

Original Research Article

Recognition of the Pavilion in Relation to the Persian Garden from the Perspective of Fractal Geometry (Case Study: Pavilions of the Fathabad Garden in Kerman)

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Received: 17/11/2023

Accepted: 10/03/2024

Available online: 21/06/2024

Abstract | Despite numerous studies conducted on Iranian gardens, the analytical investigation of the role of gardens in the shaping of pavilions has not received significant attention. In this study, utilizing fractal geometry, we can observe and analyze architectural qualities with mathematical precision and greater detail. This approach aids in re-examining the visual perceptions of the pavilion structure and identifying the missing geometrical value of the garden. This article delves into the relationship between a pavilion and a garden through fractal geometry. The findings are discussed and explored to uncover the architectural complexities of pavilions, which are influenced by the garden and its natural surroundings. A historical garden named Fathabad in the city of Kerman was selected as the case of our study. Fractal dimension analysis is employed to analyze the two pavilions' facades. The box-counting method was applied to measure the fractal dimensions of the facades at three scales. The results would reveal the relationship between each of the two pavilion facades and the garden. The findings indicate that while different facades share similar architectural elements, they exhibit diverse fractal dimensions. These dimensions reveal the position of each facade relative to the garden's geometry, and the variable fractal dimension within each level signifies distinct relationships between the levels and the garden axes. Additionally, facades parallel to the main garden pond or those without a direct view exhibit a lower fractal dimension. Although facade openness can serve as a measure of its connection to nature, fractal analysis demonstrates that facades with multiple openings have varied relationships with the garden. Furthermore, the analysis of decorative elements reveals that in parts of the facade with fewer openings, ornamentation may be influenced by the garden's natural features. In summary, fractal geometry elucidates how the garden and its elements impact different parts of the facades of the two pavilions.

Keywords | *Fractal geometry, Persian garden geometry, Persian pavilion, Fathabad garden.*

Introduction | Pavilions are an integral part of Persian gardens. The close relationship between the pavilion, the garden trees, and the paths is organized by the geometry of the garden, and many studies have examined these relationships (Ardalan & Bakhtiar, 1973; Laurie, 1975; Massoudi, 2009). However, few of these resources are analytical. In the current research, fractal geometry is used as a tool to analyze the relationship between the pavilion and the garden. It is worth noting that previous studies have also used fractal geometry to analyze the Persian garden (Agnès & Francisca, 2021; Sharghi et al., 2020). However, these studies have not focused

on the pavilion, its architectural values, and its relationship to the garden. In this line, the present study explores valuable aspects of the pavilion architecture using fractal geometry. The article is structured as follows: In the following section, we will review the geometry of the Persian garden and then the fractal and its applications in architecture, as well as the fractal studies on the Persian garden and their limitations. The second section asks the research question, and the third section explains the box-counting dimension. The fourth section describes the experimental findings on the Fathabad garden. Discussion and conclusion are presented in sections 5 and 6.

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Theoretical Foundation

• Pavilion and the geometry of Persian Garden

Precise geometric order, symmetry, and axis are the prominent features of the Persian garden. It is believed that the concept of the Persian garden is inspired by the universe (Ardalan & Bakhtiar, 1973), and geometry plays an important role in expressing this idea. The geometry of the Persian garden was developed centuries ago in the Achaemenid era (500 –300 BC). Symmetry and radial symmetry are the basis of the geometry of Persian gardens (Crowe et al., 1972; Massoudi, 2009). The direction of the axis in the Persian garden is related to the path of water movement and the location of its source (Wilber, 1994) and can be in line with the qanat that brings water to the garden (Khansari et al., 1998).

The architecture of the pavilion opens up to the surrounding area to provide airflow and a close relationship between the interior and exterior. The location of the pavilion is also related to the location of water channels and a large geometric pond (Laurie, 1975). The position of the pavilion as the main building of the Persian garden is based on the axis of the garden, and there is a close relationship between the space inside the pavilion and the garden and its axis. There are two cases regarding this relationship: the pavilion is at the intersection of two axes in the middle of the garden or it is located at the end of an axis (Naima, 2013, 32).

• The application of fractal geometry in architectural analysis

Benoit Mandelbrot conducted extensive research on the development of fractal geometry and its applications. Fractal geometry is the study of mathematical shapes and images that are remarkably similar to the forms found in nature. These shapes present an infinite chain of self-similar and intricate details (Benoit, 1977) (Fig. 1). Natural forms such as leaves, tree branches, mountains, river floodplains, wave patterns, and nerve impulses are examples of self-similar shapes (Lam & De Cola, 1993, Mandelbrot, 1967, Porter et al., 2001). Due to these similarities, fractal concepts are used in a wide range of fields, from physics to art.

Fractal geometry has various applications in architecture (Bovill, 2007). Some believe that fractal principles are observed in many forms of art, such as the shape of mosaics and floor decorations (Joye, 2007). Fractal geometry can be used as a tool to find new insights into old and classical buildings (Capo, 2004). Here, it's not crucial to prove that this type of architecture is truly fractal; rather, fractal geometry serves as a tool for providing a more complex interpretation of architectural order (ibid.). One recognized analytical method that utilizes fractal geometry in architectural analysis is the box-counting dimension method (Bovill, 2007). A study using this method compared examples of organic architecture with non-organic architecture (Salingaros, 1999). In Wright's organic architecture, there is a "chain of details" at different scales, while the box-counting dimension in Le Corbusier's

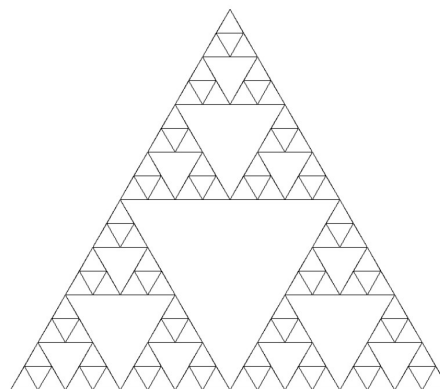


Fig. 1. Sierpinski Curve - An Example of Fractal Geometry. Source: Bovill, 2007, 27.

architecture decreases towards 1. These results suggest that Wright's organic architecture seeks to use materials in a way that depicts the complexity and order of nature, while Le Corbusier's architecture strives for purity, efficiency, and industrial concepts (Bovill, 2007). He also studied several vernacular boxes in Turkey and compared their fractal dimension with the nature of the surroundings. He found that their high fractal dimension indicated a connection between these buildings and their natural environment (ibid.).

Several studies have explored the application of fractal geometry in analyzing the Persian Garden (Agnès & Francisca, 2021; Sharghi et al., 2020). Sharghi et al. (2020) demonstrated that the geometry of the Persian Garden exhibits fractal properties such as self-similarity and repetition. This concept has also been applied to analyze certain facade decorations. Another study focused on the four-garden pattern, examining the replication of this pattern at various scales using the box-counting method. The research also explored its symbolic connection to the Islamic garden (Agnès & Francisca, 2021). While these studies employed fractals to analyze the Persian Garden, their focus primarily lies on the garden's grounds and overall geometry, with less emphasis on the pavilion (Koshk in Persian) and its relationship with the garden and its natural environment.

Research Question

As previously mentioned, pavilions are an important element of the Persian garden and have a close connection with nature and garden landscapes. Therefore, the use of fractal geometry, which is based on nature and natural features, can examine the relationship between the pavilion and its context from another perspective. The research question is as follows:

How can the system of formation of the facades of pavilions in the Fathabad Garden be analyzed by applying fractal geometry?

The answer to this question uncovers features of the pavilions that are related to the geometry and landscape of the garden.

Research Method

As mentioned, Bovill used the box-counting dimension to measure the fractal dimension of architectural buildings. This method has been used by many researchers to analyze buildings from the scale of a city to decorations (Capo, 2004; Lorenz, 2002; Ostwald & Vaughan, 2008; Shen, 2002). In this method, a grid of square boxes is placed on the image. “1/s” is the number of boxes along the length of the grid. N(s) is the number of boxes containing the image. This method is repeated by changing s to smaller sizes (half of the previous size). Then, the graph of the ratio log(N(s)) to log(1/s) is drawn. The slope of the straight line that best fits the data is an estimate of the box-counting dimension (D) (Bovill, 2007):

$$D = \frac{\log(N(s_2)) - \log(N(s_1))}{\log(\frac{1}{s_2}) - \log(\frac{1}{s_1})} \quad (1)$$

One important point in this method is the size of the boxes. In this case, visual perception and the fractal range are related. The unit measurement sizes that are meaningful for a given observer location can be determined using the following equation (ibid.):

$$(2) \text{ (Unit of measurement size)} = (\text{Distance to building}) * \tan(\text{angle})$$

Table 1 shows the best eye angles for viewing details and the appropriate scale range for the person viewing the facade. The distance will be 80 feet for the entire facade and 5 feet for details. When the box size is selected for the next step, its size is divided by two, and this process is repeated three to four times, and two to three fractal dimensions are produced. Then, the linear regression method, which is drawn based on the shortest distance to the points, is applied. The slope of the line represents the average fractal dimension (ibid.). The result of calculating the fractal dimension includes non-integers that should be between 1 and 2.

• Fractal dimension analysis for Fathabad Garden pavilions

Fathabad Garden (Figs. 2 to 5 & 7) is one of the historical gardens of Kerman city. The construction of this garden dates back to about 170 years ago, during the Qajar era (Soltanzadeh et al., 2015). In Fathabad Garden, the vegetation has dried up, and parts of it have been altered in function by farmers. Only some parts of the ponds have remained unchanged (Fig. 2). There are two pavilions in the garden (Figs. 3 & 4). The larger building has a U-shaped plan and is called the ‘main pavilion.’ The smaller one is named the ‘second pavilion.’ The garden’s ponds are shown in Figure 3.

Box counting is used for the analysis of pavilion views at three scales: For the first and second scales, according to previous research (Bovill, 2007), if the distance of the observer from the building is about 22.3 meters, the first unit of the box will be 8, and subsequently, the other sizes will be 4, 2, and 1 meter. For the interior view of the wings, the distance is about 16.8 meters and the box unit starts from 6 meters. For details

Table 1. The range of scales relative to the angle of the eye and the observer’s distance from the building. Source: Bovill, 2007, 137.

Eye angle	The distance between the observer and the building				
	5’	10’	20’	40’	80’
2	2”	4”	8”	1.4’	2.8’
5	5”	10”	1.8’	3.5’	7’
10	10”	1.8’	3.5’	7’	14.1’
15	1.3’	2.7’	5.4’	10.7’	21.4’
20	1.8’	3.6’	7.3’	14.6’	29.1’



Fig. 2. View of the main pavilion and its wings. Source: Author’s archive.

(third scale), similar to previous research (ibid.), the distance is approximately 1.4 meters, and the size of each box is 0.5, 0.25, 0.125, and 0.063 meters.

- The first scale

The first scale of analysis includes the facades of the two pavilions (Fig. 5). To calculate each façade dimension, a grid of boxes with dimensions of each unit of 8 by 8 meters was placed. Figure 6 shows this calculation on the south facade of the main pavilion. The number of boxes containing the Figure 6, and the number of boxes in the bottom row is 3 (Fig. 6). Then the dimensions of each box were halved. In this situation, the number of boxes containing the image is 20, and the number of boxes in the horizontal row is 6. According to formula (1), the fractal dimension between these two states (the difference between the logarithm of 20 minus 6 and the logarithm of 6 minus the logarithm of 3) is 1.73. By continuing this process and reducing the size of the boxes, the numbers 1.76 and 1.74 are also obtained. According to the linear regression, the appropriate slope with these points (average fractal dimension) is 1.731. The results of the fractal dimension of all facades are presented in Table 2. For the main pavilion, all facades have fractal properties, and the south facade has the highest fractal dimension. The west and east facades have a lower fractal dimension (Table 2).

In the study of the facades of the main pavilion, its internal

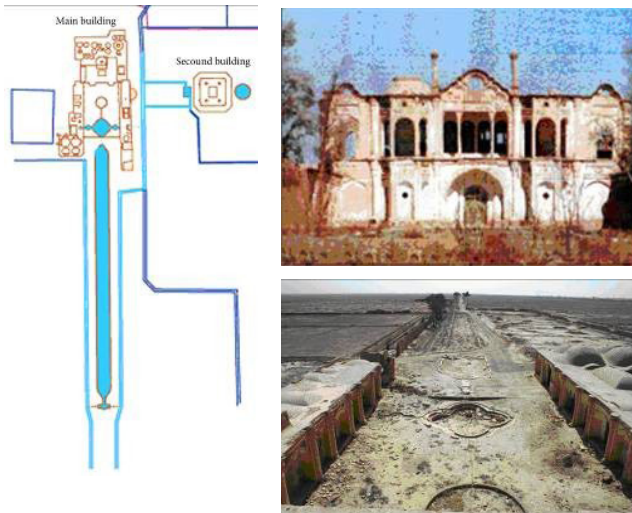


Fig. 3. Left: Fathabad garden area plan, top right: South view of the main pavilion. Bottom right: view of the garden from the south side. Source: Soltanzadeh et al., 2015, 57, 161.

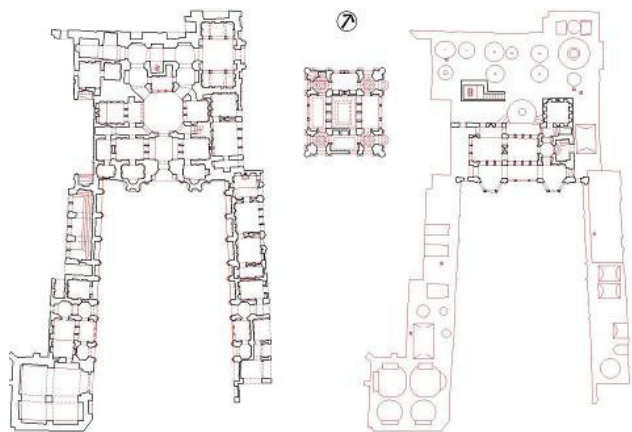


Fig. 4. Plan of Fathabad Pavilions, left: ground floor of the main pavilion, middle: plan of the second pavilion, right side: first floor of the main pavilion. Source: Authors.



Fig. 5. Facades of two pavilions, 1: South facade of the second pavilion, 2: West facade of the second pavilion, 3: North facade of the main pavilion, 4: South facade of the main pavilion, 5: West facade of the main pavilion, 6: Interior facade of the west wing, 7: Eastern facade of the main pavilion. Source: Authors.

facades were also analyzed. These are the facades of the two wings and are parallel to the main axis of the garden and are almost similar (Fig. 3), so one of them (the west facade) was analyzed (Table 1). The fractal dimension of 0.914 is less than 1, so it does not contain fractal order (Bovill, 2007). In the case of the second pavilion, the parallel facades are also similar, so only the west and south facades were analyzed. The findings showed that the west facade has more fractal properties than the south facade (Table 1).

- The second scale

In this section, the facade of each floor of the main pavilion is analyzed separately (Fig. 7). The north facade is not considered at this stage. In the north facade, the shape of the ground-floor ceiling covers the first-floor facade (Fig. 5) and is an obstacle for the first floor so that the observer cannot have a good view of the garden landscape. First, the ground floor and first floor of the south facade were analyzed. The first floor has a higher fractal dimension (Table 3). For the two-story facade on the east side, the ground floor has a higher fractal dimension than the first floor (Table 3). The two-story west facade has almost the same fractal dimension.

- The third scale

The third scale of study is the fractal analysis of decorations (Table 4). Considering the first and second scales, the south facade of the main pavilion is the most important one. At this stage, the decorations of the south facade are analyzed. The fractal dimension was analyzed in three different parts (Fig. 8). The decorations of the main entrance have a higher fractal dimension than the others.

Discussion

In this study, the bodies of the two pavilions in Fathabad Garden were studied using fractal geometry. For this objective, their facades were analyzed using the box-counting method. In the first step, the fractal dimension of the facades of each of the two pavilions was examined separately. For the main pavilion, the south facade has the highest fractal dimension and is located at the end of the main pond of the garden (Fig. 3). Therefore, this facade can have a closer relationship with the garden. However, the east and west facades of the main pavilion have a lower fractal dimension, so, likely, the area in front of them was not as significant as the pond in front of the main pavilion. The east facade has a higher fractal dimension than the west facade, which is probably due to the importance of the pond between the two pavilions (Fig. 3). Regarding the facades of the main pavilion that are parallel to the pond, although these facades are close to the pond and have similar elements to other facades related to the main pavilion, there is not much connection between them and the garden. Pavilions are extroverted buildings and have a close relationship with the garden area (Laurie, 1975). The extroverted architecture of the pavilion allows anyone to see the garden from different facades while in the pavilion (Naima, 2013). The south and

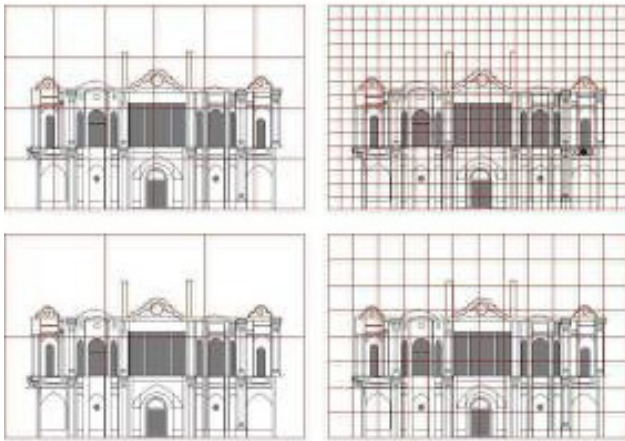


Fig. 6. South facade of the main pavilion with box counting grids on it. Source: Authors.

Table 2. Fractal dimensions of two pavilions. Source: Authors.

Building name	Facade	Box counting dimension
Main pavilion	South facade	1.731
	North facade	1.7
	East facade	1.689
	West facade	1.667
	West (and east) interior facade	0.914
Second pavilion	West facade	1.776
	South facade	1.721

Table 3. Fractal dimension of two floors of the facades of the main pavilion. Source: Authors.

Facade	level	Fractal dimension
South facade	Ground floor	1.664
	First floor	1.777
East facade	Ground floor	1.804
	First floor	1.685
West facade	Ground floor	1.682
	First floor	1.686

Table 4. Fractal dimension of decorations. . Source: Authors.

Decoration	Fractal dimension
Decoration (1): main entrance	1.72
Decoration (2)	1.618
Decoration (3)	1.581

east facades of the main pavilion and the west and east facades of the second pavilion have a higher fractal dimension. They are located at the ends of the axes. Therefore, users can see the geometry of the garden through the openings of those

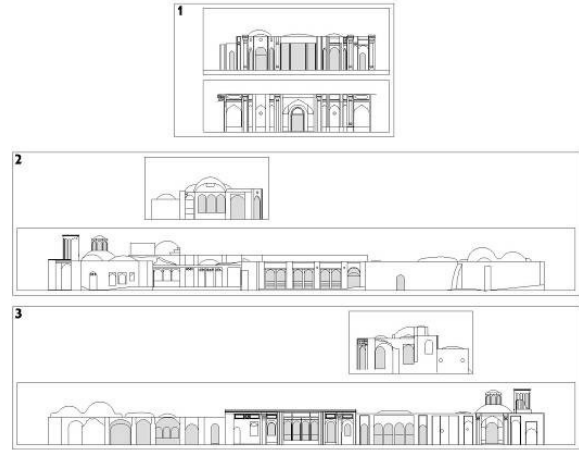


Fig. 7. Views of the main pavilion, 1: South view, 2: West view, 3: East view. Source: Authors.

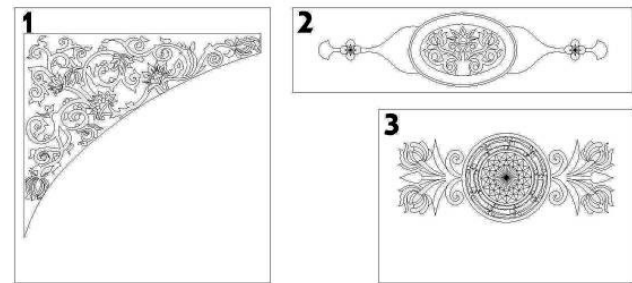


Fig. 8. Decorations of the south facade of the main pavilion, 1: Decorations of the main entrance, 2 and 3: Two decorations of the south façade. Source: Authors..

facades. It should be noted that the fractal dimension provides a more accurate result than the opening area; because there are multiple openings on each floor on the west side, similar to the east side. However, there is no axis in front of this facade. The fractal dimension results show that the west facade has a lower fractal dimension than the east facade. Now, based on the fractal dimension of the two facades of the main pavilion, one can guess the relationship of the pavilion with the geometry of the garden and the direction of the garden axis. First, for the main pavilion, the south facade has the most connection with the garden, so the main axis of the garden is likely in front of it and since the north facade has a lower fractal dimension, the axis does not continue to the north of the main pavilion (Fig. 9). Regarding the higher fractal dimension of the east and west facades of the second pavilion compared to the north and south facades, this can be due to the presence of the ponds. Therefore, it is likely that the axis continues from west to east of the second pavilion (Fig. 9).

At the second scale, the facade is divided into smaller parts, and the fractal dimension of each part is analyzed separately. It is assumed that fractal order can be repeated at smaller scales. According to the results, the first floor of the south facade (compared to the ground floor) has a closer connection with the

garden, especially for an observer who sees the axis of the garden and the pond from the second floor. If the fractal dimension of the first floor is compared with Table 1, the relationship between it and the west and east facades of the second pavilion becomes clear: all three have almost the same fractal dimension, in other words, all three facades have a similar connection to the garden and its axes based on fractal analysis. It should be noted that for the main pavilion, the axis is longer, so it is seen from the first floor, but for the second pavilion, the axis is shorter and can be experienced from the ground floor. Since the east facade of the main pavilion on the ground floor has a higher fractal dimension than the first floor, therefore, unlike the south facade, in the east facade, the axis of the garden has a greater effect on the ground floor, so here too the second axis has a greater effect on the facade of the ground floor. Regarding the west facade of the main pavilion, the two floors have almost the same fractal dimension. These numbers can be compared with other fractal dimensions. They are similar to facades that have no connection to the axis. Therefore, this analysis also shows that although the west facades are related to the garden area, there was probably no axis in front of them. Fractal analysis at the third scale is based on details that the observer perceives from a close distance. According to the results of the first and second scales, the south facade is the most important facade of the pavilion, so its decorations were analyzed. According to the results, the fractal dimension of the decorations related to the entrance is higher than the others. Therefore, although in this facade, based on the findings of the previous scale, the fractal dimension of the second floor was higher, in terms of decorations, the entrance section on the ground floor has the most connection with the nature of the garden. This shows the complexity of the type of connection between different parts of the pavilion with the surrounding nature. Based on the analyses performed (scales 2 and 3), it is possible to identify the parts of the south facade that have been most affected by the surrounding nature (Fig. 9). In summary, the analyses performed in 3 scales answer the research question. A summary of the findings is presented in Table 5. The summary of the Table 5 is presented in Figure 10. In terms of the fractal dimension, the facades and their components are divided into 5 categories, the first four categories have a fractal dimension between 1 and 2, and the last category is below one (no fractal complexity). The highest fractal dimension is due to its location in the line of sight of the water axis. For the other three categories, there is a lower fractal dimension. The placement of the two north facades of the pavilions in one category shows the architect's idea in the similarity of these two pavilions in relation to the north area of the garden. In addition, the facades of the floors of the main pavilion with each other (ground floor and first floor west, ground floor south and first floor east) have similar fractal dimensions, which can indicate their coordination in terms of details and complexity. However, previous research has not paid much attention to the pavilion and its architecture. Therefore, the present research, by focusing on the pavilion

building at different scales and its relationship with the garden and its geometry, revealed another aspect of the influence of nature on the design of the Iranian garden.

Conclusion

In this research, the pavilions of the Fathabad Garden were examined using fractal geometry to investigate their relationship with the garden and its natural elements. Fractal analysis of the Fathabad pavilions revealed the relationship between the facades and their various parts with the garden and its geometry. Based on this, the impact of the garden on the architecture of the pavilion was examined from a macro to a micro-scale. The fractal dimension showed how facades designed with similar elements have received different influences from their surrounding natural environment. On the other hand, the similarity of the fractal dimension of some facades, which indicates a harmony between them, expresses the values that were revealed by this analysis method. It is also possible to guess the direction of the axes based on the fractal dimension of different facades or different parts of a facade, which can be used in future research to better analyze the geometry of historical gardens.

Declaration of Conflict of Interest

The authors declare that there was no conflict of interest for them in conducting this research.

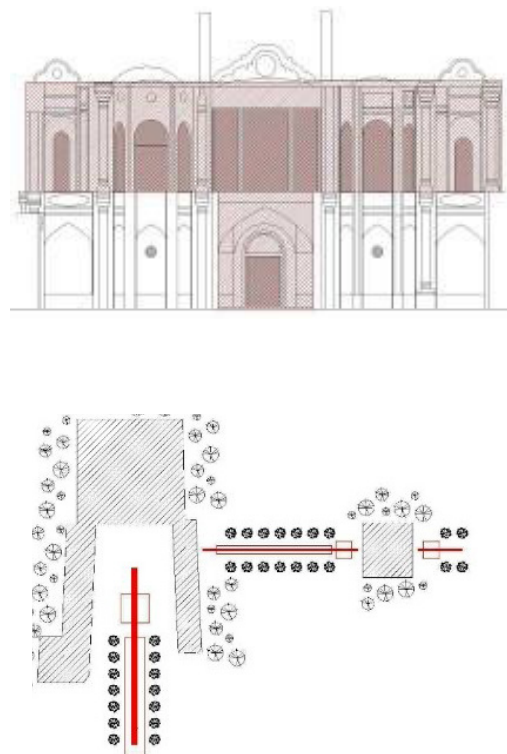


Fig. 9. UP: the south view of the main pavilion, the parts with high fractal dimensions are separated. Down: the position of possible axes of the garden based on fractal analysis. Source: Authors.

Table 5. Summarizing the findings of the fractal dimension of two booths in relation to the garden. Source: Authors.

Building name	Image	Findings of fractal dimension	Reason for changing fractal dimension
Main pavilion (first scale)	South facade	The highest fractal dimension	This facade is located in front of the axis and the main pond
	North facade	Less fractal dimension compared to the south facade	This facade faces the back of the garden and its area.
	East facade	Fractal dimension less than two north and south facades	It has a view of the second pavilion and the (sub) pond between the two pavilions.
	West facade	Fractal dimension less than two north and south facades	The area adjacent to this facade is the side part of the garden
	West interior facade	Fractal dimension below 1 (not having natural features)	It is not facing the main pond and is parallel to it.
Second pavilion	West (and east) facade	The fractal dimension is more than the two north and south facades of the same pavilion	There is a pond in front of each facade.
	South (and north) facade	Fractal dimension less than two east and west facades	Both facades have a view of the plants of the garden, which is less important than the pond
Main pavilion (second scale)	South façade of ground floor	Less fractal dimension than the first floor	This facade has less view of the main pond
	South façade of first floor	Fractal dimension more than the ground floor	It has a better view of the main pond (the highest pond in the garden)
	East façade of ground floor	Fractal dimension more than the first floor	It has a better view of the pond between the two pavilions.
	East façade of the first floor	Fractal dimension less than the ground floor	It has less view of the pond between the two pavilions.
	West façade of ground floor	The similarity of the fractal dimension with the first floor	Similar to the first floor, it has a view of the garden side area.
	West façade of the first floor	Fractal dimensional similarity with the ground floor	Similar to the ground floor, it has a view of the garden side area.
Main pavilion (third scale)	Entrance decoration	Fractal dimension more than (2 and 3)	This part is in front of the main axis and has the best view.
	Decoration (2)	Less fractal dimension compared to entrance decoration	It is not in line with the axis and the main pond.
	Decoration (3)	Less fractal dimension compared to entrance decoration	It is not in line with the axis and the main pond.

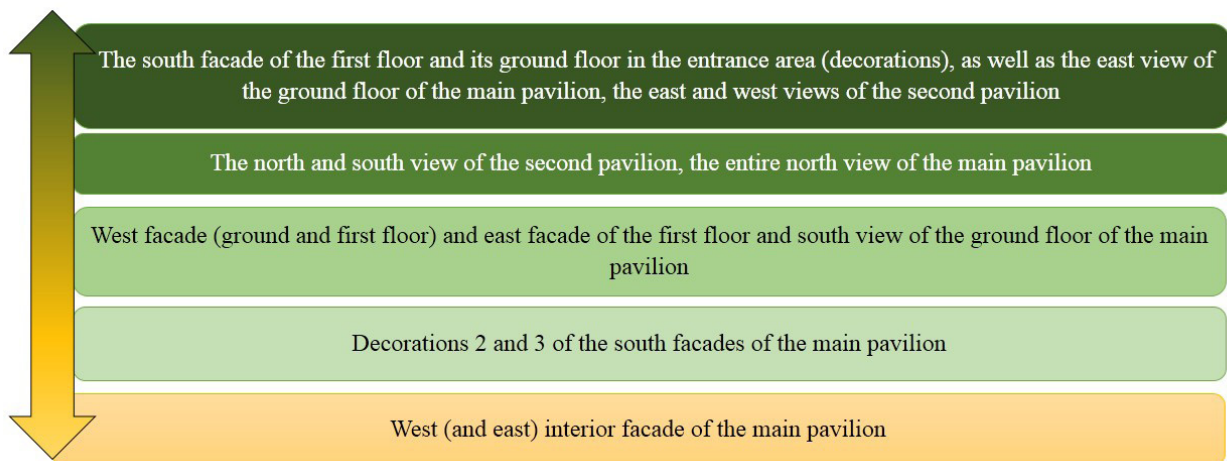


Fig. 10. Classification of facades based on the fractal dimension (increasing upward and decreasing downward). Source: Authors.

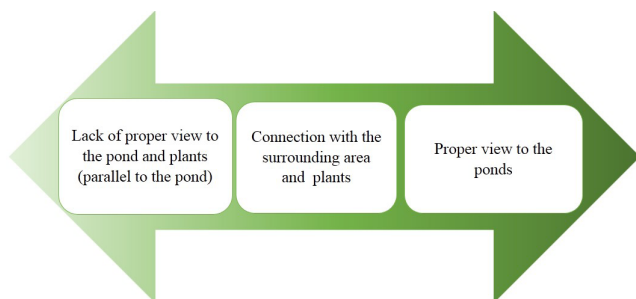


Fig. 11. Summary of factors affecting the facade's fractal dimensions. Source: Authors.

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HOW TO CITE THIS ARTICLE

Ashraf Ganjouei, M.A & Iranmanesh, M. (2024). Recognition of the Pavilion in Relation to the Persian Garden from the Perspective of Fractal Geometry (Case Study: Pavilions of the Fathabad Garden in Kerman). *MANZAR, the Scientific Journal of Landscape*, 16(67), 6-13.

DOI: 10.22034/MANZAR.2024.425783.2265

URL: https://www.manzar-sj.com/article_195725.html?lang=en

