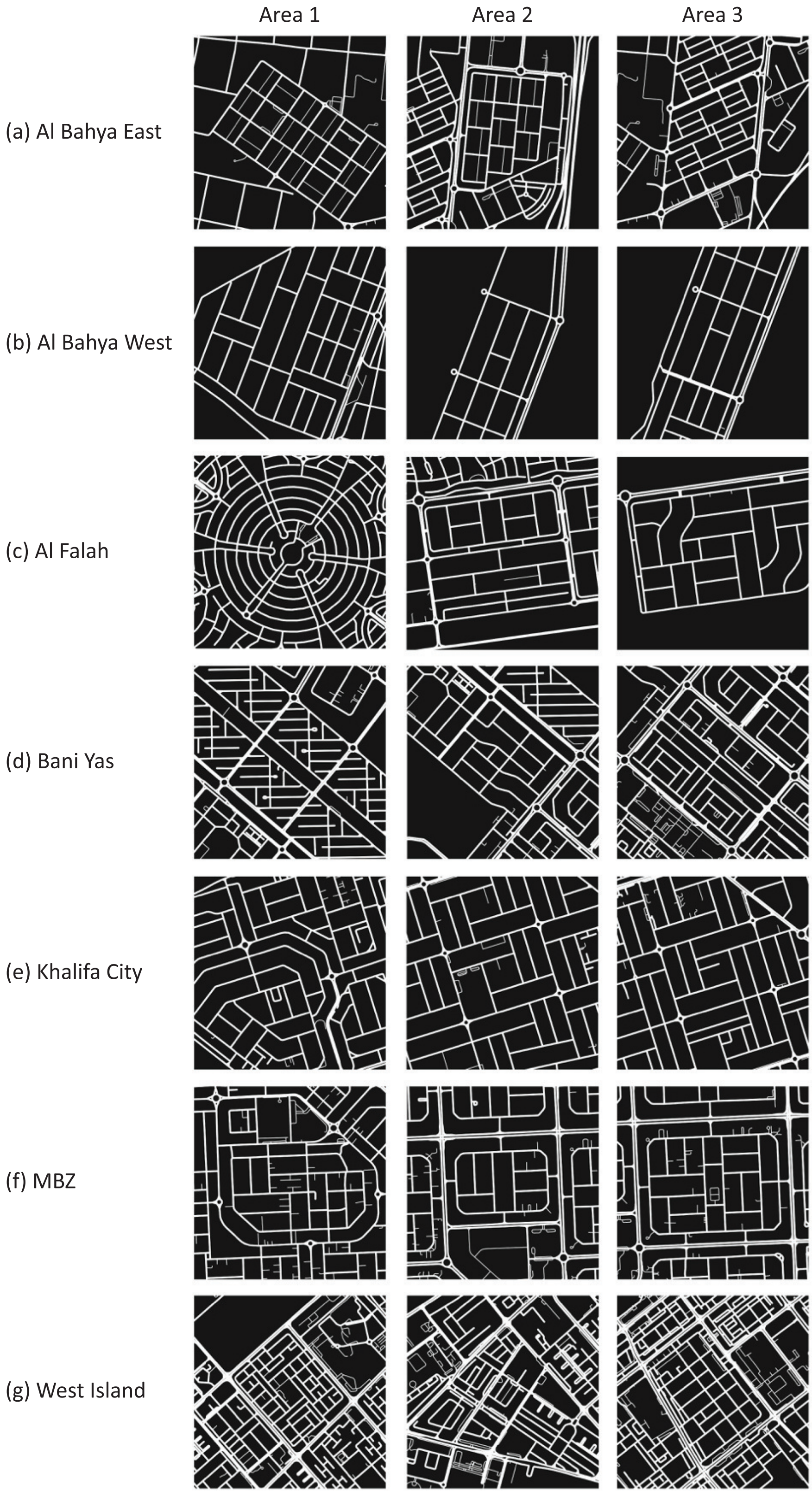

Figure 1. Street networks of Abu Dhabi's neighborhoods.

square mile, mirroring similar approaches conducted in previous studies (Jacobs, 2001; Porta et al., 2006; Scoppa et al., 2018). The street networks of Abu Dhabi and the international case studies were retrieved using OSMnx, a tool developed by Boeing (2017, 2019) that allows users to download, model, analyze, and visualize OpenStreetMap data for any location in the world. It provides a simple and efficient way to download and work with OpenStreetMap data, including street networks, building footprints, points of interest, and other features.

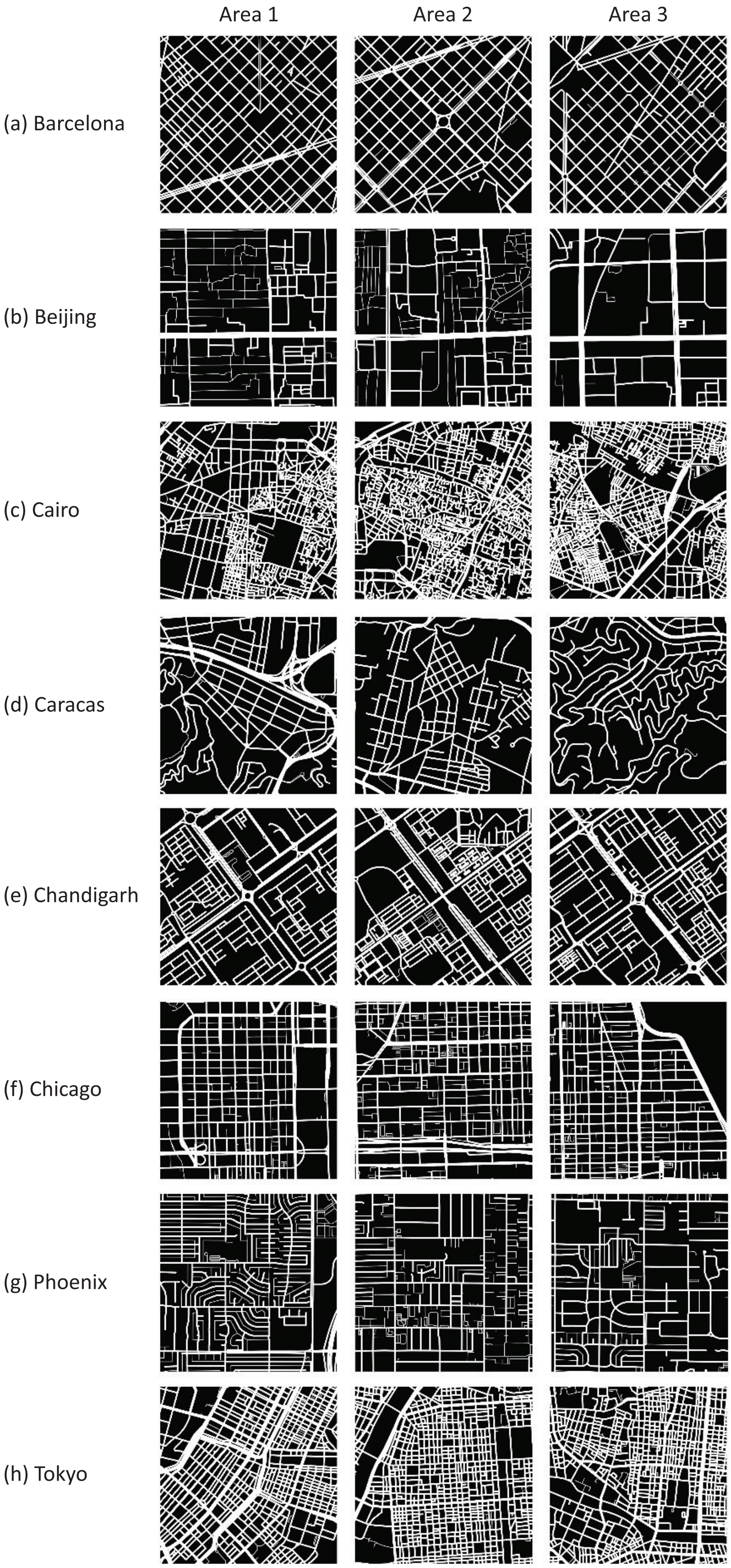

Figure 2. Street networks of selected international urban areas.

Additionally, OSMnx offers a range of network analysis tools that enable users to measure network metrics such as degree centrality, betweenness centrality, and clustering coefficients. Overall, OSMnx is a powerful tool for urban planners, geographers, and researchers interested in studying urban form and function (Yabe et al., 2022). The selection of the comparison urban areas is inspired by Jacobs' (2001) and Boeing's (2017, 2019) works. Both authors use diverse urban street networks from different regions and cultures to represent the whole gamut of street configurations, from the most connected and grid-like to the most circuitous and fragmented.

3.2. Measuring Order

According to Gudmundsson and Mohajeri (2013), the Shannon (1948) entropy of a city's network system represents the order of street orientations in that city. The higher the entropy, the higher the level of disorder in its neighborhoods. To compare the level of order of each NPU or urban area, the normalized value of orientation entropy ϕ, developed by Boeing (2017), is computed. This value represents the level of disorder or uniformity of street networks in a city or neighborhood. The smallest value of ϕ is 0, which represents complete disorder, while $\phi = 1$ represents perfect order. Values of entropy of 21 NPUs of seven neighborhoods in Abu Dhabi and 180 samples of 60 other urban areas are computed. Implementing the same size of one square mile facilitates a comparison of order levels across different geographic locations. By comparing the adaptability and order of Abu Dhabi NPUs with those of other urban areas, the mechanism for building order and adaptability in a grid network can be understood.

3.3. Measuring Adaptability

Grid is a generator of order. However, its capacity for adaptation is unknown. Kostof (1991), Lynch (1981), Porta et al. (2015), and other scholars state that a grid can adapt to different topographic regions. But the questions of how and in what way a grid can facilitate both adaptability and order and how these qualities manifest in different grid typologies remain unanswered. Alexander (1965) mentions that adaptability is represented in *overlapped elements*. He argues that a natural city (e.g., a self-organized settlement) contains various levels of overlap. This overlapping structure is what Alexander called *semilattice*, a structure that possesses many overlapping characteristics yet maintains order. To measure the flexibility of a grid and its capacity for adaptation, the article evaluates its level of overlap.

In discussing the street network, Bettencourt (2015, p. 50) argues that "while infrastructure and economic activities, for example, change radically, the fact that people need to interact over space remains." He elaborates on Alexander's idea of the overlap of a semilattice network, arguing that "it is people who, through their movement and multiplicity of functions, create overlaps between places in the city." Hence, the more the people's movement takes place on the streets, the more overlapping occurs.

Consider an example of a street segment which connects buildings A and B, as in Figure 3. When people move from building A to building B, they not only implement a movement but also carry out a functional and social activity along their path from space A to space B and vice versa. Therefore, the number of movements on the street segment represents levels of overlapping activities between buildings A and B. In centrality analysis, measuring the movement intensity of a street segment is known as betweenness, which accounts for how many times a street segment was part of multiple shortest routes connecting pairs of nodes (Porta et al., 2006). To illustrate the rationale for using betweenness as a proxy for measuring adaptability of the street networks, Figure 3 presents a diagram showing the way betweenness values represent the potential overlapping activities in a theoretical grid network. Street segment b2 represents the level of overlapping activities between A and B, A and C, and A and D. The same patterns happen with overlapping activities for B (to A, C, D), C (to A, B, D), and D (to A, B, C). A segment of streets that is selected most for walking is the segment that has the highest betweenness value. Therefore, this segment has the highest level of activity. The activities can be any social or functional movements (e.g., shopping or commuting). These activities require shared spaces, and these spaces are the streets that have high betweenness values. Thus, the authors argue that the betweenness centrality represents levels of overlapping in a network. The higher the mean value of betweenness in a street network, the more likely it will be traversed by people. This reflects the network's increased adaptability. Due to the absence of a betweenness benchmark for assessing what is the level of adaptability that is acceptable, the best assessment of betweenness values is to compare them against a cohort of cities that are known for having high levels of adaptability, such as Manhattan, Barcelona, and San Francisco (Jacobs, 1961).

To measure the adaptation, the authors calculate the betweenness values using momepy, a Python package developed by Fleischmann (2019). Using the analysis and manipulation of urban form and street networks, the package provides a range of tools for calculating various metrics related to street networks, such as block shape and size, street centrality, and connectivity. It also includes functions for visualizing and plotting network data. The momepy package is designed to work with OpenStreetMap data, making it a valuable tool for researchers and urban planners interested in analyzing and modeling urban environments.

To understand the correlation between order and adaptability, and especially to understand the impacts that order has on adaptability, a linear regression between entropies and logarithmic values of

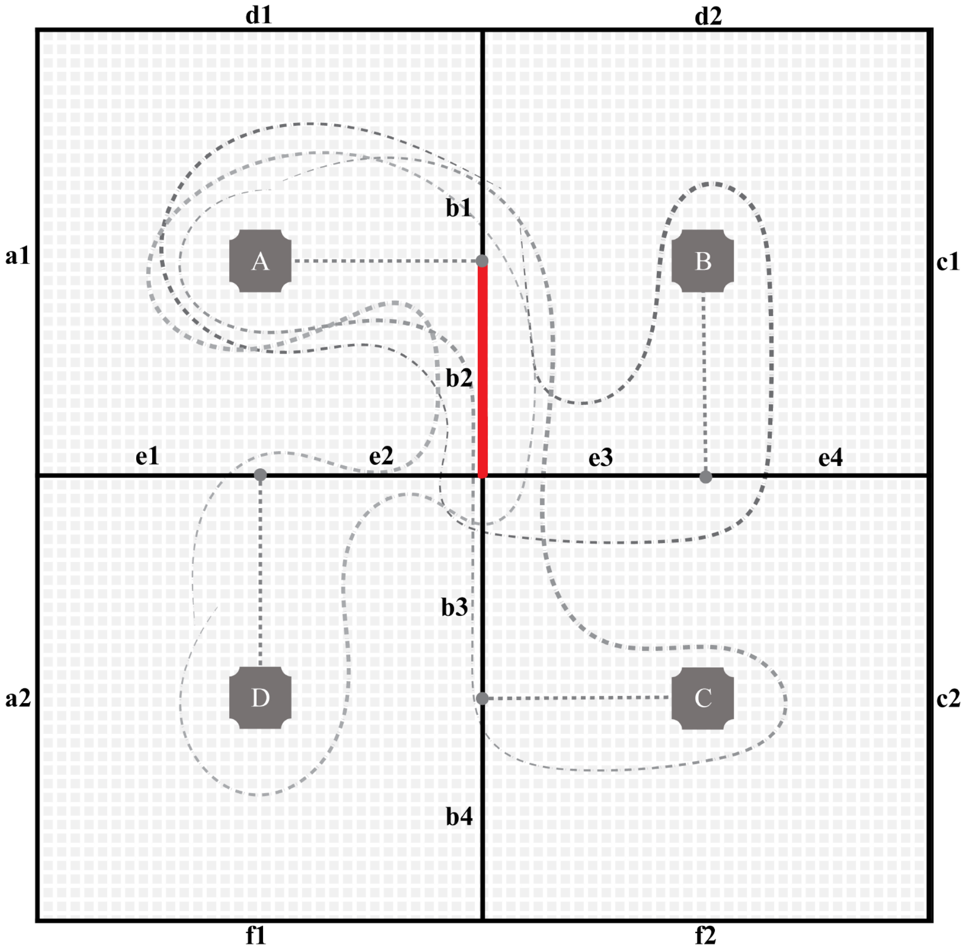

Figure 3. Overlapping activities from A to B, A to C, and A to D for the theoretical case of a grid network.

betweenness is modeled. The linear regression provides an understanding of the impact that order could have on adaptability.

4. Results

4.1. Order

Table 1 presents the indicators for the 21 samples of one square mile of the seven neighborhoods in Abu Dhabi. Among these seven neighborhoods, Al Bahya West, Khalifa City, Al Falah, and MBZ have the highest levels of order, with a ϕ of 0.98, 0.86, 0.84, and 0.83, respectively. West Island has the lowest level of order, with ϕ = 0.62. According to Boeing (2019), a perfect grid would have an entropy value of ϕ = 1. This means that West Island is 62% ordered, while Al Bahya West, at 98%, is close to being perfectly ordered. The same kind of interpretation applies to Khalifa City, Al Falah, and MBZ. The ϕ values can also be interpreted as closeness to a perfect grid. The higher the ϕ, the closer the neighborhood's street network is to a perfect grid. Moreover, order is expressed differently for the pre- and post-1990s neighborhoods. Five out of seven studied neighborhoods that have been built since 1990—Al Bahya East and West, Khalifa City, MBZ, and Al Falah—have high levels of entropy, ranging from 0.82 to 0.98. In contrast, neighborhoods built before the 1990s, including Bani Yas and West Island, have moderate to moderate-low levels of order (0.74 and 0.62, respectively). Hence, with an average value of order ϕ = 0.81 and five out of seven studied neighborhoods with ϕ values larger than 0.82, Abu Dhabi can be labeled as a city of high order.

4.2. Adaptability

Ranking Abu Dhabi neighborhoods in terms of movements—represented by the mean values of betweenness—the analysis reveals that West Island, with a betweenness value of 7,193, has the greatest number of movements (Table 1). This value indicates that West Island has the highest level of overlap. While West Island has the highest betweenness value, it has the lowest level of order, with ϕ = 0.62. In contrast, Al Bahya West has a mean betweenness value of only 118 but the highest level of order, with ϕ = 0.98. Other neighborhoods' values of order and betweenness tend to confirm the trend of lower order/higher betweenness and vice versa. The differences in betweenness values are substantially different from the highest to the lowest

Table 1. Mean values of betweenness and normalized entropies of one-square-mile samples of selected world's urban areas.

City	H_o	ϕ	B	$\log_2 B$	Block size (m)
West Island	2.74	0.62	7,193	12.81	58.3
Bani Yas	2.51	0.74	2,010	10.97	82.9
Al Bahya East	2.27	0.82	1,499	10.55	88.4
MBZ	2.3	0.83	1,323	10.37	101.1
Khalifa	2.19	0.86	838	9.71	108.6
Falah	2.17	0.84	750	9.55	136.5
Al Bahya West	1.66	0.98	118	6.88	192.8
Beijing	2.18	0.87	1,038	10.02	110
Shanghai	2.68	0.65	4,047	11.98	92.2
Tokyo	2.89	0.53	29,860	14.87	33.1
Barcelona	2.71	0.64	10,770	13.39	41.5
Moscow	2.84	0.56	21,307	14.38	43.2
Paris	2.75	0.61	7,174	12.81	50.3
Caracas	2.54	0.72	1,022	10	116.3
Boston	2.84	0.56	9,457	13.21	49.4
Chicago	2.73	0.62	10,157	13.31	47.1
Manhattan	2.58	0.69	5,895	12.53	53
Phoenix	2.44	0.76	3,315	11.69	87.8
San Francisco	2.6	0.69	11,206	13.45	45.5
Washington	2.64	0.66	12,034	13.55	47.1

values in Abu Dhabi. West Island has a betweenness value 60 times higher than the betweenness value of Al Bahya West. This significant difference among the overlapping level of Abu Dhabi neighborhoods indicates that older neighborhoods are more adaptable. Bani Yas and Al Bahya East confirm this: Bani Yas has the second-highest level of adaptability, with a betweenness value of 2,010, and Al Bahya East has the third-highest level of adaptability, with a betweenness value of 1,499.

Figure 4 demonstrates the relationship between the betweenness values and ϕ values for Abu Dhabi's NPUs. Neighborhoods in Abu Dhabi can visually be grouped into two main groups and two outliers. Bani Yas, built during the 1970s, is the only member of the first group of Abu Dhabi's neighborhoods. It has a mean value of betweenness of 2,010 and a ϕ value of 0.74, which makes it quite different from the rest of the neighborhoods but not different enough to make it an outlier as in the cases of West Island (very high betweenness/low entropy) and Al Bahya West (very low betweenness of 118/very high entropy). The second group includes Al Bahya East, MBZ, Al Falah, and Khalifa City. This group has ϕ values that increase from 0.82 to 0.86 and mean betweenness values that decrease from 1,499 to 750. As shown in Figure 4, these neighborhoods form the second group of street networks in Abu Dhabi.

5. Discussion

5.1. Abu Dhabi: A City of High Order and Low Adaptability

Abu Dhabi's neighborhoods accommodate a high level of order. Its obtained normalized entropy has a high average value of ϕ = 0.81. The level of adaptability, in contrast, is quite low. The average value of betweenness is only 1,962. Except for the two outliers of very high and low adaptability of West Island (7,193) and Al Bahya West (118), the average adaptability of the five neighborhoods Bani Yas, Al Bahya East, MBZ, Khalifa, and A Falah reaches only 1,284.

The high order and low adaptability in Abu Dhabi neighborhoods may be attributable to its history of having been planned and developed from a barren semi-island—a tabula rasa—and having used a top-down planning system since its inception. However, it is not evident whether cities with superblocks or NPUs always produce urban areas with high order and low adaptability. To unravel this issue, the authors assess a variety of grid networks, from the most fragmented to the most grid-like, of different urban regions around the world.

Sixty urban areas around the world have been selected; they represent diverse types of street networks from the most connected, organic, and grid-like to the

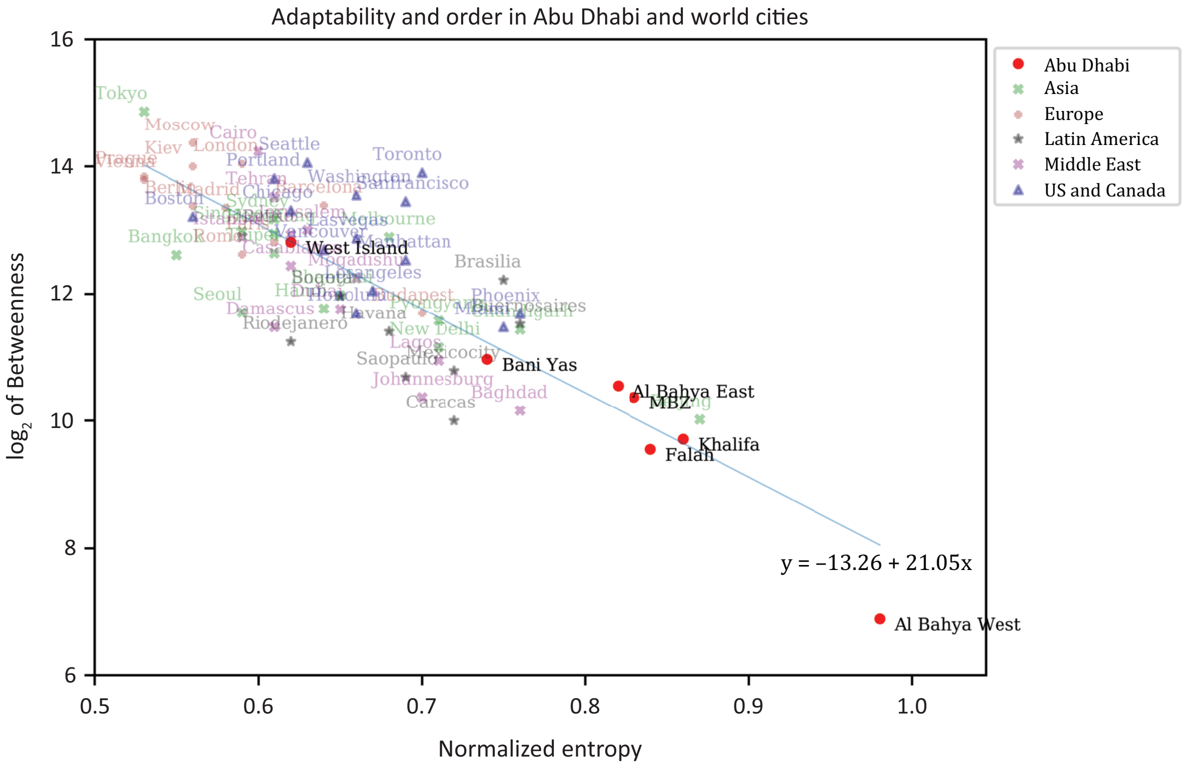

Figure 4. Relationship between order and adaptability of Abu Dhabi's NPUs against the world urban areas.

most circuitous and fragmented (Table 1). The street networks of Manhattan, Chicago, Barcelona, and Paris represent almost perfect grids yet hold a high quality of urban life (Boeing, 2019; Jacobs, 2001). Figure 4 represents the relationships of adaptability and order of different groups of Abu Dhabi neighborhoods and these global urban areas. The figure includes two outliers: Tokyo, which has an exceptionally high betweenness value and low order (29,860 and 0.53, respectively), and Beijing, which has a low betweenness value and high order (1,038 and 0.87, respectively). The adaptability and order of the world's urban areas closely follow an inverse logarithmic linear relationship. The higher the values of betweenness, the lower the values of order, and vice versa.

To assist in the evaluation of adaptability and order in grid networks, the authors propose classifications for both based on values of betweenness and normalized entropies. Values of adaptability are classified into very high (betweenness of 13,000 or higher), middle-high (5,000–13,000), middle (2,000–5,000), low (1,000–2,000), and very low (below 1,000). Similarly, values of order are classified into high ($\phi > 0.8$), middle-high ($\phi = 0.6$–0.8), and middle (ϕ from 0.5 to 0.6); the analysis revealed no middle-low or low order values among the cities tested ($\phi < 0.5$).

The comparison of levels of order between Abu Dhabi and other global urban areas reveals that Abu Dhabi's neighborhoods are more ordered than any other city in the world. For example, among the studied urban neighborhoods (except for those in Beijing), the highest level of order, $\phi = 0.76$ for Phoenix, is smaller than the value for five of the seven neighborhoods in Abu Dhabi ($\phi = 0.82$). Phoenix's ϕ value is only higher than those of Banis Yas (0.736) and West Island (0.622).

Similarly, comparing the adaptability of Abu Dhabi neighborhoods with the world's urban areas reveals that Abu Dhabi has a lower level of adaptability. Table 1 demonstrates that Al Bahya West, the neighborhood with the city's highest level of order ($\phi = 0.98$), has a mean value of betweenness of 118. This betweenness value is substantially lower than that of any comparable global urban area (the lowest mean betweenness value for the comparison cities is 1,022, in Caracas).

5.2. The Coexistence of Order and Adaptability

Figure 4 shows the relationship between normalized entropy and betweenness for Abu Dhabi and the comparison urban areas. It indicates that all neighborhoods in Abu Dhabi and the comparison cities feature an inverse logarithmic relationship between adaptability and order. For example, West Island and Prague have high levels of overlap (7,193 and 14,546, respectively) while their levels of order are low ($\phi = 0.62$ and $\phi = 0.53$).

To answer the first research question on how adaptability and order operate and are manifested in a grid network, the analysis investigates the *coexistence* of order and adaptability. An urban area that has the highest level of adaptability with a low level of order is Tokyo (the mean value of betweenness of 29,927 and $\phi = 0.53$). In Abu Dhabi, the high adaptability/low order relationship expresses a similar trend in the case of West Island with a mean betweenness value of 7,193 and ϕ = 0.62. This relationship of high adaptability/low order becomes clearer for the rest of the other neighborhoods.

In most cases, for the "good" urban network, the level of order has an upper limit around ϕ = 0.7. From the regression calculation that is developed in Section 3, a change in the value of ϕ from 0.7 to 0.6 generates an increased value of betweenness of 5,276, and a change from ϕ = 0.6 to ϕ = 0.5 generates a greater increase in the value of betweenness of 13,204. Respectively, these are 17% and 44% increases in values of betweenness compared with the value of betweenness of Tokyo, the city with the highest level of adaptability. Because the relationship between adaptability and order is an inverse-power relationship, a small decrease in order can yield a significant gain in betweenness. This observation is correct in both Abu Dhabi and the comparison urban areas. In most cases, it appears that ϕ values of 0.68–0.7 tend to be the highest threshold for cities that have a high level of adaptability. One example is Manhattan, with ϕ = 0.68 and a betweenness value of 5,838. Thus, if a city can trade a small amount of order, a significant level of adaptability can be gained. This observation answers the first question: Order and adaptability can coexist in grid networks.

To answer the question about the morphological properties of a grid that acts as a generator for adaptability and order, the article focuses on neighborhoods and urban areas with high levels of adaptability. The street networks with nonhierarchical order tend to have high adaptability—Tokyo, Cairo, and West Island are examples. The authors consider that this nonhierarchical order facilitates movement in neighborhoods. Small block sizes and small average street lengths characterize all neighborhoods and urban areas that have high levels of adaptability, and grids with values of betweenness above 5,000, in general, have average street lengths less than 60 m (Table 1). Betweenness maps of urban neighborhoods with high and low values of betweenness in cities such as Tokyo and Beijing or West Island and Al Bahya West show striking contrasts. Observing streets in the first quantile (i.e., streets in red) of betweenness reveals an important point. Thoroughfares, streets that accommodate various types of vehicular traffic and speed (Mehaffy et al., 2010), in cities with high adaptability—Tokyo and West Island, for example—usually divide the areas into several small parts. In contrast, cities or neighborhoods with low adaptability, such as Beijing and MBZ, only have two or three of these thoroughfares, which divide the areas into much larger pieces. Therefore, neighborhoods with fine-grain street networks are often conditioned for high adaptability (Figure 5). It also means that streets in cities with high adaptability configure areas into small blocks, whereas streets in cities with low adaptability divide the sample areas into large blocks. Consequently, fine-grain networks are better in terms of adaptability.

Thus, the general guidelines for designing a street network with high adaptability and an adequate level of order are small blocks, fine-grain street networks, and nonhierarchical grades of street systems (i.e., the avoidance of classification of street networks into arterials, highways, local roads, etc.). The neighborhoods with low adaptability in Abu Dhabi and the comparison cities have opposite patterns: super-block designs, disconnections between blocks, and rigid hierarchical street systems.

5.3. The Desirable Networks: Implications for Practice

The above observations have implications for the grid as the manifestation of mass production. Findings about adaptability and order in Abu Dhabi and the world's urban areas indicate that a street network with a middle-high to a high level of adaptability (a betweenness mean of around 5,000 or above) and an adequate level of order (ϕ between 0.6 and 0.7) is a desirable network. These networks are desirable because they have both qualities: adaptability and order. A high level of adaptation equates to a high level of overlap, the very quality that Alexander (1965) used to describe "natural cities." While a grid network needs an overall framework to provide an adequate level of order, it also needs fine-grain urban elements (e.g., small streets, small and diverse open spaces, small blocks, etc.) to foster adaptability.

Several implications can be drawn from this study. First, the scale of the grid (i.e., the dimensions of a network) plays a critical role in supporting or impeding the quality of urban space. The cases of Manhattan and Barcelona are examples. Both cities have the capacity to "accept and respond to growth and change" because of their low levels of order and high levels of adaptability. The key lies in their fine-grain structure. Their average street lengths are all less than 60 m: 58.3 m in West Island, 53 m in Manhattan, and 41.5 m in Barcelona. These low numbers are critical indicators of significant overlapping of movements and activities. These street lengths are quite small in comparison with those of Beijing (110 m) and Caracas (116.3 m). The betweenness maps show that streets in the first quantile of betweenness tend to run straight through most sampled areas (Figures 3.1 and 3.2 in the Supplementary File). These movements distribute the flow of people to different parts of the studied areas, not unlike the "city mobility and fluidity of use" that Jacobs (1961, p. 117) praised.

Second, this finding implies that even though the overall framework of a grid is considered rigid in form, there are conditions that can promote its adaptability. These conditions facilitate the capacity to add new or adjust old physical components—e.g., streets or small open spaces—while maintaining the overall order. If the blocks are too big, as in the cases of Beijing and Caracas, inserted elements can disrupt and bring more chaos, while small blocks such as those of Tokyo and Cairo generally allow for inserting small physical components without disrupting the area; this is, in fact, an incremental development that urbanists advocate for in their research (Alexander, 1965; Jacobs, 1961).

Figure 5. Betweenness maps of selected samples in Abu Dhabi and world cities.

6. Conclusion

This study assesses order and adaptability of street networks. It also introduces a new method to quantify the network's adaptability. While previous research has used street orientation to measure order, this article argues that betweenness values can be used to measure a street network's adaptability. The article found that West Island has the city's highest level of adaptability and an adequate level of order. The remaining studied neighborhoods have lower levels of adaptability when compared with neighborhoods in other world cities. Al Bahya West, for example, has the smallest value of adaptability.

The article discovers that order and adaptability *can coexist*. Urban areas such as Toronto, San Francisco, Manhattan, and West Island have a high level of adaptability while still possessing a decent level of order. Furthermore, if a city can sacrifice a small degree of order, a higher level of adaptability can be obtained. A reduction in the value of the normalized entropy from 0.7 to 0.6 or from 0.6 to 0.5 increases by 17% or 44%, respectively, the value of betweenness in Tokyo—the city with the highest level of adaptability.

This study reconciles the contrasting views between Alexander and Martin. At first glance, it seemed that Alexander's view of cities as "semilattices" with interconnected elements and feedback loops implied that grid networks are not capable of accommodating adaptability and organic growth and change. In contrast, Martin promoted grid networks as a tool to provide a framework for organic growth that breaks away from rigid order, offering higher degrees of freedom and overlapping in activities.

Both Alexander and Martin's views on grid networks are actually not far from each other as this article demonstrated quantitatively. The article proves that grid networks can indeed accommodate growth and change. The regularity of the grid provides a stable foundation that enables a high degree of adaptability and flexibility in a city's development over time. In other words, the grid is a flexible and adaptable structure that can support a diverse and dynamic urban environment.

This study is a revisionist view of the gridiron network—a mechanism of mass production in an urban environment—arguing that the grid has the capacity to produce adaptability and order. The question now is not whether to abandon the grid but how to enhance its adaptability. The research concludes that scales of grid networks play a critical role in supporting or impeding the quality of urban space (i.e., highly adaptable spaces enable high levels of human interaction and support informal development). These activities are manifested in human movements and fluidity. They are facilitated by fine-grain urbanism that improves urban adaptability. Finally, a mechanism for generating bottom-up or self-organized processes can help break the rigidity of the superblocks that are present in many urban areas.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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