Ain Shams Engineering Journal 16 (2025) 103459

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Full Length Article

The impact of subsequent additions on visual harmony in a designed campus: A fractal analysis of Bursa Uludağ University Görükle Campus

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ARTICLE INFO

Keywords:
Visual harmony
Fractal dimension
Complexity
Visual diversity
Design analysis
Bursa Uludağ University

ABSTRACT

The academic district of Bursa Uludağ University Görükle Campus was designed by Sezar Aygen by repeating the original architectural form in order to achieve visual harmony. Designed in 1978, the construction process on the campus started in accordance with Aygen's design, but the buildings added over time have led to divergences from the original design. This study aims to evaluate the visual harmony of the buildings added to the academic district with the original design. The fractal dimension was used as a method of analysis to assess the level of similarity between the original form and the buildings added later. This paper is one of the pioneering studies that use fractal dimension analysis to reveal the visual harmony between architectural products in a bounded area. The findings show that the later buildings are not in complete visual harmony with the original design, creating visual diversity in the academic district.

1. Introduction

Campuses are designed spaces intended to create the visual impact desired by their founders. However, there is no design rule that encompasses every campus form. Campus design can be conceived as the sum of individual architectural designs, as well as the design of each unit as small parts serving the larger whole [1]. Universities are institutional structures that have a long life span and change over time. The spatial structure of the campus is changing with the addition of new buildings over time, while at the same time increasing the number of students and staff who need more facilities and amenities [2,3]. However, studies on how these changes will affect the spatial layout are quite limited [4]. Changes in campuses are not limited to the repetition of architectural forms, but also include the need to adapt to changing architectural styles, materials, planning methods and organizational schemes over time. This situation may cause university layout decisions, which were originally designed in a unique way, to transform into different unpredictable forms over time [3]. The academic district of Bursa Uludağ University (BUU) Görükle Campus was designed with the aim of architectural harmony between physically similar-looking buildings, in order to foster interaction and knowledge sharing among students and staff located in different departments. Although the original design was somewhat distorted during the construction phase, the academic district began to take shape through the repetition of a similar form. Although the academic district began to take shape in a similar configuration to the campus plan, it has reached its current state as a result of the random placement of architectural designs that differ from the initial design over time.

The architectural elevation is the first physical element that people encounter when approaching a building and provides important clues about the functions within the building. Building elevations have a significant impact on the human experience [5]. Visual diversity and visual harmony are crucial components of contemporary design [6]. While computational approaches such as shape grammars [7] and space syntax [8–10] exist for analyzing the harmony between architectural constructs, these approaches are not suitable for analyzing an architectural elevation. Fractal dimension analysis is one alternative computational method for quantitatively measuring formal harmony in architecture. The method of measuring the fractal dimension of an object was first developed by Benoit Mandelbrot [11]. A comprehensive two-phased survey by Husain et al. [12,13] focused on the study of fractals. In these studies, the mathematics of fractals, including fractal dimension and iterated functions, is discussed in detail. The studies also examined the applications of fractals in various disciplines, including art and architecture, in depth, revealing both the aesthetic and practical importance of fractals. The use of this approach to analyze the complexity of an architectural product began with the work of Bovill [14,15]. Bovill [14,15] played a pioneering role in this field by applying

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https://doi.org/10.1016/j.asej.2025.103459
Received 26 December 2024; Received in revised form 7 April 2025; Accepted 30 April 2025
Available online 9 May 2025
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the principles of fractal geometry to the analysis of architectural forms. Utilizing statistical measurement of the density and complexity of geometric information within an image or object, fractal dimension analysis has been adopted in various fields, including architecture [16,17]. Recent studies [18–20] have used this approach as an alternative to architectural forms to reveal the structure of urban form and compare different urban forms. Fractal dimension analysis continues to be widely used in academic studies as a tool to mathematically express the geometric properties of architectural products [16,21–26]. The fractal dimension value is also effectively used to reveal the degree of harmony between different visual products. Ediz and Çağdaş [27] employed this analytical method as a generative design tool to contribute to the design process and create harmonious compositions during the preliminary design phase. In architectural research, the fractal dimension value has been used to investigate the harmony of an architectural product with its natural environment [14,28,29], the harmony between different products of an architect [30], the harmony between a fabric obtained through a generative method and the initial fabric [27], the harmony of an architectural product with the street silhouette [31], and the harmony between houses produced in different architectural styles [16].

The study aims to reveal the visual harmony and similarity between the initial design and the later buildings in the academic district of Görükle Campus, which was designed to achieve a visual harmony. Fractal dimension analysis method was used to reveal the physical harmony and similarity with quantitative data. During the construction phase, the original design developed by Sezar Aygen and planned to be repeated throughout the academic district was distorted to some extent. Revealing the amount of distortion of the original design is among the objectives of the study. The unique value of this study lies in its use of fractal dimension analysis to investigate the visual harmony of buildings in a defined area. The study will also guide future designs and interventions to check the compatibility of buildings added to an existing fabric. Fig. 1 shows the framework of the study.

2. Case area

BUU Görükle Campus is located in Nilüfer district of Bursa province (Fig. 2). The suburban campus is located 18 km. from the city center and is built on 1600 ha of land.

Architect Sezar Aygen was appointed on June 7, 1976 to design the Görükle Campus and the buildings to be located within the campus. One of the goals of the designed university was to foster interaction and information exchange among students and staff in different departments. To achieve this, it was stated that the departments within the academic fabric should be planned to have a physically similar appearance [32]. The process, which included the design of the campus plan shown in Fig. 3, concluded on September 30, 1978 with the completion of all project design works [33]. The area indicated with B in Fig. 3 covers the academic fabric. This area was designed as a repetition of the original form developed by Aygen. The campus was also designed according to its maximum growth. The design attempts to reflect the characteristic inward-facing open spaces and the flowing interior-exterior relationship of Bursa's civil architecture. The project was estimated to take 20–25 years due to financing difficulties [32]. The original form designed by Aygen in the academic district was subjected to various changes and distortions during the application. In the study, the fabric created by distorting the original form is defined as the 'initial design'. There are 6 buildings within the boundaries of the academic district that are examples of the initial design. Although Görükle Campus started to take shape with the repetition of the same layout in a setup similar to the campus plan designed by Sezar Aygen, settlement decisions that were not in accordance with the plan were started to be implemented over time and the original design decisions were not followed. The buildings and open space arrangements within the settlement area have generally been shaped in line with the decisions taken by the central administration instead of adhering to the existing plan criteria. As a result, a holistic principle was not adhered to in the settlement plan and the location of the buildings [34]. The application of original design decisions for a certain period of time in the selection of the study area, but then ignoring these design decisions and adding different architectural products to this fabric, was effective. The study investigates the level of compatibility of the architectural forms added to the academic district, which was designed with a holistic principle in order to obtain a harmonious and similar architectural character, with the initial design. Fig. 4 shows the first fabric analyzed within the scope of the study and the 11 architectural structures added later.

3. Research method: fractal dimension analysis

Fractal dimension (D), proposed by Mandelbrot [11,35] to measure irregularity and roughness in natural forms, emerges as a measure of the space-filling property of an image or object. From a holistic mathematical perspective, it's possible to say that various architectural examples (elevations, settlement fabrics, details, etc.) possess fractal dimension properties [36]. Bovill [15] defines D as a measure of the mixture of order and surprise in a structure. To measure the D value, the relative density of geometric data, the box-counting method is often used [17]. The box-counting method is the only method used to calculate the approximate D value of an object and, most importantly, the D value of an architectural drawing [30]. To calculate the D value, a grid is overlaid on each image and the number of boxes containing detail (N) is recorded. Then, the box sizes are successively reduced according to the scaling coefficient (SC) and the same process is repeated. The important point when performing these operations, called iterations, is to apply a sufficient number of iterations. Ostwald and Vaughan [17] stated that the computational process should be finalized in at least 8 iterations and ideally in 10 iterations. The obtained data are processed in the following log–log diagram [31] (# indicates the number of iterations).

$$D_{\#} = \frac{[\log(N_{(\#+1)}) - \log(N_{(\#)})]}{\log(SC)}$$

The D value obtained after performing the above operations, which

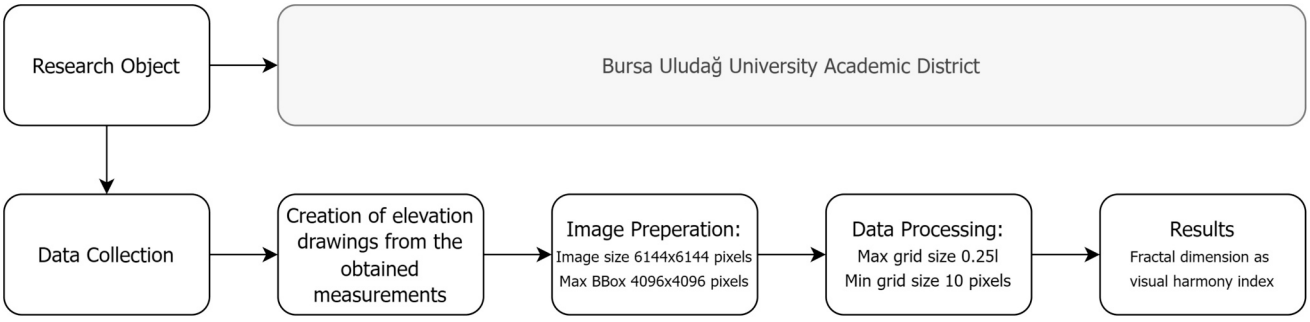


Fig. 1. Research framework.

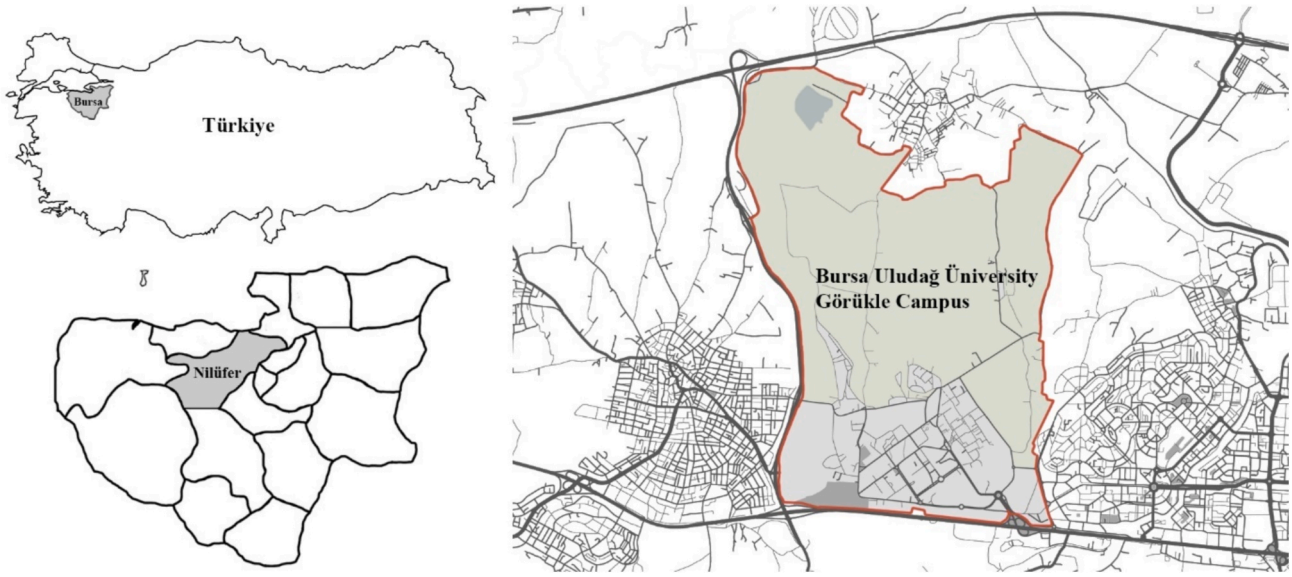


Fig. 2. Bursa Uludağ University Görükle Campus location.

indicates the degree of complexity of the architectural image, is between 1 and 2. A lower D value indicates a less complex and simple composition, while a higher D value indicates a more complex and detailed composition. Architectural [14] and urban [37] applications of the box-counting method were published in the 1990s. Ediz and Ostwald [22] obtained a very high D value of 1.807 in their multi-layered study of the elevations of the Süleymaniye Mosque, analyzing form, ornament and material layers together and comparing them. Ostwald and Vaughan [17] stated that this mosque is among the most richly detailed buildings ever built and that this should be the highest level of complexity that can be obtained from an architectural product. In another study, Vaughan and Ostwald [38] showed 1.1 as a lower limit for the lowest D value that an architectural product can have. Lionar [39] categorized the degree of complexity of the visual according to D ranges. For D value, Lionar classified 1.00–1.20 as very low, 1.20–1.40 as low, 1.40–1.60 as average, 1.60–1.80 as high, 1.80–2.00 as very high complexity. In a comprehensive study by Ostwald and Vaughan [17], the architectural features of 85 houses designed or built between 1901 and 2007 were measured and compared using fractal analysis. It was shown that the D range of the 85 buildings varied between 1.3698 and 1.5104. The D value is used to measure the relationship between complexity values as well as to investigate the similarity and harmony levels of architectural products. Vaughan and Ostwald [29] stated that the human eye can easily detect similarities between images whose difference between D values is less than 8 %. Comparisons between calculated D values can be generated using the range (R) expressed as a percentage. R between different D values is defined as “indistinguishable” if it is below 2 %, “very similar” if it is between 2 and 6, and “similar” if it is between 6 and 11 [17,28]. While evaluating the D values obtained in the study, the R values mentioned above were utilized. In the next stage of the study, it is explained how the visuals to be used in the analysis were prepared and with which variables the D values were obtained.

3.1. Image preparation

The dimensions of the architectural products used within the scope of the article were obtained from Bursa Uludag University Directorate of Building Works. The obtained measurements were prepared in a format suitable for analysis using the Autodesk-AutoCAD program. It is known that the fractal analysis method is sensitive to inconsistent image features. For this reason, the image to be analyzed should be prepared in a consistent order and preprocessed. There should be no symbolic expressions in the images to be prepared, and environmental elements such as trees and cars should not be included. In this direction, the images prepared for the analysis followed the standards in accepted publications in the literature [17,21,40]. There is no single optimal size for analyzing architectural drawings, but higher quality images will produce more accurate D values. Mayrhofer-Reinhartshuber and Ahammer [41] analyzed image sizes ranging from 128 × 128 pixels to 8192 × 8192 pixels and showed that image sizes of 1024 × 1024 pixels or higher improve the accuracy of the D value.

The images prepared for the study are all binary (black and white) and the analyzed architectural drawings are represented by lines 1 pixel thickness. The resolution of the analyzed images is 200 dpi and the content of the image is surrounded by a white space equal to 25 % of the length of the shorter side. The maximum bounding box (the smallest square that encloses the part of an image containing pixels) size covering the drawing was defined as 4096 × 4096 pixels and the image size was defined as 6144 × 6144 pixels. Fig. 5 shows an example of the image dimensioning process applied in this study. In the preparation of the images, a process similar to the one applied by Lee and Ostwald [40] was followed.

3.2. Data processing

Most researchers use software packages to calculate the D value because of the large size of the images to be analyzed and the time it would take to perform the process manually. In this paper, D values of the architectural pattern designed by Sezar Aygen and the elevations of the architectural products added later were analyzed using FracLac [42,43], a plugin of ImageJ. Karperien [43] developed FracLac, an open source software for fractal analysis using the box-counting algorithm. FracLac software has been widely used in recent studies [16,23,40] to measure the D value of architectural elevations. In order to calculate the D value accurately, parameters such as grid sizes and positions need to be used accurately [17,23]. Lee and Ostwald [44] showed the effect of maximum grid size, grid position and scaling coefficient on the D value. The initial grid size (maximum box counting size) was set to 25 % of the shorter side of the image (0.25 l) and the minimum grid size was set to 10 pixels. Results were obtained using 12 different grid positions. The scaling coefficient (SC) was defined as $\sqrt{2}$:1 (approximately 1.4142:1), which represents the degree of reduction in the size of the boxes that make up the grid. The variables and their settings used in image preparation and data processing are shown in Table 1. Each building



Fig. 3. Bursa Uludağ University Campus plan [33].

analyzed in the study has a front elevation containing the main entrance, a back elevation opposite the front elevation, and left and right elevations named according to their relationship with the front elevation.

4. Results

Among the aims of the study is to reveal the extent to which the original design by Sezar Aygen was distorted during the construction phase. In line with this goal, the D values of the back elevation of the Faculty of Economics and Administrative Sciences building, which has the highest amount of detail, and the situation designed by Aygen were analyzed (Fig. 6). The D value of the original design by Aygen was calculated as 1.4328. In the case of the building with the changes made after the decisions taken during the construction, the D value was calculated as 1.4376. The fact that the difference between the two D values is below 1 % indicates that the presence of the traces designed by Aygen was preserved after the construction. Although the situation designed by Aygen was not implemented exactly, the level of complexity of the design decisions was maintained. The main purpose of the study is to determine the level of 'visual harmony' of the buildings added to the academic district of Görükle Campus with the initial design. For this purpose, 4 elevations of the initial design and 11 different buildings added later were analyzed. 48 D values were generated from these elevations in total. The R value shows the D differences between the maximum and minimum D values within the 4 elevations of the individual buildings, the mean fractal dimension value (D_M) of the 4 elevations of the individual buildings, and the R values show how much the D_M values differ from the initial design were included in the calculation. When evaluating the analysis results, the buildings are represented by the integers in Fig. 4 and Table 2. When abbreviating the D values, the number of the building and the first letter of the calculated elevation were used. The fractal dimension value of the front (F) elevation of the Faculty of Economics and Administrative Sciences building, represented by the number 1, is abbreviated as D_{1F} and the mean value is

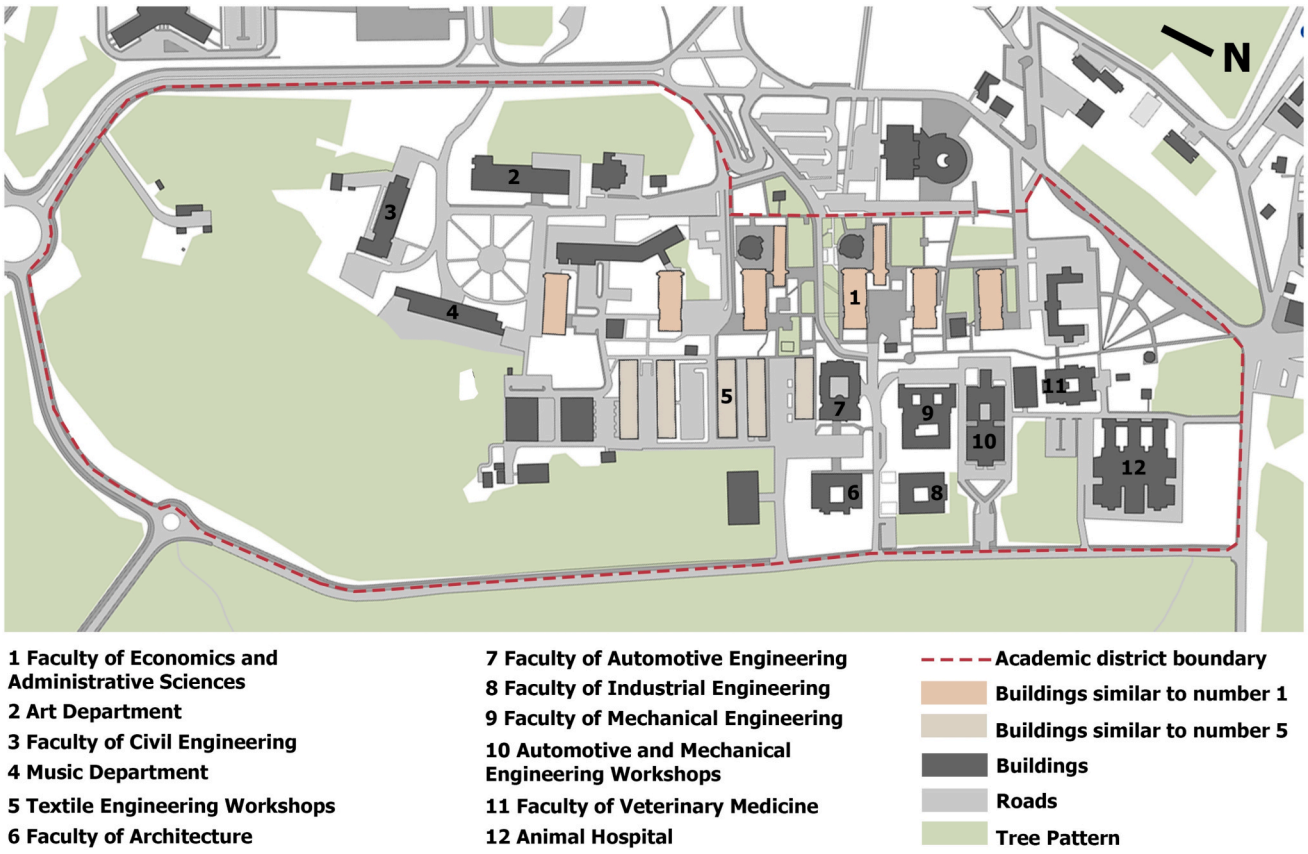


Fig. 4. Academic district and buildings analyzed within the scope of the study.

abbreviated as D_{1M}. The complete results are summarized in Table 2 and Fig. 7. All elevation drawings used in the study and nomenclatures not included in Table 1 are shown in supplementary material.

The D_M value of all 12 buildings analyzed within the scope of the study was between 1.20–1.40. This range indicates a 'low' [39] level of complexity. The highest D_M value was calculated in the initial design with 1.3974 (D_{1M}). This value is very close to 1.40, indicating an almost average level of complexity. The values obtained are lower than the value of 1.505 [29] obtained for Amasya houses reflecting local Turkish architecture. The buildings in the academic district show a very simple construction. The fact that no D_M value was measured with an R value below 2 % with the initial design indicates that there is no building with an 'indistinguishable' complexity level with the initial design. Buildings 2, 4, 8, 9, and 10 have D_M values in a visually 'very similar' range to the initial design (R% <6). The D_M values of buildings 3, 5, 7, 11 and 12 are positioned in a 'similar' range (R% <11) to the initial form. The lowest D_M value was calculated for building 6 with 1.2546 (D_{6M}). The fact that this building has an R value of 14.27 % with the initial design indicates that building 6 has a rather simpler architectural layout than the initial form.

The highest D value, D_{2B} (1,5147) and the lowest D value D_{2L} (1,1890) were measured on different elevations of building number 2. The highest value obtained is far from the 1.807 value of Suleymaniye Mosque [22], which is recommended as the upper limit, but it is very close to the highest value of 1.5104 obtained by Ostwald and Vaughan [17] from 85 buildings. The lowest value obtained within the scope of the study is close to 1.1 [38], which is considered as the lower limit. Two elevations of buildings 1 and 4 and one elevation each of buildings 2, 8 and 10 were above the D value of 1.4. Only 7 of the 48 D values obtained are at the 'average' level of detail. The highest R value was calculated for building number 2 with 0.3257. This shows that building number 2 has elevations with different architectural detail richness and its architectural elevations are designed to create contrast. Buildings 7 and 11 have R values below 6 %, indicating that all of their elevations have a 'very similar' level of complexity. The R values of buildings 1, 6, 8, 9, 10 and 12 are below 11 %, indicating that the different elevations of these buildings have a 'similar' level of complexity.

The front elevations and D values of the 12 buildings analyzed within the scope of the study are shown in Table 3. The D_{1F} value of the first design was calculated as 1.4203. This value expresses an average level of complexity. D_{1F} and D_{8F} values are calculated to be the same. This shows that the two front elevations have the same level of complexity. Except for the front elevation of building number 8, there is no elevation with an R value below 2 %. The R value of buildings 2, 3 and 10 to the D_{1F} value of the initial design is below 6 %. This shows that the elevations of buildings 2, 3 and 10 are 'very similar' to the elevation of the initial design. The R values of buildings 4, 5, 11 and 12 are below 11 %, indicating that the front elevations of these buildings are 'similar' to the front elevation of the initial design. Buildings 6 and 7 have R values above 11 %, indicating a very low level of visual similarity. The front elevations of buildings numbered 3,4,8,9 and 10 have the highest D value compared to the other individual elevations of the buildings. The highest D value was measured on the back elevations of buildings 1, 2, and 6 and on the right elevations of buildings 6, 7, 11, and 12 (Table 2). In the findings, there is no absolute approach that the front elevation has the highest complexity.

5. Discussion

Using a computational method based on fractal value to measure similarity in visual complexity is an effective tool to reveal visual harmony. In this context, the study investigated the visual harmony of the buildings added to the academic district of BUU Görükle Campus with the initial design. As can be seen in Table 2, when individual building

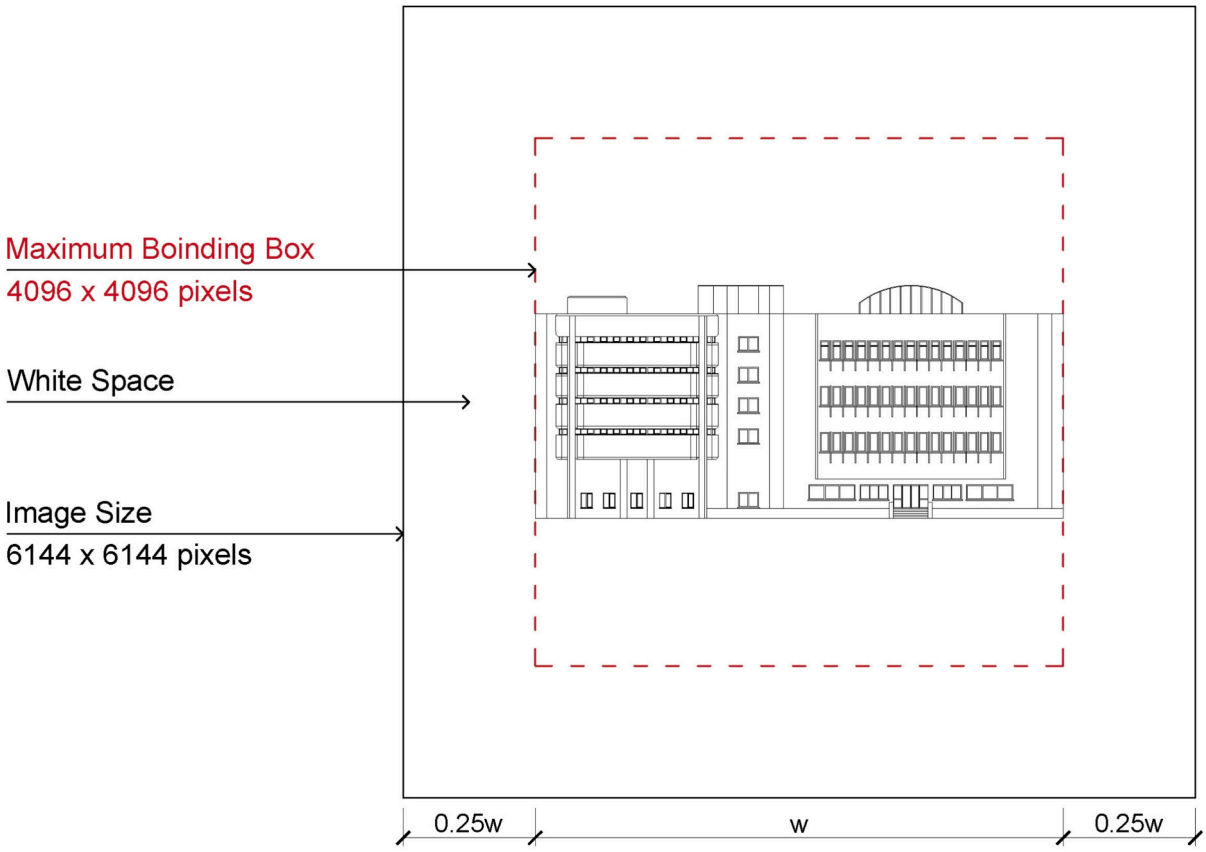


Fig. 5. Image size processing example (Left elevation of the Faculty of Economics and Administrative Sciences).

Table 1
Methodological variables, settings and resulting values used.

Stage	Variable	Setting	Notes
Image preparation	White space	50–50	Images are surrounded by a white space equal to 25 % of the length of the short side
	Image position	Centre	Images are positioned in the center of the field before being analyzed
	Line weight	1 pixel	Thickness of the created lines
	Maximum bounding box		The smallest square enclosing the part of an image containing pixels
Data processing	Number of grid positions	12	Number of grid positions added around the initial four corner positions
	Scaling coefficient (SC)	1.4142:1	Variable indicating the reduction ratio of consecutive grids
	Number of filled boxes (N)		Number of boxes with details after placing the grid on the drawing
	Maximum grid size	0.25 l	Relationship between initial grid and white space
	Minimum grid size	10 pixels	Indicates the smallest grid size for the calculation.
Results	Fractal Dimension (D)		D is a formal complexity of an architectural design
	Mean Fractal Dimension (D_M)		Mean of fractal dimension values obtained from 4 elevations of a building
	Range (R)		Difference between two fractal dimensions
	D_{1F}		The D value of the front elevation of the Faculty of Economics and Administrative Sciences building numbered 1 in Fig. 4

elevations are analyzed, there are differences in R values ranging from 5.38 % < R < 32.57 %. Of the 12 buildings analyzed in the study, the absence of an R value below 2 % indicates that there is no building with 4 elevations with an “indistinguishable” level of complexity. This shows that environmental factors and the functions of the buildings significantly affect the façade designs. The fact that the R values of buildings 7 and 11 are below 6 % (Table 2) indicates that these buildings consist of 4 elevations with “very similar” complexity. The highest R value obtained within the scope of the study was calculated as 32.57 %. This value is significantly higher than the highest R value of 14.06 % obtained by Ostwald and Vaughan [17] and the R value of 8.16 % measured between the 4 elevations of Fallingwater House [28]. This shows that there are architectural approaches that can be called ’’unrelated’’ even between different elevations of the buildings.

When the mean complexity values (D_M) obtained from 4 different elevations of the buildings are compared, differences ranging from 2.79 % < R < 14.27 % between the initial (original) building and the 11 later added buildings are observed. Although some of the later buildings have a high similarity with the original building, the fact that there is no difference below 2 % indicates that there is no building with an ’indistinguishable’ similarity with the original building. Within the limits of the methodology used and the data sources selected, the buildings added to the academic district were found to be far from the level of complexity of the initial design. This study shows that the D value of the architectural product is an effective tool for investigating the level of visual harmony, similar to studies in the literature [16,24,27,28,30,31].



Fig. 6. Original (a) and distorted or initial (b) back elevation of Faculty of Economics and Administrative Sciences.

Table 2
D and R values of 12 buildings' elevations (the highest values are represented by the green color).

Building Number	Fractal dimensions of elevations					Differences	
	Front (F)	Back (B)	Left (L)	Right (R)	Mean (D_M)	D range (R)	Range from D_{1M}
1	1.4203	1.4376	1.3538	1.3781	1.3974	0.0838	
2	1.3997	1.5147	1.1890	1.3367	1.3600	0.3257	0.0374
3	1.3928	1.3899	1.3174	1.2490	1.3372	0.1438	0.0601
4	1.4867	1.4482	1.2765	1.2262	1.3594	0.2605	0.0380
5	1.3510	1.3578	1.2682	1.2100	1.2967	0.1478	0.1007
6	1.2221	1.2039	1.2900	1.3027	1.2546	0.0988	0.1427
7	1.2834	1.3158	1.3141	1.3372	1.3126	0.0538	0.0848
8	1.4203	1.3595	1.3498	1.3484	1.3695	0.0719	0.0279
9	1.3585	1.3506	1.2917	1.3494	1.3375	0.0668	0.0599
10	1.4032	1.3351	1.3087	1.3403	1.3468	0.0945	0.0506
11	1.3173	1.3046	1.3636	1.3640	1.3373	0.0594	0.0600
12	1.3241	1.2536	1.3562	1.3565	1.3226	0.1029	0.0748

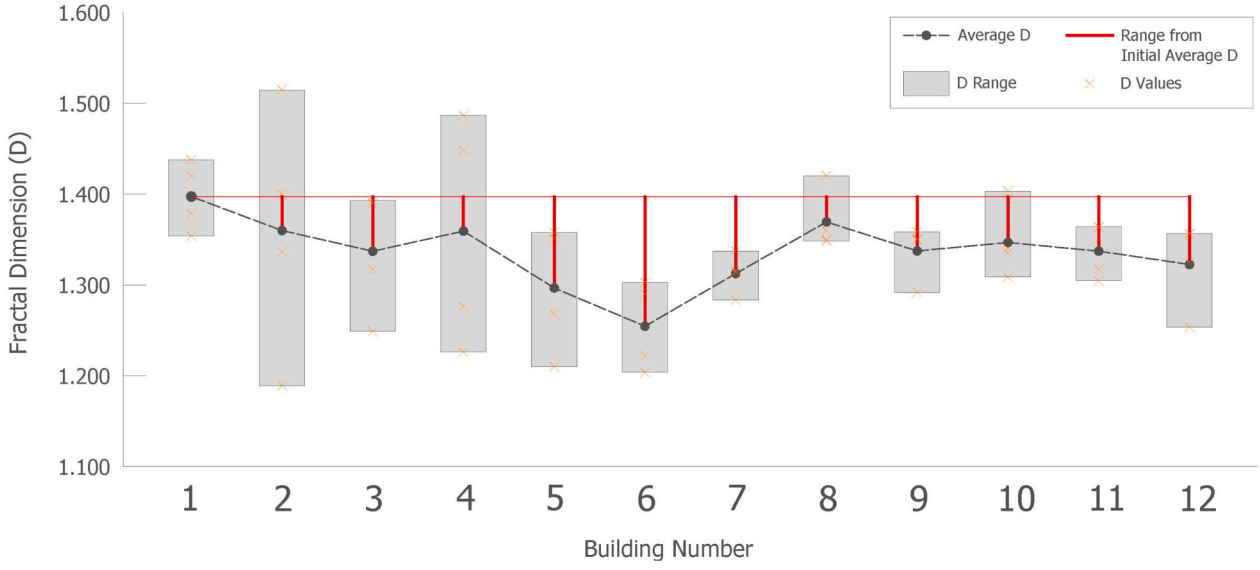
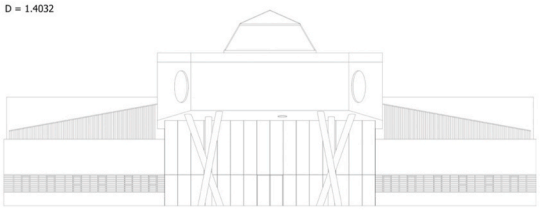


Fig. 7. D and R values of 12 buildings' elevations.

6. Conclusion

Nowadays, it is known that concepts such as 'harmony' or 'diversity' in architecture are addressed with technology-based numerical methods. The most widely used approach is the fractal value-based analysis method. Within the scope of the method; there are studies in which various architectural fabrics are examined at the plan scale, as well as studies in which architectural elements are examined at the elevation scale. In this study, the academic district, which had a unique fabric when it was designed, was analyzed within the framework of

Table 3
Front elevations and D values of 12 buildings'.

D = 1.4203 	D = 1.3997 
1 Faculty of Economics and Administrative Sciences	2 Art Department
D = 1.3928 	D = 1.4847 
3 Faculty of Civil Engineering	4 Music Department
D = 1.351 	D = 1.2221 
5 Textile Engineering Workshops	6 Faculty of Architecture
D = 1.2834 	D = 1.4203 
7 Faculty of Automative Engineering	8 Faculty of Industrial Engineering
D = 1.3585 	D = 1.4032 
9 Faculty of Mechanical Engineering	10 Automotive and Mechanical Engineering Workshops
D = 1.3173 	D = 1.3241 
11 Faculty of Veterinary Medicine	12 Animal Hospital

building elevations. Plan and site plan scales are excluded from the scope. This area, which was designed by Sezar Aygen to produce visual harmony, has been transformed as a result of new architectural interventions. The similarity of this change with the original fabric is revealed using the fractal value-based analysis method. Creating new designs in original fabrics constitutes one of the most difficult areas of architecture. While maintaining the character of the original fabric is one of the methods, creating a contrast by differentiating from the related fabric is another approach. The interventions of different architects as different architectural characters at different times make it even more difficult to preserve the character of the original fabric. The study conducted in the relevant area is a good example of this situation.

Within the scope of the study, 4 different elevations of the original design and 11 buildings that were added later were analyzed. Both the individual characteristics of the 12 buildings analyzed and their visual relationships with each other were discussed in different aspects. As a result of not maintaining the design principles developed by Aygen, the buildings added later on produced different visual approaches. Theoretically, the complexity value (D) can be a strong indicator of the common architectural language in the fabric. The interventions have caused the original architectural language to change. This is supported by the fact that the differences between the D values obtained are 6 % and above. However, the relevant value was also observed as 2.79 % in some places. The findings obtained show that although the buildings added later resemble the building designed by Aygen in some places, new buildings are generally produced by not observing a visual relationship. The combination of architectural elements of different characters affects the level of complexity of visual compositions. In order to create an aesthetically unified order, it is possible to make an evaluation using the measure of complexity because architectural diversity can cause a chaotic order as well as create originality. Universally, there is no single tool to reveal architectural harmony and diversity. The preference for harmony and diversity in an elevation can be shaped by physical and social variables. The study showed that the D value can be an effective tool for revealing the level of visual harmony as well as revealing the level of 'complexity' that the majority of architectural research utilizes [21,22,24,45]. Unlike other visual harmony studies [16,24,27,28,30,31], the study investigated the visual harmony levels of buildings located in a bounded region. The results obtained in this study repeat that the whole may be different from the sum of its parts. The use of fractal dimension analysis method as a suitable tool to observe the effect of interventions to an existing fabric on the unity of the fabric is important for designers to observe the possible effects of architectural interventions in advance. In future research, combining fractal analysis approaches with generative approaches such as generative adversarial networks (GANs), which is one of the artificial intelligence and machine learning tools, has the potential to be an effective tool for investigating the compatibility of new buildings to be added to an existing fabric at an early design stage and producing elevation approaches with the desired visual effect.

Ethical approval and informed consent statements

Not applicable.

Declaration of Generative AI and AI-assisted technologies in the writing process

No generative AI was used in the scientific paper. Everything in the study was created by the authors.

Funding statement

Not applicable.

CRediT authorship contribution statement

Barış Mert Karasu: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Özgür Ediz:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank Bursa Uludağ University Department of Construction Works for sharing the architectural measurements with the authors to be used in the study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asej.2025.103459.

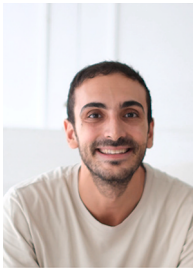
Data availability

The data that support the findings of this study are available on request from the corresponding author.

References

[1] Chapman MP. American places: In Search of the Twenty-first Century campus. Westport: Praeger Publishers; 2006.
[2] El-Darwish II. Enhancing outdoor campus design by utilizing space syntax theory for social interaction locations. Ain Shams Eng J 2022;13(1):1–7. https://doi.org/10.1016/j.asej.2021.06.010.
[3] Larkham PJ. Institutions and urban form: The example of universities. Urban Morphol 2000;4(2):63–77. https://doi.org/10.51347/jum.v4i2.3890.
[4] Hashimshony R, Haina J. Designing the University of the Future. Plan High Educ 2006;34(2):5–19. https://doi.org/10.1215/9781478022503-005.
[5] Stamps AE. Physical determinants of preferences for residential facades. Environ Behav 1999;31:723–51. https://doi.org/10.1177/00139169921972326.
[6] Stamps AE. Advances in visual diversity and entropy. Environ Plan B Plan Des 2003;30(3):449–63. https://doi.org/10.1068/b12986.
[7] Stiny G, Mitchell WJ. The Palladian grammar. Environ Plan B Plan Des 1978;5(1):5–18. https://doi.org/10.1068/b050005.
[8] Hillier B, Hanson J. The social logic of space. Cambridge: Cambridge University Press; 1984.
[9] Şen E, Baran M. Examination of Traditional Residences in Bitlis on the Zeydan District Scale in the Context of Space Syntax Analysis Techniques. SAGE Open 2020;10(2):1–16. https://doi.org/10.1177/2158244020919519.
[10] Hanson J. Decoding Homes and Houses. Cambridge: Cambridge University Press; 1999.
[11] Mandelbrot BB. Fractals form, chance and dimension. San Francisco: W.H. Freeman and Company; 1977.
[12] Husain A, Nanda MN, Chowdary MS, Sajid M. Fractals: An Eclectic Survey. Part II Fractal Fract 2022;6(7):1–38. https://doi.org/10.3390/fractalfract6070379.
[13] Husain A, Nanda MN, Chowdary MS, Sajid M. Fractals: An Eclectic Survey. Part-i Fractal Fract 2022;6(2):1–35. https://doi.org/10.3390/fractalfract6020089.
[14] Bovill C. Fractal Geometry in Architecture and Design. Boston, MA: Birkhäuser; 1996.
[15] Bovill C. Fractal Geometry as Design Aid. J Geom Graph 2000;4(1):71–8.
[16] Lee JH, Ostwald MJ. The 'visual attractiveness' of architectural facades: measuring visual complexity and attractive strength in architecture. Archit Sci Rev 2023;66(1):42–52. https://doi.org/10.1080/00038628.2022.2137458.
[17] Ostwald MJ, Vaughan J. The Fractal Dimension of Architecture. Birkhäuser: Springer International Publishing; 2016.
[18] Bellala A, Dahmani K. Towards the authentication of urban pattern through fractal analysis: the case of Blida. Algeria URBAN Morphol 2024;28(1):45–58. https://doi.org/10.51347/UM28.0003.
[19] Boeing G. Measuring the complexity of urban form and design. Urban Des Int 2018;23(4):281–92. https://doi.org/10.1057/s41289-018-0072-1.
[20] Chuanchuan Y, Mu J. Single-clan settlements and multiple-clan settlements: a case study based on the evolution of spatial fractals in four traditional villages in the Xianggan region of China. J Asian Archit Build Eng 2024;00:1–16. https://doi.org/10.1080/13467581.2024.2412390.
[21] Ostwald MJ, Ediz Ö. Measuring Form, Ornament and Materiality in Sinan's Kılıç Ali Paşa Mosque: an Analysis Using Fractal Dimensions. Nexus Netw J 2015;17(1):5–22. https://doi.org/10.1007/s00004-014-0219-3.
[22] Ediz Ö, Ostwald MJ. The Süleymaniye Mosque : a computational layering in Sinan's masterwork. Arq Archit Res Q 2012;16(2):171–82.
[23] Lee JH, Ostwald MJ. Mathematical beauty and Palladian architecture: Measuring and comparing visual complexity and diversity. Front Archit Res 2024;13(4):729–40. https://doi.org/10.1016/j.foar.2024.03.004.
[24] Dawes MJ, Ostwald MJ, Lee JH. The Mathematics of 'Natural Beauty' in the Architecture of Andrea Palladio and Le Corbusier: An Analysis of Colin Rowe's Theory of Formal Complexity Using Fractal Dimensions. Fractal Fract 2023;7(2). https://doi.org/10.3390/fractalfract7020139.
[25] Driscoll JC. Fractal Patterns as Fitness Criteria in Genetic Algorithms Applied as a Design Tool in Architecture. Nexus Netw J 2021;23(1):21–37. https://doi.org/10.1007/s00004-020-00490-4.
[26] Zhang L, Duan Z, Liu F, Zhang Q. Analyzing the Architectural Style of Railway Stations Based on Geometry and Visual Complexity: Case Studies of Liaoning

Terminal and Beijing Railway Station on the Peking–Mukden Railway. Nexus Netw J 2024;26(4):789–810. https://doi.org/10.1007/s00004-024-00793-w.
[27] Ediz Ö, Çağdaş G. A computational architectural design model based on fractals. Open House Int 2007;32(2):36–45. https://doi.org/10.1108/ohi-02-2007-b0005.
[28] Vaughan J, Ostwald MJ. Measuring the geometry of nature and architecture: comparing the visual properties of Frank Lloyd Wright's Fallingwater and its natural setting. Open House Int 2022;47(1):51–67. https://doi.org/10.1108/OHI-01-2021-0011.
[29] Vaughan J, Ostwald MJ. Using fractal analysis to compare the characteristic complexity of nature and architecture: re-examining the evidence. Archit Sci Rev 2010;53(3):323–32. https://doi.org/10.3763/asre.2010.0024.
[30] Ostwald MJ, Vaughan J. Calculating visual complexity in Peter Eisenman's architecture, Proc. 14th Int. Conf. Comput. Aided Archit. Des. Res. 22-25 April, Asia, Yunlin, Taiwan: 2009, pp. 75–84.
[31] Lionar ML, Ediz Ö. Measuring Visual Complexity of Sedad Eldem's SSK Complex and Its Historical Context: A Comparative Analysis Using Fractal Dimensions. Nexus Netw J 2020;22:701–15. https://doi.org/10.1007/s00004-020-00482-4.
[32] Aygen S. Bursa Üniversitesi Kampus Planması. Bursa: Bursa Uludağ Üniversitesi; 1976.
[33] Aygen S. Bursa Üniversitesi Kampus Planlaması. Mimar Derg 1978;16:49–52.
[34] Uludağ Üniversitesi 2006 Yılı Faaliyet Raporu 2006:129. http://www.uludag.edu.tr/sgdb/default/konu/4829.
[35] Mandelbrot BB. The Fractal Geometry of Nature. Am J Phys 1982;1.
[36] Ostwald MJ. Fractal Architecture : The Philosophical Implications of an Iterative Design Process. Commun Cogn 2003;36:263–95.
[37] Batty M, Longley P. Fractal cities: a geometry of form and function. Academic press; 1994.
[38] Vaughan J, Ostwald M. Approaching Euclidean limits: a fractal analysis of the architecture of Kazuyo Sejima, in ANZAScA08 Conference Proceedings, 2008: 285–293.
[39] Lionar ML. Fraktal Boyuta Dayalı Çok Katmanlı Bir Analiz: Eldem ve Doshi Mimarlığı. Bursa Uludağ University; 2021. PhD Thesis.
[40] Lee JH, Ostwald MJ. Fractal dimension calculation and visual attention simulation: Assessing the visual character of an architectural façade. Buildings 2021;11(4). https://doi.org/10.3390/buildings11040163.
[41] Mayrhofer-Reinhartshuber M, Ahammer H. Pyramidal fractal dimension for high resolution images. Chaos 2016;26(7). https://doi.org/10.1063/1.4958709.
[42] Karperien A. Fraclac for Imagej, n.d. https://imagej.nih.gov/ij/plugins/fraclac/FLHelp/Introduction.htm (accessed October 11, 2024).
[43] Karperien A. FracLac for ImageJ: FracLac Advanced User's Manual. Charles Sturt Univ Aust 2007:1–36.
[44] Lee JH, Ostwald MJ. Complexity and Diversity in Palladian Facades. Nexus Netw J 2023;25:15–21. https://doi.org/10.1007/s00004-023-00678-4.
[45] Zhang H, Li C, Fan J, Yun K, Wu J. Exploring the Impact of Urban Road Network Characteristics on City Fringe Tourist Areas: A Case Study of Xi'an. China Sustain 2024;16. https://doi.org/10.3390/su16114359.



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