Non-Euclidian Methods to Replicate Urban and Garden Patterns in P.R. of China

Zhi Yue, Songlin Wei, and Jon Bryan Burley

***Abstract*—**Planners and designers are interested methods and procedures to create and replicate environments for historic preservation and blend new built environments with existing. Both fractal and logistic regression spatial quantitative methods are relatively new tools to describe the built environment. We applied the fractal reverse box-counting method to the Master of the Nets garden in Suzhou, Jiangsu, China and to a housing pattern on Lamma Island, Hong, Kong to study and replicate the fractal pattern We discovered the fractal number in the garden for the "turning points" along the garden's pathway system (1.577), calculated the fractal number of the center points of polygons in the garden (1.305), and Lamma Island's fractal number for the spatial pattern of houses was (1.158). By applying the reverse box-counting method, we were able the replicate the general compositional style of this garden and the pattern of housing on Llama Island. In addition, through logistic regression we were able to predict the location of the main water feature and subordinate spaces in the Masters of the Nets garden by knowing the distance from existing garden walls ($p \leq 0.05$).

***Keywords*—**Environmental design, historic preservation, landscape analysis, landscape architecture.

I. Introduction

Historians and scholars of landscape designs are often interested in studying the design principles driving the creation of space and built from, especially across cultures. In the West, design can be characterized as a search for individual expressions of ideas where each design attempts to find a unique solution to derive meaning, expression, and content as illustrated by Jellicoe ([1]. However, in the East, at times the task was to create a landscape that was centered around an expected norm and to not deviate to much from this expected form.

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Western designers may use a special and unique concept may drive the design as noted in the United States of America plus other examples from gardens in Italy, France, Portugal, and the United Kingdom [2 & 3]. In contemporary China, the Dalian World Peace Park, designed by a French team is an example of this approach, where the design has a unique concept [4]. Today, many Eastern designers accept this approach to make unique statements or follow norms when creating public spaces as illustrated by Wang and Wang [5]. But in the past, in places like China, only the nobility and emperor could make such individualist statements such as the Ming Tomb in Nanjing, Jiangsu Province [3]. Nevertheless there was still a certain amount of predictability in the design of Ming tombs in both Nanjing and near Beijing, following precedents for cloud adorned archways, tablets carried by the Dragon's son describing the merits of the deceased, sacred ways (pairs of stone statues along a walkway), and many more similar features. Meanwhile, the small gardens, such as the gardens around the city of Suzhou in Jiangsu Province seem to closely resemble each other. Many of the gardens do have concepts and ideas, but they are subtly presented as opposed to boldly stated by Western garden design traditions.

To describe the spatial features of Western design, Euclidian geometry is often employed. The designs such as the Italian garden of Villa Lante can be described with bilateral symmetry, rectangular and circular shapes, and discrete measurements [3]. In contrast many traditional Eastern landscape designs defy Euclidian geometry tools of description because they are naturalistic/organic in configuration.

Knowledge about Chinese gardens has been slow in forthcoming. Western scholars have known much more about Japanese gardens for a much longer period than Chinese gardens. Publications by Valder and by Keswick have assisted in understanding the breadth and depth of Chinese gardens [6 & 7]. In addition, the publication of professor Congzhou's, (the late professor of architecture at Tongji University in Shanghai, China) essays about Chinese gardens, written in 1978 to 1982, the essays offer tremendous insight into the philosophical and theoretical design considerations of these gardens [8]. In addition Congzhou's Garden Synthesis book and Tong's Garden Discussion book offer other viable insights concerning the planning and design of the Chinese garden [9 & 10]. Valder also provides insight into the symbolism and use of vegetation in the Chinese garden [11]. Knowledge about the Chinese garden continues to grow and expand as illustrated by the recent works of Xiaofeng, a professor from Tsinghua, University in China, plus Zongwei, and Xingxi [12, 13, & 14]. However, each of these expositions and studies are unable to quantify the physical pattern of the Chinese garden. Consequently, we were interested in attempting to see if we could quantify the spatial pattern of a Chinese garden with a relatively new method barrowed from a French team of investigators to describe more organic shapes.

For the past decade, a French team has been exploring the descriptions of landscapes through the use of fractals [15]). They have been able to measure naturalistic patterns and through the development of the Reverse or Inverse-Box Counting method replicate naturalistic patterns that Euclidian geometry was unable to characterize. In 2009, Fleurant (et al.) illustrated how to use this approach to replicate a stand of trees for surface mining reclamation [15].

Since Euclidian geometry would not suffice to describe traditional Chinese gardens, we were interested in applying the Inverse-Box Counting method to study the pattern for a garden a Suzhou. Plus in the future we were interested in employing the application of geographical prediction methods to aid in the understanding of the placement and features of the Suzhou garden.

The study team was also interested in expanding the application of fractal methods to other types to other spaces, such as urban form. Frankhauser has studied urban form with fractals, but did not investigate applications to reproduce urban form [16]. We were interested in investigating the pattern of buildings in a site in China, Lamma Island, Hong Kong to determine the fractal pattern of this study area. Scholars are interested in understanding urban form of traditional environments and blending these forms with modern development [17, 18].

Finally, both Euclidian and non-Euclidian methods combined are not capable of describing the relationships of all spatial patterns and we explored the application of logistic regression to describe some features in a garden at Suzhou. Our aim is to illustrate the use of landscape metrics to describe the physical arrangement of environment and to encourage other investigators to explore the spatial patterns and contents of environments that are of interest to them. In the future, a meta-analysis of these studies my lead to further insights.

II. Study Areas and Methodology

A. Fractal and the Master of the Nets Garden

The traditional Chinese gardens have been mysteries for a long time. Each visitor will be surprised that so many pleasant environments can be designed in such a small garden. The unrevealed secrets to the design of such gardens remain hidden, partly because we do not have the right tools to describe them. Possibly, fractal approaches might be suitable to describe the complex organic forms in these gardens. These gardens all have a simple boundary composited of many similar units in some irregular way (Fig. 1, 2, 3, 4, 5, 6, and 7). This common character of spatial form is similar to what fractal analysis can qualitatively describe. Is it possible for the traditional Chinese garden can be described with fractal geometry?

We chose the Master of the Nets garden (網師園; Wǎngshī Yuán) in Suzhou, Jiangsu Province, in China for our study. It is a relatively small garden and a UNESCO World Heritage site. The garden originated in the Song Dynasty, around 1140 AD and continued to evolve into the 1790s and 1800s during the Qing Dynasty, with restoration in the 1940s. The garden is essentially a metaphor for "going fishing" as experienced in a counter-clockwise fashion around a pond with plants and landscape features that symbolize the fishing experience. We chose the pathway system in the garden to form the fractal analysis.. We chose the pathway system because it was a form-giver to the arrangement of planting areas, water features, landforms, and pavilions. We attempted to describe the pathway system with two types of pathway related variables: the fractal number for turning points along the pathway and the fractal number for the center of polygons formed by the pathway segments. We started with a 110 m by 110m grid. The garden was visited by the study team in 2007 and 2009.

Fig. 1. A view of the central pond area of the Master of the Nets garden, Suzhou, Jiangsu, P.R. of China (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

Fig. 2. A view looking in the reverse direction of Fig.1 (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

Fig. 3. Mountain and pavilion in the Master of the Nets Garden (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

Fig. 4. View of the vegetation covered mountain in the garden.

Fig. 5. Pathway along wall after the pond is revealed (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

Fig. 6. View of the garden from the large pine tree (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

Fig. 7. View of pavilion overlooking the pond. (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

B. Fractal of Housing Pattern Llama Island

Lamma Island (南丫島) is the third largest island in the Hong Kong Island chain and has a series of structures spread across the island. The housing locations were mapped in 2008 (Fig. 8) and visited in 2009 (Fig. 9, 10, 11). We started with a 600 m by 600 m grid to apply the box-counting process.

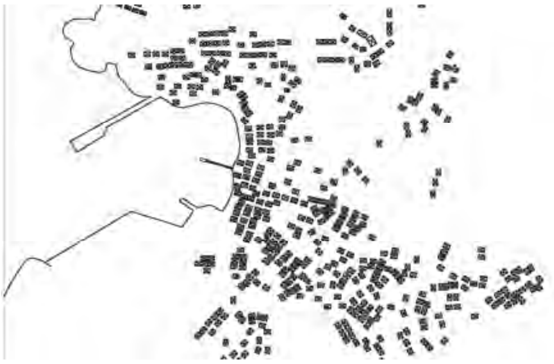

Fig. 8. The location of structures on Lamma Island used in the study. (copyright © 2009 Songlin Wei, all rights reserved, used by permission).

Fig. 9. A view from a hilltop overlooking the Lamma Island study area (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

Fig. 10. A view of the Lamma Island study area with the hilltop from Fig. 9 in the background (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

Fig. 11. A view of the bay in the study area from the boat pier (copyright © 2009 Jon Bryan Burley, all rights reserved, used by permission).

C. *Logistic Regression and the Master of the Nets Garden*

The study team investigated logistic regression concerning the placement of the pond within the garden. Logistic regression examines the presence or absence of a variable based upon predictor variables [19]. In our case, the location of the various walls surrounding the garden were believed to predict where the pond would be placed. We desired to determine the strength of this relationship. We used a Geographic Information Systems (GIS) map of the site (in MF Works) with the location of the walls and the location of the pond, exported the files as a text file and ran logistic regression of the text files [20].

III. Results

Fig. 12, 13, 14, 15, 16, 17 illustrate the box counting method and its procedure of counting route turning points along the pathway in the Masters of the Nets Garden. The box sizes pertinent to calculating the fractal dimension are 27.5m to 3.4375m. For the center points of the polygon generation box sizes starting with 27.5m and ending with 0.859375m (Fig. 18, 19, 20). Tables 1 and 2 represent the pairs of values necessary to compute the fractal dimensions with regression analysis. Regression analysis revealed the fractal dimensions of $D_{tp=}1.577$, with a standard error as 0.135 for the pathway turning points and $D_{cp}=1.305$, with a standard error as 0.098 for the center points of the polygons.

Table 1. Values for regression analysis of path.

Pair	Grid size meters	Filled Boxes
1	27.5	12
2	13.75	30
3	6.875	70
4	3.4375	116
5	1.71875	146

Table 2. Values of regression analysis of polygons.

Pair	Grid size (meters)	Filled Boxes

1	27.5	11
2	13.75	26
3	6,87	66
4	3.4375	90
5	1.71875	99
6	0.859375	102

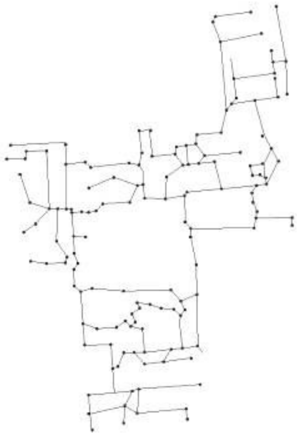

Fig. 12. Turning points of the Master of the Nets Garden

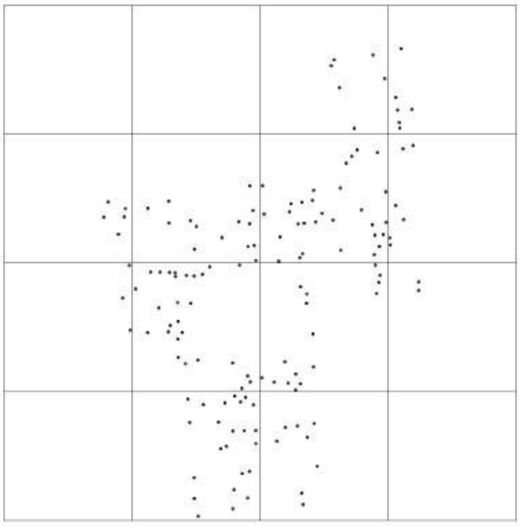

Fig. 13. First grid with empty boxes, grid 27.5m.

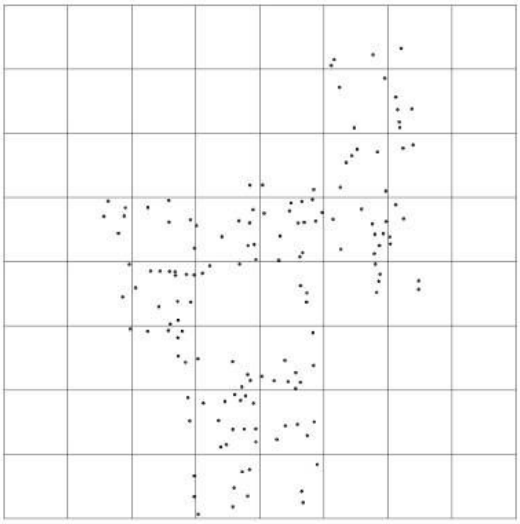

Fig. 14. Second grid with empty boxes, grid 13.75m.

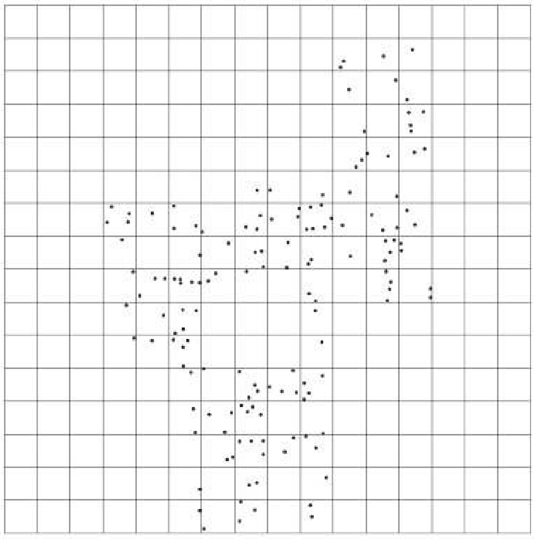

Fig. 15. Third grid with empty boxes, grid 6.875m.

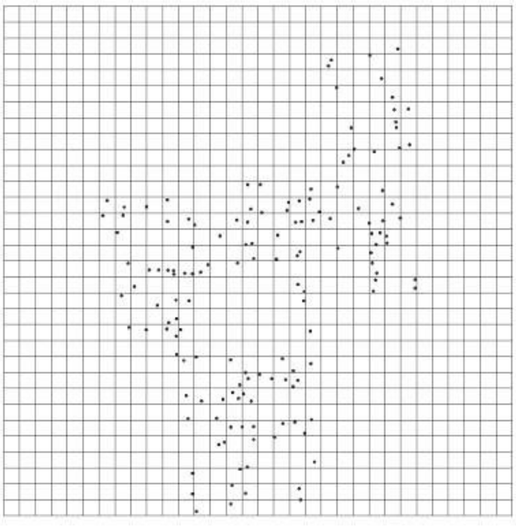

Fig. 16. Fourth grid with empty boxes, grid 3.4375m.

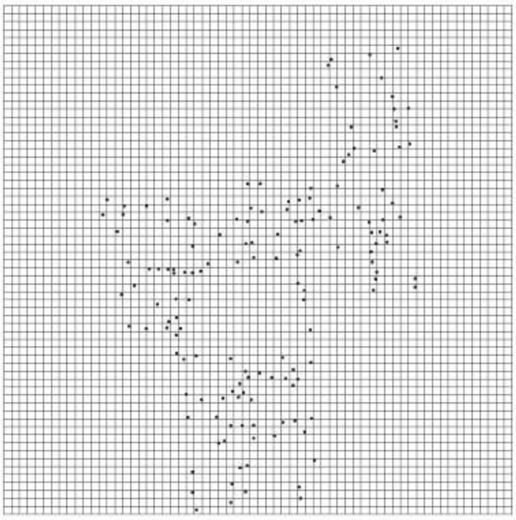

Fig. 17. Fifth and last grid as each point is in a separate box, grid 1.71875m.

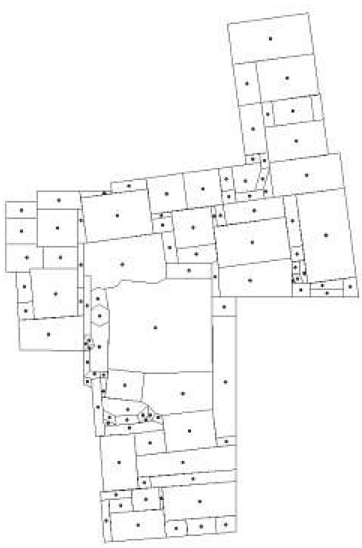

Fig. 18. Center points of polygons.

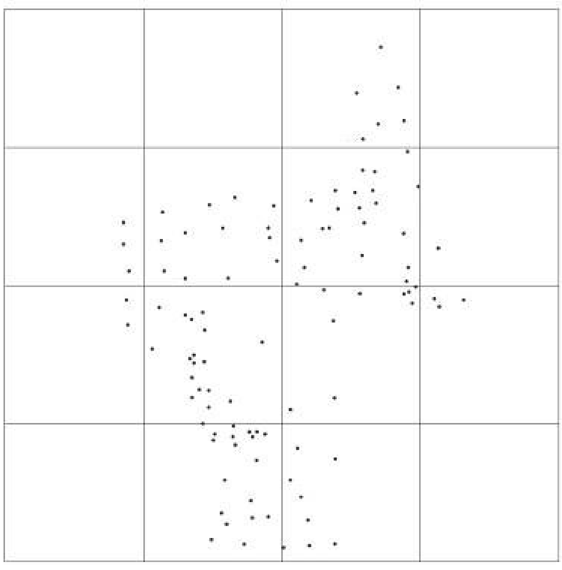

Fig. 19. First grid with empty boxes, grid 27.5m.

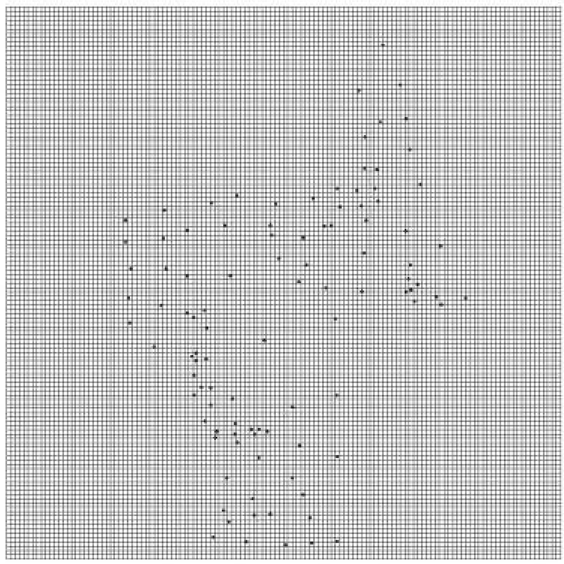

Fig. 20. Last grid with each point in its own box, grid *0.859375*.

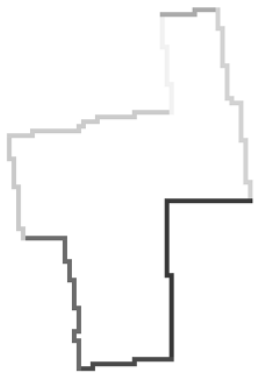

Fig. 21. 10 wall segments in the Master of Nets Garden.

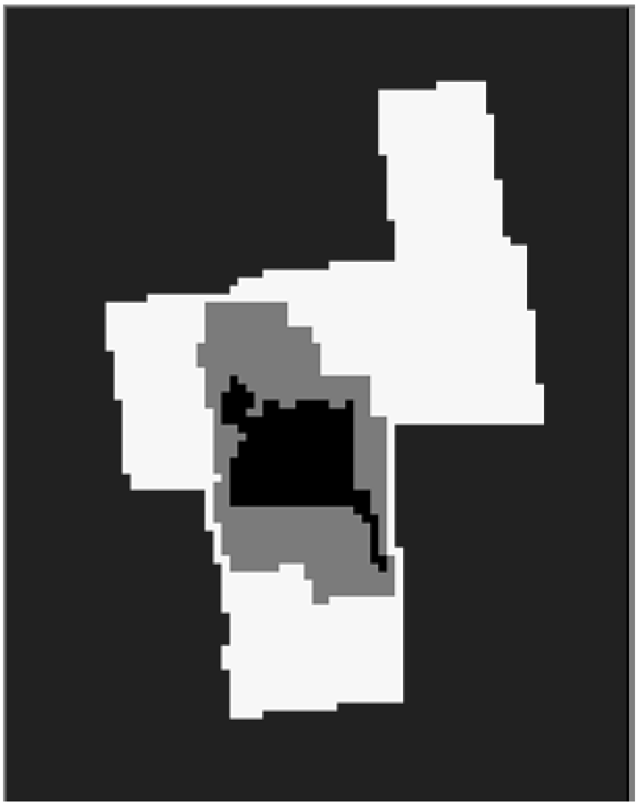

Fig. 22. Zones within the garden with the dark area in the center being the pond, the gray the plazas and the white other spaces.

For the logistic regression prediction, Fig. 21 presents the wall segments (the predictor variables) and Fig. 22 presents the three spaces in the garden: pond, plaza, other areas for pavilions and plantings. These three spaces are the dependent variables.

Tables 3, 4, and 5 present the logistic regressions for predicting the location of the pond areas, the plaza areas and the other spaces. Equations 1, 2, 3, 4, 5, and 6 present the equations derived from these tables.

Table 3. Logistic regression results for locating the distance to water from the wall segments.

Pearson Chi-square Statistic: 1359.327 (P = 1.000)
Likelihood Ratio Test Statistic: 839.207 (P = <0.001)
-2*Log(Likelihood) = 515.450
Hosmer-Lemeshow Statistic: 18.613 (P = 0.017)

Ind. Variable	Coefficient	Standard Error		P value
Constant	111.801	20.526	29.668	<0.001
dist1	-0.586	0.194	9.107	0.003
dist2	-2.560	0.472	29.458	<0.001
dist3	0.387	0.154	6.302	0.012
dist4	0.575	0.296	3.779	0.052
dist5	-1.153	0.176	42.842	<0.001
dist8	-1.286	0.392	10.770	0.001
dist9	-1.079	0.210	26.460	<0.001
dist10	0.313	0.206	2.293	0.130

Table 4. Logistic regression results for locating the plaza spaces next to the water.

Pearson Chi-square Statistic: 1058.346 (P = 1.000)
Likelihood Ratio Test Statistic: 932.348 (P = <0.001)
-2*Log(Likelihood) = 1187.221
Hosmer-Lemeshow Statistic: 12.891 (P = 0.116)

Ind. Variable	Coefficient	Standard Error	P value	
Constant	113.759	9.690	<0.001	
dist1	-0.562	0.120	<0.001	
dist2	-1.611	0.149	<0.001	
dist3	0.686	0.0790	<0.001	
dist4	-0.421	0.0851	<0.001	
dist5	-0.950	0.105	<0.001	
dist8	-1.647	0.127	<0.001	
dist9	0.685	0.0853	<0.001	
dist10	-0.684	0.0984	<0.001	
dist water	0.141	0.0510	7.703	0.006

Table 5. Logistic regression results for locating vegetation and pavilions areas.

Pearson Chi-square Statistic: 605.357 (P = 1.000)
Likelihood Ratio Test Statistic: 2061.874 (P = <0.001)
-2*Log(Likelihood) = 507.332
Hosmer-Lemeshow Statistic: 4.880 (P = 0.770)

Ind. Variable	Coefficient	Standard Error	P value	
Constant	-284.692	23.843	<0.001	
dist1	3.459	0.334	<0.001	
dist4	0.759	0.121	<0.001	
dist5	2.873	0.275	<0.001	
dist6	-0.974	0.167	<0.001	
dist7	1.441	0.267	<0.001	
dist8	1.118	0.202	<0.001	
dist9	-1.146	0.155	<0.001	
dist10	0.796	0.151	<0.001	
dist water	1.175	0.0916	164.464	<0.001

$$\text{Logit P(water)} = 111.801 - (0.586 * \text{dist1}) - (2.560 * \text{dist2}) + (0.387 * \text{dist3}) + (0.575 * \text{dist4}) - (1.153 * \text{dist5}) - (1.286 * \text{dist8}) - (1.079 * \text{dist9}) + (0.313 * \text{dist10}) \quad (1)$$

$$\text{Location of Water} = 1/(1+e^{-\text{Logit P (water)}}) \quad (2)$$

$$\text{Logit P (main space)} = 113.759 - (0.562 * \text{dist1}) - (1.611 * \text{dist2}) + (0.686 * \text{dist3}) - (0.421 * \text{dist4}) - (0.950 * \text{dist5}) - (1.647 * \text{dist8}) + (0.685 * \text{dist9}) - (0.684 * \text{dist10}) + (0.141 * \text{dist water}) \quad (3)$$

$$\text{Location of Plaza} = 1/(1+e^{-\text{Logit P (main space)}}) \quad (4)$$

$$\text{Logit P (other areas)} = -284.692 + (3.459 * \text{dist1}) + (0.759 * \text{dist4}) + (2.873 * \text{dist5}) - (0.974 * \text{dist6}) + (1.441 * \text{dist7}) + (1.118 * \text{dist8}) - (1.146 * \text{dist9}) + (0.796 * \text{dist10}) + (1.175 * \text{dist water}) \quad (5)$$

$$\text{Location of other areas} = 1/(1+e^{-\text{Logit P (other areas)}}) \quad (6)$$

D. Lamma Island Fractal

For Lamma Island, the box sizes pertinent to calculating the fractal dimension are 600m to 18.75m. The resulting fractal dimension for the values listed in Table 6 was 1.158. Fig. 23 presents the last grids for analysis with about 3.4% of the boxes filled.

Table 6. Values of regression analysis for Lamma Island.

Pair	Grid size (meters)	Filled Boxes
1	600	12
2	300	25
3	150	62
4	75	167
5	37.5	356
6	18.75	556

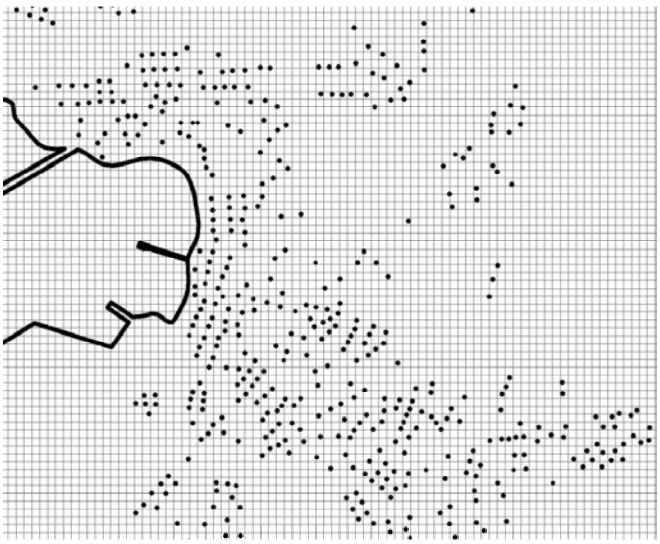

Fig. 23. Last grid with each point in its own box for Lamma Island, grid 18.75m.

IV. Discussion and Conclusion

With fractal numbers calculated. we were interested in attempting a replication of the garden. The replication would not be an exact copy but rather a design with the same general character of the original garden. Thus we replicated the garden, employing a method more fully described by Fleurant et al., to establish routing turning points and center points of polygons [14]. With the points plotted, we used some general rules about creating the pond, plaza areas, pathways and polygons:

1. Equations 2 is employed to make the pond area (Fig. 24).
2. Equation 4 is employed to make the plaza area (Fig. 25).
3. To make the pathway make sure all of the turning points have a connection to some other turning point. In route turning point maps, try connecting all points.
4. In routing the pathways, the center of the garden should contain an enclosure shape that forms the pond.
5. In routing the pathway, connect the pathway around the pond to pathways beyond the pond at the proposed turning point maps.

The result is a general design as illustrated in Fig. 26. The design fills the space with turning points for pathways and defines the spaces for the polygons. In addition the design illustrates the location of the pond.

The results do not mean that all Chinese gardens are represented by these fractal numbers and equations, but rather it is possible to ascertain the fractal pattern and logistic relationships of one garden and replicate this pattern. Investigators are invited to determine the factual numbers of other gardens in China and to study the similarities and differences.

Fig. 24. The predicted locations of the pond based upon equation 2. The green areas are the areas most likely to be the pond, with the blue areas second and the magenta third.

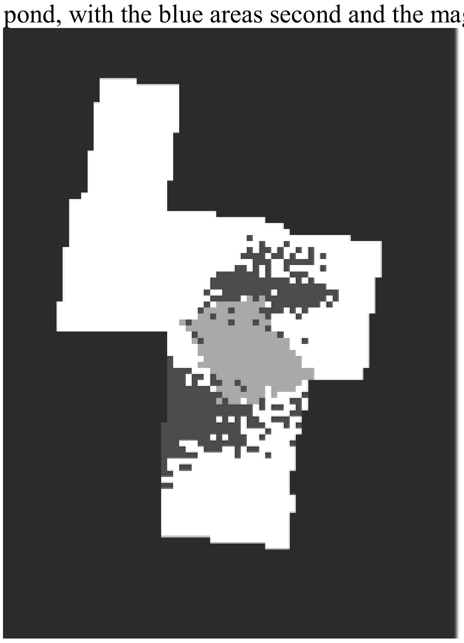

Fig. 25. The grey areas are the predicted location of plazas based upon equation 4.

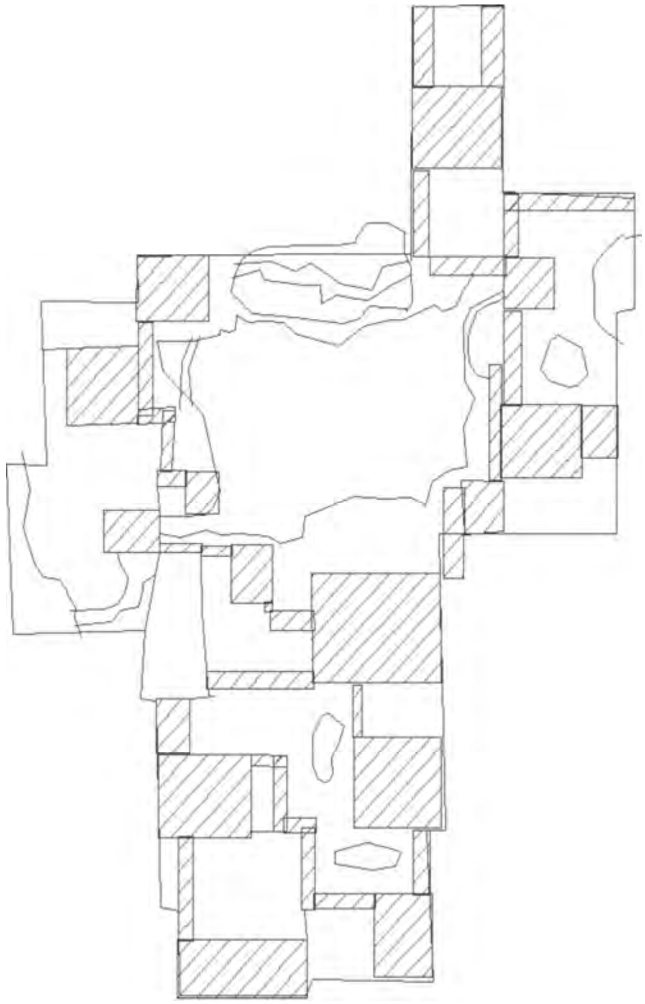

Fig. 26. A fractal and logistic based design for the garden.

In addition our study of Lamma Island, Hong Kong indicates that the reverse box fractal method may be useful for replicating the placement pattern of urban structure as the fractal number of a housing pattern can be calculated and then reproduced in the same manner as Fleurant (et al.) did in their study of tree locations [15]. To replicate the pattern, suppose one had a 100 box grid area with 18.75 m lengths for each box. Then approximately 3 of the boxes would need to have locations for structures. Table 7 presents 100 random numbers with each number assigned to a box. Since 3% of the boxes need to be filled, the numbers equal to or less than 3 represent locations where the structures are located and numbers greater than 3 are empty. The first row in Table 7 represent the numbers in the first row of Fig. 27. Since no number is less than or equal to 3, all of the boxes in the first row are empty. Three of the numbers in the table are less than or equal to 3, identifying the locations of the structure.

Table 7. Values of regression analysis for Lamma Island.

87	9	8	81	51	52	5	38	19	17
30	77	41	32	91	32	78	75	98	53
32	42	81	74	55	5	94	44	26	93
63	87	96	75	61	12	96	9	51	91
6	37	35	35	19	5	61	57	21	35

70	20	69	97	61	93	95	52	21	71
11	74	5	78	86	31	8	43	6	95
58	61	65	73	71	5	99	3	55	95
62	28	20	63	95	62	81	20	100	3
52	80	66	96	12	90	13	96	3	72

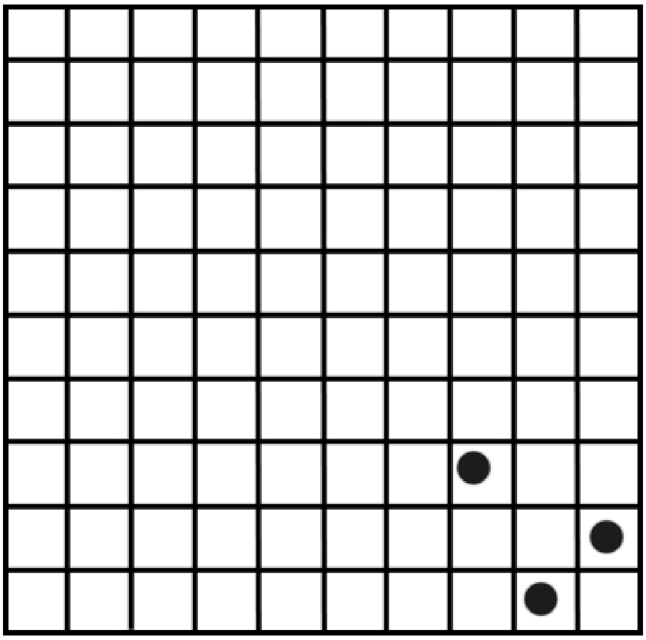

Fig. 27. The location of structures in Lamma Island for 18.75 m squares.

We believe that the quantitative study of form in planning and design has many applications and opportunities. We encourage other investigators to explore and build prediction models for environments important to them.

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