Built Heritage

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Patterns in the spatial configuration of Sultani Mosques in the Qajar period: a comparative study using space syntax and layout-based analysis

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Abstract

The pattern of built heritage provides insights into spatial organisation principles, revealing recurring traits among buildings of a similar type. Such constructions illuminate how building components are aligned and interconnected to embody a unified design ethos. However, well-preserved instances of a sequential series of similar buildings that were built in the same period based on historical evidence are rarely located. Thus, the Sultani Mosques, a prominent collection of mosques built in Iran between 1806 and 1840 under King Fath-Ali Shah of the Qajar dynasty's auspices, are particularly noteworthy, attracting scholarly attention from figures such as Ritter, Hillenbrand, and Scarce for their distinctive spatial organisation of architectural elements such as *iwans*, domes, naves, and courtyards. To comprehensively study the shared spatial organisation concept within these mosques through a comparative study, this research aimed to verify the spatial layout using analytical techniques such as space syntax and layout-based justified graphs. By juxtaposing these graphs and depth values, this research elucidated the spatial integration and privacy delineation within these religious structures. Moreover, an examination of layout-based graphs and immersive three-dimensional assessments reinforced and confirmed the prevailing layout configuration. The research findings reveal a cohesive architectural concept in Sultani mosques, as multifaceted accessibility was emphasised, and spatial layouts were structured to facilitate movement and interactions. Qajar architects likely established a consistent design approach across these mosques, integrating essential elements while accommodating educational spaces. When schools were included, courtyard dynamics were reshaped, which impacted spatial connections and access routes. Variations in building division configurations, vault spans, and spatial relations tailored to local contexts highlight the unique design and spatial value of each mosque. Preserving these spatial relationships in restoration efforts is crucial for maintaining the intrinsic spatial language and historical design significance of these mosques.

Keywords Sultani Mosques, Space Syntax, Justified Graphs, Spatial Configurations, Relations, Layout-based Analysis

1 Introduction

In their design and layout, heritage buildings embody the traditions, lifestyles, craftsmanship, and cultural essences of bygone eras. While some heritage structures evolve organically over time, specific collections are erected under a singular founder's direction, possibly following a master plan overseen by an architect. However, understanding the spatial arrangement patterns envisioned by historical architects may be challenging due to limited

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written records or concrete evidence. The main inquiry revolves around whether there is a specific design concept for a chain of buildings with similar founders that is formulated by their builders and architects.

The design of mosques represents a significant category of historical buildings, displaying various configurational patterns tailored to their unique settings across different regions. The typology of mosques forms an essential body of study for understanding the design patterns of historical structures, as these buildings showcase key stylistic features from various periods. Among the array of historical mosques, one particular category stands out as exceptional. In the first half of the 19th century (13th H.), several mosques were built or restored in major Persian cities, as shown in the timeline provided in this research (Fig. 1).

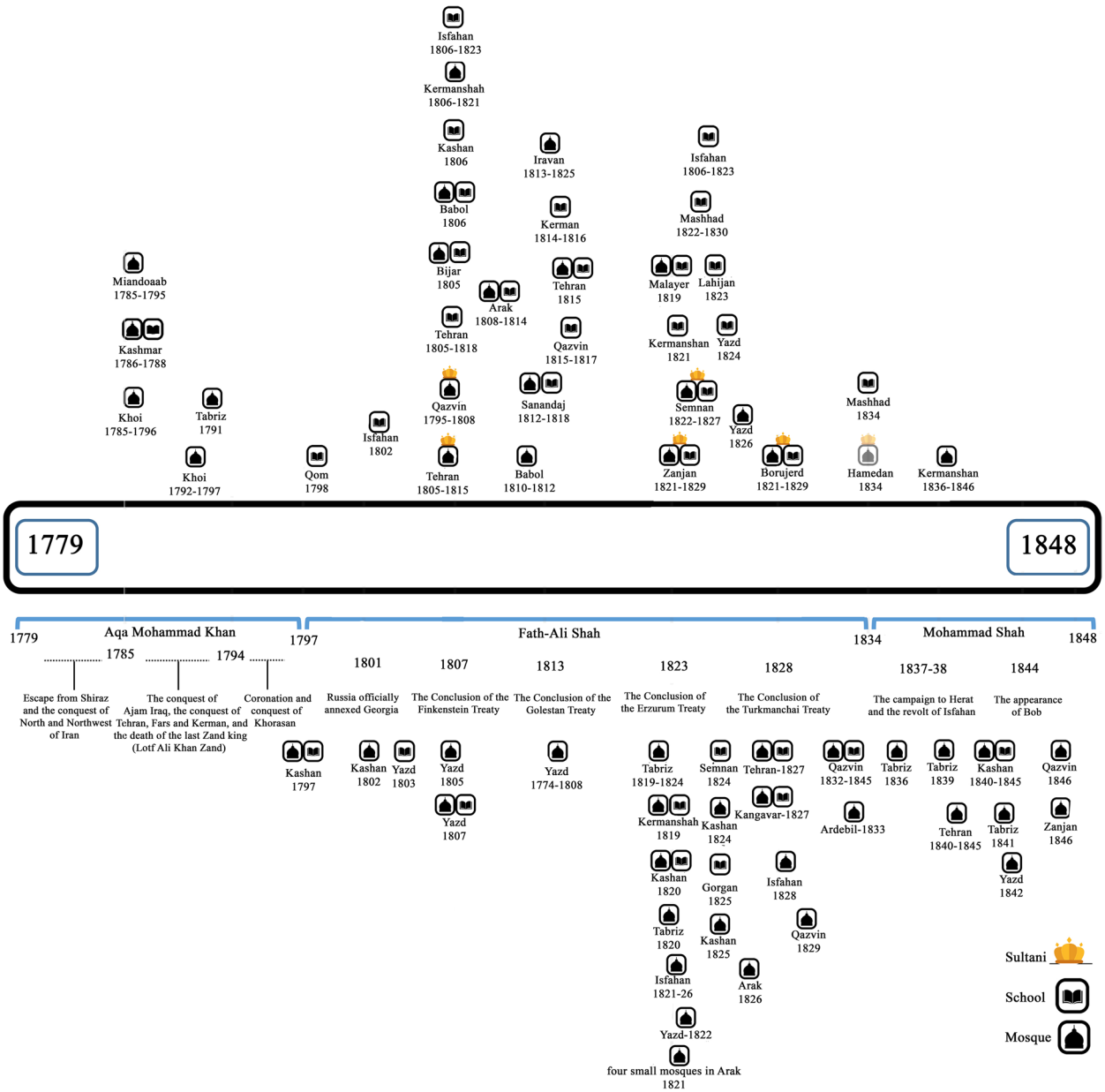


Fig. 1 This timeline illustrates the mosques and schools constructed in the Qajar period between 1779 and 1848 (although the Qajars took power in 1789, they ordered the construction of several holy structures approximately 10 years prior to the Agha Mohammad Khan coronation), categorised by the name of the cities in which they were built. The diagram separates the cases built by courtiers and the Sultanate at the top and cases built by clergymen and scholars at the bottom (Source: Ritter 2003)

After Fath-Ali Shah (second king of Qajar) came to power in 1797 until his death in 1834, many mosques and schools were built in Iran, specifically in the cities of Semnan, Tehran, Qazvin, Zanjan, Hamadan, and Borujerd (Fig. 2). Among the mosques built in this period, some that were larger and more important were named 'Sultani' or 'Shah' (king). The construction, development and attention given to these buildings were examples of the Qajar kings being religious, expressing their religion and their need to gain legitimacy (Algar 1980).

The grand mosques and schools built during the Fath-Ali Shah era have a consistent shape and were influenced by the courtly grandeur of the Safavid era (1501 to 1736). These buildings transitioned from elaborate construction to a more uniform and modest architectural style that became prevalent across the country (Ritter 2003). Several studies have focused on Sultani mosques. For example, Markus Ritter tried to categorise Qajar Mosques into various groups, emphasising the courtyard and the configuration of two important elements of the mosque: the first is the dome, and the second is a key elements of Iranian mosques, the *iwan*, which typically consists of a vaulted, rectangular hall or space, enclosed on three sides, while one end remains completely open. It is located in the middle of each side of the courtyard. Therefore, the Sultani Mosques that fall under the category of Four-*Iwan* Mosques feature domes. The primary feature is the emphasis placed on axes, whether through the elevation of *iwan*s or the central portions of each side of the building. Additionally, there is a clear hierarchy in the design of the arches, with greater attention given to the design and ornamentation of entrances and the courtyard façade (Ritter 2003). Additionally, Robert Hillenbrand acknowledged the conservative approach to courtyard mosques with *iwan*s during the Qajar period while noting the incorporation of traditional and innovative elements in their facades (Hillenbrand 1983). Scarce also highlighted that despite restrictions on the use of the

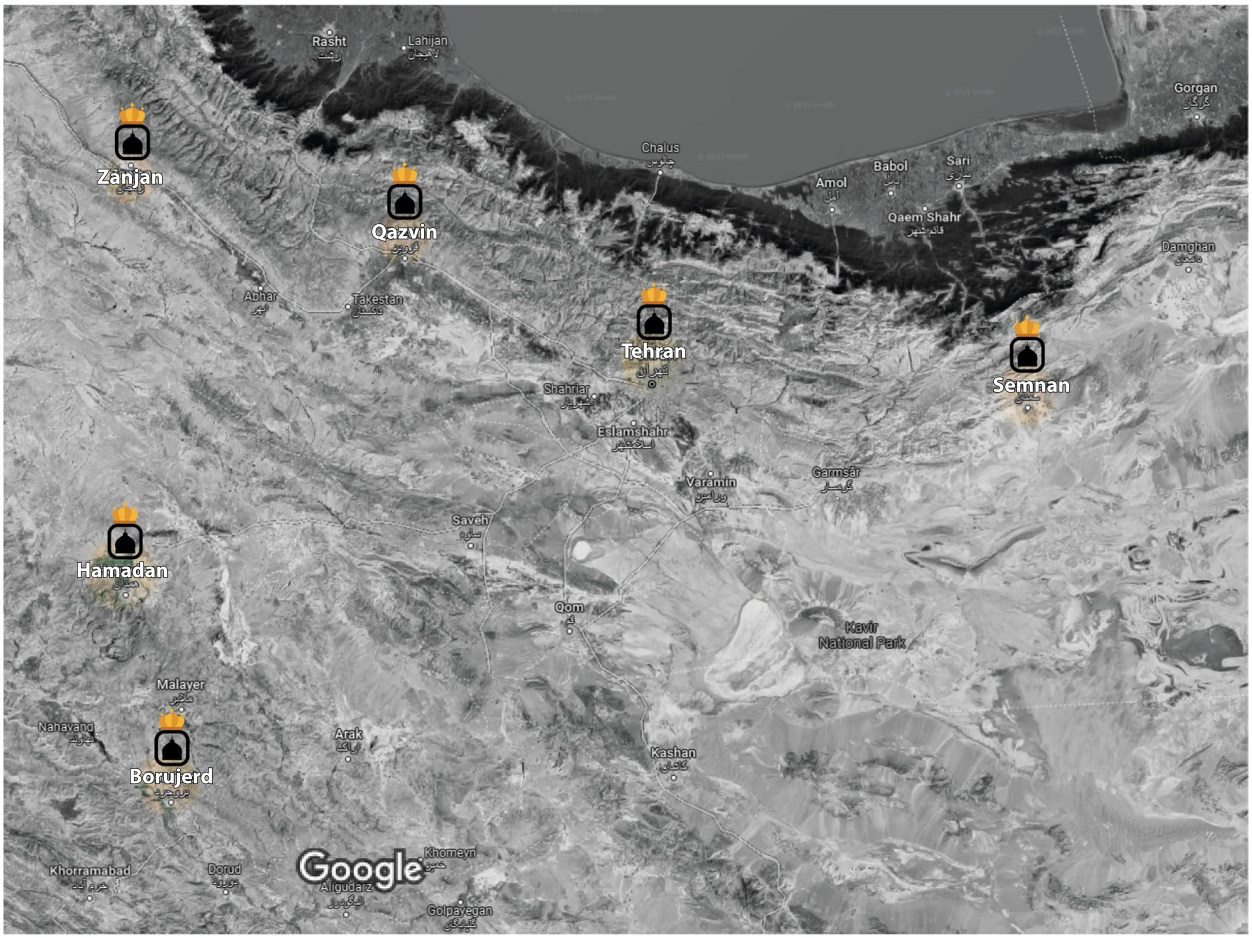


Fig. 2 The geographical distribution of Sultani mosques on the satellite map of Iran. Mosques from northeast to southwest: Semnan, Tehran, Qazvin, Zanjan, Hamadan and Borujerd (source: the auhtors, based on Google Map)

four-*iwan* model, it still allows for creativity in design and implementation, so there is room for diverse building elements and components (Scarce 2008).

However, upon closer examination of Sultani mosques, variations in the decorations, execution methods, construction techniques, proportions, and distinctive spatial organisation of each mosque division have emerged. These differences arise from the integration of local features in these buildings, so it cannot be asserted that these structures are entirely foreign to their surroundings (Ritter 2003).

2 Research aim, method and related works

Based on the works that have previously examined Sultani mosques, three study gaps, including historical, social, and spatial studies of these buildings, have been identified. This means that historical records need to be further analysed to establish accurate dating. Furthermore, the social dynamics within a space, influenced by the arrangement and interconnections of various divisions, also need to be examined. Patterns should be identified to establish similarities in the design and construction of successive Sultani mosques. In this way, this research seeks to answer the question of how the spatial organisation of the Sultani mosques, constructed by the Qajar court in a relatively short period, can be interpreted to reveal common patterns as well as alterations and evolution.

This research aims to explore the novel advancements and design patterns of an important corpus of mosques, the Sultani mosques of the nineteenth century (13th H.), to compare and provide a better understanding of their common spatial layout, configurations and specific differences. Understanding the design pattern of the layout and arrangement of various sections of Sultani mosques is vital for analysing design specifications. Therefore, the major elements and divisions of the mosques, the relations between spaces, their configuration, and topological links need to be precisely analysed to determine the pattern of common and specific configurations. The research's analytical framework is depicted in Fig. 3.

This research utilised space syntax analysis, a set of analytical, quantitative, and descriptive tools introduced by Hillier and Hanson (1984) and Steadman (1983), to analyse the spatial configurations of the Sultani mosques. Specifically, the details of the Space Syntax Selected Mathematical Formulae Mean depth (md) = I/ (K—1) are as follows (I: (all depth values between a node and all other nodes in a graph)). (1) The depth value between two nodes in a graph is equal to the minimum number of connections that must be taken to reach from one to the other (the shortest path) (Osman and Suliman 2005). The space syntax method involves assigning a node or circle to each space in a building, city, or landscape and connecting these spaces with lines that represent their permeability

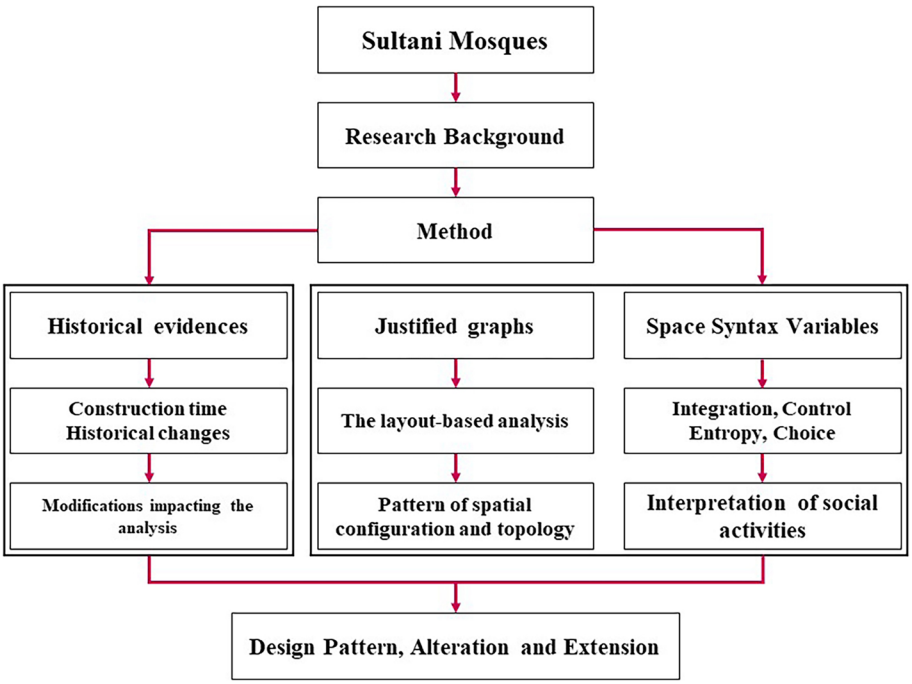


Fig. 3 Analytical framework of the research. (Source: the authors)

or connections with each other. Once a depth value is assigned to each space based on the minimum number of steps needed to reach it from the starting point, a 'justified gamma graph' that clearly shows the basic features of space syntax, such as symmetry and asymmetry, distribution, and non-distribution, can be created (Hillier and Hanson 1984). Space syntax uses four important variables to specify relationships between different building divisions as follows:

1. Integration: The determination of public and private spaces relies on their level of integration.
2. Control: This value signifies the degree to which a node in a graph (representing a space in a configuration) is strongly interconnected with other nodes.
3. Entropy: The availability of spaces is influenced by their entropy factor.
4. Choice: This factor indicates the frequency with which each node is included in the shortest path between other nodes (Nourian 2016).

The calculations of variables and the resulting graph can be performed via different methods and tools, such as UCL Depthmap, DepthmapX, and Axwoman. These tools provide a quantitative analysis of spaces based on the four specified variables. However, since this study aims to contribute to domain knowledge, this research utilised the state-of-the-art tools of space syntax by Syntactic. The Syntactic plugin in Grasshopper of Rhino provides computer calculation methods for creating and analysing building configuration diagrams and justified graphs (Nourian 2016). Notably, the graphs generated by the Syntactic plugin are more visually comprehensible, which makes them easier to understand and interpret (Fig. 4).

This research introduces a new approach by reorganising the justified graphs of space syntax analysis for the main pattern of relations and expanding the application of space syntax graphs and variables to include layout-based analysis. Notably, a comprehensive method that transcends conventional two-dimensional analysis is needed for understanding the spatial relations of intricate historic buildings. Although space syntax graphs show the sequence of spaces, they cannot show the number of accesses according to the openings or how the spaces are co-located and placed in relation to each other according to topological links. For example, if the courtyard is at the centre of a mosque, the naves are arranged around the yard. The spatial organisation of divisions that leads to understanding the pattern is achieved by analysing the plan. Therefore, the novelty of the analysis involves overlaying the justified graphs onto the building's layout and scrutinising simplified floor plans and volumetric diagrams to enrich the spatial organisation analysis and extraction of the topological links in the design pattern.

Several studies have examined the application of space syntax in mosque analysis. Tarabieh et al. (2018) used the space syntax tool 'depthmapX' to analyse typical mosque prayer halls with a common configuration of bilateral symmetry and four columns. Visibility graphs, axial lines, and Isovist field properties were considered in the analysis. Emad et al. (2021) studied the mosque hierarchy in historic Shiraz, revealing that public spaces such as the *shabestan* or nave are prioritised, while other areas offer more privacy. They examined four mosques using space syntax and found dual entrances connecting neighbourhoods in Shiraz's mosques.

Mostafa and Hassan (2013) explored mosque spatial configurations and found that the courtyard layout exhibited the highest functional efficiency in relation to space syntax analysis among various layouts. This finding elucidates the intricate relationship between spatial design and functional effectiveness within mosque architecture.

Bemanian et al. (2022) studied the formal composition and spatial configuration of mosques in the historic city of Isfahan to better understand the significance of Islamic architecture in the design of these mosques using space syntax measures.

Research employing space syntax has explored the interconnections and spatial structure of mosques. Various studies have employed space syntax in mosque analysis, using depthmapX to examine prayer halls. These studies focused on visibility graphs and Isovist field properties, highlighting an emphasis on public spaces and connections to neighbourhoods. These analyses highlighted the optimal functional efficiency of courtyard layouts in mosques through space syntax assessments. However, no specific study has focused on Sultani mosques or the mosques and schools of the first half of the 19th century (13th H.) in Iran. Notably, the significance of these studies lies in their aim to identify novel applications to understand the permeability, visual accessibility, and social interaction of mosques rather than to test or validate the space syntax method.

In this research, space syntax analysis served as a tool for generating explanatory graphs, comparing them, calculating defined metrics, and revealing spatial typologies and underlying architectural patterns. The pattern goes beyond obvious features such as a central courtyard or a southern domed hall in a mosque. This approach has also been instrumental in elucidating the spatial and social dynamics within these mosques. The research findings demonstrate how space syntax, through topological analysis and indicator calculations, can offer fresh insights into preserved architectural heritage.

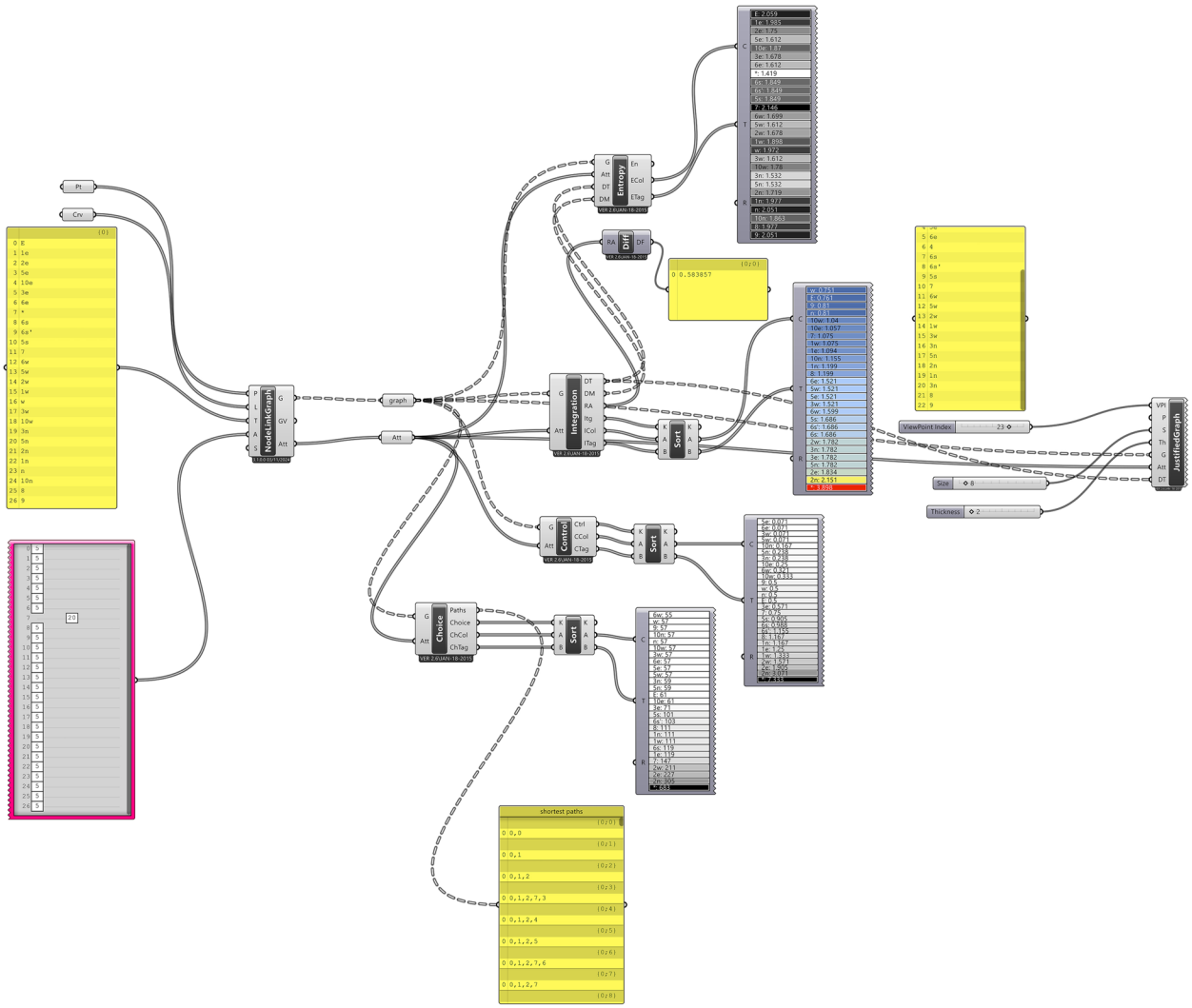


Fig. 4 The process of connecting the necessary tools in the Syntactic plugin to generate a justified graph of the Sultani Mosque of Borujerd in Grasshopper. The process of working with the tool is visual and proper for architects to follow (Source: snapshot of SYNTACTIC plugin of Grasshopper)

3 Background of the Sultani Mosques

3.1 History

The Sultani mosques selected for this research were constructed during the rule of Fath-Ali Shah in the early 19th century (13th H.). However, a more thorough historical analysis of these mosques is necessary to form a more cohesive collection. Thus, inscriptions, dedication letters, and historical evidence were reviewed for this research, and it was found that the construction of some of these mosques began before this era. The Sultani mosques in Tehran, Semnan, and Zanjan were constructed during Fath-Ali Shah's reign (1212 to 1250 Hijri (H.), 1797 to 1834). (Khavari and Fazlullah 2001; Habibi 2010).

However, inscriptions on the northern portal and southern nave of the Sultani Mosque in Qazvin city, dated to 1210 H. (1795), indicate that the construction of this mosque began before Fath-Ali Shah's reign in 1212 H. (1797) (Eastwick 1864). Determining the construction time of the Sultani Mosque in Borujerd city was more challenging because the inscriptions were ambiguous. One of two assumptions can be made: either the mosque was developed over an older mosque for which construction began in 1209 H. (1794) but was not completed, or it was built from scratch during Fath-Ali Shah's reign. The latter assumption seems more likely, as the date on the stone plinth of the northern *iwan* is 1290 H. (1873), and further restorations were carried out between 1290 and 1296 H. (1873 to 1878). The construction of the Sultani mosque of Hamedan began under Fath-Ali Shah's direction but was left unfinished when he passed away early in the building process. (Etemad-al-Saltana 1988) Although the date of inscription on the southern *iwan* is 1253 H. (1797) (Archive of ICHHTO 1987), a later completion after Fath-Ali Shah's death has been suggested; this particular Sultani mosque linked to him has not been examined in this research (Table 1).

3.2 Name

In this research, the buildings mentioned are named as outlined in the booklet 'Khalsejat va Mouqufat Diwani' (Royal estates and civil endowments of the Qajars). According to these documents, all these buildings are referred to as 'Sultani Mosque' (Bayani and Ettehadiyeh 2008). However, discrepancies arise from some of these dual-function structures, such as schools or *madrasa*, which may be overlooked if only the singular label 'mosques' is used. Scholars such as Nazari (2017), Hillenbrand (Hillenbrand 1983) (Hillenbrand 2000), Scarce (2008), and Ritter (2003) have suggested other names and perspectives on these edifices. Based on the inspection of inscriptions, documents, and historical texts from the Qajar era, the coexistence of mosques and schools is revealed. Hillenbrand referred to them as Semnan Shah Mosque, Tehran Shah Mosque, etc., while Ritter scrutinised Boroujerd Shah Mosque and Zanjan Jame Mosque. Evidence such as teaching areas and faculty presence supports the contention that these sites functioned as both mosques and educational hubs or *madrasa* simultaneously. The thorough documentations and physical evidences from this period elucidate the multifaceted functions that these buildings served.

3.3 Alterations

Exploring the continuity of authenticity in Sultani mosque designs and validating their shared design patterns through an analysis of mosque alterations is crucial for this research. Based on historical evidence, images, and physical examination, it can be concluded that the layout and spatial relationships of the Sultani mosques

Table 1 Summary of the history of Sultani mosques based on inscriptions and documents

Sultani Mosque	Temporal Constraints on the Construction of the Mosque: Investigating the Construction Time Period	Completion of the decoration based on the dated inscriptions
Qazvin	Early Qajar and before 1210 to 1223 H. (1795 to 1808). (Based on the inscriptions of the building)	1223 H. (1808)
Tehran	Between 1217 H. (1802) and 1225 H. (1810) (As per the date of the purchase documents for the required land (Bayani and Ettehadiyeh 2008) and Mirza Saleh's report on the completion of construction in 1225 H. (1810) (Shirazi 1985)	1230 H. (1814)
Zanjan	Between 1224 H. (1809) and 1239 H. (1823) (Derived from the period when Abdullah Mirza assumed leadership in Zanjan in 1224 H. (1809), the mosque's endowment letter dating to 1238 H. (1822) (Zeinali 2008) and Keppel's report on the mosque's construction in 1239 H. (1823) (Keppel 1827)	1245 H. (1829)
Boroujerd	The first hypothesis: pre-1209 H. (1794) to 1245 H. (1829) The second hypothesis: between 1224 H. (1809) and 1245 H. (1829) (In reference to Hessam al-Saltaneh's assumption of rule in Borujerd in 1224 H. (1809) (Sepehr 1998). and the mosque's endowment letter dating to 1245 H. (1829) (Ritter 2003).)	The building lacks any inscriptions or historical decorations from this period
Semnan	Between 1237 H. (1821) and 1242 H. (1826)	1243 H. (1827)
Hamedan	Late in the reign of Fath-Ali Shah	Unfinished

have remained largely unchanged since they were constructed. While the Sultani mosques in Semnan and Qazvin have remained uniform, those in Zanjan, Tehran, and Borujerd have undergone some changes, as indicated in Table 2.

The Sultani Mosque of Zanjan underwent a renovation that was not appropriate for its historical style. A photograph from 1862 shows the dome, the south *iwan*, the front entrance portal, and the west *iwan* of the mosque. Unfortunately, the main entrance of the mosque, which was in the style of the Jame Mosque of Tehran, was destroyed and replaced with a new entrance portal made of incompatible materials. Two small minarets that are decorated with tiles were also added to the new entrance portal (Fig. 5).

4 Analysis of the spatial organisation

4.1 The justified graphs of space syntax

To generate justified graphs of the Sultani mosques using the Syntactic plugin, the major building divisions are provided and listed. These divisions include 1) the main entrance portal, 2) the *hashti* (an entrance vestibule with an octagonal shape), the entrance vestibule, 3) the nave (*shabestan*-pillared hall for prayers) with a single span of vaults, 4) the courtyard (number is accompanied by symbol *), 5) the *iwan* (semi-open vaulted hall), 6) the nave with multiple spans of vaults, 7) the dome and domed hall, 8) the entrance for the ablation room, 9) the ablation room (*vozookhaneh*), 10) the room for students, 11) the raised platform with access to student rooms (*mahtabi*), and 12) the roof. To ensure brevity, the spaces are numbered, with the geographical direction of each space indicated by a suffix.

By providing the necessary data to complete the algorithm for drawing graphs in Rhino3D software, the initial communication graph of the spaces is provided, along with various justified graphs (Nourian 2016). The justified graph for each space was produced by Syntactic plugin of Rhino3D software (Fig. 6). Each mosque has three entrances located on the north, east, and west sides, and three graphs were drawn for each mosque.

While the graph generated with the Syntactic plugin is legible, it was decided to redraw the graph to improve the interpretability of the relationships between spaces and avoid the complexity of the graph due to the repetitive

Table 2 Summary of changes in Sultani mosques

Sultani Mosque	Modifications impacting the analysis of spatial relationships and the layout of Sultani mosques
Tehran	Incorporating a corridor into the southeast nave of the mosque
Zanjan	1- Removing the northern gate 2- Blocking the entrances to both sides of the northern *iwan*
Borujerd	1- Erecting a nave on the western side of the mosque and establishing an entry inside the western octagonal vestibule 2- Crafting an entry within the wall of the western dome-side nave to establish a direct link with the winter nave located in the southwest of the mosque

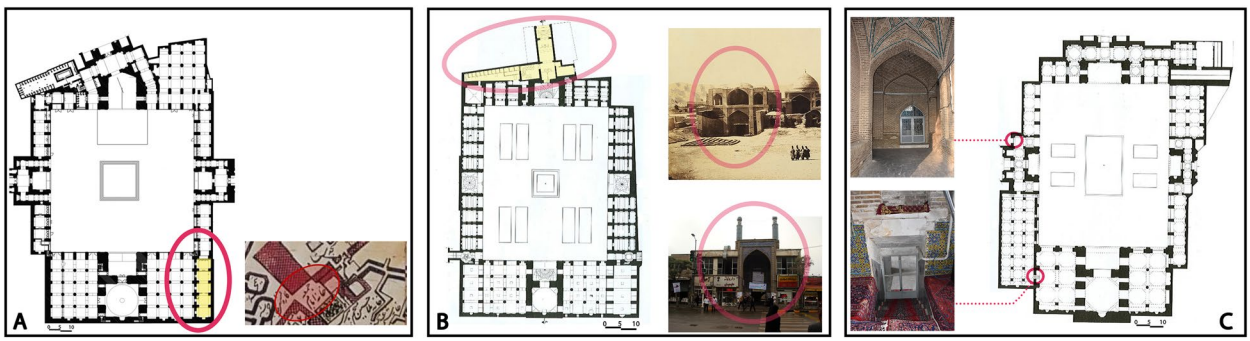
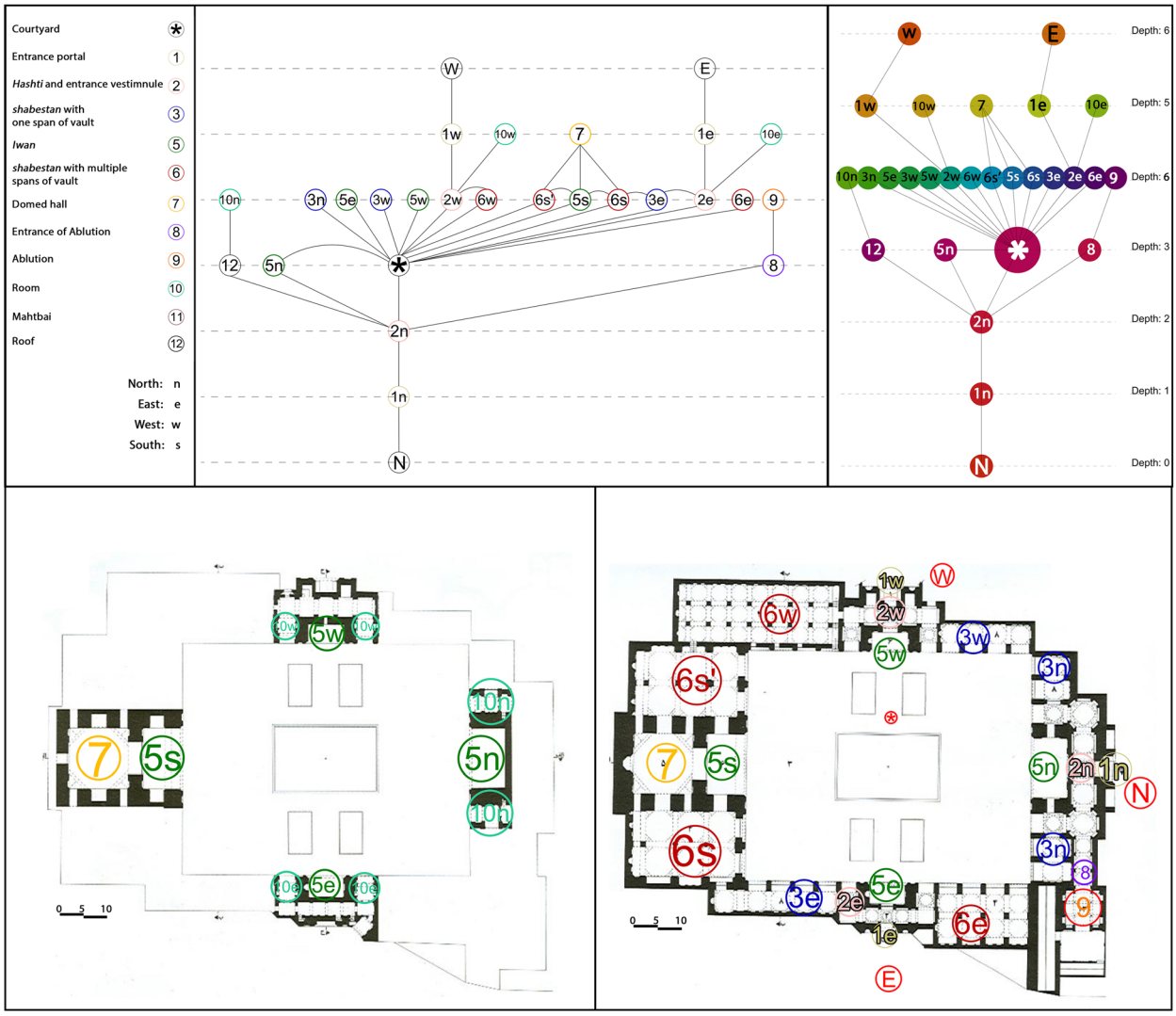


Fig. 5 **A** The comparison of the Sultani Mosque of Tehran in the map of 1275 (Source: Shirazian 2016) and its plan (Source: Archive of ICHHTO 1987) reveals that a corridor is incorporated into the southeastern nave of the mosque. B Comparison between a photo from 1862 showing the original entrance of the Zanjan mosque (Source: http://www.negarestandoc.ir/documentdetail.aspx?id=104846) and a contemporary photo of the mosque's new entrance (Source: Archive of ICHHTO 1987).; C images of Crafting an entry inside the western octagonal vestibule and another one within the wall of the western dome-side nave of the Sultani Mosque in Borujerd (Source: The authors), which are shown in the plan of the mosque (Source: Haji Qassimi et al 1998, Haji Qassimi et al. 2004a, 2004b)



Integration	Control	Entropy	Choice (betweenness)
E: 0.759	5e: 0.071	N: 1.96	5w: 59
W: 0.759	5w: 0.071	1n: 1.889	3w: 59
9: 0.815	6e: 0.071	2n: 1.642	W: 59
N: 0.815	3w: 0.071	8: 1.889	6w: 59
10n: 0.815	3n: 0.071	*: 1.46	10n: 59
10e: 1.048	10w: 0.25	5n: 1.543	10w: 59
10w: 1.048	10e: 0.25	12: 1.889	5e: 59
7: 1.048	5n: 0.271	9: 1.96	3n: 59
1w: 1.082	6w: 0.321	6e: 1.646	6e: 59
1e: 1.082	W: 0.5	2e: 1.792	N: 59
1n: 1.2	10n: 0.5	3e: 1.723	5n: 59
8: 1.2	E: 0.5	6s: 1.874	9: 59
12: 1.2	N: 0.5	5s: 1.874	E: 63
3w: 1.5	9: 0.5	6s': 1.813	10e: 63
5e: 1.5	3e: 0.571	6w: 1.673	3e: 73
3n: 1.5	6s': 0.655	2w: 1.792	5s: 105
6e: 1.5	7: 0.833	5w: 1.646	6s': 105
5w: 1.5	5s: 0.988	3w: 1.646	1n: 115
6s': 1.61	6s: 0.988	5e: 1.646	1w: 115
5s: 1.65	1n: 1.2	3n: 1.646	12: 115
6s: 1.65	8: 1.2	10n: 1.96	8: 115
6w: 1.65	12: 1.2	10e: 1.908	1e: 123
3e: 1.737	1w: 1.25	1e: 2.018	6s: 125
2e: 1.784	1e: 1.25	7: 2.092	7: 157
5n: 1.784	2e: 1.905	10w: 1.908	2w: 219
2w: 1.784	2n: 2.071	1w: 2.018	2e: 235
2n: 2.129	2w: 2.071	E: 2.09	2n: 359
*: 3.667	*: 7.867	W: 2.09	*: 739

Fig. 6 The justified graph of the Sultani Mosque of Borujerd from its northern entrance, obtained from the Syntactic plugin (right) and its redrawn version (left). The tables below list the values of the features (Source: Haji Qassimi et al. 2004a, 2004b)

relations and nodes. The new graph is based on a hierarchical cluster of simplified or grouped similar nodes that provides a better understanding of the level of connections between spaces (Fig. 7). In some mosques, there are multiple rooms that serve similar functions and have identical spatial relationships to other parts of the mosque. When redrawing the graphs of these mosques, instead of representing each room as a separate node, a single node was chosen to represent all of the rooms that share the same geographical direction and spatial relationships. This approach simplifies the graphs by reducing the number of nodes and relationships without changing the overall pattern. The goal is to create a graph that clearly shows the significant common patterns among the rooms in the mosque.

A series of spaces are more accessible from each entrance, which makes each entrance independent. Since Sultani mosques are large, the location of three entrances on three sides of these mosques has made these buildings more accessible to the surrounding neighbourhoods and streets. This layout allows people to use all three entrances without the necessity of bypassing the mosque when entering. The aim of creating justified graphs from each of the three entrances is to illustrate the variety of accesses from each entrance. Among all these mosques, the northern entrance is the most important. It is located in the direction of the qibla, and people are placed directly in front of the dome after entering. Additionally, it is larger in size and offers more access points, including easier access to ablution in comparison to other entrances.

In most cases, the courtyard is located at the 3rd level of depth and establishes the largest spatial connections between other parts of the mosque. The northern entrance of each mosque has more spatial connections than other entrances, indicating its importance. The Sultani Mosque of Semnan has the greatest number of connections to the northern vestibule, with six accesses, while the Sultani Mosque of Zanjan has the least, with two accesses (Table 3).

Notably, the greatest variance in access depth is observed in the rooms because they have diverse means of entry—some can be accessed from the roof and others from the yard or platforms. The adaptation of the school into the mosque, accompanied by an increased number of nodes, leads to notable variations. For instance, in the Zanjan Sultani Mosque, rooms are positioned at a depth of four rather than five, and in the Sultani mosques of Borujerd and Semnan, rooms are accommodated at depths of five or six alongside the prevailing depth of four.

The variety of access to the naves (*shabestans)* in these mosques is different for each entrance. However, it can be said that in each of these mosques, at least one nave is placed at the depth of the third access compared to one of the entrances so that it is more accessible compared to other naves. Due to the size of Sultani mosques, this variety of access has made the nave of Sultani mosques provide more convenient access for worshipers. The reason for creating the justified graphs of each of the three words was to show the same issue.

Among the entrances of these buildings, the northern entrance and its vestibule have more spatial connections than other entrances, which shows the importance of this entrance. Most connections of the northern vestibule are in the Sultani Mosque of Semnan, with six accesses, and the fewest are in the Sultani Mosque of Zanjan, with two accesses. The ablution is also more accessible from the northern entrance of these buildings if this space is located at the last access depth compared to the eastern and western entrances, which is another indication of the importance of the northern entrance in these mosques.

As seen in the justified graph of the buildings, the greatest spatial diversity in terms of access is related to the Sultani Mosque in Semnan. The four *mahtabi* (a platform to sleep at night and view *mahtab* or moonlight) in the four corners and their nodes, which are not found in other buildings, make this mosque more complex in terms of spatial communication than other buildings.

4.2 Space syntax variables

The numeric values of important variables of space syntax, such as integration and entropy, provide a better understanding of comparative studies of spatial relations. Here, the integration, control, entropy, and choice numeral value of important divisions of the Sultani mosques are specified by the tool, which is presented in Table 4.

According to the integration analysis of the Sultani Mosque in Borujerd, the most public space is the courtyard, with an integration rate of 3.667.

The northern entrance follows with a rate of 2.129, which represents the second level of public space. The placement of the northern entrance on the qibla axis, which contrasts with the dome and the south *iwan*, contributes to its attention and significance. This can be further supported by the greater degree of integration of the northern entrance vestibule in all these mosques, ranging from 2.168 to 2.099, compared to that of the eastern and western vestibules, which range from 2.04 to 1.743 (Fig. 8). The northern vestibule and

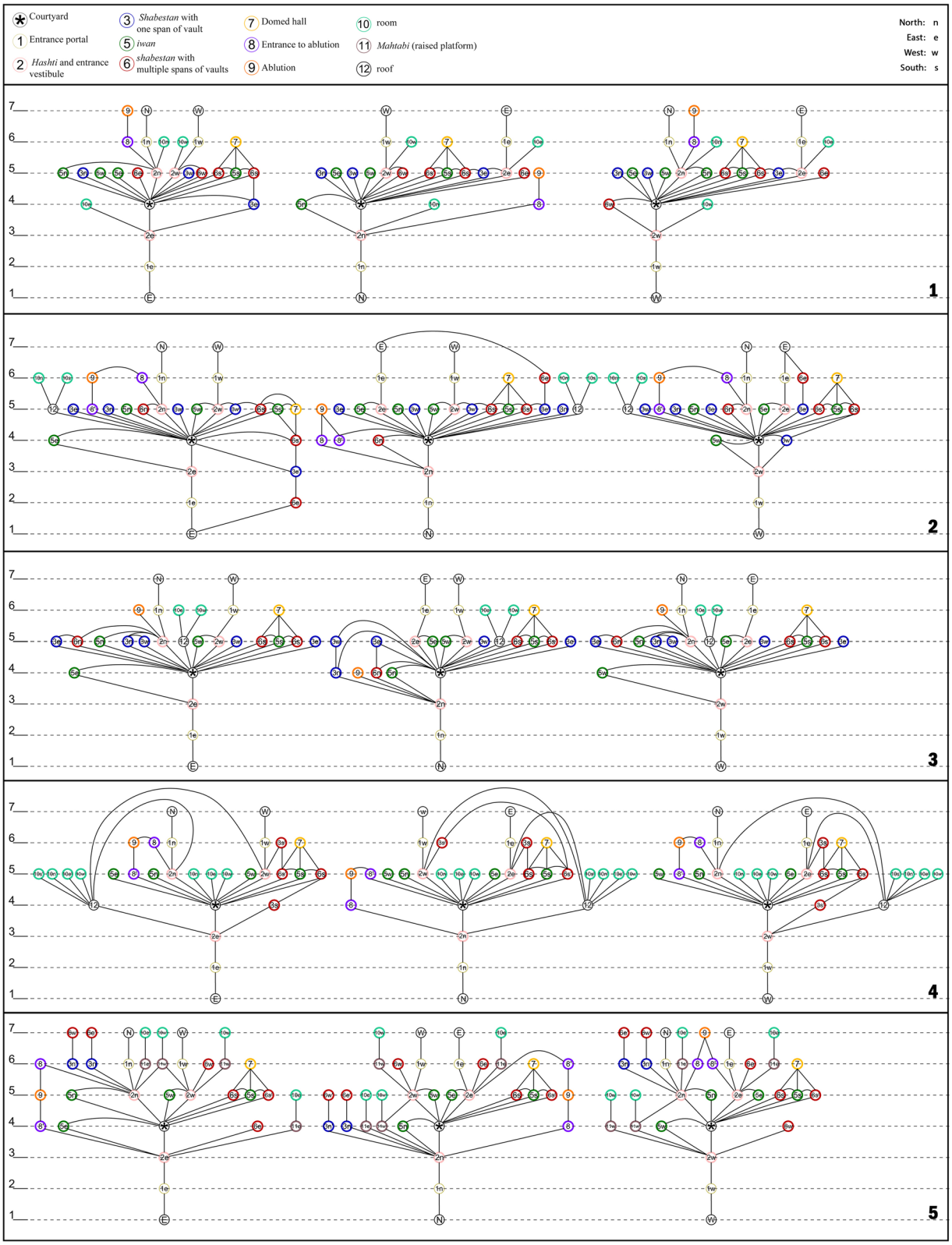


Fig. 7 Modified Justified graphs of the entrances of various Sultani mosques—**1** Borujerd, **2** Qazvin, **3** Tehran, **4** Zanjan, and **5** Semnan (Source: the authors)

Table 3 The depths of Sultani mosque spaces obtained from the justified graphs of the northern entrance

	N	N ENT	N vestibule	Courtyard	N *Iwan*	E *Iwan*	W *Iwan*	S *Iwan*	W vestibule	E vestibule	S *Shabestan*	E ENT	W ENT	Domed Hall	Rooms		E	W
Qazvin	**0**	**1**	**2**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**5**	**5**	**5**	**5**		**6**	**6**
Tehran	0	1	2	3	4	4	4	4	4	4	4	5	5	5	5		6	6
Zanjan	0	1	2	3	3	4	4	4	4	4	4	5	5	5	4		6	6
Boroujerd	0	1	2	3	3	4	4	4	4	4	4	5	5	5	4	5	6	6
Semnan	0	1	2	3	4	4	4	4	4	4	4	5	5	5	4	6	6	6

In each of these mosques, there are six spaces that allow movement from the exterior of each entrance to the exterior of the other entrances. Considering the northern entrance as the starting point, similar spaces across the Sultani mosques typically share common access depths. The courtyard is commonly situated at a depth of three, while access to the qibla naves, *iwan*s (excluding the north *iwan*), and the eastern and western octagonal vestibules is found at a depth of four. The dome is consistently located at a depth of five

Table 4 Integration, control, entropy and choice value of important divisions of the Sultani mosques

Important spaces of Sultan mosques	Sultani mosque		Integration	Control	Entropy	Choice
The courtyard of Sultani mosques	Qazvin		4.897	8.583	1.318	901
	Tehran		4.798	7.25	1.304	715
	Zanjan		3.06	8.5	1.54	1105
	Boroujerd		3.667	7.867	1.46	739
	Semnan		2.614	2.875	1.554	995
Dome of the Sultani mosques	Qazvin		1.204	0.75	1.956	155
	Tehran		1.094	0.917	1.87	147
	Zanjan		1.049	0.75	2.132	255
	Boroujerd		1.048	0.833	2.092	157
	Semnan		0.966	0.917	1.95	207
The northern octagonal vestibule of Sultani mosques	Qazvin		2.099	1.559	1.577	241
	Tehran		2.151	2.729	1.719	233
	Zanjan		2.16	1.22	1.521	527
	Boroujerd		2.129	2.071	1.642	359
	Semnan		2.168	3.444	1.876	851
The eastern octagonal vestibule of Sultani mosques	Qazvin		1.933	1.059	1.585	167
	Tehran		1.89	1.062	1.584	161
	Zanjan		2.04	1.22	1.615	477
	Boroujerd		1.784	1.905	1.792	235
	Semnan		1.743	3.111	1.95	511
The western octagonal vestibule of Sultani mosques	Qazvin		1.985	1.392	1.657	199
	Tehran		1.89	1.062	1.584	161
	Zanjan		2.04	1.22	1.615	477
	Boroujerd		1.784	2.071	1.792	219
	Semnan		1.743	2.944	1.95	595
The qibla nave of Sultani mosques	Qazvin	6 s	1.883	1.741	125	0.975
		6 s′	1.985	1.657	119	0.975
	Tehran		1.782	0.646	1.678	103
	Zanjan		1.563	1.16	1.891	239
	Boroujerd	6 s	1.65	1.874	125	0.988
		6 s′	1.61	1.813	105	0.655
	Semnan		1.411	0.694	1.828	143
North *iwan* of Sultani mosques	Qazvin		1.708	0.059	1.501	65
	Tehran		1.834	0.229	1.486	61
	Zanjan		1.413	0.077	1.709	87
	Boroujerd		1.784	0.271	1.543	59
	Semnan		1.677	0.236	1.661	71
The western *iwan* of Sultani mosques	Qazvin		1.836	0.309	1.526	67
	Tehran		1.782	0.396	1.532	57
	Zanjan		1.413	0.077	1.709	87
	Boroujerd		1.5	0.071	1.646	59
	Semnan		1.533	0.278	1.767	73
The eastern *iwan* of Sultani mosques	Qazvin		1.836	0.392	1.526	63
	Tehran		1.782	0.396	1.532	57
	Zanjan		1.413	0.077	1.709	87
	Boroujerd		1.5	0.071	1.646	59
	Semnan		1.533	0.278	1.767	75

Table 4 (continued)

Important spaces of Sultan mosques	Sultani mosque	Integration	Control	Entropy	Choice
The south *iwan* of Sultani mosques	Qazvin	1.883	0.892	1.741	115
	Tehran	1.836	1.062	1.75	101
	Zanjan	1.597	0.91	1.856	87
	Boroujerd	1.65	0.988	1.874	105
	Semnan	1.434	1.111	1.828	141

its octagonal entrance vestibule show a greater number of spatial connections, highlighting their significance. The ablution area is more accessible from the northern entrance than from the eastern and western entrances, as it is located at a deeper level of access (Fig. 8).

The northern vestibule of the Sultani Mosque in Semnan, with six access points and a control rate of 3.444, exhibits the highest degree of control. This feature connects to the subsequent discussion in this paper regarding mosque integration with the school.

The dome represents the most private space with a rate of 1.048 of integration, which adds to its sanctity of space, specifically with the presence of the most sacred element of a mosque, the *mihrab*.

The courtyard demonstrates the highest level of control, with a value of 7.867, whereas the western and eastern *iwans* exhibit the least amount of control, with a value of 0.071 in this mosque. Therefore, the courtyard has a greater frequency of connections to divisions other than iwans, indicating that it is more interconnected within the mosque.

In the Sultani Mosque of Borujerd, the courtyard shows the highest level of entropy, with a value of 1.46, whereas the dome exhibits the lowest level, with a value of 2.092 (Fig. 9).

In the Sultani Mosque of Borujerd, the courtyard has the highest choice value of 739, while the east, west, and north *iwans* have the lowest choice value of 59 (Fig. 9). These features are connected to the social behaviour of various divisions, which will be discussed in the following section.

4.3 Space syntax variables and social activities

The spatial features represented by each space syntax variable can be interpreted socially through consideration of the types of activities that typically occur in each of these spaces. In all the Sultani mosques, the courtyard typically exhibits the highest degree of control (except for the Sultani Mosque of Semnan) and integration, signifying its prominence as the most public area of these structures and the central hub connecting the surrounding spaces. Following the vestibules, the courtyard commonly displays the most relationships with adjacent spaces.

The distinction in the control factor of the vestibules in Sultani mosques arises from the varying degrees of relationships with adjacent spaces. These vestibules in Sultani mosques are sometimes linked to adjacent naves, roofs, *mahtabi* (if present), and ablutions. Notably, among the vestibules, the northern vestibule exhibits the highest control factor, possessing the most relationships with its adjacent spaces. In all these mosques, the northern vestibule exhibits a higher level of integration than do the eastern and western vestibules. This, combined with the placement of the northern entrance along the qibla axis and its alignment with the dome and southern *iwan*, distinguishes the northern entrance and vestibule from the other two vestibules in these buildings. Additionally, the ablution area is more easily accessible from the northern entrance of these buildings, even though this space is situated deeper than the eastern and western entrances, highlighting the importance of the northern entrance.

In each building, the eastern, western, and northern *iwans* have the least amount of control, which shows that these three mosque spaces have the least level of relationships with other spaces and are located in the middle of each side. Therefore, an *iwan* acts as an in-between space between the exterior and interior and a division that aligns the main axes of the mosque. In addition to the courtyard, the southern *iwan* leads to the dome and the naves around it and has a greater control factor, which is almost equal to that of the dome.

The dome is the manifestation of the Sultani mosques in the city, and as the recorded images show, these domes stood out as one of the most important spaces of these mosques in the city; however, the results show that the least amount of integration is among the main spaces of these mosques. The domes are dedicated to themselves. This issue, along with the depth of the domes with the number 5, which is the maximum depth of access among the spaces of these mosques, shows that the dome is less accessible than other spaces. This hierarchy of access and the lowest level of spatial

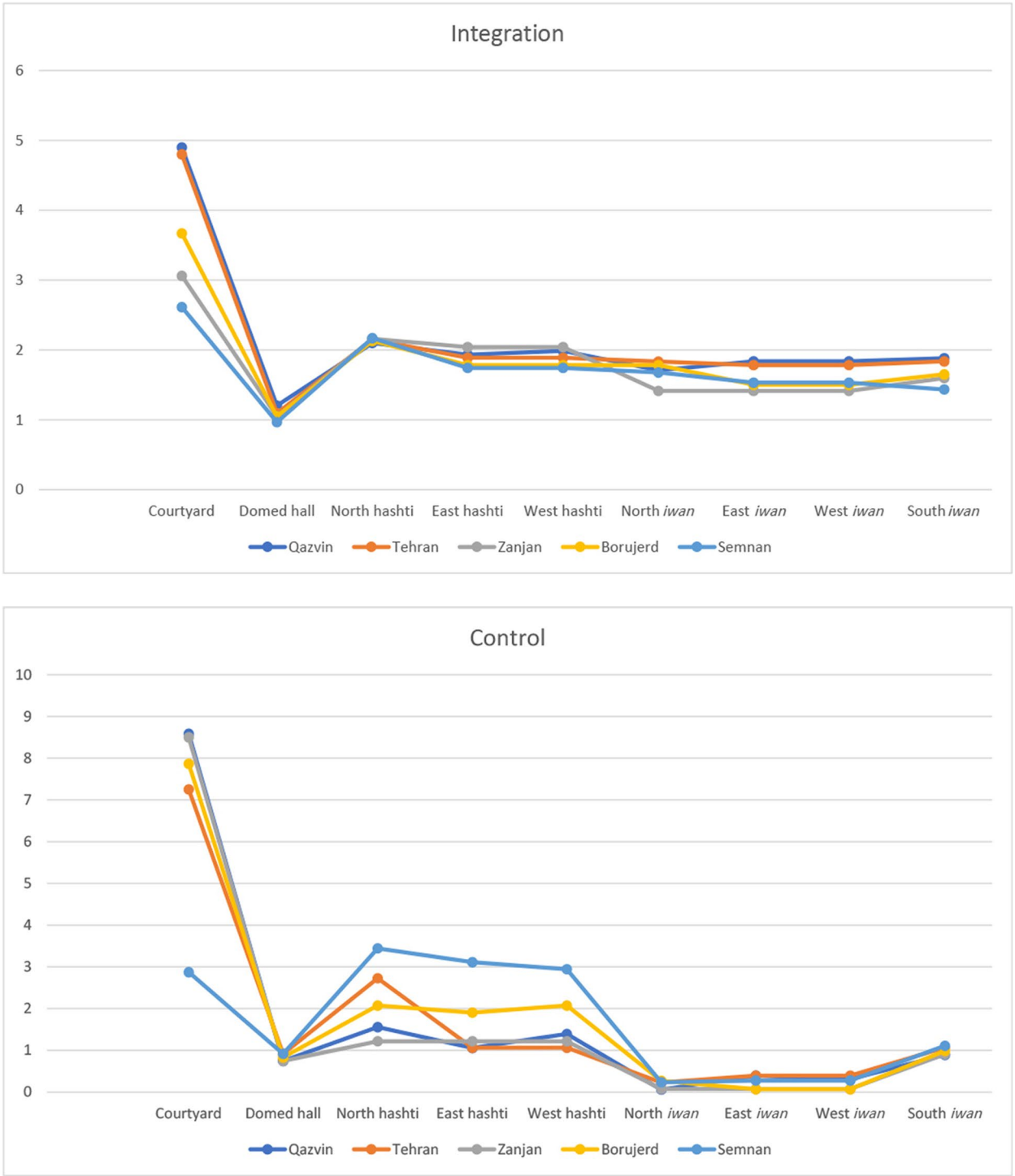


Fig. 8 Integration and control factor diagrams for the main divisions of the Sultani mosques (Source: the authors)

generality can be interpreted as reproducing the sanctification of the dome, which was the most magnificent part of these mosques and hosted the *Pishwa or Imam.* The most sacred element of the mosque is the *mihrab.* The domes exhibit the highest entropy factor and are acknowledged as the focal point for worship within the mosque due to the positioning of the mihrab and the presence of the imam.

Fig. 9 Choice and entropy factor diagrams for the main divisions of the Sultani mosques (Source: the authors)

The courtyards show the least entropy and the most choice, signifying their crucial role as the central hub connecting various spaces within the mosque. Conversely, the eastern, western, and northern *iwans* in all the Sultani mosques have the least choice factor. Therefore, *iwans* play the least role in the spatial distribution of these layouts, and people use them less to pass through to respect worshippers' tranquilly.

A noticeable shift over time, especially with schools being added to these mosques, is the increased entropy and choice factor of the vestibules. This change can be attributed to the addition of *mahtabi* and rooms to these buildings, which are not reserved for general users, and only students can access them through vestibules, thereby emphasising their crucial role in facilitating spatial distribution. Therefore, in the Sultani Mosque of Semnan, the control factor of the courtyard is lower than that of the vestibules. This happened by submerging the *shabestan*s halfway into the ground to create *mahtabi* and cutting off the direct connection of the spaces around the mosque (*mahtabi*, naves or *shabestan*, and ablution) with the courtyard. Access to these spaces is redirected through the vestibules, elevating the importance of the vestibules over the courtyard near the adjacent spaces in the Sultani Mosque of Semnan. Consequently, while the courtyard acts as a thoroughfare for the public and organises the surrounding spaces, its access to areas such as study rooms is limited, reflecting a deliberate evolution in Sultani mosques with educational functions. This evolution is evident in the reduced disparity in integration between the courtyard and the other spaces.

The inclusion of schools in Sultani mosques has altered courtyard dynamics by diminishing their integration factor. This design choice redirects access to areas such as study rooms through vestibules, elevating the vestibules' significance over the courtyard. While the courtyard remains a passageway for the public and spatial organiser, its direct access to study zones is restricted, symbolising a purposeful evolution in Sultani mosques embedding educational functionalities.

4.4 Layout-based justified graphs

While space syntax factors are used to analyse spatial relationships, a layout-based inquiry explores common spatial organisation. Justified graphs, devoid of topological implications in their shape, merely depict node connections. However, overlaying the graph onto the plan reveals crucial topological details such as adjacency and division orientations, providing insights into the building layout. This study offers new solutions beyond traditional space syntax variables by introducing a simplified graph of the mosque's layout derived from the floor plan. Thus, the available use of space syntax in the form of graphs is extended to show the adjacencies of divisions based on their configuration in the layout and their topological relation.

Thus, the following common features for the configuration of divisions and elements of the four sides of the courtyard were recognised in this research:

- Qibla side (south):

The qibla side of the mosques consists of the dome and its sided naves. In every mosque, the courtyard, the qibla *iwan*, and the dome are connected linearly. Common relations are visible: The qibla two naves have access to the courtyard through each of their vaulted spans. However, their connection to the qibla *iwan* and the dome hall in every mosque is possible through one access on both sides of the qibla *iwan* and three accesses on both sides of the dome. The dome is behind the *iwan* and indirectly connected to the centre of the courtyard (Fig. 10). This pattern can be strongly observed in the Sultani mosque.

- Entrance side (north):

The northern entrance side consists of the entrance portal, octagonal vestibule and entrance corridors, ablutions, and the northern nave. Except for minor differences on the northern side of the mosque and school in Semnan and Zanjan, the remaining buildings exhibit similar relationships. Here, the common relations are verified by passing through the northern entrance, entering the northern octagonal vestibule, which leads to the ablutions of the mosque, the northern naves at both sides of the *iwan*, and the courtyard (Fig. 10). In the Mosque and School of Semnan, the northern nave can be accessed not through the courtyard but through the octagonal vestibule. Therefore, the courtyard is less accessible and more private for students.

Each *iwan*'s northern wall features a window with porous tilework, allowing a view of the courtyard from the octagonal vestibule but without direct access, providing both light and a view from the mosque's interior (Fig. 11).

- The eastern and western sides

These two sides consist of the entrance portal, octagonal vestibule, *iwan*, and side naves (Fig. 10). There are fewer relation accesses from the east and west entrance octagonal vestibules than from the north entrance octagonal vestibule. The common spatial relationships of the eastern and western fronts are similar. The common approach is to access the courtyard from the entrance to the octagonal vestibule and then to the corridors on two sides of the *iwan*. In the Sultani Mosque and School of Semnan, Sultani Mosque of Qazvin, and Tehran, both the east and west *iwan*s have access to the corridor from one side. However, in the Sultani Mosque

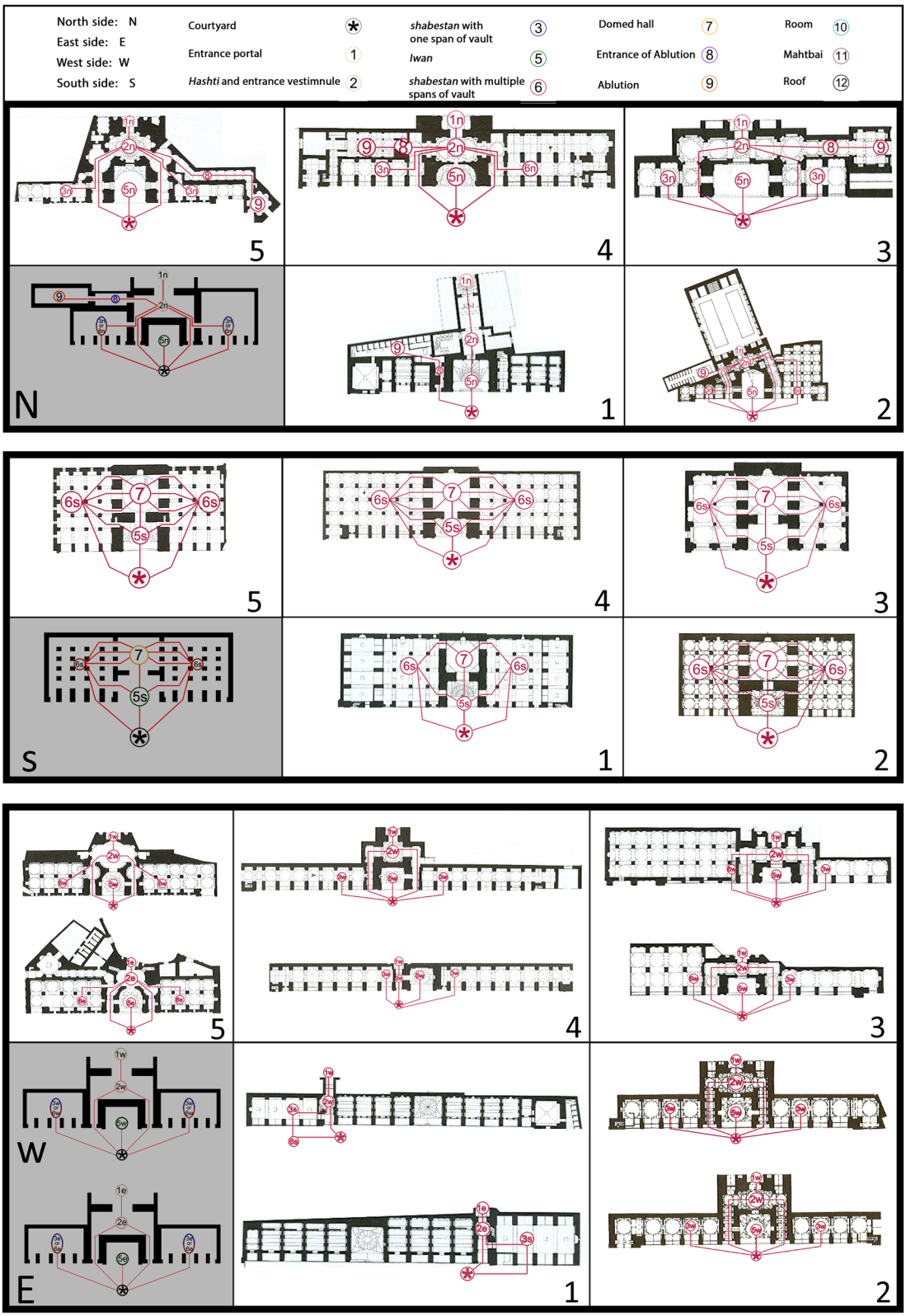


Fig. 10 The common layouts of the northern side (N), qibla side (S), and western and eastern sides (W and E) of various Sultani mosques were adapted to the Sultani mosque plan and are labelled as follows: No. 1) Zanjan 2) Tehran, 3) Borujerd, 4) the West and East fronts of the Sultani Mosque of Qazvin, 5) Semnan (Source: Haji Qassimi et al 1998, Haji Qassimi et al. 2004a, Haji Qassimi et al 2004b)

Fig. 11 **1**- The porous tile work (Fakhr and Madin) of the north iwan of the Sultani Mosque of Borujerd, **2**- The opening of the north iwan of the Sultani Mosque of Semnan (Source: the authors)

of Borujerd, these *iwan*s do not have access to the corridor on their sides. Unlike other Sultani mosques, the Sultani Mosque of Zanjan has eastern and western *iwan*s that are not combined with the entrance system and are separate. Therefore, there is a variety of access and relations between the eastern and western sides of the Sultani mosques.

5 Results

5.1 Pattern *of major* divisions and elements

The pattern of major divisions and elements of the mosque, derived from an analysis of the four sides of the courtyard, elucidates an evolution in mosque design, particularly concerning the spatial configuration of key elements, as shown in Fig. 12. Moreover,

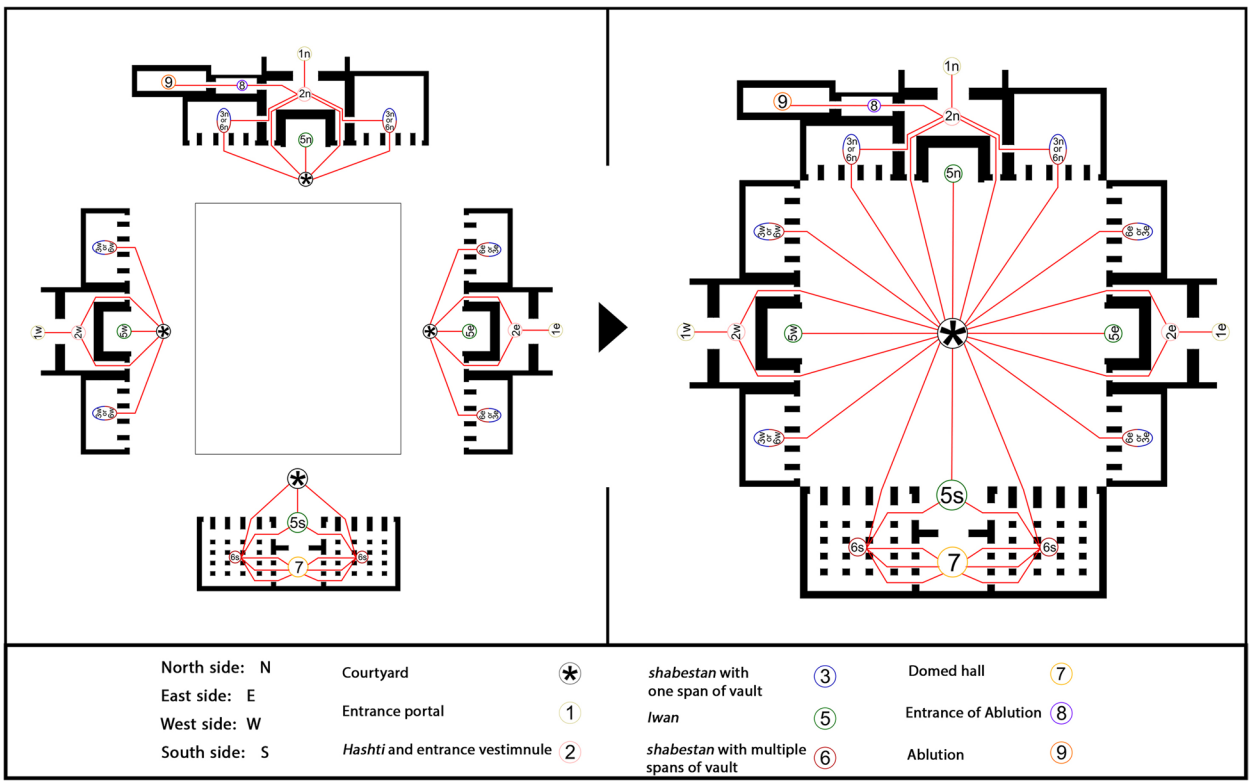


Fig. 12 Common layouts of the different sides of mosques, which are placed around the courtyard, and justified graphs are matched with the plan (Source: the authors)

the layout-based justified graph of common patterns is shown in Table 5, with lexical explication of the pattern by using topological links. The pattern can be interpreted as follows:

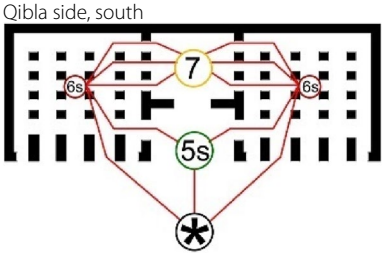
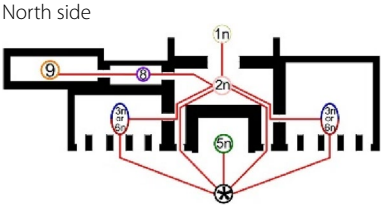
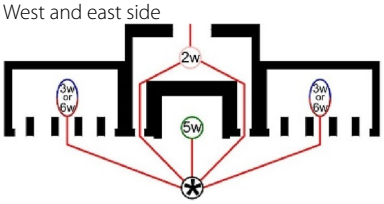
- Entrances

This study revealed crucial integration and control factors, showcasing the facilitated distribution of people within the mosque through multiple entry choices. The average choice and control values were 442.2 and 2.20, respectively. Notably, the mosques feature three main entrances on three sides, except for the qibla side, emphasising accessibility and integration with neighbouring passageways. In all these mosques, the degree of integration of the north entrance vestibule, with an average of 2.14, is greater than the degree of integration of the east and west vestibules, with average values of 1.87 and 1.88, respectively, showing its importance.

- The courtyard

While the spatial pattern revolves around a central courtyard and two axes are directed by *iwan*s, the study highlighted the paramount importance of the courtyard with extensive spatial connections. It has an average integration of 3.8, a control factor of 8.58, an entropy of 1.43, and a choice factor of 891.

Table 5 Common pattern of spatial relations and configuration of Sultani mosques (Source of the figures: the authors)

Mosques	Common configuration	Compatibility and differences
Qibla side, south 	Yard➔*iwan*➔dome Nave➔*iwan* (one opening) Nave➔dome (three openings) Nave at both sides of dome *Iwan* in front of dome *Iwan* + dome in the middle of south side	Qazvin: Compatible Tehran: Compatible Zanjan: The two primary and middle openings of the dome to the side naves have been removed Borujerd: compatible Semnan: compatible
North side 	Entrance portal➔octagonal vestibule➔sided vestibules➔yard North iwan➔yard Naves➔yard Octagonal vestibule➔corridor➔ablution Nave at both sides of iwan *Iwan* in the middle of north side Octagonal vestibule behind of *iwan*	Qazvin: Compatible Tehran: Compatible Zanjan: north entrance is destroyed Borujerd: connection from octagonal vestibule to naves are omitted Semnan: the relations between courtyard and naves are omitted
West and east side 	Entrance portal➔octagonal vestibule➔sided vestibule➔yard East–west *iwan*➔yard Nave➔yard Nave at both sides of yard *Iwan* in the middle of the side Octagonal vestibule behind *iwan*	Qazvin: compatible Tehran: compatible Zanjan: entrance is moved to corners of the yard Borujerd: compatible Semnan: relation from yard to nave is omitted and nave has relation with octagonal vestibule

- The dome

The dome holds significant importance in mosque architecture and contains the sacred mihrab, indicating the qibla direction. Despite its monumental nature, the dome stands as the deepest space, accessible through various layers of movement, filtered by the grand qibla *iwan*. Nevertheless, the dome space provides multiple accesses to side naves, facilitating movement to the mosque's crucial area, the qibla nave with an average integration of 1.07, a control of 0.83, an entropy of 2, and a choice factor of 184.2. Emphasising the importance of the qibla, the main entrance and the domed hall are strategically located axially towards it, accentuating their prominence.

- The naves

Prayer is the primary activity in a mosque, so the naves have multiple connections with the courtyard and the user has multiple access options. They have an average integration of 1.69, a control of 0.87, an entropy of 1.78, and a choice factor of 137. The naves are easily accessible through multiple spans of their vaults around the courtyard, allowing prayers to enter and exit without any hurry.

5.2 Alterations and extensions of the design pattern

An analysis of the layout-based modified justified graphs of the Sultani mosques reveals both similarities and differences in their relations and configurations. A comparative analysis using a consistent scale was conducted to examine the simplified layout of the Sultani mosques and identify the variations (Fig. 13).

- Differences in nave

In the Sultani mosques, there are differences in the configuration and layout of the naves. In the Sultani Mosque of Qazvin, the naves on the sides of the dome are connected to the southern naves of the east and west *iwan*s, which strengthens the relations between the naves. However, in the Sultani Mosque of Tehran, the addition of the entrance portal and eastern octagonal vestibule, the addition of one more vault span to the qibla nave, and three vaulted spans to the northeast nave make differences. Additionally, parts of the eastern and western nave and the southern nave were removed in comparison with the common configuration, which may be due to the presence of buildings near the mosque before its construction (Fig. 13).

The Sultani Mosque of Borujerd underwent construction and renovations in different periods, leading to a less cohesive plan compared to the Sultani mosques of Qazvin and Tehran. Notably, the underground nave on the southwest side of the Borujerd mosque is approximately two and a half metres lower than the courtyard level and is accessed by eight steps leading to the western nave of the dome. Although it has a lower level, efforts were made to maintain symmetry by adding an open arcade to the facade and aligning it with other naves. Additional modifications include a vaulted span added to the northeast side of the winter nave and deductions in certain corners of the mosque, possibly influenced by neighbouring buildings or a longer construction timeline.

In the Sultani Mosque of Zanjan, the number of arched spans of its qibla nave is similar to that of the Sultani Mosque of Qazvin, but each of the qibla naves is divided into two parts by creating a height difference of approximately one metre from inside to create two smaller naves without columns on both sides of the qibla nave. These two naves may have also played the role of a classroom (*Madras*) for this mosque.

All the naves of the Sultani Mosque in Semnan, except for the southern ones, have gone half-storey underground and are illuminated with the help of the openings from the courtyard. The southern, eastern, and western parts of this mosque and school have one more arch than the Sultani Mosque of Qazvin, and unlike the latter, the eastern and western naves of the former are not connected to the qibla nave, and the southern naves are limited to the courtyard on both sides.

- A notable variation: the addition of a school (*Madrasa*) to the mosque

This research examines the impact of integrating schools (*Madrasa*) into the overall design of the Sultani mosques, leading to diverse ground-floor and first-floor layouts. The analysis of these layouts is conducted through the use of simplified volumetric diagrams (Fig. 14).

One effective solution involved adding rooms to the second floor. This configuration was implemented in the northern and southern *iwan*s of the Sultani Mosque of Qazvin, the eastern and western *iwan*s of the Sultani Mosque of Tehran, and the northern, eastern, and western *iwan*s of the mosque of Borujerd for rooms and classrooms.

Two other methods have been employed to add rooms and classrooms to the Sultani mosques of Semnan and Zanjan. In the Sultani Mosque of Zanjan, the surrounding naves, except for the qibla side, have been converted into rooms (Fig. 14).

In the Sultani Mosque of Semnan, a new element called *mahtabi* (a platform to sleep at night and view Mahtab or moonlight), which is a platform with rooms on two

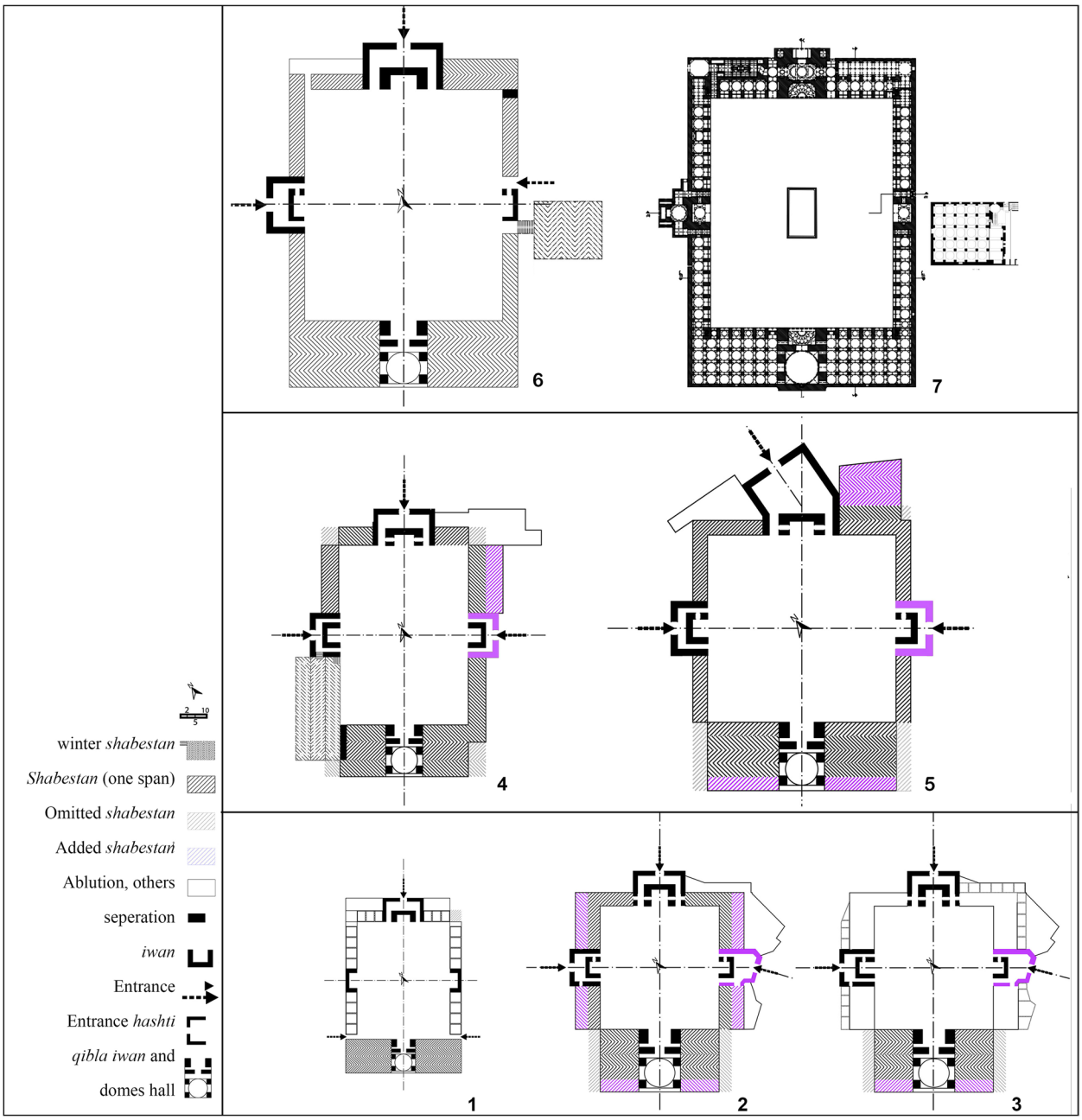


Fig. 13 The simplified layout of the Sultani mosques. The map includes six locations: **1** Zanjan, **2** and **3** Semnan ground floor and first floor, **4** Borujerd, **5** Tehran, and **6** Qazvin. Additionally, the ground floor plan of the Qazvin is included. Alterations and differences are marked in purple for each mosque (Source: the authors, based on the plans cited from Haji Qassimi 1998, Haji Qassimi et al. 2004a, 2004b)

sides and naves below it, has been designed. The level of the surrounding naves, except for the qibla nave, is lower than the level of the courtyard, allowing the space above it to be allocated to student rooms and platforms on all four sides of the mosque. Unlike other Sultani mosques, the Sultani Mosque of Semnan has a small entrance located in the southern part, leading through a corridor to the back of the mosque to facilitate access from Bazaar.

6 Discussion

The layouts observed in Sultani mosques display various spatial relations, diverse degrees of integrity, and multiple choices for their primary sections. It is crucial to explore whether comparable layouts can be found in other mosques constructed within the same timeframe.

An examination of the timeline and architectural schematics of the Sultani mosques (Fig. 1) highlights

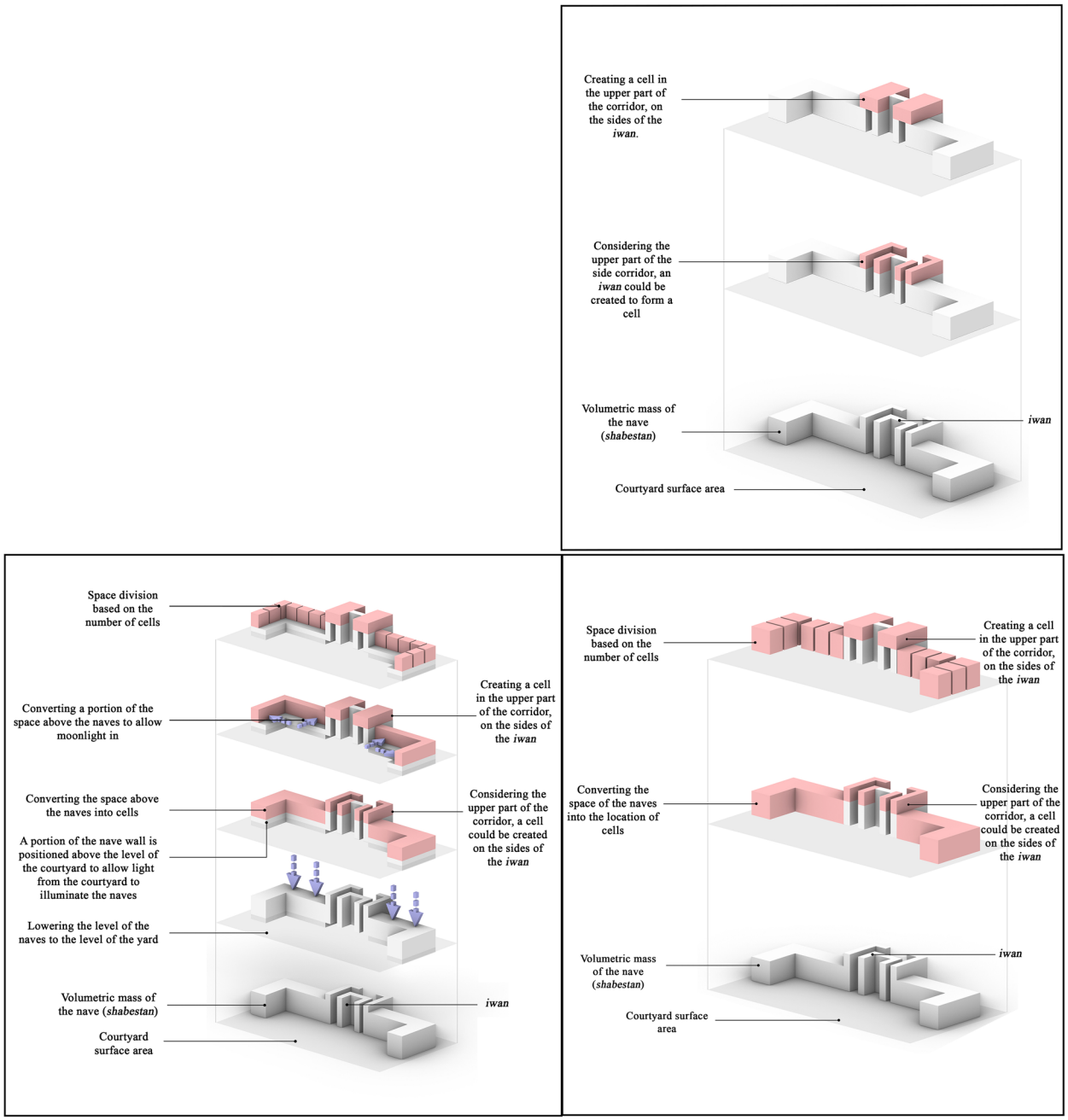


Fig. 14 A volumetric diagram illustrating the incorporation of rooms and classrooms (madrasas) into the Sultani mosques of Semnan and Zanjan (Source: the authors)

their distinctive scale and intricate details. Interestingly, the Seyyed Mosque in Isfahan was found to bear the closest resemblance to the Sultani mosques (Fig. 15). This study compared the spatial configuration of the Seyyed Mosque to that of other Sultani mosques and found that the configuration of the Seyyed Mosque is similar to that of the Sultani Mosque of Semnan (Table 6).

One of the significant differences between these two mosques is the removal of the middle and back entrances of the western *iwan*s and their transfer to the southeast and west corners of the courtyard. In addition, the tomb of the founder of the mosque was added to the northeast part of the Seyyed Mosque, which distinguishes it from other Sultani mosques (Fig. 15). In the Soltani Mosque of Semnan, it was possible to access the *mahtabi* from

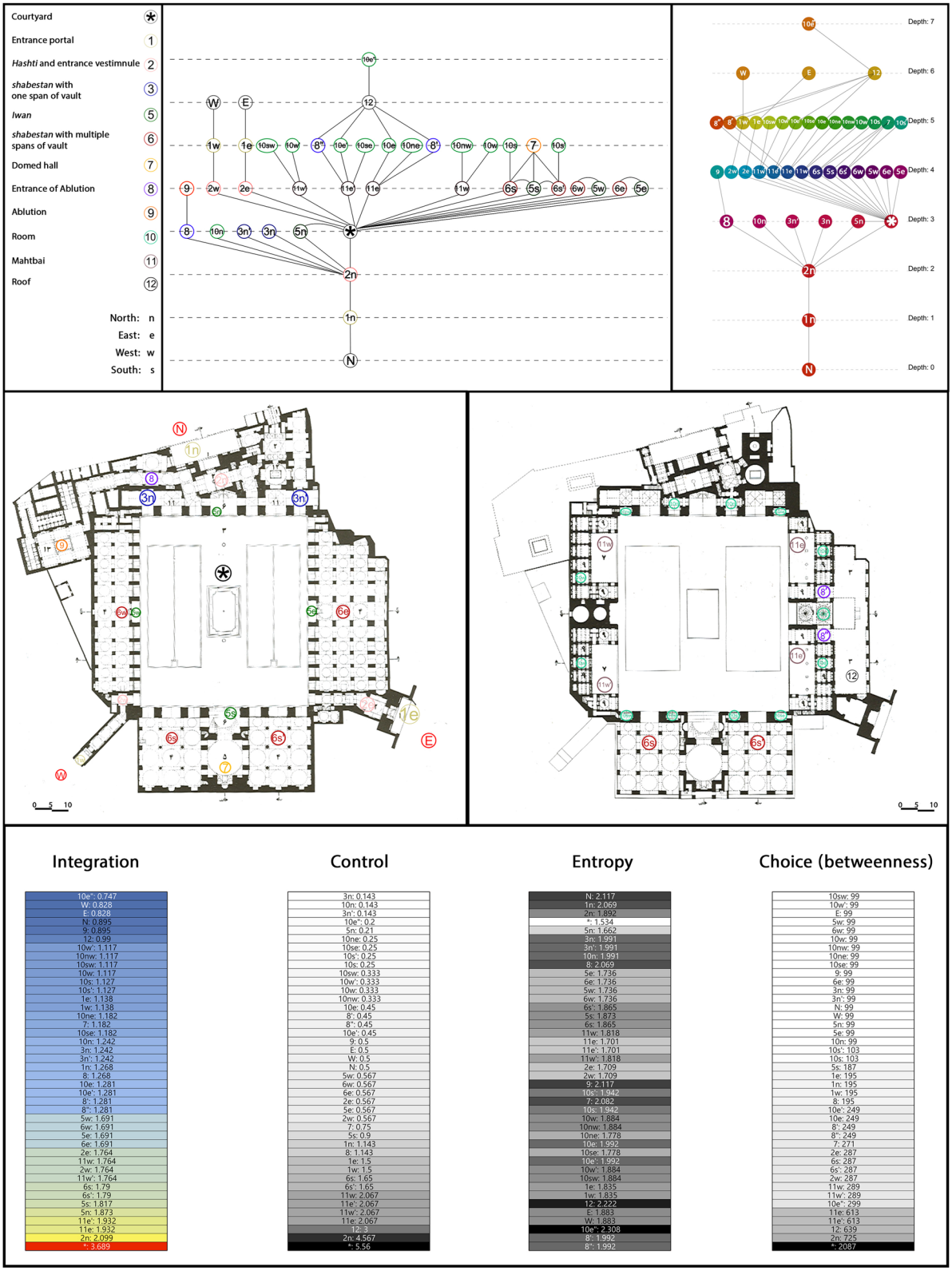


Fig. 15 The right graph is a justified graph of the Seyyed Mosque from its northern entrance, obtained with the help of the Syntactic plugin. The left graph is a redrawn modified version. Four tables related to integration, control, entropy, and choice analysis were obtained for the Seyyed Mosque using Syntactic. (Source: Haji Qassimi et al. 2004a, 2004b)

Table 6 Integration, control, entropy and choice value of important divisions of the Sultani Mosque of Semnan and Seyyed mosque

	Courtyard	Domed hall	North hashti	East hashti	West hashti	North *iwan*	East *iwan*	West *iwan*	South *iwan*
Integration Of Semnan mosque	2.614	0.966	2.168	1.743	1.743	1.677	1.533	1.533	1.434
Integration Of Seyyed mosque	3.689	1.182	2.099	1.764	1.764	1.873	1.691	1.691	1.817
choice Of Semnan mosque	995	207	851	511	595	71	75	73	141
choice Of Seyyed mosque	2087	271	725	287	287	99	99	99	187
Entropy Of Semnan mosque	1.554	1.95	1.876	1.95	1.95	1.661	1.767	1.767	1.828
Entropy Of Seyyed mosque	1.534	2.082	1.892	1.709	1.709	1.662	1.736	1.736	1.873
Control Of Semnan mosque	2.875	0.917	3.444	3.111	2.944	0.236	0.278	0.278	1.111
Control Of Seyyed mosque	5.56	0.75	4.567	0.567	0.567	0.21	0.567	0.567	0.9

the vestibule of the entrances behind the eastern, western, and northern porches, but in the Seyed Mosque of Isfahan, access to these *mahtabi*s is possible only from staircases positioned in the four corners of the courtyard. In other words, the depth of access to *mahtabi* in this mosque is one more than that of the Sultani Mosque in Semnan, and it is placed at the 4th depth of the justified graph (Fig. 15).

Based on a comparison of the values of the space syntax factors, the similarities in the pattern of value ratios among the spaces of these two mosques were identified, despite their differences. This similarity is well demonstrated in the graphs (Fig. 16).

The construction of this mosque was undertaken by a prominent clergyman in Isfahan, reflecting a design similar to that of the Sultani mosque. This choice illustrates

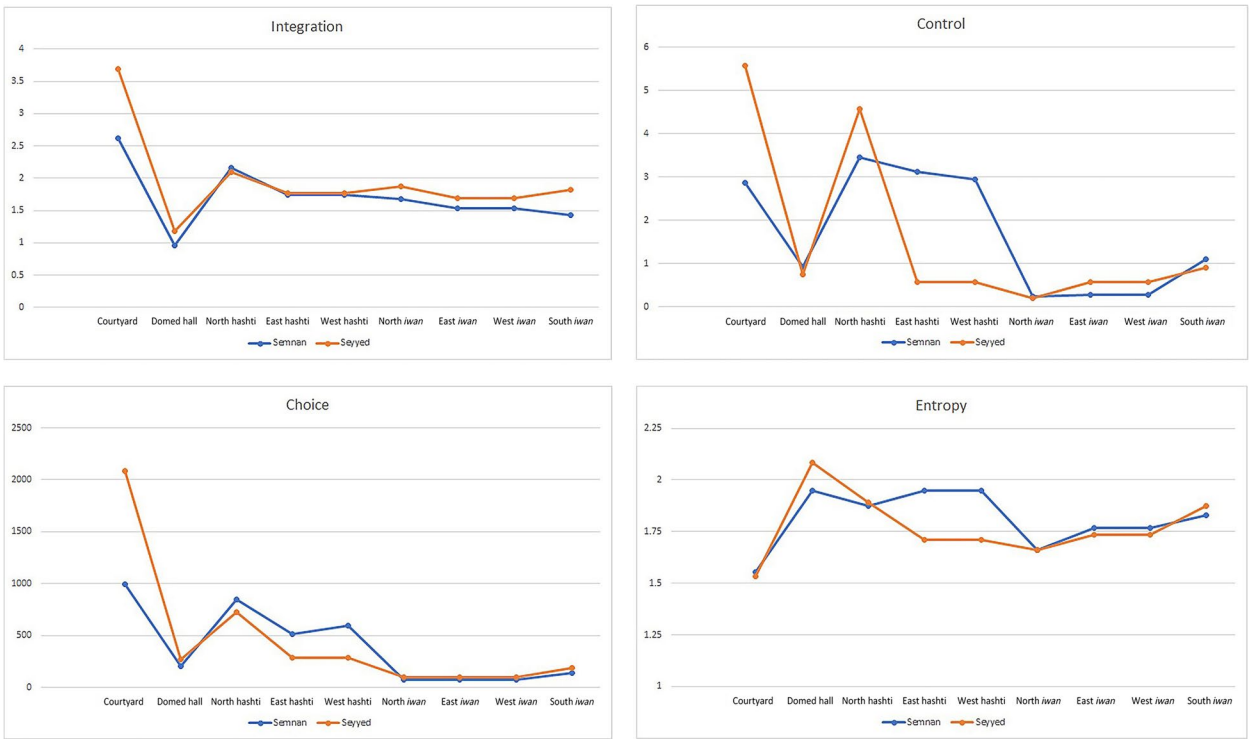


Fig. 16 Integration, control, choice and entropy factor diagrams for the main divisions of the Sultani mosque of Semnan and the Seyyed mosque (Source: the authors)

the founder's desire for his mosque to exhibit a grandeur and scale akin to the Sultani mosques—a vision that extended to its use for teaching in a *madrasa* and ultimately as the location of his tomb.

7 Conclusion

This study examined Sultani mosques dating back to the early 19th century (13th H.) using space syntax analysis and layout-based investigation to uncover intricate design patterns within the mosque's fundamental components. In answering the research question, the results of this research could reveal a well-designed common pattern in Sultani mosques characterised by multilayered accessibility and diverse movement options that significantly enhance spatial relationships. The mosques exhibit a structured layout for accessing key components such as the entrance vestibule, courtyards, four *iwans*, naves, and dome. The important north entrance and the southern dome accentuate the significant north–south axis, aligning with the qibla direction that unites the positioning of all worshippers during prayers. The mosque architecture highlights a hierarchical spatial organisation in relation to social activities as follows:

1. The courtyard functions as a social space with multiple choices of access but with multilayered access from the outside.
2. The dome, representing sanctity, is reached through layered pathways, reflecting a sense of reverence.
3. Numerous entrances not only improve internal mosque circulation but also connect the mosque to the surrounding neighbourhood, with the primary entrance positioned directly across the dome.
4. *Iwans* act as transition areas between courtyards and naves, catering to smaller groups for various activities such as schooling, religious ceremonies, and holy text reading, which are distinct from the main congregational spaces.
5. The naves serve as focal points for communal activities, enabling people to gather for collective prayer. They offer numerous entry points from the courtyard and the dome, facilitating movement and circulation.

To address the question of how mosques have changed and evolved over time, the research concludes that analysing the architectural plans of Sultani mosques reveals the evolution of their design patterns. This is particularly evident in the incorporation of school facilities into the mosque complex. The Sultani mosques of Qazvin, Tehran, Zanjan, and Borujerd highlight diverse design variations, with modifications such as room additions and entrance relocations reflecting evolving spatial complexity and integration. Nonetheless, each mosque differs in building division configuration, *iwan* and nave vault span proportions, and spatial relations tailored to the local context.

Space syntax and layout-based analysis can validate the pattern, alterations, and evolution of Sultani mosques. This extends prior research on the use of space syntax, enabling not only an understanding of spatial configuration and the depth of divisions but also the realisation of their topological relationship and a consistent configurational pattern. In conclusion, the Sultani mosque has value in terms of its design and spatial configuration, as well as its decorative and facial values. Each division and element of the mosque plays a role in the overall pattern that can be seen as a language of spatial relations. Therefore, it is vital to preserve the spatial relations and configuration of Sultani mosques in conservation and monitoring plans to ensure that the connections between spaces and movement patterns are valued and maintained.

Abbreviations

md	Mean depth
H	Hijri
ICHHTO	Iranian Cultural Heritage, Handicraft and Tourism Organization

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