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FRACTAL CHANGE OF FACADES OF HIGH-RISE BUILDINGS ACCORDING TO ARCHITECTURAL PERIODS (1)

MİMARİ DÖNEMLERE GÖRE YÜKSEK YAPILARIN CEPHE ÖZELLİKLERİNİN FRAKTAL DEĞİŞİMİ

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Öz: Bu çalışmada sayısal bir yöntem olan fraktal analiz yöntemi kullanılarak, farklı tarihsel dönemlere ait yüksek yapı örneklerinin a) silüet ve (b) form+süsleme+malzeme değişkenlerine göre sayısal analizleri yapılmaktadır. **Amaç:** Çalışmanın hipotezi; yüksek yapılar genellikle monoton ve tekdüze cam kutular olarak eleştirilmelerine rağmen, sayısal olarak ölçüldüklerinde yapıların yüksek çeşitlilik ve detay zenginliğine sahip oldukları fikri üzerinedir. **Metot:** Bu doğrultuda yüksek yapılar için sekiz mimari dönem belirlenmiş ve her bir döneme ait tanınmış beşer yapı üzerinden fractal analizler gerçekleştirilmiştir. **Bulgular:** Değerlendirilen tüm yapılar silüet değişkeni (DS) bakımından düşük, form+süsleme+malzeme değişkeni (DFOM) bakımından ise yüksek fraktal değerler almıştır. Cephe detay bakımından en düşük değere sahip dönem, Uluslararası Dönemdir. En yüksek değere sahip dönem ise Serbest Form Dönemidir. Yapı silüeti detaylılığı açısından ise Teknolojik Dönem öne çıkmaktadır. **Sonuç:** Yüksek yapılar tasarımsal açıdan sanılanın aksine monoton ve tek düze cam kutular olmak yerine, oldukça karmaşık ve çeşitliliğe sahip yapılardır. Yüksek yapı tasarımları gelecekte daha karmaşık ve çeşitliliğe sahip yapılar olarak önemini sürdürmeye devam edecektir.

Anahtar Kelimeler: Yüksek Yapı Tasarımı, Mimari Dönemler, Form, Cephe, Fraktal Analiz Yöntemi

Abstract: In this study, using fractal analysis method, high-rise buildings from different historical periods are analyzed according to a) silhouette and (b) form+ornament+material variables. Purpose: The hypothesis of the study; although tall buildings are often criticized as monotonous and simple glass boxes, it is on the idea that buildings have a high variety and richness of detail when measured numerically. Method: In this direction, eight architectural periods were determined for tall buildings and fractal analyzes were carried out on five well-known structures belonging to each period. Results: All evaluated structures had low fractal values in terms of silhouette variable (DS) and high fractal values in terms of form+ornament+material variable (DFOM). The period with the lowest value in terms of facade detail is the International Period, while the period with the highest value is the Free Form Period. In terms of the detail of the building silhouette, the Technological Period stands out. **Conclusion:** Contrary to popular belief, tall buildings are rather complex and diverse structures, rather than monotonous and uniform glass boxes. Tall building designs will continue to be important in the future as more complex and diverse structures.

Keywords: Tall Building Design, Architectural Periods, Form, Façade, Fractal Analysis Method

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INTRODUCTION

There is no definitive definition valid worldwide for tall buildings. The definitions and height limits of buildings may differ according to countries, cities and even regions, as well as according to occupations and fields of expertise. According to the Tall Building Council (CTBUH), which is an important authority in this regard; buildings are considered as tall buildings only if they meet at least one or more of the three criteria below[1]. These criteria are height according to context, height according to proportion and technological superiority of the structure. In the definition of height according to the context, the height of the surrounding buildings is taken as a reference. For example, in cities with very tall buildings such as Chicago and Hong Kong, a 14-storey building may not be considered a tall building, but a tall building for a European city. In the definition of height by proportion, the aspect ratio of the building is decisive. Although many buildings are not very high, they can be tall buildings in terms of slenderness. On the contrary, structures that are wider than they are tall, are not considered as high structures in terms of their proportions, even if they are high. In the approach where the buildings are evaluated according to their technological superiority; having special vertical transportation systems and upwind structural systems are characteristics specific to tall buildings. According to the Tall Building Council, a building is considered a tall building if it meets at least one of these criteria. On the other hand, according to the CTBUH, a building with 14 floors or more than 50 meters is typically considered a tall structure, although it is a poor indicator of describing a high-rise building due to the varying height between buildings and functions.

Tall Building Facade Characteristics

The facade derives from the Latin word facies and expresses the intersection between the street and the building in architecture. When the facade is mentioned, the front of the buildings facing the street, that is, the entrance areas, is usually meant (Krier, 1988: 122-131). The facade is not only shaped by the organization of the spaces behind it, but also according to many data from the cultural situation of the time the building was built to its technological development and develops in relation to the form and the structure. While the facade is sometimes formed by the external perception of the structural system, it sometimes surrounds the structure like a shell. Form is also the envelope of the structure that enables the interaction of the building with its environment at various scales. While determining the form of high-rise buildings, it is shaped depending on many factors, from the aerodynamic effects of natural forces acting

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on the city to its appearance from long distances or central axes. Facade and form formation have a very important role in the emphasis of height, mass formation, perception in the city and symbolic quality of buildings (Krier, 1988: 122-131).

Tall buildings have often been criticized as monotonous and uniform glass boxes in terms of their forms and facade designs in the historical process. These structures, which are very similar to each other, consisting only of glass and grid boxes, are generally held responsible for the destruction of the distinctive features of cities and the formation of similar cities (Appleyard, et al., 1977: 81-100; Goldberger, 1981: 69; Jencks, 1977: 1-35). However, the form and facade features of high-rise buildings have undergone a great change from the first examples in New York and Chicago to the present day. Changes in architectural styles, technological developments, structural innovations, regulations, and ideologies were reflected in the facade designs and forms as periodic differences. Many different approaches have been developed regarding the design of tall buildings, from the classical 'base-shaft-top' triple mass order advocated by Sullivan, to Mies' emphasis on structure, to Jencks' historical references (Al-Kodmany, 2013: 25-44; Jencks, 1977: 1-35). Therefore, contrary to common belief, instead of having uniform and monotonous glass surfaces, high-rise buildings contain very complex and varied forms and facade layouts.

The first attempts to design tall buildings took place in the late 18th and early 19th centuries. Changing construction techniques have brought about visible changes in traditionally used building materials; stone, brick and wood materials have been replaced by modern materials such as glass, cast iron and concrete (Aytıs, 1991: 46-54). While the change in materials directly affected the structural system of the buildings, a slower transformation took place on the facades. While the structure of the buildings consists of steel frames, the use of traditional materials such as stone and brick in their outer shells and the decoration approach continued to exist until the 1950s. As cast iron and steel systems developed, columns and beams became thinner, and thin walls and large windows began to shape the facades. In the 1930s, the structural system and the facade were separated from each other, and curtain walls, known as the outer shell system, were formed independent of the building structure. Curtain facades, which were made with thin masonry elements until the 1950s, became produced with light materials such as glass, metal, steel and aluminum with the development of technology and materials after the Second World War. Particularly in the 1950s, the curtain wall systems that exploded have become the

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symbols of high-rise buildings and have found widespread use on the facades of modern buildings (Sezer, 2003: 311). After the 1970s, with the increase in height limits, structural elements began to shape the facades of tall buildings. In the 80s, as a criticism of these structures consisting of glass and grids, more massive, colorful, and postmodern approaches that combine different styles shaped the facades. Today, the facades of high-rise buildings have become thinner and lighter thanks to technological developments. Facades shape structures as light and flexible systems that only separate indoor and outdoor spaces, do not carry loads other than wind and their own load (Begeç, et al., 2004: 1-10). Today, very flexible, and free forms have been developed with the opportunities provided by technology in terms of form and facade design.

AIM

Theories regarding the facade design of tall buildings have remained largely untested due to the difficulty of quantitatively analyzing the complex formal features of buildings. Thus, the study presents a new set of mathematically derived metrics by which theories about trends in tall building architecture can be reviewed and evaluated.

This study uses fractal analysis method both to overcome this problem and to test those tall buildings do not consist of monotonous and simple glass facades as is often claimed (Appleyard, et al., 1977: 81-100; Goldberger, 1981: 69; Jencks, 1977: 1-35). At the same time, the study not only provides important quantitative data that can be used to test past theories about tall buildings, but also allows buildings to be compared both with their contemporaries and with different periods. It expresses numerically what kind of changes occur in the form and facade designs of tall buildings over time.

SCOPE

In the study, first, an eight-period historical category was created to question the differences between the forms and facade formations of high-rise buildings according to the periods and the factors affecting the designs. In the creation of the category, studies in the literature in which tall buildings are classified according to their architectural periods were used. Firstly, 4 categories were created by Pelli in 1982 as functional period, eclectic period, modern period, and post-modern period (Pelli, 1982: 134-151). Secondly, Bennett developed this category in 1995 and analyzed it in seven categories as functional period, eclectic period, Art-Deco period, international period, super high period, social skyscraper period and Post-Modern period (Bennett, 1995: 128). In Sev's study in 2009, the social skyscraper period was removed from Bennett's category and a new era was added

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as the ultimate technology period (1985-2000) (Rian, et al., 2007: 1-15). In this study, however, a new category was added as the Free Form Period for the period from 2000 to 2020, while adhering to the category of Sev. For each historical category, firstly, theoretical explanations were made to explain the facade designs, then a quantitative analysis based on the fractal method was carried out according to the pioneering examples of the periods in terms of design and structure. The database of the Tall Building Council (CTBUH) was used in the selection and procurement of buildings belonging to each period. The facades of the buildings obtained from CTBUH's database are abstracted in black and white in scale and in two dimensions. The obtained images were used by rearranging them in accordance with the fractal analysis method, which is frequently used in the numerical measurement of images and objects.

Table 1. Architectural Periods and Examples of Tall Buildings Used in the Study

Functional Period (1880-1900)	Auditorium Building, Guaranty Building, Home Insurance Building, Masonic Temple, Monadnock Building
Eclectic Period (1900-1920)	Flatiron Building, Municipal Building, Singer Building, Times Square, Woolworth Tower
Art-Deco Period (1920-1940)	Chrysler Building, East Wacker Building, Empire State Building, Tribune Tower, Wrigley Building
International Period (1950-1970)	Lake Shore Drive, Lever House, Marina City, One Prudential Plaza, Seagram Building
Super High Building Period (1965-1980)	Aon Center, John Hancock Building, Sears (Willes) Tower, Transamerica Pyramid, World Trade Center
Postmodern Period (1980-2000)	AT&T Building, One Canada Square, Petronas Towers, PPG Building, Two Prudential Plaza
Ultimate Technology Period (1985-2000)	Burj Al-Arab Building, HSBC Headquarters, Landmark Tower, Malayan Bank, NBC Tower
Free Form Period (2000-2020)	150 North Riverside, Burj Khalifa, Shanghai WTC, Swiss Re Building, Taipei Financial Center

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METHOD

The fractal analysis method is a method often used to measure the characteristic richness and diversity of details of an image or three-dimensional object. It measures the density and distribution of geometric information and reports it as a single result, the fractal dimension (D). This method was first developed by Benoit Mandelbrot in 1977 and used in many different fields (Mandelbrot, 1977). The fractal analysis method was first used in architectural and urban studies in the 90s, and today the optimal calculation version, the variety of variables and the algorithm process in architectural applications are defined clearly and comprehensibly (Bovill, 1996: 194; Ostwald, 2013: 644-663; Ostwald, et al., 2016: 423).

The fractal analysis method is generally used to calculate the fractal size of two-dimensional images, rarely three-dimensional. In this method, the more refined the image, the more accurate the result. In the application of the method, a minimum of 10 different scales are renewed, and the reliability of the results increases as the number of renewals is increased (Ostwald, et al., 2014: 1-17). For the analysis phase, a grid is placed on the image and the process is repeated a minimum of 10 times, reducing the grid dimensions each time. The density of the squares where the grids overlap the drawing is determined and the spread of information is calculated. As a result of each repetition, a D value is obtained, and the fractal dimension value of the image is determined by taking the average of these values. Measurements can be made manually as well as there is many software that can be used practically. ArchImage and its plug-in Fraclac were used in this study because it gives reliable results and current versions are available and accessible.

The fractal dimension value obtained because of the analysis of the images is expressed with a decimal value between 1 and 2. This value is used to express the richness, diversity, or complexity of the image. The decimal fractal size of multi-layered textures with high detail richness is close to 2. As the detail richness decreases, that is, as it becomes abstract, the texture approaches Euclidean geometry and the fractal dimension value approaches 1. In modernist, purist and minimalist approaches, this value is 1 or close to 1, as if proving simplicity (Ediz, et al., 2005: 71-83). On the other hand, the fractal dimension value approaches 2 in buildings with many ornaments and architectural details. In numerical terms, an image has less roughness or detail diversity if its fractal dimension value is between 1,1-1,5. If the fractal dimension value is between 1,6-1,9 but the integer value is less than 2, it has high roughness and detail diversity (Rian, et al., 2007: 1-15). In addition, some studies have found that a low or high fractal value negatively affects aesthetic judgment.

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Images with fractal dimension values between 1.1-1.2 and 1.6-1.9 were preferred by the participants at a low rate. Thus, the most ideal values were determined as values between 1.2-1.6 (Spehar, et al., 2003: 813-820; Street, et al., 2016: 213).

For the fractal analysis method in architectural studies, typically building plans or facade images are used. For the method to be comparable, the images must be abstracted and rearranged in a certain quality. Factors such as shadow, light, color, and abstract scans in building images need to be eliminated. Images should be expressed in lines only and in black and white, without grayscale elements and fills. The thickness of the lines, the resolution and size of the images, the position and size of the buildings in the images should be in accordance with an optimal standard. All these steps should be followed to ensure that the final calculations are accurate and reproducible (Ostwald, et al., 2014: 1-17).

Images obtained from the database of the Tall Building Council (CTBUH) were reproduced in accordance with fractal analysis within the scope of the study. Regardless of the scale, images were reproduced in black-and-white and bitmap formats via Photoshop program on the same paper sizes (A3), same resolution (120 dpi) and 1 pixel line thickness. Since it is beyond the scope of this study to analyze all the facades of the buildings for calculations, the study is limited to only the most important facades of the buildings - usually the entrance facades. After the necessary arrangements were made in the Photoshop program for the images, they were first converted to binary in the fractal analysis program Imagej, and then the data were analyzed with a minimum of 20 repetitions in the program's plug-in Fraclac. The average of the numerical values obtained from the data presents the D_S and D_{FOM} values of each building facades.

RESEARCH RESTRICTIONS

The geometric information on the facades of the building samples was analyzed in two stages: (a) silhouette, (b) form+ornament+material layout. While the silhouette layer expresses the outer contour lines of the building, the form+ornament+material layer expresses all the elements that make up the façade. In similar studies on the subject in the literature, facades have been examined in variable layers. For example, in Lionar and Ediz's work in 2020, there are 4 hierarchical visual layers: detailed facade layers with and without materials, basic masses with and without structural systems. In the study of Ostwald and Ediz in 2014, there are 3 hierarchical visual layers: form, form + ornament, form + ornament + material. In this study, however, no distinction was made in terms of ornamentation and structural elements of the high-rise facades examined. Due to the size of the sample

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set, the study was limited to two variables. The fractal measurement value of the silhouette variable is represented by the symbol D_S, and the fractal measurement value of the form+ornament+material variable is represented by the symbol D_{FOM}. The difference between both values is expressed as D_{DIF}.

RESULTS

a. Functional Period (1880-1900)

Social transformation and technological advances in Chicago and New York initiated an era of tall buildings where functionality was at the forefront. Examples of this period reflect developments in structural engineering. With the use of cast iron and steel skeleton systems, it has become possible to build higher structures than masonry systems (Bostancıoğlu, 2021: 6). During this period, architects adapted existing building types and styles to the facades of tall buildings. While the structural system of the buildings generally consists of a light material such as steel, massive materials such as stone and brick were used on the facades of the buildings, independently of the structure (Ali&Armstrong, 1995: 227-284). The buildings generally developed in square and rectangular forms and were generally completed with a tower that completed the roof. On the facade, there are Renaissance motifs, decorations and details that are independent of the structure. Although the buildings were built to meet functional requirements, the facade was transformed over a long period of time.

Built by William Le Baron Jenney in 1885, the Home Insurance Building is considered the first tall building of its time and the world, according to the Tall Building Council and Emporis[2]. Buildings of the period are typically large and monumental in scale. In terms of height, a limited height has been achieved due to both the restrictive effect of the regulations and the new use of systems such as elevators and plumbing systems. Generally, there is a construction that does not exceed 100 meters in height. The triple mass order (base-shaft-top) of the classical period is also present in the buildings of this period (Eşsiz, et al., 2006: 85-92). In buildings of the period, steep roofs are usually perceived from the front, while in some buildings the roof is hidden behind a wide pediment.

2 https://www.emporis.com/

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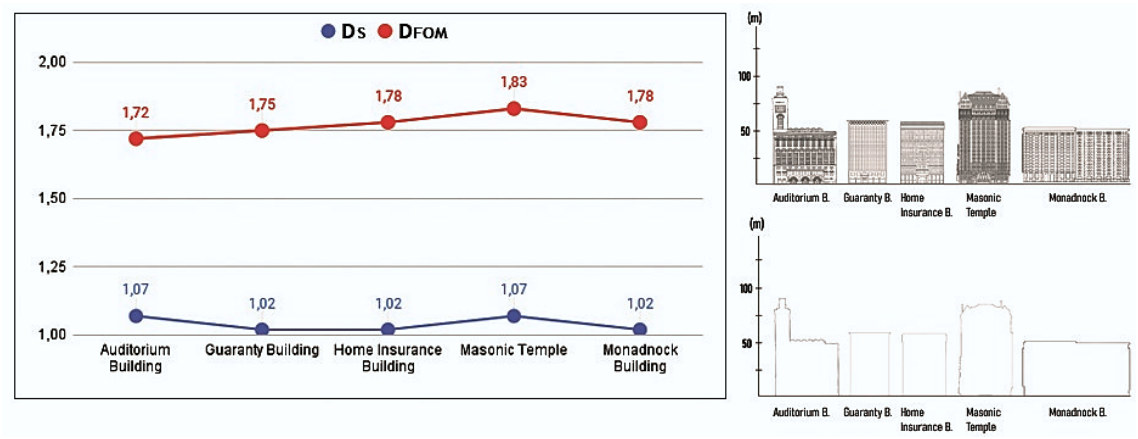


Figure 1. Tall Buildings of Functional Period and Fractal Dimension Values

When the common examples of the period are examined in terms of fractal dimension values; they exhibit a balanced distribution in terms of silhouette features. The tower on the roof in the Auditorium Building and the short towers on either side of the roof in the Masonic Temple caused a slight increase in D_S values over the other three buildings (Guaranty B., Home Insurance, and the Monadnock Building). But in general, the diversity of silhouettes of the buildings has taken very low values. D_{DIF} between D_S values of buildings is 0,05 or %5. When the buildings are evaluated in terms of facade diversity; the building with the lowest D_{FOM} value is the Auditorium building, while the building with the highest value is the Masonic Temple. D_{DIF} between façade values of structures is 0,11 or %11. But in general, the facade diversity and detail richness of the buildings have high fractal values.

b. Eclectic Period (1900-1920)

With the technology that started to develop at the beginning of the 20th century and the materials changing in parallel, a more conservative approach was displayed in tall building designs. Building designs and facades have more decorations than the previous period. The richness of motifs offered by structures such as Renaissance palaces, French Castles, Greek temples and Gothic cathedrals were reflected in the tall buildings of the period. Monumentality is strongly felt in the buildings. Therefore, it is common to use pointed towers to emphasize monumentality. In this period, when the structure of the buildings is hidden by masonry building elements, the facades generally resemble ornamented pedes-

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tals and classical columns (Pelli, 1982: 134-151; Eşsiz, et al., 2006: 85-92).

Another distinctive feature of this period is that it offers aesthetic solutions through the application of historical models. The architects of the period adapted the verticality of Gothic forms to tall buildings. A partial balance began to emerge between the functions of the buildings and their appearance. The formal images were somewhat softened, and the Gothic revival gained popularity instead of the style of the classical perio The structural system of the buildings and the use of materials are like the previous period; massive exterior facades made of stone or brick with a steel structural system. With the influence of Gothic forms, there is a more dynamic and gradual approach in the form of the buildings compared to the previous period. The height effect of the buildings is felt more. In terms of facade decorations and detail, there is a more intense use of ornamentation compared to the previous period. The triple division in the mass (base-shaft-top) is one of the prominent features of the facades of this period.

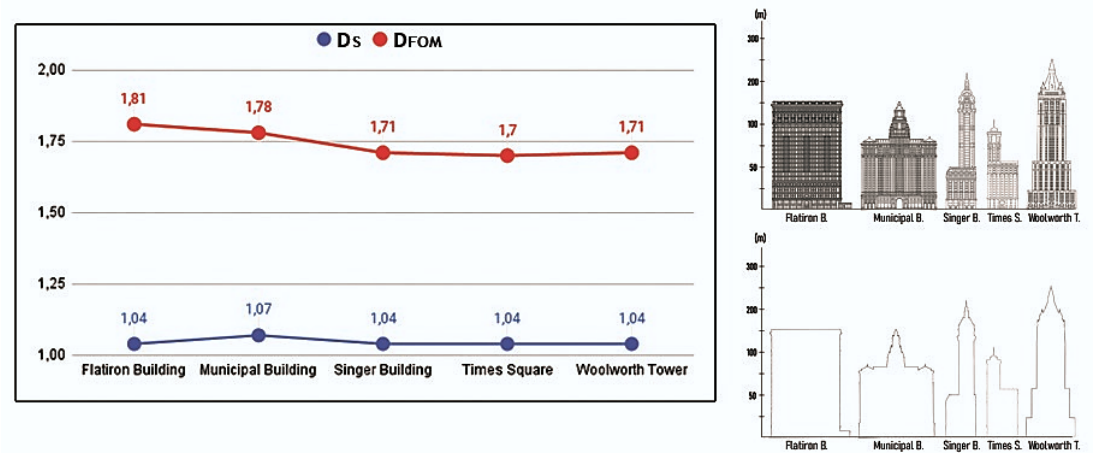


Figure 2. Tall Buildings of Eclectic Period and Fractal Dimension Values

When the common examples of the period are examined in terms of fractal dimension values; they show a balanced distribution in terms of D_S features. However, there is little increase compared to the functional period. The Municipal Building received the highest D_S value, and the silhouette values of other buildings are the same. Consisting of a completely rectangular and flat surface, the Flatiron Building has the same silhouette values as Singer B., Times Square and Woolworth Tower. The average D_S values, which are like the functional period, have taken very low values. D_{DIF} between silhouette values of bu-

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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

ildings is 0,03 or %3. When the buildings are evaluated in terms of facade diversity; the building with the lowest D_{FOM} value is the Times Square Building, and the building with the highest value is the Flatiron Building. D_{DIF} between façade values of structures is 0,11 or %11.

c. Art-Deco Period (1920-1940)

The late 1920s and early 1930s witnessed a height race. As an extension of the eclectic era, the Art-Deco style offered more imaginative, attractive, and extravagant decorations and combined all cubism, futurism and expressionism with Asian motifs, Aztec, Chinese and Mayan architectural styles. The most distinctive feature of the period is that the decorations are more prominent than the structure of the building. One of the characteristic features of the high-rise buildings built in this period is the completion of the upper sections with different finishes. The most important stylistic examples of the period are the Chrysler Building and the Empire State Building, which were built in the 1930s. In this period, the 300-meter limit was exceeded with the Chrysler Building and the 400-meter limit was exceeded with the Empire State Building. Both structures were mentioned as the tallest structures in the world for a very long time (Ali, 1995: 227-284).

When the buildings of the period are compared with the previous three periods in terms of structure and material usage, it is seen that they have similar characteristics. However, the enormous increase in heights led to a different understanding in building details and decorations. The decorations are still dense, but they have grown in scale and have gained intensity on the roof and plinth parts of the buildings, where the visibility is high. The triple mass order (base-shaft-top) in the design of the buildings is also present in this period.

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(2015/04018 – 2015/GE/17595)

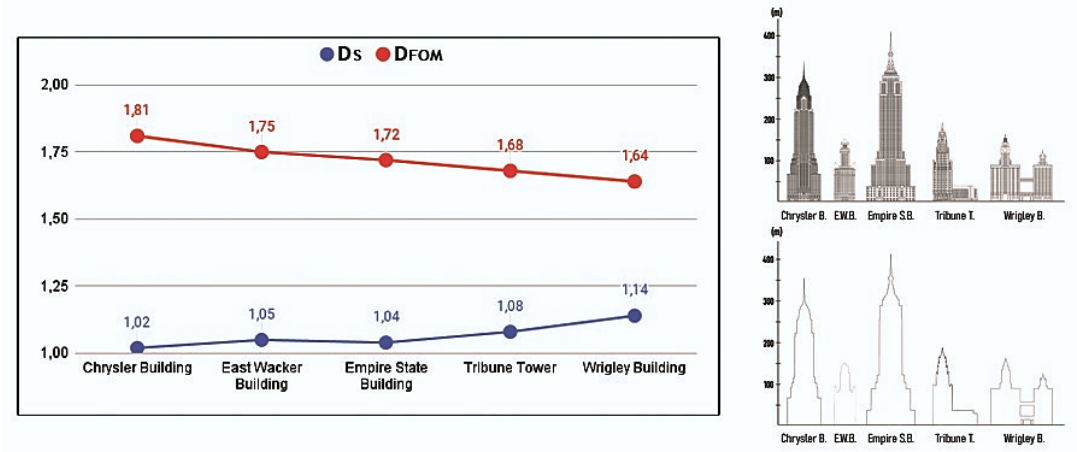


Figure 3. Tall Buildings of Art-Deco Period and Fractal Dimension Values

When the common examples of the period are examined in terms of fractal dimension values, there is a regular increase in D_S values from the Chrysler Building to the Wrigley Building. The Wrigley Building offers a high diversity in D_S compared to other buildings with its bridges at different levels that connect the two buildings. Also in the Tribune Tower, the plinth, which expands towards the right side of the building, slightly increases the D_S value. D_{DIF} between D_S values of buildings is 0,12 or %12. When the buildings are evaluated in terms of facade values, a decreasing trend is observed in D_{FOM} values. As the D_S values of the buildings increase, the D_{FOM} values decrease. The D_{DIF} between the Chrysler Building with the highest D_{FOM} and the Wrigley Building with the lowest D_{FOM} is 0,17 or %17. There is a higher differentiation compared to other periods. While the idea of detailing the facade as the height of the building's increases, it is seen that the idea of a simple facade is starting to settle in the buildings with less height. In the next period, this break in the facades can be read very clearly. Although there is a decrease in the detail and richness of the facades of the buildings, they have received high fractal values like the previous periods in terms of fractal dimension values.

d. International Period (1950-1970)

With the Great Depression and World War II, there was a decline in the construction of tall buildings until the 1950s. After the 1950s, the boom in the construction industry and the advent of computers facilitated the development of new structural systems and forms. With the help of computers, it has now become possible to analyze and investigate different struc-

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Mayıs / Haziran / Temmuz / Ağustos Yıl: 2022 Sayı: 26 İlkbahar Yaz Dönemi
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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

tural systems and components. Rigid frame systems have begun to be replaced by tubular systems that allow much higher structures to be built (Khan, 1974: 99-128; Guise, 1991: 92-99).

This style, which started to revive in Europe at the beginning of the 20th century, spread to the America by immigrant architects and designers who fled from Europe after the Second World War and became completely dominant in the 1950s. The towers built during this period had to be high, but also economical and functional. While glass, steel and concrete materials are generally used on the facade, all the decorations belonging to the previous periods were removed. The buildings of the period were designed and built in a simple and elegant way. In this period, lower and wider structures were produced instead of high and very remarkable buildings like other periods. Compared to the skyscraper, less-storied, plain, and simple buildings were built, and importance was given to function and cost. Square and rectangular forms were used quite often. The architects of this period adopted a more technological and rational expression of the building form, rejecting ornamentation and historical references. As a direct expression of material and functionality, International Style buildings resemble monolithic boxes. The triple order in classical structures was almost never used in these structures (Ali&Armstrong, 1995: 227-284).

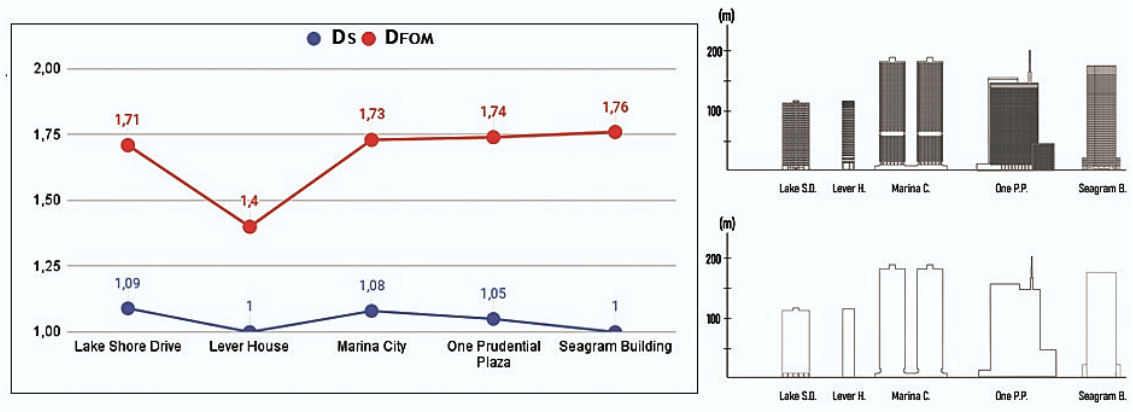


Figure 4. Tall Buildings of International Period and Fractal Dimension Values

When the common examples of the period are examined in terms of fractal dimension values; D_S values are close to 1 and 1,1, as if proving the simplicity advocated by Ediz, et al., 2003: 71-83. The twin masses in the Marina City building and the masses of different

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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

heights in the One Prudential Plaza slightly increase the D_S values, but these values are 1 in the Lever House and the Seagram Building, which is the known structure of the period. D_{DIF} between D_S values of buildings is 0,9 or %9. When the buildings are compared in terms of D_{FOM} values, Lever House has a very low value of 1,40. Other buildings are generally between 1,7 and 1,8 values and exhibit a balanced distribution. The difference between Lever House, which has the lowest value in terms of D_{FOM} values, and the Seagram Building, which has the highest value, is 0,36 or %36. Although the buildings except Lever House have high fractal values, their average D_{FOM} values are lower than in previous periods.

e. Super High Period (1965-1980)

The 1960s was a period when tall buildings symbolized the power of economic and commercial entrepreneurship. This period has been characterized as an indicator of commercial identity and image. Therefore, as an indicator of power and image, it was planned that the buildings would stand out from their surroundings in terms of height and even have a reputation beyond the borders of the country. Unlike the previous period, the buildings of this period emphasize the developments in design and construction technology instead of emphasizing technological sophistication. Although it is very similar to the International Style, the structural expression is more emphasized with the effect of height, and even the structural expression has turned into a new art form independent of architecture in this period.

The tubular systems taking their full shape in this period is the most important factor in this transformation. Tubular systems developed by Fazlur Khan in 1960 made it possible to build structures much higher in height than rigid frame systems (Khan, 1974: 99-128). However, in this system, the columns and diagonals used at frequent intervals on the facade began to reflect the effect of the structural system on the facade. In this period, diagonals covering the entire building, horizontal bands and wide structural elements draw attention (Eşer, et. al., 2021: 92). Sears Tower, also known as Willes Tower, which was built during this period, continued to be the tallest structure in the world until the 90s.

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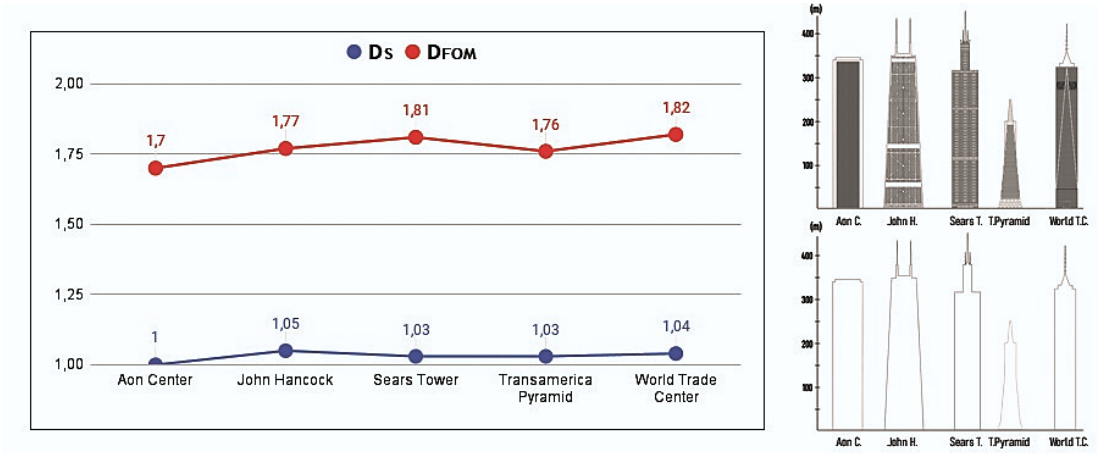


Figure 5. Tall Buildings of Super High Period and Fractal Dimension Values

When the buildings of the period are examined in terms of fractal dimension values; they have received low D_S values like the buildings of the previous International Period. D_{DIF} between D_S values of buildings is 0,5 or %5. This little difference was caused using antennas in other buildings, except for the Aon Center. When the buildings are compared in terms of D_{FOM} values; the expression of the structural system has increased the complexity and detail of the facades. Although the buildings are quite modern and simple, the structural details have increased the diversity of the facades. Aon Center has the lowest D_{FOM} value with 1,70 and World Trade Center has the highest D_{FOM} value with 1,82. D_{DIF} between both builds has a low value of 0,12 or %12. The buildings generally have high fractal values in terms of D_{FOM} values. In addition, the fact that the structural elements became more visible on the facade in this period increased the fractal dimension values of the buildings compared to the previous international period.

f. Post-Modern Period (1980-2000)

In place of the monotonous and simplistic approach of the International Style, in the early 1970s some architects initiated a movement known as postmodernism. This architectural approach is a reaction to the glass box structures of cubism and offers a modern eclectic approach consisting of ornate and sculptural forms. This period, in which various forms, domes, pyramids, asymmetrical surfaces and colors were used together, drew attention as a radical departure from traditional architecture (Jencks, 1977: 1-35).

The triple mass order (base-shaft-top) is generally present in the buildings, and towers,

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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

layered masses and historical motifs are predominant in form. Modern materials, construction techniques, ornament details and polychromatic colors are used together. The buildings of this period evoked historical images and represented a conscious reorganization of modern architecture with historical principles. In the buildings of this period, the form and façade formation are quite free. The combination of different materials and styles draws attention. In terms of height, the Petronas towers took the title of Sears Tower and became the tallest new building in the world. In addition, Petronas towers pioneered the spread of high-rise construction to the Far East and Arabian Peninsula, leaving the American monopoly. Therefore, postmodernism emerged in these countries in a different way. According to Ali and Moon, it is not possible to see a direct equivalent of postmodernism in Asian countries (Ali, et al., 2007: 205-223). The design motivations of the buildings here are mostly provided by the continuation of their own regional architectural and cultural traditions.

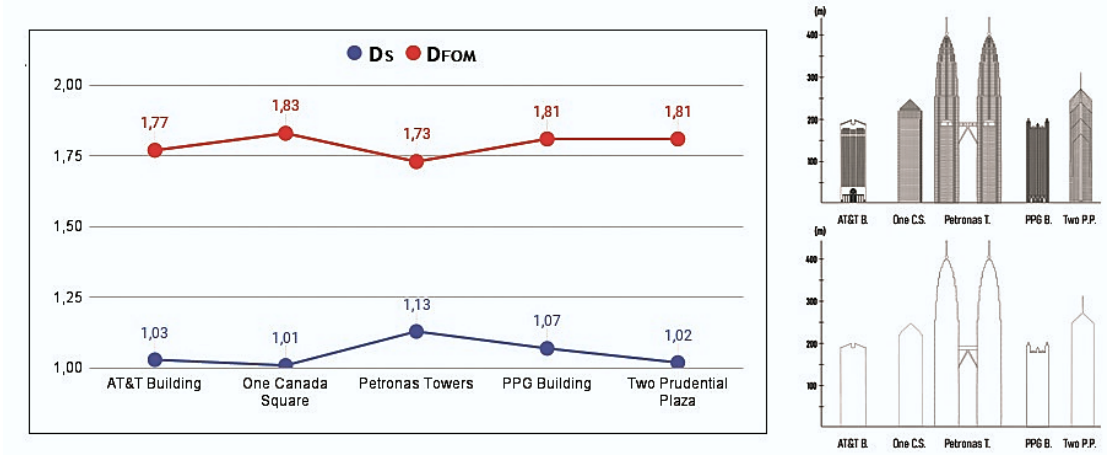


Figure 6. Tall Buildings of Postmodern Period and Fractal Dimension Values

When the structures of the period are examined in terms of fractal dimension values, it is seen that they vary in terms of silhouette features. The lowest value One Canada Square structure has a D_S of 1,01, and the highest value Petronas Towers has a D_S of 1,13. D_{DIF} between D_S values of buildings is 0,12 or %12. The fact that Petronas Towers consists of twin towers and that both structures are connected by a bridge has been effective in this difference. The other buildings of the period are quite plain in terms of D_S values compared to the Petronas Towers. The biggest difference from the previous periods

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Mayıs / Haziran / Temmuz / Ağustos Yıl: 2022 Sayı: 26 İlkbahar Yaz Dönemi
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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

is that the roof forms of the buildings were emphasized more strongly in the Postmodern Period. When the buildings are compared in terms of D_{FOM} values, Petronas Towers has the lowest value with 1.73, and One Canada Square has the highest value with 1,83. D_{DIF} between both builds has a low value of 0,1 or %10.

g. Technological Period (1985-2000)

In this period, which developed in parallel with the Postmodern Period, the buildings draw attention with their technological development. In this period, the buildings did not show a significant improvement in terms of height, but there were many innovations in terms of the structural system. For example, in the Burj Al Arab Building, the structure of the building is constructed outside the facade surface. Giant columns reaching 300 meters, together with horizontal cage systems, are effective in the resistance of the structure against lateral and vertical loads. A similar approach was used in the HSBC Headquarters building, and the structural system of the building was designed as a second surface outside the façade.

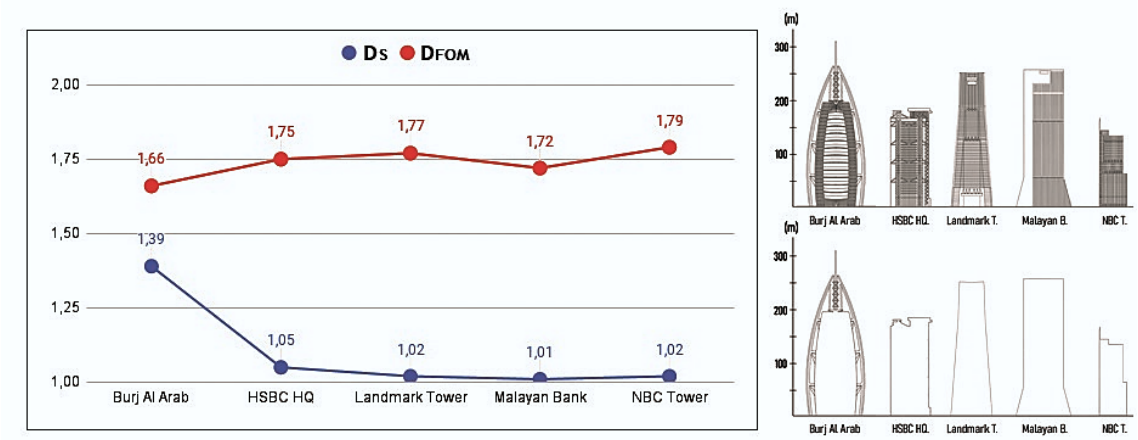


Figure 7. Tall Buildings of Technological Period and Fractal Dimension Values

When the structures of the period are examined in terms of fractal dimension values, it is seen that they vary in terms of silhouette features. The value of the Malayan Building with the lowest D_S value is 1,01, and the value of the Burj Al Arab building with the highest value is 1,39. The D_{DIF} between both buildings has a high value of 0,38 or %38. The most important reason why the buildings have high differences is that the structural system is located outside the facades. Structural elements are decisive on the exterior silhouette of the

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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

buildings. When the buildings are compared in terms of D_{FOM} values; NBC Tower, which has both a low value in terms of D_S and a lower height compared to other buildings, received the highest D_{FOM} value with a value of 1,79. Burj Al Arab building, which has the highest D_S value, has the lowest value. The difference between both buildings is as low as D_{DIF}: 0,13 or %13. The buildings generally have high fractal values in terms of D_{FOM} values.

h. Free Form Period (2000-2020)

With the beginning of the 2000s, there have been significant developments in both the heights of the buildings and their designs. Taipei Financial (Taipei 101), built in 2004, exceeded the height limit of 500 meters, and Burj Khalifa, built in 2010, exceeded the height limit of 800 meters and became the tallest structure in the world. In other words, the structures built in this period doubled the height limits that previous periods could reach. The development of structural systems in high-rise buildings has been effective in this process. By replacing the steel-framed core with the reinforced concrete core, the strength of the structure against lateral loads has been solved more effectively (Ali and Moon, 2018: 1-34). At the same time, thanks to the possibilities of the structural system, many building designs were implemented in curvilinear and fractured forms instead of familiar geometric forms such as rectangular and square. One of the best-known examples is the Swiss Re Building, built in London in 2004. Since the building is in a historical part of London, it is a very innovative building in terms of design, although it is lower in height than other tall buildings.

Light, transparent, and reflective surfaces draw attention among the common building features of this period. Steel grids are no longer visible, and glass surfaces usually come to the fore on the entire facade (Al-Kodmany, 2013: 25-44).

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Mayıs / Haziran / Temmuz / Ağustos Yıl: 2022 Sayı: 26 İlkbahar Yaz Dönemi
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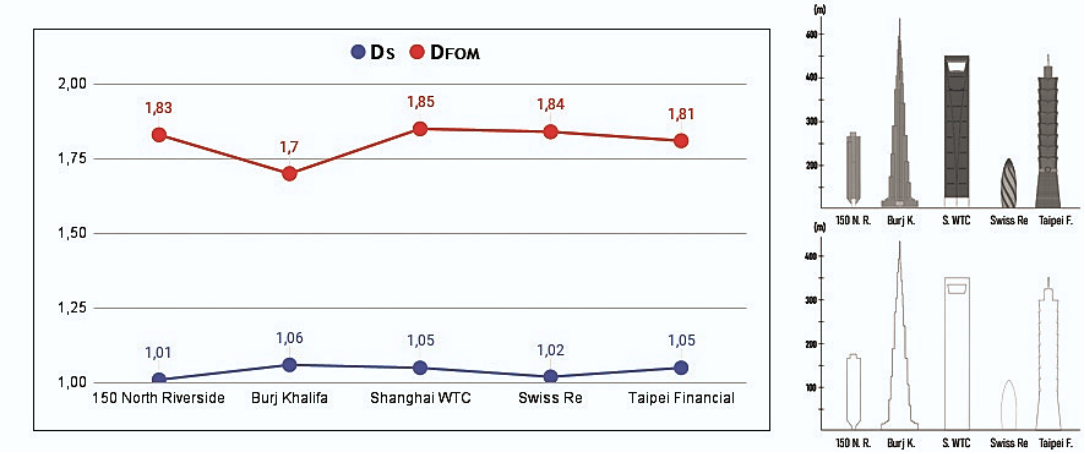


Figure 8. Tall Buildings of Free Form Period and Fractal Dimension Values

When the buildings of the period are examined in terms of fractal dimension values, it is seen that they exhibit a balanced distribution in terms of silhouette features. D_{DIF} between D_S values of buildings is 0,05 or %5. When the buildings are compared in terms of D_{FOM} values, it is seen that they have an uneven distribution. The building with the lowest D_{FOM} value is the Burj Khalifa and has a value of 1,70. Shanghai WTC building has the highest value with a value of 1,85. The difference between both structures is as low as D_{DIF}: 0,15 or %15. Like the findings obtained in other periods, the building, which had the highest D_S value in this period, received the lowest D_{FOM} value. At the same time, the buildings generally received high fractal values in terms of their D_{FOM} values.

CONCLUSION

In the functional period, when the first skyscrapers were implemented, the internal structure of the buildings consisted of light frame systems. On the contrary, the use of traditional materials and masonry systems is common on exteriors, and this situation continued until the international period. Steep roofs, towers, pediments, arches, rose windows, cornices, Greek columns, and plasters shaped the facades. The triple mass order (base-middle-top) can be clearly read on these facades in classical order. In the International Period, with the development of curtain wall systems, massive facades began to be replaced by facades consisting of glass and metal grids. On the facades completely free of ornaments, the triple mass order continued to exist by decreasing. The enormous increases in the heights of the buildings after the 1960s made it necessary to use of struc-

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Mayıs / Haziran / Temmuz / Ağustos Yıl: 2022 Sayı: 26 İlkbahar Yaz Dönemi
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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

tural elements on the façade against lateral loads. Wide diagonals, truss systems, mechanical installation floors and horizontal support elements draw attention on the facades. In the 1980s, with the influence of post-modernism, the monotonous glass and metal grilles on the facades began to be replaced by the combination of different materials and styles. From the 1990s onwards, with the development of computer technologies, different forms, more dynamic and curvilinear facades shaped the buildings. Ornamentation has now left its place to different form experiments.

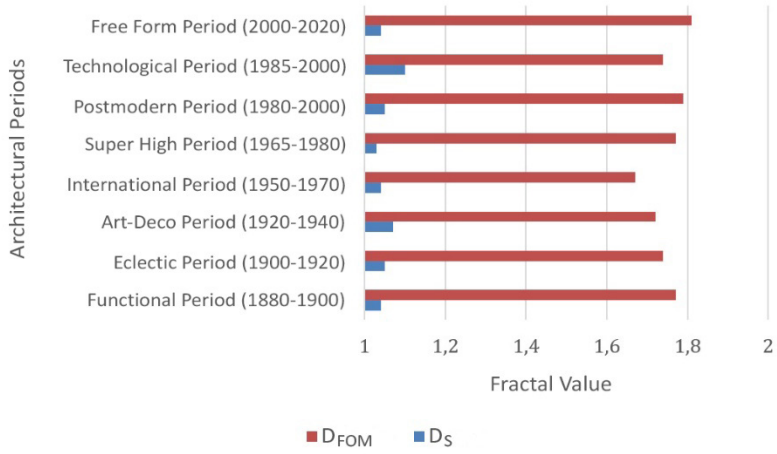


Figure 9. Architectural Periods and Their Fractal Values

As can be seen in the table, when the average D_S values of the buildings are examined according to the periods, it is understood that the variety of D_S values of the buildings are close to each other, and they have low values in terms of fractal dimension. Factors such as the design of the buildings as twin structures and the establishment of connections between them with bridges at various levels or the exposing of the structural system on the facade are effective in increasing the D_S values. The excess of the full-empty space ratios in the buildings and the setbacks also increased the diversity of the silhouette. When the average D_{FOM} values of the buildings are examined according to the periods, it is seen that all periods have high fractal values. The International Period (1950-1970) had the lowest average facade value, and the Free Form Period (2000-2020) had the highest D_{FOM} value. These results were influenced by the fact that the decorations and details in the buildings gradually lost their effect on the facade and the buildings gradually turned into plain and simple designs. Later, with the Super Tall Building period (1965-1980), the D_{FOM}

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Mayıs / Haziran / Temmuz / Ağustos Yıl: 2022 Sayı: 26 İlkbahar Yaz Dönemi
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(Marka Patent No / Trademark)
(2015/04018 – 2015/GE/17595)

values started to rise again. Support elements, columns, beams, and diagonals developed against lateral loads have increased the visual diversity and richness of the facades. At the same time, the development of the Tubular system by Fazlur Khan in the 1960s is one of the most important factors in this transformation (Khan, 1974: 99-128). With the use of tubular systems instead of rigid frame systems in buildings, the structural system has become more dominant and legible on the facade. In the 2000s, the use of reinforced concrete cores instead of steel cores caused the facades to be simplified and glass surfaces to come to the fore. In parallel with the change of structural systems, facade systems have also undergone changes. After the 2000s, the use of free forms, curved and fractured surfaces on the facades has increased the complexity and diversity of the facades.

Another finding of the study is that although they show differences within themselves, tall buildings generally have high fractal dimension values in terms of D_{FOM} values. Although tall buildings are often criticized as monotonous and simple glass boxes, the data obtained in this study are important in terms of showing that the D_{FOM} values of the buildings have high fractal values.

Another important finding of the study is that when the form values of the buildings increase, the D_{FOM} values usually decrease, or on the contrary, the facade values increase as the form values decrease. For example, in the Flatiron Building (eclectic period), Chrysler Building (Art-Deco period), Seagram Building (International period), One Canada Square Building (Postmodern period), NBC Tower (technological period), and 150 North Riverside Building (free form period) the D_S values have the lowest values according to their periods while the D_{FOM} values have the highest values. On the other hand, in the Auditorium Building from the Functional Period, the Wrigley Building from the Art Deco Period, and the Burj Al Arab from the Technological Period, the D_S values took the highest values compared to the other buildings of the period, while the D_{FOM} values took the lowest values.

When the study data are evaluated as a percentage, they have the lowest 3% and the highest 38% in terms of D_S values. In terms of D_{FOM} values, they have the lowest 10% and the highest 36% values. According to Oswald and Vaughan (2016), the maximum difference should be 4% for two objects to be considered similar. Therefore, when the study data is evaluated, it is seen that there is a great diversity within the periods. The similarity rates of the buildings belonging to each period are low compared to each other.

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