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Explorative study for the structural elements of Mimar Sinan mosques: an evaluation with k-means clustering algorithm

Ekrem Bahadır Çalışkan*[1], Filiz Karakuş[2]

[1]*Ankara Yıldırım Beyazıt Üniversitesi, Mimarlık ve Güzel Sanatlar Fakültesi, Mimarlık Bölümü, Ankara, Türkiye, bahadir.caliskan@gmail.com*
[2] *Ankara Yıldırım Beyazıt Üniversitesi, Mimarlık ve Güzel Sanatlar Fakültesi, Mimarlık Bölümü, Ankara, Türkiye, ferdemir06@gmail.com*

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Abstract

Mimar Sinan, who served as master architect for nearly fifty years in the 16th century, when the Ottoman Empire was at its strongest, designed landmark buildings that left their mark on the city identities within the empire's borders. The subject of this study is to evaluate the mosques designed by Mimar Sinan, the most well-known architect of the 16th-century Islamic Region, in the capital, Istanbul, and other cities. The structural components and features of 44 mosques designed/built by Mimar Sinan (dome diameter, height of the dome from the ground, width/height dimensions, number of minarets and minaret balconies, location, top covering elements (domes, half domes, small domes, quarter domes), number of load-bearing elements, transition elements to the dome and their numbers) were analyzed in order to identify and discuss possible relationships and patterns between them. Since the number of studies evaluating and exploring structural system properties of Mimar Sinan mosques is very few, this study is very important in terms of the contribution to the existing literature. The data from the literature review are searched with the K-means clustering algorithm, a machine learning method, and the relationships and patterns between them are revealed. The results are converted into definitions of variables for discussion and evaluation.

1. Introduction

In Classical Turkish Architecture, the search for a central space in mosque designs has been predominant starting from the Central Asia Civilization Period. The domed central space is an indispensable element of Turkish mosque architecture, and diverse architects carried out many original experiments in this direction. For the classical Ottoman period, Mimar Sinan's experiments in creating a central space with a dome and related elements presented advanced examples. Sinan, the master architect of the Ottoman period, made important attempts to expand the main space, enlarge the dome's diameter, and bring new dimensions to the identity of the central space. Mimar Sinan's central planned buildings are shaped according to the dome structure, and dome compositions shape the space and mass [1]. Sinan, who used the dome to create the central space and a symbolic effect, handled the space differently in each mosque by using different dome variations in his buildings.

Mimar Sinan used different dome types in his mosques, and in designs where structural principles predominated, he handled the dome space differently in various examples. In Mimar Sinan's mosques, a domed baldachin forms the core of the space. The baldachin substructure, a structural system, is a spatial arrangement formed by the dome covering the space, sitting on various carriers (piers, pillars, columns, corner walls, wall piers) [2]. The material usage substructural elements composition differs from building to building, and with these attempts, he tried to succeed in structural layout and flow of forces within a limit in physical laws. Starting from the period of Suleiman the Magnificent, Mimar Sinan served as the chief architect for about 50 years during the reigns of Selim II and Murat III. During this period, he designed and repaired more than 470 architectural structures with various functions in different regions, especially in Istanbul. Mimar Sinan's understanding of architecture, in addition to a wide variety, incorporates structure, space, proportion, form, environment, and aesthetic elements.

Many studies examine the mosques of Mimar Sinan individually or classify them depending on the style and other issues, and of the period. It is also possible to mention structural analysis studies that examine the load distribution starting from the main dome to the foundation. With today's techniques and technologies, static and dynamic structural analysis of these mosques as masonry buildings could be performed, and structural analysis can be revealed. However, the formal pattern of the structural elements from the dome to the foundation, which have variations or different approaches in each mosque, has not been questioned much. In other words, no research asks and seeks with a holistic approach the diversity of architectural elements that come together to create a central interior space. For this reason, the study seeks patterns in the formal assemblage of structural components and their relationships through many mosques for which information on Mimar Sinan is available. Since the mosques are located at different regions, site study could not be held for all of the buildings. Besides, the mosques in which the measurement and dimensions for research method can be reached are taken into consideration. Then, mosque clusters are queried in a structured methodology using a widely used machine learning algorithm. The K-Means algorithm was used to search for similarities and patterns in the combination of the presented structural components of the mosques. The computational results presented at the end of the study reveal previously unrecognized similarities, identify errors, and provide an important discussion on the structural organization of mosques.

2. Method

Mimar Sinan and his buildings have been studied in various publications [1-9]. . Sinan's characteristics, his position as a state architect, his responsibilities, the theoretical background of his designs, his material and construction technology, and his decoration program constitute the main theme of the publications. However, there are a limited number of studies that deal with Mimar Sinan's buildings in an analytical sense, that are carried out on the building dimensions of Sinan mosques, which constitute monumental examples of classical period Ottoman Mosque architecture, and that examine these buildings in terms of structural system. Sönmezer (2003), in his doctoral thesis titled "Dimensional Relationship between Space and Free Vertical Carriers in Sinan Mosques in Istanbul", examined 19 Sinan mosques in Istanbul in terms of the relationship between space and free vertical carrier dimensions [10]. Şeker (2011), in his doctoral thesis titled "Investigation of the Behavior of Mimar Sinan Mosques under Static and Dynamic Loads", performed static and dynamic analyses on three-dimensional models of 28 Sinan mosques based on the finite element method [11]. Köroğlu (2010), "A Research on Structure Morphology in Mimar Sinan Mosques: Kılıç Ali Paşa Mosque", the design of the structural system of the Üsküdar Mihrimah Sultan, Süleymaniye and Kılıç Ali Paşa mosques with square baldachin schemes built by Mimar Sinan in different periods were analyzed with an analytical approach based on the modular system [12].

Within the article's scope, the Mosques' components were identified and noted by considering these differences in the literature. It aims to examine the buildings' structural components and features to discover and discuss the possible relations and patterns. The research flow is presented in Figure 1. First, the knowledge of the mosques of Mimar Sinan is captured, and then the knowledge is refined to maintain an explorative library. The refined knowledge is converted into data sets as preparation for the K-means clustering algorithm. Machine learning activity investigates the relations and patterns, and results are converted to variables' definitions for discussion and evaluation.

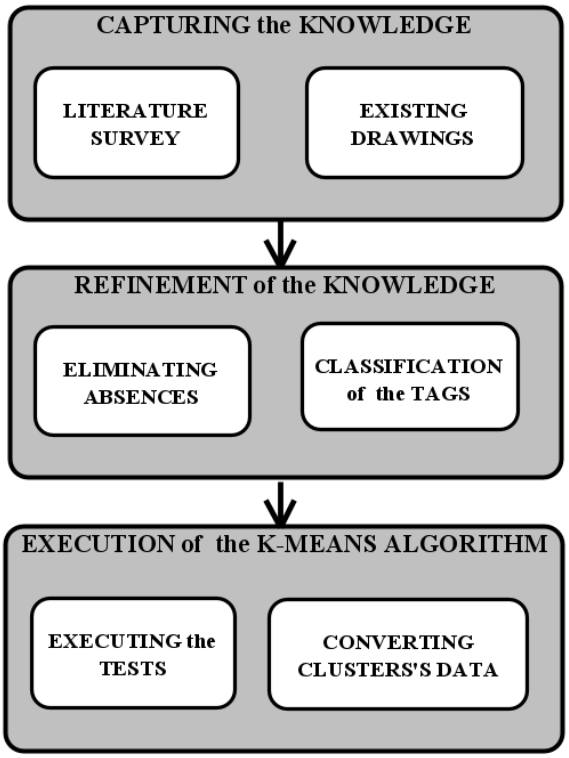


Figure 1. Research flow.

K-Means clustering algorithm, one of the machine learning activities, is executed to analyze patterns and relations in data sets and create identifying knowledge. Computers could make the learning of machines learn from data to discover patterns [13]. The concept of human learning, like decision trees, affected to development of many machine-learning activities [14]. There are types of classification for machine learning activitie. Mostly stated one is based on human supervision while learning activity. Supervised, unsupervised, and semi-supervised learning for machines is machine learning systems in this manner [13]. Clustering is an unsupervised machine-learning algorithm that is used to discover and identify the inherent groupings in the data sets [13, 15-17]. Data clustering is an important method in data mining to discover knowledge from data that is used in pattern recognition, document clustering, image processing, bioinformatics, social networks, crime prediction, location prediction, behavioral analysis, and so on [18-23]. K-means clustering algorithm is one of the most used clustering algorithms for the descriptive analysis of data

sets. It starts with a random selected number of cluster centroids, and then every data is assigned to the nearest centroid; the means of assigned data are calculated by repeating iterations of new centroids until finding the similar or same value of group means and centroids [17, 19, 24]. The objective of K-Means is to seek pattern of different entries with diverse variables by minimizing the sum of the distances and their respective cluster centroids [25].The sum of the distances will decrease as the number of clusters increases, but the reduction ratio may be remarkably large or low. The optimum number of clusters is the point at which the sum of the distances does not change or decreases relatively less. Clusters and their members can belong to any pattern or relation that a machine analyses inside a predetermined relation framework or that humans evaluate owing to objections. The goal is to investigate whether patterns exist in the provided data set.

2.1. Capturing and refinement of the knowledge

The total number of mosques mentioned in Tezkiretü'l Bünyan, Tezkiretü'l Ebniye, and Tuhfet'ül Mimarin, which provide information about Mimar Sinan and his buildings, is 107. According to the determination made by Kuran (1988), of the 107 Sinan mosques recorded in the three main sources, six are unknown or unidentified, Mimar Sinan did not design 16 but only repaired, 13 have not survived, and 16 have lost their original form completely or to a great extent [26]. Kuran divides the remaining 56 mosques into groups: those with masonry domes and those with "sakıflı". This study excludes the wooden-roofed mosques called "sakıflı" and focuses on the masonry domed buildings. Among these mosques, the Bolvadin Rüstem Pasha Mosque was excluded from the study due to a complexity identified in the literature on it[1] . Piyale Mosque was excluded from the study due to its equal and multi-domed structure. Hatay Payas Mosque and Gözleve (Kırım) Tatar Khan Mosque were excluded from the study since their section drawings were unavailable. All mosques which are used in this study are presented in Table 1. The table is prepared by authors by using the studies of using Ülgen, 1989; Kuran, 1986; Günay, 2006; Necipoğlu, 2013; Sönmezer, 2003, Orbeyi, 2016, archives of the authors and various web pages [2, 4, 6, 10, 27, 28].

2.2. Preparation for the K-means algorithm and execution

The measurements and drawings of the buildings are based on the works of Aptullah Kuran (1986), Orbeyi (2016), and Sönmezer (2003). Sönmezer measured a total of 21 Sinan mosques, including the Selimiye Mosque in Edirne, the Sokullu Mehmet Pasha Mosque in Lüleburgaz, and 19 others in Istanbul, using Ali Saim Ülgen's survey drawings. Orbeyi (2016), in order to investigate the modular system in 18 Sinan mosques with double porticoes, drawings of Ali Saim Ülgen and Gülru Necipoğlu to produce plans and sections are explored. The measurement used in the study is descried in Figure 1.

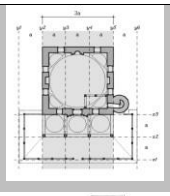
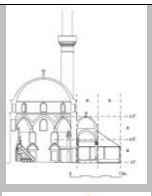
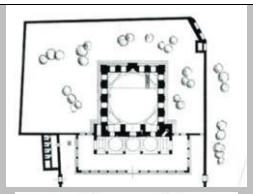
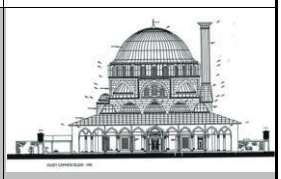
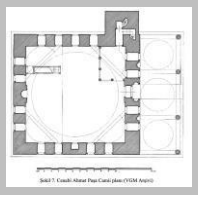
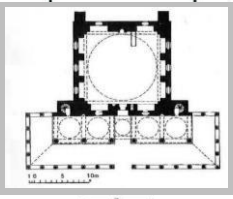
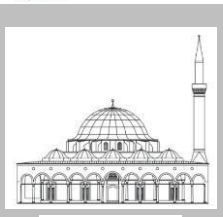
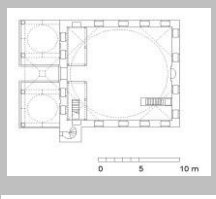
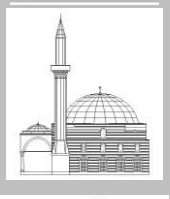
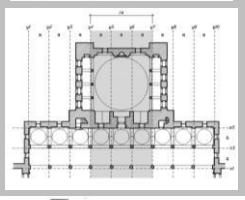
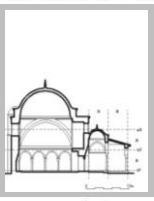
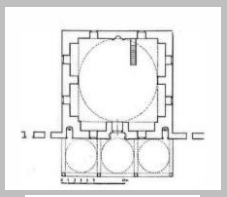
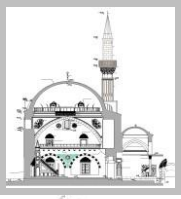
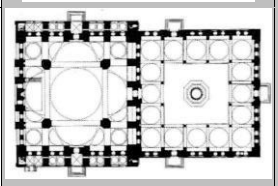
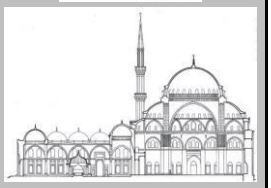
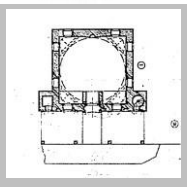
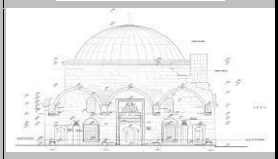
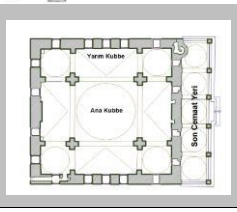
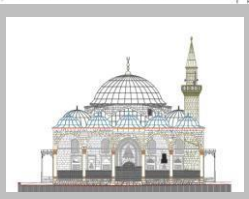
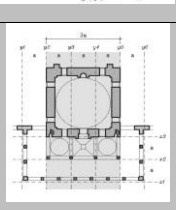
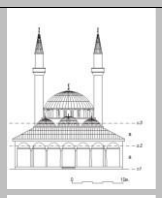
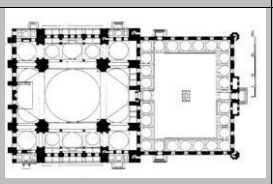
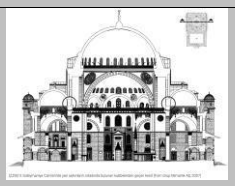
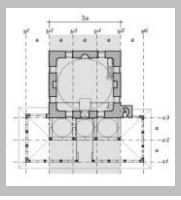
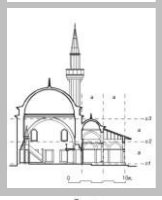
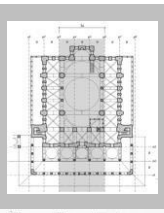
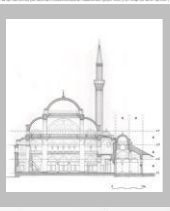
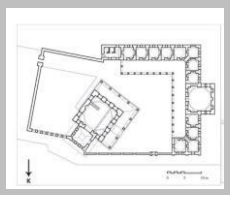
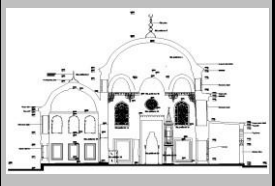
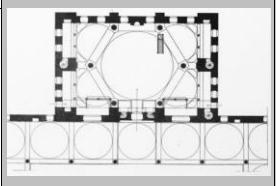
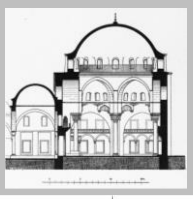
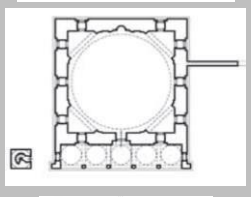
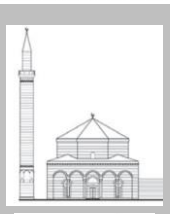
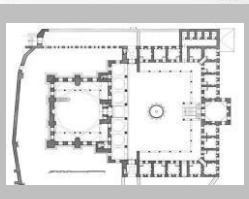
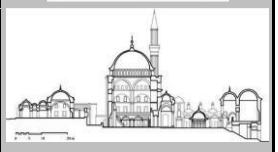
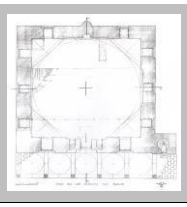
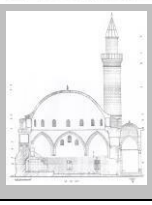
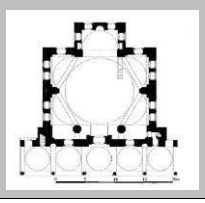
K-Means clustering algorithm works upon the mathematical calculations of distances and cluster centroids. However, every piece of knowledge should be paired with a numerical value for the execution of the algorithm. The values should be inconsistent in their groups. It is assumed that assigning the number of weights in accordance with the relation of knowledge will result in better evaluation and understanding of clusters. There are existing numerical values and assigned values. All of the assigned values are shown in Table 2. At the first columns of the table, the measurable values such as "dome height to ground" or "Area" are shown by the units of "m" and "m2". These measurements were ensured either from the statements of literature or dimensions from the existing drawings.

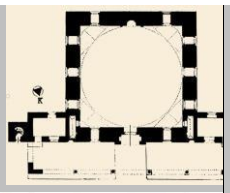
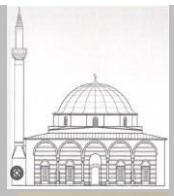
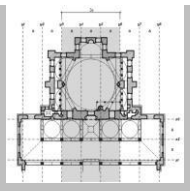
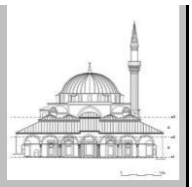
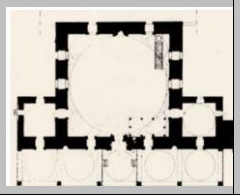
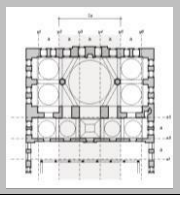
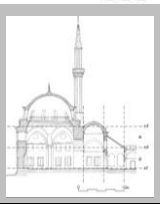
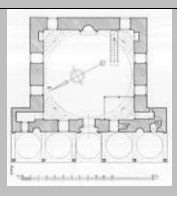
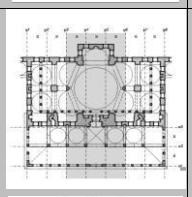
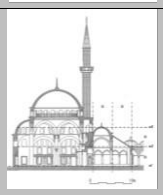
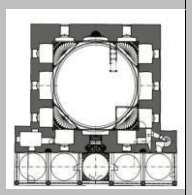
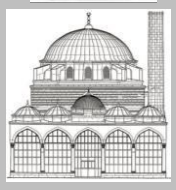
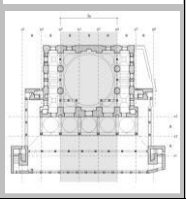
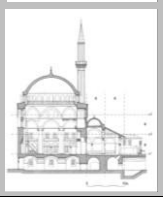
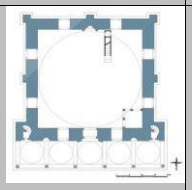
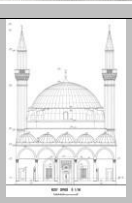
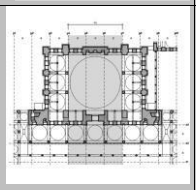
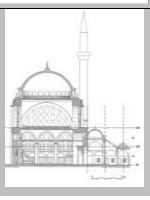
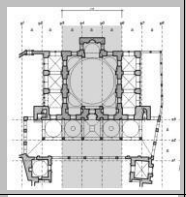
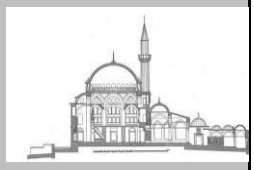
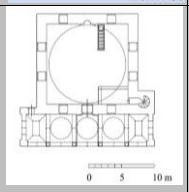
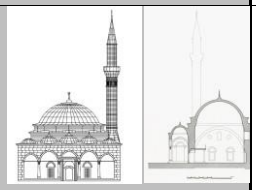
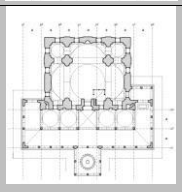
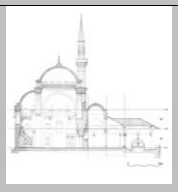
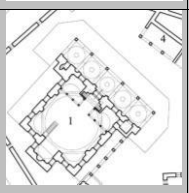
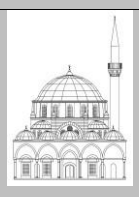
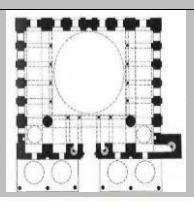
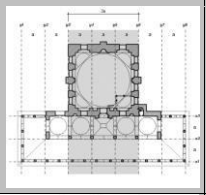
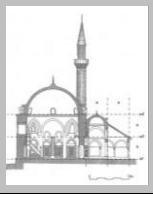
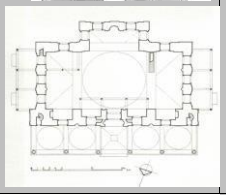
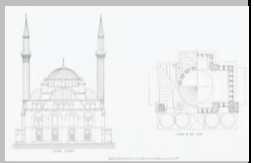
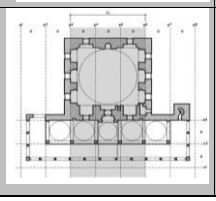
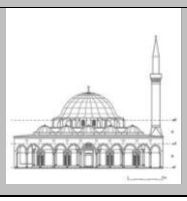
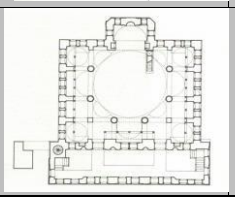
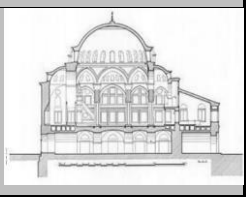
For the second set of columns, which is colored blue, the countable components are stated. For example, the number of "squintch" or mihrap is noted from the main prayer areas of the mosques. These two sets of knowledge are already computable data for any clustering algorithm. The last set is related to definitive knowledge of the mosques, such as material type. Thus, a number is assigned for these two columns, shown in brown. For the location, a "1" tag is assigned for the mosques inside İstanbul, and "2" is assigned for out of Istanbul. The additional information related to Mimar Sinan's Mosques, which is not used to seek patterns for structural components, is not presented in the research and could be found in other article of authors.

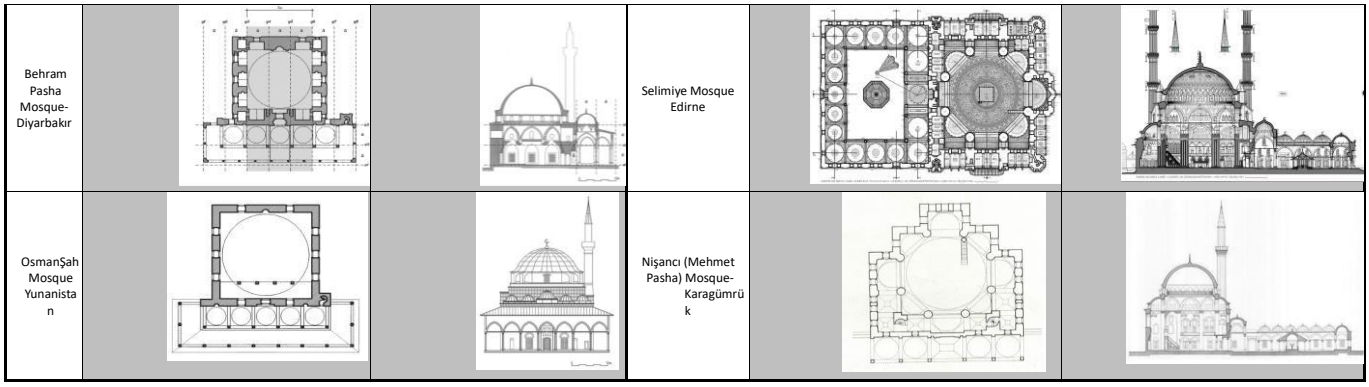
The computer software Jamovi (2022) and Javomi module snow Cluster (2022) are used to execute the K-Means Clustering Algorithm [29, 30]. The proposed tests are defined and executed for searching patterns, which are defined in further sections. As a limitation, it should be stated that a lack of computable data and big numbers may result in bias, which will be evaluated in the discussion section. 44 mosques of Mimar Sinan were analyzed and implemented into research by K-Means Clustering Algorithm. All these mosques have one main dome, and which has lack of dimension were kept out of the research.

[1] Uysal (1985) states that the building mentioned as Rüstem Pasha Mosque in the work titled 'Foundation Works in Turkey- I' is Bolvadin Lala Sinan Pasha Imaret Mosque [30]. Mimar Süreyya (1932) wrote that the mosque built by Mimar Sinan on behalf of Rüstem Pasha in Bolvadin was destroyed by an earthquake and not even a trace of it remains today [31]. Another source states that instead of the domed mosque built by Mimar Sinan, the new mosque built by the mosque building society founded by Osman Hulusi Efendi from the müfti's office of Bolvadin was opened for worship in 1904 by the architect Georgios Parmakyan from Afyon [32].

Table 1. List of Mosques Examined.

Name	Plan	Section/Elevation	Name	Plan	Section/Elevation
Mosque(Karagözbey) -Mostar Hacı Mehmet Pasha			Yeni Cuma Mosque-İzmit (Pertev Mehmet Pasha)		
Cenabı Ahmet Pasha Mosque-Ankara Ulucanlar			Kurşunlu Mosque-Kayseri (Hacı Ahmet Pasha Mosque)		
Defterdar Mustafa Pasha Mosque-Edirne			Sokullu Mehmet Pasha Mosque-Lüleburgaz		
Lala Mustafa Pasha Mosque-Ilgın			Şehzade Mosque-İstanbul		
Havsa Sokullu Mosque-Kasım Bey Mosque			Lala Mustafa Pasha Mosque-Erzurum		
Şam Süleymaniye Mosque			Süleymaniye Mosque-İstanbul		
Ferhad Pasha Mosque-Çatalca			Kılıç Ali Pasha Mosque-Tophane		
Şemsi Ahmet Pasha Mosque-Üsküdar			Topkapı Kara Ahmet Pasha Mosque		
Hadım Ali Pasha Mosque-Diyarbakır			Kadırga Sokullu Mehmed Pasha Mosque		
Köse Hüsrev Pasha Mosque Van			Fındıklı Molla Çelebi Pasha Mosque		

İskender Pasha Mosque-Diyarbakır			Babaeski Semiz Ali Pasha Mosque		
Hüsrev Pasha Mosque-Halep			Sinan Pasha Mosque-Beşiktaş		
Haseki Mosque-İstanbul			Atik Valide Mosque-Üsküdar		
Hadım İbrahim Pasha Mosque-Silivri			Rüstem Pasha MosqueTahtakale		
Karapınar Sultan Selim Mosque			Mihrimah Sultan Mosque Edirnekapı		
Firdevs Bey Mosque-Isparta			Mesih Mehmet Pasha Mosque Fatih		
Lala Hüseyin Pasha Mosque-Kütahya			Mihrimah Sultan Mosque-Üsküdar		
Habeşi Mehmet Ağa Mosque Çarşamba İstanbul			Zal Mahmud Pasha Mosque Eyüp		
Rüstem Pasha Mosque-Tekirdağ			Muradiye Mosque-Manisa		
Adliye Mosque-Halep (Dukakinzâde Mehmed Pasha Mosque)			Azapkapı Sokullu Mosque		



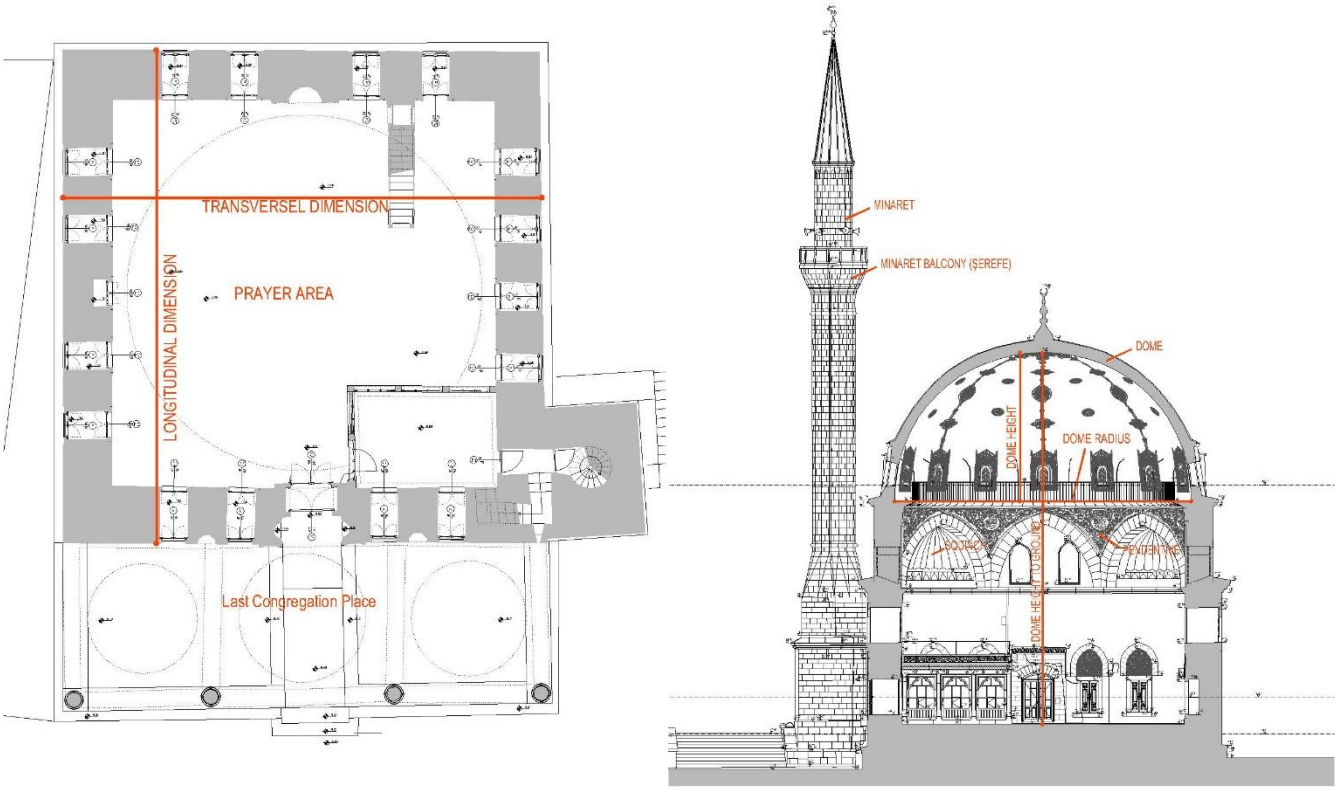


Figure 1. Features of the Mosques (example from Cenabı Ahmet Pasha Mosque-Ankara Ulucanlar) drawn by authors.

Table 2. Numerical values for variables.

ID	Name	Date	Dome Radius (m)	Dome Height (m)	Height of Kasnak (m)	Dome Height to Ground (m)	Trans. Dimension (m)	Long. Dimension (m)	Area (m2)	Mihrap	Squinch	Pend.	Column	Main Dome	Half Dome	Quarter Dome	Small Dome	Vault	Minaret Number	Minaret Balcony Number	Column Number	Location	Last C.P. ID	Last Congregation Place	Mat. ID	Material
1	Mosque(Karagöz bey)-Mostar Hacı Mehmet Pasha	1558	10,65	5,25	3	18,75	10,65	11,2	237,16	0	4	8	0	1	0	0	0	0	1	1	0	**2**	3	3 Sectioned Portico	1	Cut Stone
2	Cenabı Ahmet Pasha Mosque-Ankara Ulucanlar	1566	12,83	7,33	2,63	18,27	13,9	13,75	191,125	0	4	8	0	1	0	0	0	0	1	1	0	**2**	3	3 Sectioned Portico	1	Cut Stone
3	Defterdar Mustafa Pasha Mosque-Edirne	1575	12	5,25	2,5	13,3	12,54	12,8	220,062	0	4	8	0	1	0	0	0	0	1	1	0	**2**	3	3 Sectioned Portico	3	Almaşık*
4	Lala Mustafa Pasha Mosque-Ilgın	1577	11,95	5,28	1,45	17,66	15,15	16,18	245,127	0	0	4	0	1	0	0	0	0	1	1	0	**2**	3	3 Sectioned Portico	1	Cut Stone
5	Havsa Sokullu Mosque - Kasım Bey Mosque	1577	11,45	5,27	2,89	15,21	14,5	16,15	234,175	0	4	8	0	1	0	0	0	0	1	1	0	**2**	3	3 Sectioned Portico	1	Cut Stone
6	Şam Süleymaniye Mosque	1555	10	3,25	2	14,1	10,2	10,35	156,25	0	0	4	0	1	0	0	0	0	2	1	0	**2**	3	3 Sectioned Portico	2	Mixed
7	Ferhad Pasha Mosque-Çatalca	1597	9,2	3,5	1,25	12,6	9,2	9,2	132,25	0	0	4	0	1	0	0	0	0	1	1	0	**1**	3	3 Sectioned Portico	1	Cut Stone
8	Şemsi Ahmet Pasha Mosque-Üsküdar	1580	7,5	3,15	1,75	12,66	8,02	8,02	129,696	0	4	8	0	1	0	0	0	0	1	1	8	**1**	3	3 Sectioned Portico	1	Cut Stone
9	Hadım Ali Pasha Mosque-Diyarbakır	1537	14,4	0	0	14,8	14	15,2	297,563	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	2	Mixed
10	Köse Hüsrev Pasha Mosque-Van	1568	14,84	5,5	2,5	17,3	15,35	15,8	380,25	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	2	Mixed
11	İskender Pasha Mosque-Diyarbakır	1551	14,5	6,5	2,5	19,8	13,2	14,6	217,563	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	2	Mixed
12	Hüsrev Pasha Mosque-Halep	1536	18,5	8,75	5,75	27,1	17,54	19,55	528	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
13	Haseki Mosque-İstanbul	1539	11,3	4,25	2,5	16,4	11,15	12,05	222,01	0	4	8	0	1	0	0	0	0	1	1	0	**1**	5	5 Sectioned Portico	3	Almaşık*
14	Hadım İbrahim Pasha Mosque-Silivri	1551	12	5	3	21,2	15,74	14,4	309,875	0	4	8	0	1	0	0	0	0	1	1	4	**1**	5	5 Sectioned Portico	3	Almaşık*
15	Karapınar Sultan Selim Mosque	1563	15,8	6,25	3,5	24	14,35	15,1	316,84	0	0	4	0	1	0	0	0	0	2	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
16	Firdevs Bey Mosque-Isparta	1561	13	5,5	2,75	17,8	12,35	13,7	240,25	0	0	4	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
17	Lala Hüseyin Pasha Mosque-Kütahya	1570	12,46	4,5	1,5	15,2	12,7	12,2	240,25	0	0	4	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
18	Habeşi Mehmet Ağa Mosque-Çarşamba İstanbul	1585	11,8	5	3,25	19,6	13,31	13,55	255,75	0	4	8	0	1	0	0	0	0	1	1	0	**1**	5	5 Sectioned Portico	3	Almaşık*
19	Rüstem Pasha Mosque-Tekirdağ	1553	13,28	4,75	2,5	17,5	15,05	13,7	289	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
20	Adliye Mosque-Halep (Dukakinzâde Mehmed Pasha Mosque)	1556	15,4	7	2,75	20,4	20,1	19,45	529	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone

21	**Behram Pasha Mosque-Diyarbakır**	1573	15,9	6,75	3,75	21	19,6	20,64	540,5	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	2	Mixed
22	**Osman Şah Mosque-Yunanistan**	1567	18	7,5	4,5	31,5	18,26	19,14	478,125	0	0	4	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	3	Almaşık*
23	**Yeni Cuma Mosque-İzmit (Pertev Mehmet Pasha)**	1580	16,39	7,75	3,5	26,6	14,7	19,17	431,25	0	4	8	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
24	**Kurşunlu Mosque-Kayseri (Hacı Ahmet Pasha Mosque)**	1586	12,3	5,5	2,25	15,6	15,9	16,2	337,25	0	0	4	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
25	**Sokullu Mehmet Pasha Mosque-Lüleburgaz**	1570	12,35	4,75	2	18,26	17,52	15,62	360	0	0	4	0	1	0	0	0	0	1	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
26	**Şehzade Mosque-İstanbul**	1548	19	7,75	4,25	41,9	40,43	40,48	1945,75	0	8	4	1	1	4	8	4	0	2	2	4	**1**	1	Courtyard	1	Cut Stone
27	**Lala Mustafa Pasha Mosque-Erzurum**	1563	10,56	4,75	3	17,45	25,3	23,7	870,25	0	0	4	1	1	0	0	4	4	1	1	4	**2**	5	5 Sectioned Portico	1	Cut Stone
28	**Süleymaniye Mosque-İstanbul**	1557	26,2	10,75	5	49,5	57,33	58,56	4270	0	4	4	1	1	2	4	10	0	4	3	4	**2**	1	Courtyard	1	Cut Stone
29	**Kılıç Ali Pasha Mosque-Tophane**	1581	10,4	3,75	2,25	23,1	23,28	29,53	662,625	0	4	4	1	1	2	4	4	11	1	1	4	**1**	5	5 Sectioned Portico	1	Cut Stone
30	**Topkapı Kara Ahmet Pasha Mosque**	1558	12	5,5	3,25	23,5	24,01	15,64	484,5	0	4	6	1	1	4	0	0	0	1	1	6	**1**	1	Courtyard	1	Cut Stone
31	**Kadırga Sokullu Mehmed Pasha Mosque**	1572	13	8	3,5	32,6	18,99	15,67	412,5	0	4	6	0	1	4	0	0	0	1	1	6	**1**	1	Courtyard	1	Cut Stone
32	**Fındıklı Molla Çelebi Pasha Mosque**	1589	11,8	5,75	3	21	14,85	16,64	446,5	1	0	6	1	1	5	0	0	0	1	1	6	**1**	5	5 Sectioned Portico	1	Cut Stone
33	**Babaeski Semiz Ali Pasha Mosque**	1569	14	5,5	3	22	18,3	14,1	440,75	1	0	6	0	1	5	0	0	0	1	1	6	**2**	7	7 Sectioned Portico	1	Cut Stone
34	**Sinan Pasha Mosque- Beşiktaş**	1556	12,6	3	2,75	15,6	28,3	19,13	540	0	0	6	1	1	0	0	4	0	1	1	6	**1**	5	5 Sectioned Portico	3	Almaşık*
35	**Atik Valide Mosque-Üsküdar**	1577	12,7	4,5	2,75	18	31,7	15,06	579,5	1	0	6	1	1	5	0	0	0	2	1	6	**1**	5	5 Sectioned Portico	1	Cut Stone
36	**Rüstem Pasha Mosque-Tahtakale**	1562	15,2	4,5	3,25	20,3	24,73	18,6	436,5	0	4	8	1	1	4	4	0	2	1	1	8	**1**	5	5 Sectioned Portico	1	Cut Stone
37	**Mihrimah Sultan Mosque-Edirnekapı**	1565	18	6	3,25	30,2	34,28	23,91	1106	0	0	4	1	1	0	0	6	0	1	1	4	**1**	7	7 Sectioned Portico	1	Cut Stone
38	**Mesih Mehmet Pasha Mosque-Fatih**	1586	12,8	4,75	2,25	17,7	24,6	15,5	426,563	1	4	8	0	1	1	4	6	0	1	1	8	**1**	5	5 Sectioned Portico	1	Cut Stone
39	**Mihrimah Sultan Mosque-Üsküdar**	1548	11,4	4,75	2,5	24,2	23,92	18,11	645,188	0	4	4	1	1	3	4	2	0	2	1	4	**1**	5	5 Sectioned Portico	1	Cut Stone
40	**Zal Mahmud Pasha Mosque-Eyüp**	1580	12,4	4	3	21,8	22,6	19,15	519,75	0	0	4	1	1	0	0	2	0	1	1	4	**1**	5	5 Sectioned Portico	3	Almaşık*
41	**Muradiye Mosque-Manisa**	1585	10,6	4,5	3	28,5	22,5	12,6	494	1	0	4	0	1	0	0	0	3	2	1	0	**2**	5	5 Sectioned Portico	1	Cut Stone
42	**Azapkapı Sokullu Mosque**	1578	11,8	4,75	3	18,9	20,58	16,7	517,313	1	4	8	1	1	3	4	4	0	1	1	8	**1**	2	Closed	1	Cut Stone
43	**Selimiye Mosque-Edirne**	1575	31,22	14,4	6,33	42,25	56,32	54,26	3055,92	1	0	8	1	1	5	0	0	0	4	3	8	**1**	1	Courtyard	1	Cut Stone
44	**Nişancı (Mehmet Pasha) Mosque-Karagümrük**	1589	14,2	6,5	3,25	25,7	24	19,18	702	1	4	8	1	1	4	4	0	4	1	1	8	**1**	5	5 Sectioned Portico	1	Cut Stone

3. Results

Within the scope of the study, 44 Mimar Sinan Mosques were examined with the architectural components that are part of the structural layout. By creating diverse combinations (Table 3) between the various features of the structures, 10 tests were conducted with the K-means algorithm method. The tests were organized to seek a wide range of patterns. They were not limited, and all meaningful variations of structural elements were examined.

Table 3. The variables examined for each test.

Tests	Variables						
	1	2	3	4	5/6	7/8	9/10
1	Dome Radius	Dome Height to Ground	Trans. Dimension	Long. Dimension	Squinch, Pendentive	Main Dome, Half Dome	Small Dome, Vault
2	Dome Radius	Dome Height to Ground	Squinch	Pendentive	Column Number		
3	Dome Radius	Dome Height to Ground	Trans. Dimension	Long. Dimension			
4	Dome Radius	Dome Height to Ground	Main Dome	Half Dome	Quarter Dome, Small Dome	Vault	
5	Dome Radius	Dome Height to Ground	Main Dome	Half Dome	Quarter Dome,Area		
6	Dome Radius	Dome Height to Ground	Area				
7	Dome Radius	Dome Height to Ground	Area	Location			
8	Area	Material	Minaret Number	Minaret Balcony Number			
9	Dome Radius	Dome Height to Ground	Area	Column Number			
10	Trans. Dimension	Long. Dimension	Last Cong.Place				

The results of the tests performed with the K-means algorithm method are shown in Table 4-13. The centroid calculations' results among different variables for each test are presented. The optimum cluster number is selected by the elbow method of the K-means clustering algorithm. According to each performed test, the mosques were tagged in a cluster. The clusters and mosques are presented in Table 14.

4. Discussion

Within the study's scope, the buildings' structural elements were analyzed with the k-means algorithm method. According to the features of dome radius, dome height to the ground, kibla and harim dimension, pendant and tromp numbers, main dome, half dome, small dome, and vault, 3 clusters emerged in Test-1. There are 20 buildings in Cluster 1, 21 in Cluster 2, and 3 in Cluster 3. The three buildings in Cluster 3 are Istanbul Şehzade, Süleymaniye Mosques, and Edirne Selimiye Mosque. It is seen that these buildings constitute the largest group in terms of dome diameter, height of the dome from the ground, and plan dimensions. When the upper covering system is analyzed, it is seen that there are no vaults in all three, and there are half domes outside the main dome. However, while the Şehzade Mosque and Süleymaniye Mosque have exedra (quarter dome) and small dome, Selimiye does not. Likewise, Şehzade and Selimiye mosques are in the 4-foot baldeken group, while Selimiye Mosque is in the 8-foot baldeken group. Most of the multi-domed mosques (15) are located in Cluster 1, while 1 (Fındıklı Molla Çelebi Paşa Mosque) is located in Cluster 2. Five of the single-domed mosques are located in Cluster 1 and 20 in Cluster 2. The buildings in Cluster 1 have larger dome diameter, dome height from the ground, and harim width/length dimensions than those in Cluster 2. In Cluster 2, the single-domed mosques do not have half domes, exedra, or small domes other than the main dome. Among the single-domed mosques, Aleppo Hüsrev Paşlai Aleppo Courthouse Mosque, Diyarbakır Behram Pasha, Greece Osman Şah and İzmit Pertev Mehmet Pasha mosques are located in Cluster 1.

In Test 2, where the Dome Radius - dome height to the ground, number of pendentives, trump, and columns (pillars) were analyzed, 3 clusters emerged. There were 13 buildings in Cluster 1, 3 in Cluster 2, and 28 in Cluster 3. In cluster 2, where the dome diameter, the height of the dome from the ground, and the building's width/length dimensions are the highest, there are Şehzade, Süleymaniye, and Selimiye mosques. Cluster 1, which ranks 2nd in terms of size, includes multi-domed mosques and four single-domed mosques (Aleppo Husrev Pasha, Karapinar Sultan Selim, Greece Osman Şah, Izmit Pertev Mehmet Pasha mosques). In cluster 3, where the dimensions are smaller, there are single-domed mosques and six multi-domed mosques (Azapkapi Sokullu, Fatih Mesih Mehmet Pasha, Tahtakale Rüstem Pasha, Üsküdar Atik Valide Mosque, Beşiktaş Sinan Pasha and Fındıklı Molla Çelebi mosques). When the number of trumpets, pendentives, or the number of supporting columns (pillars) is compared with the size of the building and the size of the dome, it is seen that there is no direct connection. In hexagonal and octagonal baldachins, it is seen that the number of feet also gives the number of pendentives.

In Test 3, where Dome Radius- dome height to the ground, harim, and kibla dimension were analyzed, 3 clusters emerged. There were 20 buildings in Cluster 1, 21 in Cluster 2, and 3 in Cluster 3. In cluster 3, where the dome diameter, the height of the dome from the ground, and the building width/length dimensions are the highest, there are Şehzade, Süleymaniye, and Selimiye mosques. Cluster 1, which ranks 2nd in terms of size, includes single-domed mosques such as Aleppo Husrev Pasha, Aleppo Courthouse Mosque, Diyarbakır Behram Pasha, Greece Osman Şah and İzmit Pertev Mehmet Pasha mosques and multi-domed mosques, while cluster 2, where the dimensions are the smallest, includes single-domed mosques and multi-domed mosques such as Fındıklı Molla Çelebi Pasha Mosque.

Table 4. Results of Test 1.

	Cluster No	Dome Radius	Dome Height to Ground	Squinch	Pendentive	Transversal Dimension	Longiditunal Dimension	Main Dome	Half Dome	Small Dome	Vault
1	1.00	13.792	23.307	2.400	6.100	22.865	18.726	1.000	1.750	1.600	1.200
2	2.00	12.162	17.191	2.286	6.381	13.316	13.639	1.000	0.238	0.000	0.000
3	3.00	25.473	44.550	4.000	5.333	51.360	51.100	1.000	3.667	4.667	0.000

Table 5. Results of Test 2

	Cluster No	Dome Radius	Dome Height to Ground	Squinch	Pendentive	Column Number
1	1.00	14.207	26.215	2.154	5.385	3.231
2	2.00	25.473	44.550	4.000	5.333	5.333
3	3.00	12.378	17.370	2.429	6.643	2.071

Table 6. Results of Test 3

	Cluster No	Dome Radius	Dome Height to Ground	Transversal Dimension	Longiditunal Dimension
1	1.00	13.792	23.307	22.865	18.726
2	2.00	12.162	17.191	13.316	13.639
3	3.00	25.473	44.550	51.360	51.100

Table 7. Results of Test 4

	Cluster No	Dome Radius	Dome Height to Ground	Main Dome	Half Dome	Small Dome	Vault
1	1.00	15.748	29.417	1.000	0.667	1.000	0.500
2	2.00	11.864	16.288	1.000	0.050	0.700	0.200
3	3.00	13.300	21.660	1.000	2.333	0.800	1.133
4	4.00	25.473	44.550	1.000	3.667	4.667	0.000

Table 8. Results of Test 5

	Cluster No	Dome Radius	Dome Height to Ground	Main Dome	Half Dome	Quarter Dome (eksedra)	Area (m2)
1	1.00	25.473	44.550	1.000	3.667	4.000	3090.558
2	2.00	12.958	20.175	1.000	0.976	0.585	409.836

Table 9. Results of Test 6

	Cluster No	Dome Radius	Dome Height to Ground	Area (m2)
1	1.00	18.500	36.050	1525.875
2	2.00	12.832	19.924	392.431
3	3.00	28.710	45.875	3662.962

Table 10. Results of Test 7

	Cluster No	Dome Radius	Dome Height to Ground	Area (m2)	Location
1	1.00	25.473	44.550	3090.558	1.333
2	2.00	12.958	20.175	409.836	1.561

Table 11. Results of Test 8

	Cluster No	Area (m2)	Material ID	Minaret Number	Minaret Balcony Number
1	1.00	3090.558	1.000	3.333	2.667
2	2.00	409.836	1.463	1.122	1.000

Table 12. Results of Test 9

	Cluster No	Dome Radius	Dome Height to Ground	Area (m2)	Column Number
1	1.00	18.500	36.050	1525.875	4.000
2	2.00	12.832	19.924	392.431	2.400
3	3.00	28.710	45.875	3662.962	6.000

Table 13. Results of Test 10

	Cluster No	Transversal Dimension	Longiditunal Dimension	Last Congregation Place ID
1	1.00	23.841	19.152	4.706
2	2.00	13.818	13.973	4.250
3	3.00	51.360	51.100	1.000

Table 14. Clusters Due to Tests

ID	NAME /TESTS	1	2	3	4	5	6	7	8	9	10
1	Mosque(Karagözbey)-Mostar Hacı Mehmet Pasha	2	3	2	2	2	2	2	2	2	2
2	Cenabı Ahmet Pasha Mosque-Ankara Ulucanlar	2	3	2	2	2	2	2	2	2	2
3	Defterdar Mustafa Pasha Mosque-Edirne	2	3	2	2	2	2	2	2	2	2
4	Lala Mustafa Pasha Mosque-Ilgın	2	3	2	2	2	2	2	2	2	2
5	Havsa Sokullu Mosque-Kasım Bey Mosque	2	3	2	2	2	2	2	2	2	2
6	Şam Süleymaniye Mosque	2	3	2	2	2	2	2	2	2	2
7	Ferhad Pasha Mosque-Çatalca	2	3	2	2	2	2	2	2	2	2
8	Şemsi Ahmet Pasha Mosque-Üsküdar	2	3	2	2	2	2	2	2	2	2
9	Hadım Ali Pasha Mosque-Diyarbakır	2	3	2	2	2	2	2	2	2	2
10	Köse Hüsrev Pasha Mosque-Van	2	3	2	2	2	2	2	2	2	2
11	İskender Pasha Mosque-Diyarbakır	2	3	2	3	2	2	2	2	2	2
12	Hüsrev Pasha Mosque-Halep	1	1	1	1	2	2	2	2	2	1
13	Haseki Mosque- İstanbul	2	3	2	2	2	2	2	2	2	2
14	Hadım İbrahim Pasha Mosque-Silivri	2	3	2	3	2	2	2	2	2	2
15	Karapınar Sultan Selim Mosque	2	1	2	3	2	2	2	2	2	2
16	Firdevs Bey Mosque-Isparta	2	3	2	2	2	2	2	2	2	2
17	Lala Hüseyin Pasha Mosque-Kütahya	2	3	2	2	2	2	2	2	2	2
18	Habeşi Mehmet Ağa Mosque-Çarşamba İstanbul	2	3	2	2	2	2	2	2	2	2
19	Rüstem Pasha Mosque-Tekirdağ	2	3	2	2	2	2	2	2	2	2
20	Adliye Mosque-Halep (Dukakinzâde Mehmed Pasha Mosque)	1	3	1	3	2	2	2	2	2	1
21	Behram Pasha Mosque-Diyarbakır	1	3	1	3	2	2	2	2	2	1
22	Osman Şah Mosque-Yunanistan	1	1	1	1	2	2	2	2	2	1
23	Yeni Cuma Mosque-İzmit (Pertev Mehmet Pasha)	1	1	1	1	2	2	2	2	2	2
24	Kurşunlu Mosque-Kayseri (Hacı Ahmet Pasha Mosque)	2	3	2	2	2	2	2	2	2	2
25	Sokullu Mehmet Pasha Mosque-Lüleburgaz	2	3	2	2	2	2	2	2	2	2
26	Şehzade Mosque- İstanbul	3	2	3	4	1	1	1	1	1	3
27	Lala Mustafa Pasha Mosque-Erzurum	1	3	1	2	2	2	2	2	2	1
28	Süleymaniye Mosque-İstanbul	3	2	3	4	1	3	1	1	3	3
29	Kılıç Ali Pasha Mosque-Tophane	1	1	1	3	2	2	2	2	2	1
30	Topkapı Kara Ahmet Pasha Mosque	1	1	1	3	2	2	2	2	2	1
31	Kadırga Sokullu Mehmed Pasha Mosque	1	1	1	1	2	2	2	2	2	2
32	Fındıklı Molla Çelebi Pasha Mosque	2	3	2	3	2	2	2	2	2	2
33	Babaeski Semiz Ali Pasha Mosque	1	1	1	3	2	2	2	2	2	2
34	Sinan Pasha Mosque- Beşiktaş	1	3	1	2	2	2	2	2	2	1
35	Atik Valide Mosque-Üsküdar	1	3	1	3	2	2	2	2	2	1
36	Rüstem Pasha Mosque-Tahtakale	1	3	1	3	2	2	2	2	2	1
37	Mihrimah Sultan Mosque-Edirnekapı	1	1	1	1	2	1	2	2	1	1
38	Mesih Mehmet Pasha Mosque-Fatih	1	3	1	2	2	2	2	2	2	1
39	Mihrimah Sultan Mosque-Üsküdar	1	1	1	3	2	2	2	2	2	1
40	Zal Mahmud Pasha Mosque-Eyüp	1	1	1	3	2	2	2	2	2	1
41	Muradiye Mosque-Manisa	1	1	1	1	2	2	2	2	2	1
42	Azapkapı Sokullu Mosque	1	3	1	3	2	2	2	2	2	1
43	Selimiye Mosque-Edirne	3	2	3	4	1	3	1	1	3	3
44	Nişancı (Mehmet Pasha) Mosque-Karagümrük	1	1	1	3	2	2	2	2	2	1

In the 4th test, four clusters emerged, where dome radius, dome height to the ground, main dome, half dome, quarter dome, small dome, and vault were analyzed, and 4 clusters emerged. There are five buildings in Cluster 1, 20 in Cluster 2, 15 in Cluster 3, and 3 in Cluster 4. In Cluster 4, where the dome diameter and height are the highest, there are Şehzade, Süleymaniye, and Selimiye mosques, and there are no vaults in these buildings. In Cluster 1, which ranks 2nd in terms of dome diameter and height of the dome from the ground, there are the mosques of Osman Şah in Greece, Pertev Mehmet Pasha in İzmit, Sokullu Mehmet Pasha in Kadırga, Mihrimah Sultan in Edirnekapı, and Muradiye in Manisa. Of the buildings in Cluster 3, 10 are multi-domed, and five are single-domed (Diyarbakır İskender Paşa, Silivri Hadım İbrahim Paşa, Karapınar Selimiye, Aleppo Adliye and Diyarbakır Behram Paşa mosques).

In Test 5, where Dome Radius, dome height to the ground, main dome, half dome, quarter dome, and building area were analyzed, 2 clusters were formed. There are three buildings in the 1st Cluster and 41 in the 2nd Cluster. The buildings in Cluster 1 are Şehzade, Süleymaniye, and Selimiye mosques, where the average dome diameter is 25.473 m, and the dome's height from the ground is 44.55 m. In Cluster 2, the average dome diameter of the buildings is 12.958 m, the dome's height from the ground is 20.175 m, and the average area of the buildings is 409,836 m2.

In the 6th test, where dome radius, dome height to ground, and area were analyzed, 3 clusters emerged. There are two buildings in Cluster 1, 40 in Cluster 2, and 2 in Cluster 3. In Cluster 3, the largest buildings in terms of dome height and the dome's height from the ground and area are Selimiye and Süleymaniye Mosques. At the same time, Şehzade Mosque and Edirnekapı Mihrimah Sultan Mosques are ranked 2nd in terms of dome and area size in Cluster 1. The remaining buildings other than these four are clustered in Cluster 2.

In Test 7, where dome diameter, the height of the dome from the ground, building area, and building location were evaluated, 2 clusters were formed. There are three buildings in Cluster 1 and 41 buildings in Cluster 2. Two buildings in Cluster 1, where Istanbul Süleymaniye, Şehzade and Edirne Selimiye Mosques are located, are in Istanbul and one in Edirne. This situation can be attributed to Mimar Sinan not wanting to build a larger building than Süleymaniye in Istanbul.

In Test 8, the buildings were evaluated in terms of the building area, the material of construction, the number of minaret and şerefe and 2 clusters emerged. There were three buildings in Cluster 1 and 41 buildings in Cluster 2. In Cluster 1, it was observed that all three of the Istanbul Süleymaniye, Şehzade, and Selimiye Mosques were built with cut stone, and the number of minaret and şerefe was more than 1. All of the buildings in Cluster 2, which have a smaller area compared to those in Cluster 1, have single minarets, and 5 of them (Manisa Muradiye, Üsküdar Mihrimah Sultan, Üsküdar Atik Valide, Karapınar Sultan Selim, Damascus Süleymaniye and Havsa Sokullu/Kasım Bey mosques) have two minarets. Of these five buildings, one was built for Sultan Suleiman the Magnificent, one for Sultan Selim II, one for Sultan Murat III, and the other two for sultans (Mihrimah Sultan and Atik Valide Sultan). 34 of these buildings were built with cut stone. In contrast, 7 of them (Edirne Defterdar Mustafa Pasha, Istanbul Haseki, Silivri Hadım İbrahim Pasha, Istanbul/Çarşamba Habeşi Mehmet Ağa, Greece Osman Şah, Beşiktaş Sinan Pasha and Eyüp Zal Mahmut Pasha mosques) were built with an alternating system of cut stone and brick. In 5 of the buildings built with cut stone (Damascus Süleymaniye, Diyarbakır Hadım İbrahim Pasha, Van Köse Hüsrev, Diyarbakır İskender Pasha and Diyarbakır Behram Pasha Mosques), two colors of stone were used. It is understood that all the mosques where a two-color cut stone was used are outside Istanbul and have local characteristics.

In Test 9, dome radius, dome height to the ground, area, and number of supporting columns were analyzed, and 3 clusters were formed. There are two buildings in the 1st and 3rd Cluster and 40 in the 2nd Cluster. In Cluster 3, where the building area and dome dimensions are the largest, there are Edirne Selimiye and Istanbul Şehzade mosques. Both buildings have supporting pillars; Selimiye Mosque has eight, and Süleymaniye Mosque has four pillars. Cluster 1, which ranks 2nd in size, includes Istanbul Şehzade Mosque and Edirnekapı Mihrimah Sultan Mosque. Both of these mosques have four pillars. Edirnekapı Mihrimah Sultan Mosque has a main dome and six small domes, three on each side. Şehzade Mosque has a main dome, four half domes, eight quarter domes (exedra), and four small domes in the corners. Among the buildings in Cluster 2 with the smallest building dimensions, 25 have single domes and we see walls as a carrier. The other 15 buildings have multiple domes supported by 4, 6, and 8 piers. Of these, only Manisa Muradiye Mosque does not have elephant legs but piers on the wall. The main dome rests on the piers on the north wall with three suspension arches in two directions. The piers are on both sides of the entrance and are rectangular in shape.

In Test 10, building dimensions and the last congregation space features were added, and 3 clusters were formed. In Cluster 3, where the building dimensions are the largest, Istanbul Süleymaniye, Şehzade, and Edirne Selimiye mosques are integrated with the courtyard and do not have a separate last congregation space. In cluster 1, which ranks 2nd in terms of building dimensions, there are four multi-domed mosques and four mosques with additional domes (Aleppo Husrev Pasha, Aleppo Adliye, Diyarbakır Behram Pasha, and Greece Osman Shah Mosques), and most of these buildings have 5-aisled last congregation spaces. However, Azapkapı Sokullu Mosque has a closed congregation space, and Edirnekapı Mihrimah Sultan Mosque has a 7-aisled last congregation space. Cluster 2, which has the smallest building dimensions, has single-domed mosques and three multi-domed mosques (Kadırga Sokullu Mehmet Pasha, Fındıklı Molla Çelebi and Babaeski Semiz Ali Pasha Mosques).

5. Conclusion

Edirne Selimiye and Istanbul Süleymaniye mosques are in the same Cluster in all tests. These two buildings, which have different characteristics in terms of plan features, show very similar characteristics in terms of

dome diameter, dome height, and area size. This may explain why Mimar Sinan did not build these two sultan mosques in the same city.

When the buildings are compared in terms of dome diameter, height, and covering systems (half dome, quarter dome, etc.), it is seen that Selimiye, Süleymaniye, and Şehzade mosques differ from the others. In other mosques, it was observed that single-domed mosques were grouped within themselves, and multi-domed mosques were grouped within themselves. However, it was observed that some of the single-domed mosques were grouped with multi-domed mosques, and some of the multi-domed mosques were grouped with single-domed mosques. Among the single-domed mosques, Aleppo Hüsrev Pasha, Aleppo Adliye Mosque, Diyarbakır Behram Pasha, Greece Osman Şah and İzmit Ferhat Pasha mosques are among the buildings grouped with multi-domed mosques. The fact that these buildings are generally located outside Istanbul can be explained by the fact that they were built with more splendor to show the empire's power. Among the multi-domed mosques, the Fındıklı Molla Çelebi and Fatih Mesih Mehmet Pasha mosques are grouped with single-domed mosques in some tests. This strengthens the idea that the two buildings were built in the late 1580s, perhaps by Davut Aga, one of Mimar Sinan's students.

In Mimar Sinan's mosques, it is seen that especially cut stone is preferred as a construction material. It was observed that the interlocking system (stone-brick mixed) was not used, especially in a sultan's mosque. The fact that the mosques of Damascus Süleymaniye, Diyarbakır Hadım İbrahim Pasha, Van Köse Hüsrev, Diyarbakır İskender Pasha and Diyarbakır Behram Pasha, where a two-colored cut stone was used, are all located outside Istanbul strengthens the idea that Mimar Sinan was not present in these buildings from the beginning to the end of the work and that local craftsmen and architects built them in accordance with local characteristics.

The minaret, an integral part of the mosque program of the classical period, rises on both sides of the building in sultan mosques, which is important in balance. Since it is against the tradition to build two or more minarets except for the sultans, the asymmetrical façade layout created by a single minaret has been a problem that the Ottoman period architects sought solutions to. In the study, it was observed that there were four minarets in Süleymaniye and Selimiye mosques and two minarets in other sultan mosques. However, Üsküdar Mihrimah Sultan and Üsküdar Atik Valide mosques had two minarets as an exceptional case.

Analyses and tests show that among the mosques built by Mimar Sinan, Edirne Selimiye, Istanbul Süleymaniye, and Istanbul Şehzade mosques stand out in terms of size and dome dimensions, and some tests show that Edirnekapı Mihrimah Sultan Mosque is in the same group with Istanbul Şehzade Mosque. Mimar Sinan used multiple support systems in the dome structure, such as four, six, and eight supports (baldaken). After trying these support systems, he returned to a system he had used before and tried to improve it again.

In this study, a method with implementation of clustering algorithm were used to analyze the patterns and relationship of building/structural components of the Mimar Sinan's Mosque. The results of tests and evaluations over them are promising, since the querries and relations composed by machine processing brought new perspectives for classifying the mosques due to these features and validate some former descriptive studies.

Author contributions

Filiz Karakuş: Conceptualization, Investigation Methodology, Writing-Original draft preparation, Writing-Reviewing and Editing. **Ekrem Bahadır Çalışkan:** Visualization, Data curation, Software, Validation, Writing-Reviewing and Editing

Conflicts of interest

There is no conflict of interest between the authors.

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