THE FRACTALITY OF A GARDEN CITY: A COMPARISON OF THE RELATIONSHIP OF ROAD NETWORK AND GREEN SPACES IN SINGAPORE AND QUEZON CITY, PHILIPPINES

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ABSTRACT

This study is a comparison between a model garden city and an aspiring garden city in terms of the relationship between the spatial pattern and distribution of the road network and the structural characteristic of the surrounding green spaces using fractal analysis. ArcGIS was utilized to determine the fractal dimension of the road network and green spaces of Singapore and Quezon City. The box-counting method of measuring fractal dimension (FD) was employed to define the degree of irregularity and heterogeneity of green space fragments and road network. With the aid of correlation and covariance analyses, the research identifies the degree of relationship between the two variables in the two study areas. Results show that the FD of patches in Singapore is higher than its road network compared to the patches in Quezon City which has lower FD than its road network. But a stronger relationship between the two variables was seen in Quezon City which may suggest that the road network in Quezon City has more influence on the fractality of its patches. The obtained values, however, were not conclusive enough to determine the fractal attributes of a garden city's road network and ecological patches. Differentiating the fractal attributes of the variables in the two study areas may gather more substantial fractal description through continued research using a more refined scale, other methods of measuring FD and involvement of other factors such as landcover and characteristics of roads.

Keywords: *: ecological patches, fractal dimension, garden city, green spaces, urban roads*

1. INTRODUCTION

Alongside urbanization, cities are being defined by roads and due to its impact on the economy of an area, more roads are continually being built. No matter what the purpose, roads, road establishment, road maintenance, and road travel have a broad variety of effects on ecological condition and functioning at different scales (Committee on Ecological Impacts of Road Density, 2005). Despite the increasing scientific evidence pertaining to the ecological damages of roads, the governments around the world have failed to address such impacts into their policy frameworks. In the Asian tropical southeast, there has been low protection coverage in roadless areas with high ecological value index (Ibisch et al, 2016). The effect of roads is far more pervasive than what was perceived and include disparate consequences such as population and habitat fragmentation, soil erosion acceleration, compromised forest regeneration, forest habitat loss and increased invasion of exotic plants along roadways (Angelstam et al, 2017; Chen et al, 2019; Rowland et al, 2005). Roads affect wildlife and habitat by being a major contributor to habitat fragmentation. They alter large landscapes by dividing them into smaller patches and converting interior habitat into edge habitat (Noss & Cooperrider, 1994). Habitat fragmentation has numerous ways of being quantified. In addition to the rate of reduction of total habitat area and increase in the number of fragments, the measurement of the extent of isolation of habitats, area of edge, shape of fragments and degree of heterogeneity have been included. A number of literature verified that roads greatly facilitate habitat fragmentation than forest clear-cuts do, not to mention other direct impacts on biota (Spellerberg & Morrison, 1998). The permeability of roads may hinder the connectivity of ecological habitats depending on the structure of roads, structure of the landscape and characteristics of species (Assis et al, 2019). Such studies show a correlation between road network and landscape structure. In a study by Eker & Coban (2010), potential impacts of road network on the spatial structure of forest compartments were demonstrated through their shape index using fractal dimension.

In this study, both the road network and the surrounding patches would be analyzed using fractal geometry and would be later on correlated on how they influence one another with respect to their spatial characteristics. In fractal theory, the geometry of patches generated by a similar landscape transformation process should be statistically similar (Imer & Bogaert, 2004). The building of roads is the inducer of landscape transformation in this context and it is hypothesized that it has a significant geometrical impact on the surrounding patches. The distribution of patches in the study area did not occur by chance and is at least a product of road development and road impacts.

Fractal dimension measures the complexity and how an object fills the space in which it is located. It is a set with dimension strictly greater than its topological dimension (Mandelbrot, 1983). Compared to topological dimension, fractal dimension has a non-integer value because it is more sensitive to shape variation and calculates the coverage of the object's edges and curves in a finer scale. The topological dimension of a set is always an integer. It is zero (0) if the points are totally disconnected, one (1) if each point has arbitrarily small neighborhoods with boundary of dimension zero (0) (Falconer, 1990). The fractal dimension of a series of points in a line is between zero (0) and one (1) because the space it occupies is greater than that of a single point but occupies less than a line. In the same way, a wavy line's fractal dimension is between one (1) and two (2) since it covers more space than a straight line but does not cover more than a plane could. Same goes with a rough surface with a fractal dimension more than two (2) but less than three (3) since it is not a solid cube (Sreelekha, et.al, 2017). However, in this study, ecological patches and road networks does not have similar topological properties because of their shape. But it has been analyzed that despite of this difference, the spatial distribution of built-up spaces and road networks can still be compared through the use of fractal correlation analysis (Thomas & Frankhauser, 2013). Hence, similar to built-up spaces, which are topologically two-dimensional, green spaces or the ecological patches, may also be correlated to the spatial distribution of road networks. Furthermore, in characterizing road network, its network density showed the highest correlation to fractal dimension in a study by Sreelekha, et.al, (2017) indicating that fractal dimension reflects the spatial pattern of the transport network filling up a specified area.

Following Singapore's Garden City Strategy Through the Relationship of their Road Network and Green Spaces

Despite being highly urbanized, Singapore holds the title of being a garden city and in fact, is transitioning to become a city in a garden. In 2012, there are 9,081 lane-km of roads in Singapore, which is 12 percent of its total land area according to Singapore's Ministry of Transport. As of 2016, it has a land area of 719.7 square kilometers. Their green spaces occupy 45.59 percent of the total land area, with 1034 number of patches or is equivalent to 328, 107, 540 square meters.

In the Philippines, Garden City was the concept in both the 1941 Frost Plan and the 1949 Masterplan of Quezon City. Quezon City has a total land area of 161.12 square kilometers. Its 273 patches or green spaces occupy 29.74 percent or 47, 916, 678 square meters. As of 2009, the city's total road length is 2,247.75 kilometers and constructions of more minor roads and transformation of minor to major roads are currently on-going. With further establishment of roads to meet the growing demands in Quezon City, the protection and conservation of the existing ecological patches will be at stake and may even be taken for granted. Also located in the tropical region in Asia, Singapore on this matter, is able to maintain and even improve their status as a Garden City despite the density of their road network. In this research, the relationship between the spatial pattern and distribution of the road networks and the structural characteristic of patches in the two study areas will be analyzed through their fractal geometry. The resulting fractal attributes of Singapore will serve as a basis for planning and policy guide for Quezon City in its endeavor to become a Garden City. This research aims to answer the following questions:

How does the relationship between the spatial pattern and distribution of the road networks and the structural characteristic of ecological patches differ between Singapore and Quezon City?

How does the fractality of the road network and the fractality of the patches relate to each other in the two study areas?

Can a garden city be described in terms of the relationship of the fractal geometry of its road network and surrounding patches? What are the attributes?

2. MATERIAL AND METHODS

The relationship of the spatial pattern and distribution of road network and the structural characteristic of the green spaces were analyzed in Singapore and Quezon City, Philippines. The differences were identified in order to obtain distinct attributes of a garden city in terms of the fractality of its two main features being studied, the road network and the green spaces network. This was attained through the data processing methods as shown in figure1.

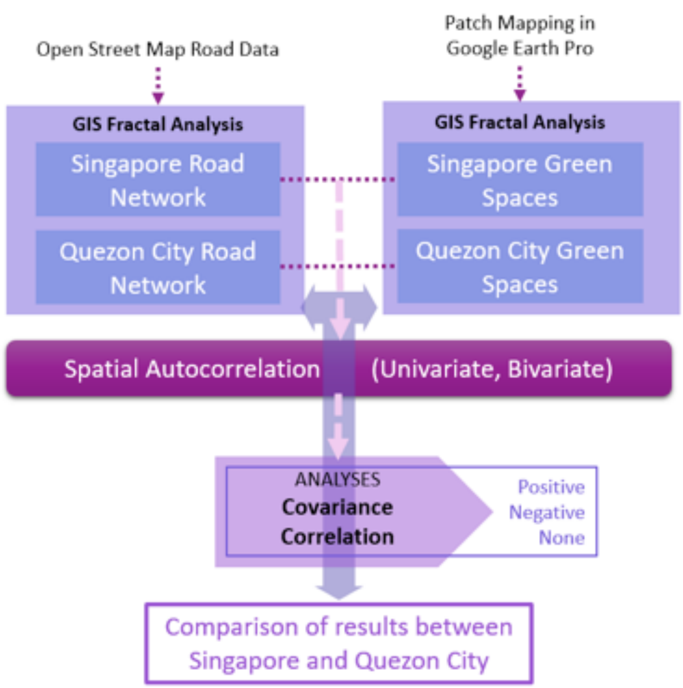

Figure 1: Research Design

To obtain the data of the existing patches in Singapore and Quezon City, Google Earth Pro was utilized for its accessibility and up-to-date satellite imagery. Commercial high-resolution maps are available at high cost and do not provide datasets for small cities like Quezon City. Data from the two study areas must originate from the same production to lessen conflicts during comparative analyses. Hence, the vector data of the patches were manually produced using Google Earth Pro. A viewing scale at eye altitude 2.50 to 2.70 km was maintained while using the polygon tool to delineate the boundaries of the patches. This is to aid in setting limit to the visible physical features and size of the patches to be included. Only green areas with a minimum size of 0.5 hectare or 5000 square metre were included. Concurrently, the network of roads in both study areas were derived from OpenStreetMap Database. The polygonised patches and road networks were digitized in ArcGIS software.

There are several methods of calculating the fractal dimension of different features. One of the most popular algorithm for computing FD in one dimensional and two dimensional data is the box-covering method (Annadhason, 2012). In the study by S. Deng, et.al (2015), two methods for computing FD was used and revealed that box covering method gives better scaling relation for small network systems. Thus, in this study box-covering method was employed since road network, similar with metro systems, has small features and fitting difficulties while calculating the coverage will not be a problem.

Seven box sizes were used in the measurement – 1000 m, 500 m, 250 m, 125 m, 62.5 m, 31.25 m, and 15.625 m boxes. The FD of the road networks and sets of patches from the two study areas were arranged in a Scatterplot graph to investigate the linear relationship between the two variables (road network FD and patches FD) within the two study areas. The box fractal dimension was obtained through calculating the slope of this double logarithmic plot of grid size and box count.

Given the FD results, the two variables in each of the study areas were individually subjected to spatial autocorrelation using Moran Index to determine how spatially related are its parts to its network before these two variables were correlated to each other. Another round of spatial correlation was done between the road network and the patches in each of the study area. This time, it was to reveal the spatial relationship of the two variables being examined. These results were further analyzed using Covariance and Correlation matrices. Covariance was used to identify the direction of the relationship, whereas Correlation was also applied to assess both the strength and the direction of the relationship.

3. RESULTS AND DISCUSSION

The results of the spatial autocorrelation of each of the variable in the two study areas showed a very low positive Moran index, suggesting that some high FD values cluster near low FD values although most of the high FD values cluster near other high FD values and the low FD values are near other low FD values (refer to figures 2 to 5). Only the patches in Quezon City has a p-value of 0.09 (above 0.05 which is the cut-off value to reject the null hypothesis) which suggests that there is a small possibility that the spatial processes of the observed pattern of FD values is random chance (see Figure 2). These also show that the patches or green spaces in Singapore, having less than 5 percent likelihood of being randomly clustered (see Figure 4) compared to the green spaces in Quezon City, are more connected in terms of their morphology in their urban environment.

In figures 6 & 7, when the two variables were spatially correlated in each of the study area, both resulted to a positice Moran index and statistically significant p-values. THis suggests that when it comes to fractal properties, the patches and roads with the same or near FD values cluster or are more spatially related. This result do not reveal any significant difference in the relationship of the two variables in the two study areas.

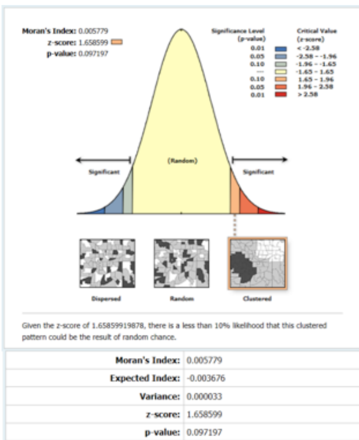

Figure 2 : Spatial autocorrelation of patches in Quezon City

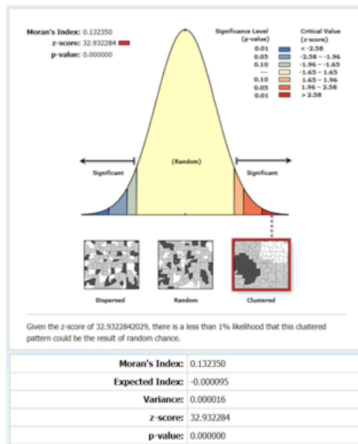

Figure 3 : Spatial autocorrelation of roads in Quezon City

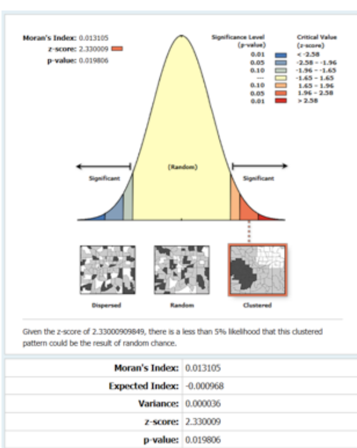

Figure 4 : Spatial autocorrelation of patches in Singapore

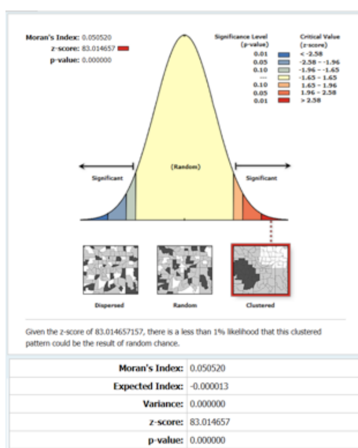

Figure 5 : Spatial autocorrelation of roads in Singapore

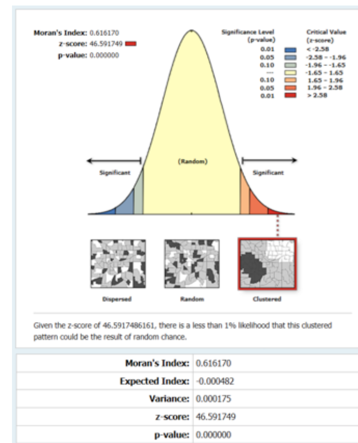

Figure 6 : Spatial correlation of roads and patches of Quezon City

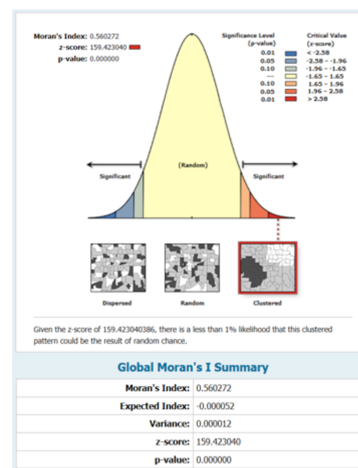

Figure 7: Spatial correlation of roads and patches in Singapore

In Figure 8, the slope of the scatterplot reveals that the fractal property of the road network in Quezon City is 1.61, which is higher than the FD 1.36 of the patches. This indicates that the roads are more spatially related than the patches. Whereas in Singapore, the FD of the patches is 1.87, slightly higher but close enough to that of the road network, 1.81 (Figure 9). These values may reflect how green spaces are being managed in the two study areas and how road construction is being planned in accordance with green space conservation and greening initiatives. It may be reflective of Singapore's efforts in the maintenance of trees and vegetation along the roads and even on the walls of many of their infrastructure.

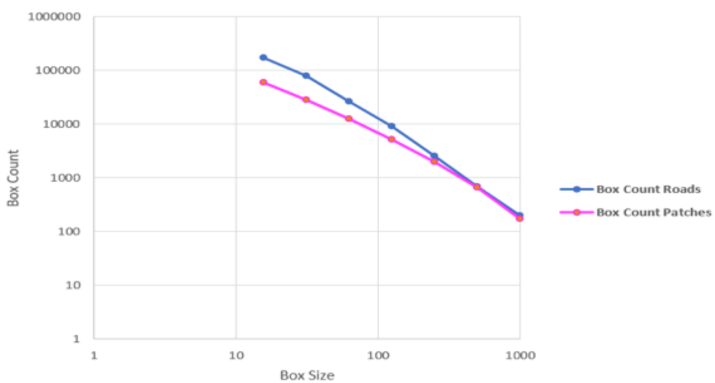

Figure 8 : Results of Box-counting for Quezon City's Road Network and Patches

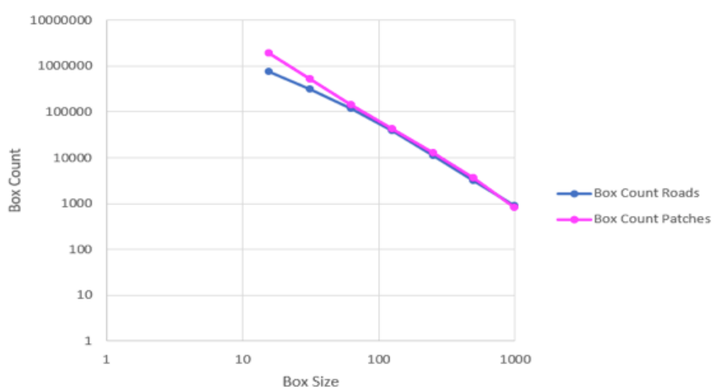

Figure 9 : Results of Box-counting for Singapore's Road Network and Patches

In correlation analyses, a stronger relationship of the two variables was found in Quezon City, with a value of 0.11 (table 1), compared to Singapore's 0.03 (table 2). This may be due to the impact of road network of Quezon City to its patches. Furthermore, the result of the covariance analyses revealed that both in the study areas, the two variables go in the same direction, such that as the FD of one variable increases, so as the other. This may denote that FD increases parallel to the disturbances which can affect the ecological patches and road networks may have far FD values from that of the patches since other extrinsic factors may also influence the structural characteristic of the patches not only the roads and the activities taking place on them.

High fractal dimension suggests low spatial difference and strong spatial correlation between urban parts (Chen, Wang, & Feng, 2017). Thus, the higher the FD value of the road network compared to the patches', the more possible that fragmentation has resulted from the establishment of roads.

Table 1: Strength and direction of the relationship between road network and patches in Quezon City

COVARIANCE MATRIX

Layers	Patches	Road Network
QC Patches	1.881358e-002	6.684610e-005
QC Road Network	6.684610e-005	1.738078e-005

CORRELATION MATRIX

Layers	Patches	Road Network
QC Patches	1.00000	0.11690
QC Road Network	0.11690	1.00000

Table 2 : Strength and direction of the relationship between road network and patches in Singapore

COVARIANCE MATRIX

Layers	Patches	Road Network
SG Patches	1.853674e+004	1.881345e+004
SG Road Network	1.881345e+004	1.801050e+007

CORRELATION MATRIX

Layers	Patches	Road Network
SG Patches	1.00000	0.03256
SG Road Network	0.03256	1.00000

The identified relationship between the urban road network fractal properties and patches' fractal properties provides a guide for urban planning and policymaking with regards to future road developments and road construction considering the prevention of further fragmentation and conservation of ecological patches in cities to attain a garden city status.

The spatial autocorrelation showing the clustering of features with closer FD values may also reveal the extent of fragmentation in a study area (see figures 10 & 11). Very low positive or negative Moran index of the variables being studied suggests that high FD patches are surrounded by low FD patches indicating the degree of fragmentation in the study area.

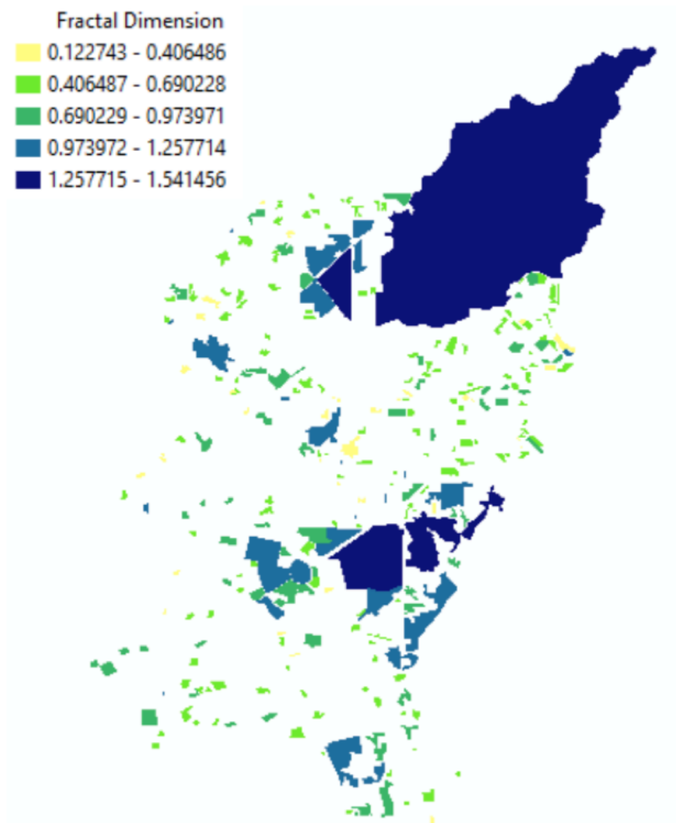

Figure 10 : The fractal dimension of individual patches in Quezon City

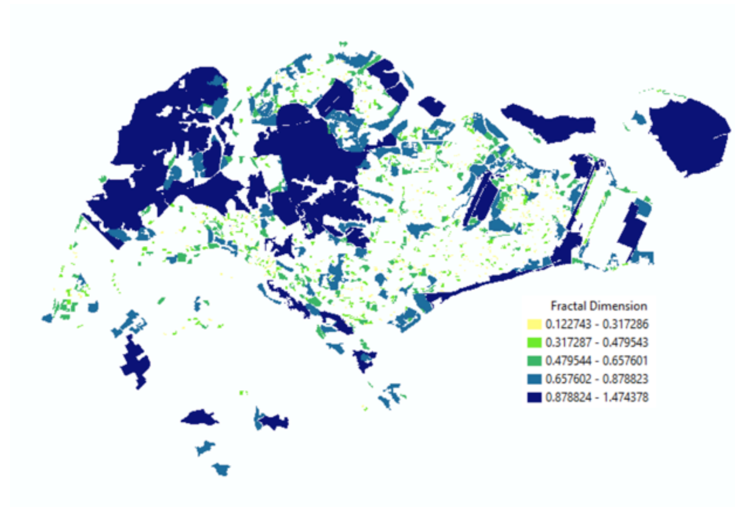

Figure 11 : The fractal dimension of individual patches in Singapore

Fractal dimension can be used to determine relationship between road network and ecological patches. However, the identified connections in this study were not strong and conclusive enough to determine the difference between the attributes of a model garden city and a city which aspires to be one. Although there were small differences and patterns which were pointed out and discussed in this study, still, other factors may have brought out those changes and influences on the fractal properties of the patches.

At this contemporary period, it is important for cities and regions, especially those that are in the periphery of highly urbanized ones and those that are considered to be rural, to secure reliable database of the physical elements of their spaces such as description of roads (e.g. road density, width, etc.) and green spaces. With the aid of modern technology, complex information may be organized and calculated to aid in minimizing negative impacts of new infrastructure developments and develop a more effective and sustainable urban plans and decisions.

4. CONCLUSION

It has been established here that fractal dimension index can be a useful assessment tool in making plans and decisions pertaining to road and other infrastructure development that may further exacerbate fragmentation. Fractal dimension can be considered as an indicator to determine areas that must be protected against road construction and expansion. The results suggest that it may be more sustainable to build roads in areas with low FD and limit road construction in patches showing high FD, although the patches demonstrated in this study do not reflect the assurance of high ecological significance. But green spaces provide the assumption that these patches support species habitat and render certain ecological services.

This study can be further supported through research using a more refined scale to obtain more substantial findings. Also, using a variation of methods on computing FD values may reveal a clearer and more conclusive attributes of a garden city with respect to the fractal properties of its road network and ecological patches. In the study done by Jiang & Liu, (2012), they presented a detailed discussion on the issues of using the box-counting method in the case of Beijing City. They proposed improved techniques which was tested through the comparison of their FD results to an image with known FD. Their techniques were proven to provide a more reliable estimation of FD values of urban forms and may be used to gather more reliable FD values, which may provide a more conclusive description of the fractality of a Garden City. Moreover, determining the impacts of road network to patches at varying scales may also be researched further through considering the different characteristics and types of roads and patches.

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