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Spatial Organization Analysis of The Historical and Contemporary Houses in Mashhad by Using the Space Syntax Method

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ABSTRACT

Houses have undergone many changes since the distant past and, different factors have always influenced their structure. Up to a recent century, housing developments have often taken the form of multi-family life, the evolution of which can be seen in the Qajar period. In recent decades, with the development of facilities, lifestyle changes, population growth, land shortages, etc., the spatial structure of housing has also changed. This study aims to analyze the spatial organization of historical and contemporary houses in Mashhad. The main question of the research is what changes have taken place in the spatial configuration of Mashhad houses? And how have these developments adapted to individuals' living conditions? This research uses a sequential exploratory strategy, that in the first step, The qualitative approach in a descriptive-analytical method and data collection has been done by documentary-library studies and field research completion. Then the quantitative approach with the space syntax, an analysis tool is that examines topological relations in spatial structures and analyzes the interrelationships of spatial organization and social activities. Calculations and analyzes using Convex Space Map, Isovist, and Visibility Graph techniques have been performed in UCLDepthmap and Agraph. The research results indicate changes in the spatial organization, type of spaces, and diversity of human activities in the spatial configuration houses. Despite the changes in the topological structure of residential in Mashhad, in each period, a suitable solution has been presented to create a hierarchy of access, optimal performance of spaces, and privacy, following the living conditions of individuals.

Keywords: *functional efficiency, Mashhad houses, space syntax, spatial legibility, spatial organization.*

1. Introduction

So far, researchers from many different philosophical, psychological, cultural, and social aspects have studied the subject of housing. Home as a socio-cultural unit and responsive to human needs - from physiological to mental and psychological needs- has always been one of the leading research topics in architecture and urban planning. The house consists of a set of spaces and elements, each of which allows to perform different activities.

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The efficiency of a house is related to the degree of proper coordination and adjacency of various house elements together. The relationship between these spaces provides its inhabitants with different physical and spiritual needs.[1]

Mohammad Reza Haeri, the architectural researcher and author of the book "House, Culture, Nature" (2008) in examining the changes in the patterns of houses in the past century, three types of housing in Iranian cities in the period before 1300S.H, from the early century Until middle 1330S.H and from 1340 SH to the contemporary era and by comparative study of various formal, functional and semantic features in historical and contemporary houses, provides the possibility of recognizing the Spatial organization. He believes; The analysis of the historical houses of Iranian cities shows that Iran represents land that, despite the diversity of climate and geography, the tribes living in this vast land have reached similar conclusions for habitation. Traditional Iranian houses have an axial quality in their space, which can be traced in concepts such as spatial flexibility, diversity, legibility, and family privacy. During the years 1300 to 1340 SH, urbanization began rapidly, and from the 1340 SH onwards, the characteristics of contemporary houses are tied to urban developments and urbanization and urban management. Recent houses are faced with the domination of objects over the spatial organization and the diminishing role of space. New space patterns equipped with piped water, electricity, telephone, etc., were highly regarded. Incorporating the concept of life into function and reducing the idea of function to a biological need such as sleep and food, also increasing the importance of objects and their arrangement in the spatial organization of contemporary houses, left the role of spaces to things.[2]

In the last century, cultural, social, and technological developments have changed the topological structure of residential spaces. The spatial configuration of houses in the past was multi-family, and the spaces were multifunctional and flexible. Gradually, with the change in the structure and lifestyle of families, the spaces have a Specified function, and their flexibility has decreased.

Mashhad is one of the oldest cities in the northeast of the country that, like other cities, historic houses have been destroyed. Based on the pursuing and according to the documents available in the Cultural Heritage Organization and related organizations, there are no identifiable houses in Mashhad from the Safavid period, and most of the remaining houses belong to the Qajar and Pahlavi period [3]. So far, no comprehensive studies have been done on the changes in the topological structure of Mashhad houses. Certainly, explaining the evolution of the spatial organization of houses will lead to a more appropriate design for today's houses. Thus this study aims to analyze the spatial organization of historical and contemporary houses in Mashhad. The main question of the research is what changes have taken place in the spatial configuration of Mashhad houses? And how have these developments adapted to individuals' living conditions? One of the most significant achievements is recognizing and analyzing the spatial structure of Mashhad houses, expressing changes in the topological structure of houses, and creating a study platform for future research.

2. Literature Review

2.1. Residential Context in Mashhad

In different eras, housing with various criteria such as the location, orientation, its neighborhoods, the ratio of full and empty space, volume and dimensions of the building, shape, form and structural characteristics, also The accessibility and arrangement of the spaces, etc., have been studied and analyzed. One of the most important documents that can be considered to understand the history of housing in cities is comprehensive and detailed plans. Mashhad has three comprehensive plans; khazeni (1350S.H), Mehrazan (1372S.H), and Farnahad (1390S.H). The khazeni plan does not have significant studies on the Typology of housing, but the comprehensive plan of Mehrazan and Farnahad has provided studies to identify housing in different eras.

The book "In Search of Urban Identity Mashhad" [4] examines several factors in the physical evolution of the city while pointing out that the context of the town is strongly influenced by its residential context, based on the first and second comprehensive plans, introduces the Typology of housing in traditional, middle, and new contexts. The traditional context of houses includes the old

core of the city around the shrine of Imam Reza, in the central and eastern part of the city. Depending on the passages, the pieces of land have been irregular and small and have been very diverse in terms of shape [4]. In the historical houses of Mashhad, the yard in between is often common. The arrangement of spaces in the main and secondary fronts has been effective in relation to the house's spaces [5]. The essential element of a traditional house is the yard. The main part of the house is established in the north of the yard, and the use of the southern front in summer, also the distribution of services and kitchen on other fronts is significant. In the process of evolution, the central yard gradually assigned its role to the middle courtyard, and by changing the shape of the land lengthwise and reducing its width, part of the house was placed adjacent to the passages, and the other part was on the opposite side. In the first Pahlavi era, the middle courtyard became a lateral courtyard. The house's spatial organization changed during this period, and usage of the porch in the houses was limited [3]. The Typology of housing in the middle context consists of two parts, one in the north and northwest and the other in the south and southeast of the city's old core. Its network of passages is more based on the accommodation and movement of cars than the city's old core. Most buildings have one or two floors. The building is mostly north of the ground. The new texture includes all the sections within the city limits, except the traditional and middle context, that main passages are a network of perpendicular streets based on the necessity of cars and can be divided into three groups with high, medium, and low density [4]. The characteristics of this context are car access to residential units and lack of coordination and compliance with regional and climatic conditions and cultural values. In recent decades, apartments have shaped the city's public view due to rising land prices and increasing building density in most areas [4]. High-rise constructions in the form of residential complexes are another pattern that has been welcomed.

2.2. Research Background

Although many researchers have studied various aspects of traditional houses in Iranian cities, not many studies have been done on the spatial organization of houses in Mashhad. There is no comprehensive knowledge in this regard. Developments in Mashhad in the late Qajar period and after have led to changes in the city's spatial structure and spatial configuration of houses.

Among the researches done about Mashhad houses, we can refer to Morteza Mahmoudi's studies (2009) on the Typology of Mashhad houses. He states; Despite the variety in the arrangement of spaces, similarities are observed. From reviewing and comparing the studied houses, he has selected three criteria for the Typology of Mashhad houses, and based on each of them, presented a different typology. Based on the arrangement of full and empty spaces, the types of the yard in between and the building in between are introduced. The arrangement of spaces on the main and secondary fronts includes different types; The Houses with porches, the Indicator space in the center, the communication space in the center, the interconnected Hierarchical spaces, and in a few cases, they did not have an arrangement system. Finally, they are separated according to how the main fronts are accessed outside the house, along the street, and the houses of residential context. Farahbakhsh et al. (2017) also classify Mashhad houses based on the formal differences of the houses; The manner and ratio of the placement of spaces, the quality, and details of the physical elements and components of architecture and the relationships between them and the way of correlation with public thoroughfares, are divided into three categories, including two Qajar types (first and second half) with introverted architecture and Third, the first Pahlavi with an extroverted form. It is noteworthy that changes caused by Western architecture in the transformation of the Iranian architectural pattern have also included changes in socio-cultural structures.

2.3. Space Syntax Method

Some architectural researchers, including Franz and Wiener (2008), have argued that spatial organization and environmental configuration influence human spatial behaviors and experiences.[6] Therefore, in architectural research, to identify a space, the physical features of the space concerning the behaviors and activities of individuals are examined. According to Davy and Ostwald (2013), space syntax theory is a set of techniques for analyzing spatial configurations and their adaptation to human activities [7]. This theory produces an abstract model for

studying spatial features that, by converting features into topological graphs, can quantify the social features of the architectural design without considering the formal aspects. Therefore, in this study, to analyze the topological structure of Mashhad houses, space syntax analysis is used.

Common techniques of space syntax analysis include the convex spaces and Justified Plan Graph (JPG), Axial Line [8], isovist [9], Visibility Graph Analysis (VGA) [10], and intersection points [11]. In all of these techniques, maps are transformed into graph diagrams and processed based on mathematical methods to interpret the social features in spaces. Each of the methods is selected based on the purpose of the research. Convex space analysis provides spatial features in the socio-cultural context and analyzes spatial relationships in buildings and monuments [12]. The whole plan is divided by the minimum number of convex spaces in the first step for convex space analysis. In the second step, to draw a Justified Plan Graph, each convex space becomes a node in the graph, and the connection between them forms the edges of the graph. The connectivity between two spaces is usually defined as a feature of adjacency and relationship that allows direct access. Different spaces according to their position relative to the root (carrier point), which is at the zero level, are placed in the next levels of the Justified Plan Graph, respectively. After the abstraction process and drawing the Justified Plan Graph, the configuration analysis is performed by measuring the quantitative parameters.

Graph mathematics is based on the concepts of connectivity and depth. From this analysis, a set of features is obtained; The total depth (TD), Mean depth (MD), Relative Asymmetry(RA), integration (i), control value (CV), etc., were obtained according to Table (1). The Justified Plan Graph can be analyzed mathematically as a complete system. Quantitative relationships can be calculated in some software such as Depthmap and AGraph.

One of the practical concepts in the spatial configuration that depends on how the spaces relate to each other is "spatial accessibility," which is directly related to spatial flexibility. The space flexibility is desirable when it has low depth, convenient access, and commensurate height with the function. The number of access points can effectively organize, ease of adaptation, and variety of applications in a building. In space syntax theory, the "Space – link ratio" examines spatial accessibility and functional relationships. In this method, all spaces are divided into four types **a, b, c, d**. In the Justified Plan Graph, space **a** is related to only one other space. This type of space increases depth lacks proper access, and reduces integration. Type **b** includes spaces connected to at least two other spaces, which often connect public and private areas [13].

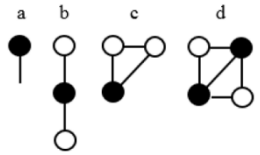

Fig1 - Classification of spaces in terms of accessibility (Spaces a, b, c, d) (Source: Manum, 2009)

Type **c**, spaces are in a loop, and type **d**, spaces are connected to at least two loops. Type **c** and **d** spaces cause to reduce the depth, ease of access, and flexibility of the space [14].

According to the purpose of this study, the convex space method and drawing Justified Plan Graph are used to study the topological structure and spatial hierarchy in the configuration of the Mashhad houses. Of course, in some plans, convex spaces may not be easily defined to create nodes, and another point is that due to the abstraction of the convex shape to a node in the graph, the exact map of this space is not clear. Failure to provide visual relationships between spaces leads to a static approach to space that ignores the way of movement and visual view in space and does not analyze the exact spatial positions in the plan well. The techniques that cover some of the shortcomings of the convex space method are isovist and visibility Graph. In the isovist technique, each point in space has a specific geometric relationship with its surroundings, including a visible and accessible area from that point, and is characterized by a polygon called an "isovist."[9] This technique studies visual perception and individual behavior [12]. Isovists is a method of visual perception that provides a spatial description from the point of view of people who perceive it and move through it [10]. Based on empirical evidence, Turner and Penn (2002) argue that isovist clearly describes the characteristics of the interior space from the observer's point of

view, and the features of isovist points are coordinated with the experience and behavior of individuals in space [16]. The field isovist involves constructing a set of regular isovists in a building or space, which is analyzed as a visibility Graph in Depthmap. [12] These analyzes provide fundamental properties of the environment geometry that help to assess the quality and visual capability. The visibility graph is obtained from a two-dimensional set of points or a specific area with a low level of abstraction because each node in this graph is a real point in space, and nodes can have specific geometric properties such as position and isovist properties [7]. Thus, while the convex space technique describes social patterns in the configuration properties of a design, isovist represents a visual experience in space from a particular situation.

Table 1 - Quantitative parameters of space syntax method (Source: Dawes & Ostwald,2013; Manum, 2009)

Parameters	Explanation	Formula
Total Depth (TD.)	The sum of the number of connections between a particular node (the carrier or root) and every other node in the set.	$TD=(0\times n_x)+(1\times n_x)+(2\times n_x)+\cdots(X\times n_x).$ X, number of levels in the graph – n_x, number of nodes in each graph level.
Mean Depth (MD.)	The average degree of depth of a node in a JPG.	$MD=\frac{TD}{(K-1)}.$ TD, total depth - K, number of spaces
Relative Asymmetry (RA.)	A measure of how deep a system is (for a given carrier) relative to a symmetrical or balanced model of the same system	$RA=\frac{2(MD-1)}{K-2}$ MD, mean depth - K, number of spaces.
Real Relative Asymmetry (RRA)	Describes the degree of isolation or depth of a node not only in comparison to its system or set but also in comparison with a suitably scaled and idealized benchmark configuration, D. The idealized building (D) is always relative to a particular K value (a "lookup" chart in Hillier and Hanson [1984] provides a value for D_K)	$RRA=\frac{RA}{D_K}$ $D_k=\frac{2\left(k\left(log_2\left(\frac{(k+2)}{3}\right)-1\right)+1\right)}{(k-1)(k+1)}$ RA, relative asymmetry- D_K, The relative asymmetry of space in a diamond graph with the number of spaces equal to K.
Integration (i)	A measure of the degree of integration or relative centrality of spaces in a system. i is the reciprocal of RA.	$i=\frac{1}{RA}$ $i=\frac{1}{RRA}$ RA, relative asymmetry- RRA, Real Relative Asymmetry
Control value (CV)	Checks access to adjacent spaces by considering the number of connections in each. It is described as the amount of penetration exerted by a space in a network. The amount of control is less than one indicator of poor space control.	$Control=\sum_{i=1}^{n}\frac{1}{D_i}$ D_i, neighborhood degree of a node - n, the number of all neighboring nodes
space – link ratio (R)	It depends on how the spaces relate to each other. Space accessibility is directly related to the degree of spatial flexibility.	$R=\frac{L+1}{K}$ L, Total number of links between spaces. K, Total number of available spaces

3. Research Method

this research has a qualitative approach in the first step and uses a descriptive-analytical method. The study of historical samples has been done with the help of existing documents and their completion with field research. Due to the scattering of historic houses in different parts of Mashhad, lack of sufficient documents and plans of some buildings, lack of cooperation of some owners to visit the building, and such reasons, finally, houses from different neighborhoods were given priority, that sufficient evidence available, less changed and accessible if needed. To select

samples with spatial structure and composition related to recent decades, including private houses (villas) and single or multi-unit apartments, studies and research, especially dissertations related to middle and new context houses, have been examined. Since it is necessary for this study to cover the spatial configuration features of Mashhad houses well in the research period, in the first step, purposive Sampling and the second step, random Sampling, have been used.

Based on the criteria and categories performed in the background research and according to the purpose of the study, studied samples based on the placement of full and empty spaces, the arrangement of spaces in the main and secondary fronts, and locating the functional areas of the houses were selected. samples include houses with yards and porches, Indicator space in the center, the communication space in the center, and in recent decades, private homes or apartments with joint stair boxes. By collecting plans and eliminating items with similar spatial structures, 25 sample plans were finally selected and listed in Table 2. One home from each category was chosen randomly for space organization analysis for quantitative calculations.

Table 2- Introduction and classification of the selected studied sample (Source: Authors)

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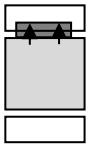
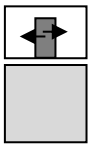
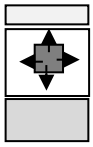
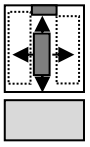
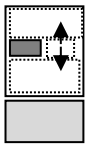
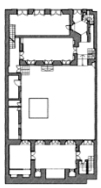
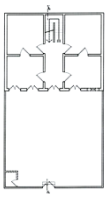
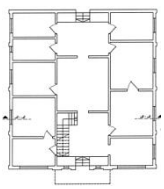
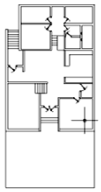
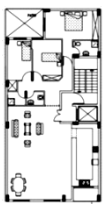
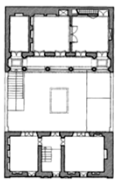
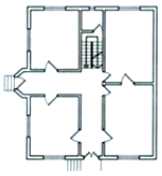
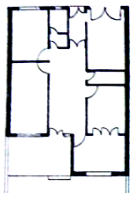
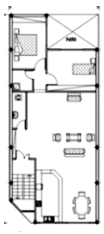
				
Existence of central or side yard-Existence of porch-Presence of mass on two or three sides of the yard-Existence of entrance hierarchy (hashti)- Lack of specific function allocation to most spaces.	Existence of yard-Communication space in center-Mass on one side of the yard-Existence of a stairway - connecting to the upper floor (in some examples) - Lack of specific function-allocation to most spaces.	Existence of a central hall- Mass on one side- some cases have backyard- connecting to the upper floor (in some examples) - The function of some spaces has been determined.	Relative separation of private and public spaces - Existence of the relationship between the living room and kitchen - Opening of the guest space to the hall and come close to the entrance - Transfer of bedrooms to the upper floor in some samples - Formation of new spaces called patio (interior skylight)- Backyard.	Existence of stairs and elevators for the relation between units on the floors - reduction of the average area of the living space - integration of the guest space and living room - opening of the kitchen - separation of private and public spaces.
studied sample				
1	2	3	4	5
				
Ghafouri House	Ahmadian House			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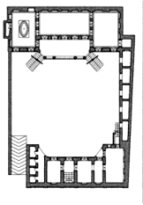
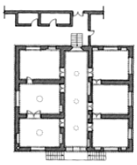
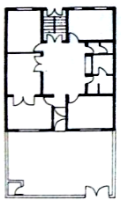
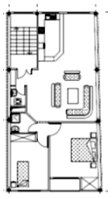
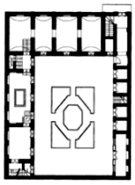
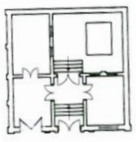
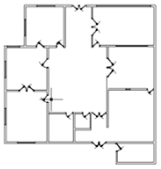
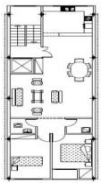
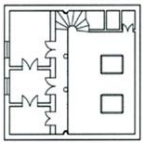
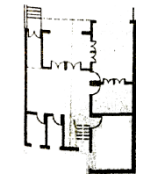
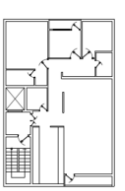
				
Daroughe House	Salmasi House			
				
Davoudi House	Salari House			
				
Malek House	Amini House			

The second part of the research has a quantitative approach, and the data analysis tool is the space syntax method. One of the most important theories in architecture that examine the interaction of spatial relationships and social functions of spaces and analyze the spatial hierarchy visual and movement is the theory of space syntax raised by Bill Hillier and Julienne Hanson "The Social Logic of Space"(1984). According to Bafna (2003), this theory shows the relationship between human society and the physical features of architecture.[17] Hillier (2005) believes that spatial configuration features play an influential role in shaping human activities and can reflect a social pattern. A specific social pattern can also affect the formation of spatial organization [18]. In the space syntax method, related variables are obtained by drawing and analyzing graphs based on architectural drawings. These variables do not have a specific value by themselves; Rather, through the relationship between these variables and the social qualities in the context, this analysis becomes valuable and a tool for understanding the spatial structure [19]. In other words, in this method, the architectural plan becomes an abstract plan, and the numerical quantities show how the patterns of social behavior and spatial neighborhoods relate.

In analyzing, three features of spatial organization, functional efficiency, and spatial legibility in the spatial configuration of Mashhad houses and their physical and functional changes have been studied. Relevant quantitative parameters including depth, integration, connectivity and accessibility, spatial separation, and control value have been calculated in AGraph and Depthmap software. Also, the adaptation of

software data with field research and arrangement of architectural spaces and components of the studied samples has been made.

3.1. Theoretical Framework

The theoretical framework of the research is based on the structural features of spaces and their relationship with the functional characteristics of spaces. Thus, the arrangement and adjacency of spaces, the separation of private and public spaces, how visual communication and access to different spaces, the legibility and functional efficiency of spaces based on quantitative parameters of space syntax theory are calculated and analyzed (Table 3). Hanson (2003) believes; Spatial hierarchy is an essential criterion for understanding the interrelationship of spaces that emerges during the transition from public to private space and includes information about cultural and social features. Private and public zoning are examined based on depth and integration. Integration shows how likely it is to be a private or public space. The more integrated space is shallower and more easily accessible to other spaces in a configuration [8]. Spaces with the highest depth and lowest degree of integration are considered private areas, and this feature can be generalized in different layers of spatial configuration. Connectivity is the degree to which each space relates to other spaces [20]. Private spaces are less integrated, and public spaces are less depth and more connected to adjacent spaces.

Quantitative analysis of space syntax helps to understand how spaces function and to evaluate the interrelationship between changes in lifestyle and behavioral-activity systems of individuals with the spatial organization, so it is one of the most important approaches that can be It examined the concept of functional efficiency in artificial environments [13]. The optimal efficiency of a space is to minimize the impact of other unrelated activities and the proper organization of activities in coordination with each other, which finally leads to the creation of spaces with accessibility, high permeability and integration, better productivity From spaces, and improving the structure of users' social relationships[14]. The location of the space in building structure, the degree of integration and its relationship with adjacent spaces, the amount of access to space, and its depth relative to the entrance can be effective in space efficiency. Therefore, the functional efficiency of a spatial configuration depends on spatial features such as depth, integration, connectivity, and accessibility.

Spatial legibility is directly related to the two parameters of integration and connectivity. The more connected space to adjacent spaces has more spatial legibility and will be more accessible to routing. Therefore, measuring this feature can examine the complexity or ease of spatial relationships and how people are routed. (Figure 2)

Table 3: How to select appropriate techniques for Spatial organization analysis of Mashhad houses.

Purpose	Hypothesis	Analysis Technique	analysis tool	Quantitative parameter
Investigation of functional efficiency of spaces based on topological relationships in building configuration.	The functional efficiency of spaces depends on the amount and nature of their relationships.	Convex space	Justified Plan Graph (JPG) Agraph	depth integration connectivity space – link ratio
Examining the hierarchy of access to spaces	How to access the spaces and their location effectively creates a spatial hierarchy.	Convex space isovist	Justified Plan Graph (JPG) Agraph Depthmap	Integration connectivity mean dept Isovist area
Investigation of spatial legibility and how people are routing.	Observations and people's visual perception effectively Routing them in the building.	visibility Graph	Depthmap	Component R^2 in the spatial legibility diagram
Investigation of the layout of spaces, how to establish and communicate spatially, proper location, functional, private, and public spaces	The privacy and publicity of the spaces depend on how they are arranged in the plan and the degree of connectivity with other spaces.	Convex space VGA	Justified Plan Graph (JPG) Agraph Depthmap	Integration connectivity Relative Asymmetry Control Value Isovist area
Analysis of behaviors and spatial experiences based on	People's visual perception of environmental conditions	isovist VGA	Depthmap	integration connectivity

visual abilities of people in the environment.	depends on their position in space.			Isovist area

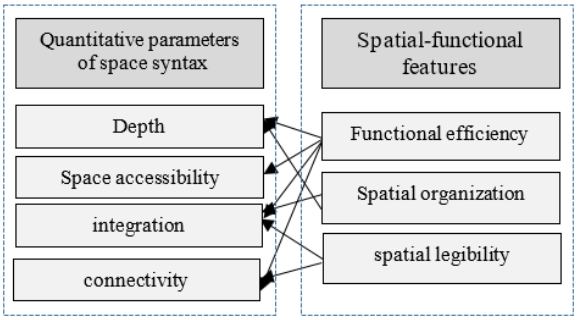
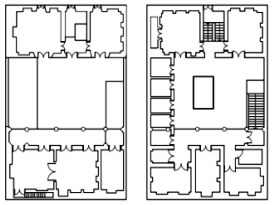
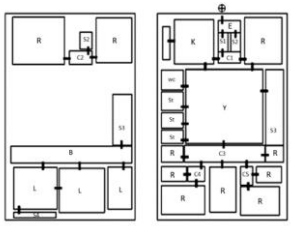
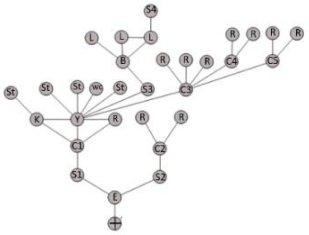
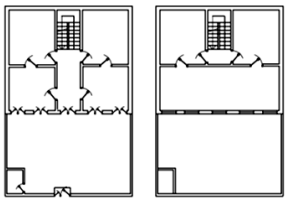
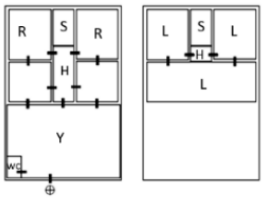
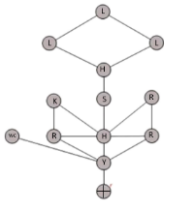
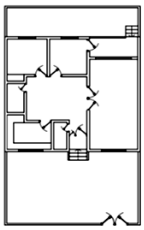
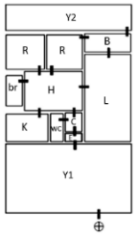
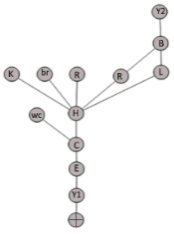


Figure 2: Theoretical Framework

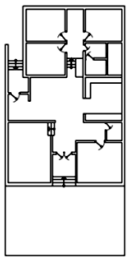
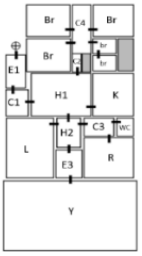
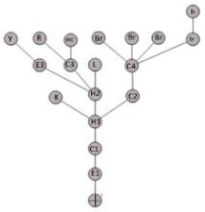
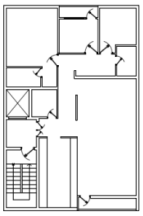
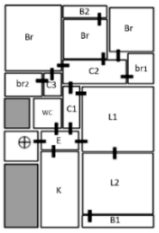
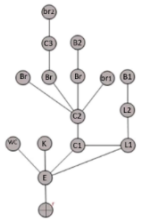
4. Studied Sample Analysis

Spatial organization, functional efficiency, and spatial legibility in the studied samples were analyzed using the convex mapping and Justified Plan Graph (Table 4), the Isovist, and the visibility Graph (Table 10). Quantitative drawings and calculations were performed in Depthmap and Agraph. The results of computation of the desired parameters, in the form of maximum, minimum, and average numerical values, are given in Table 5 and are analyzed based on the related documents and drawings.

Table4 - Introduction of the studied sample, convex map, and justified plan graph 3

case	Architectural plan of the building	convex map	Justified Plan Graph (JPG)
1			
2			
3			

[3]. Abbreviations in maps and graphs: entrance (E), communication space / hashti (C), courtyard (Y), stairs (S), room / living room (R), porch / terrace (B), guest space (L), Central Hall (H), Service space / storage (St), Toilet (Wc), Bedroom (Br), Bathroom (br), Kitchen (K). Gray sections in the plans include patios, public staircases and elevators.

4			
5			

4.1. Spatial Organization

Software calculations show that the yard's integration (9.89) and control value (5.75) is higher than all spaces in sample one. Examination of the corresponding amount in other examples shows that the yard in older houses has played an essential role in forming the spatial organization and the relationship between functional spaces. The yard's proper and optimal function in the past patterns has improved the functional efficiency and spatial circulation. The porch is also used as a semi-open space for some residents' daily activities, with less integration than the yard. In recent decades we have gradually seen a decrease in the degree of integration in the yards. In multi-unit apartments, the yard's role in the functional organization and spatial access has been almost forgotten. Decreased integration index in the porches has lost its functional and communicational role and has been replaced by the terrace.

Chart 1 shows the similarity between the minimum, maximum, and average of the integration in the studied samples due to the similarity of social and functional activities in the configuration of the houses. Table 7 shows that the enormous numbers of spaces are located in the middle depths. In samples, one and two, the courtyard and porch, and later examples, the central hall, are responsible for spatial distribution and functional zoning.

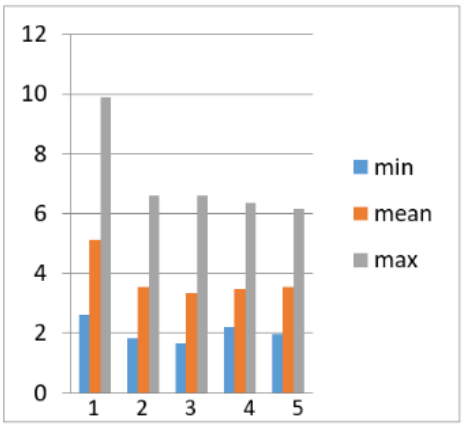


chart 1: Comparison of integration in studied sample

Table 5: Comparison maximum, mean and minimum of main parameters in studied samples

studied sample		TD	MD	RA	i	cv
1	min	78.00	2.51	0.10	2.61	0.11
	mid	130.62	4.21	0.21	5.14	1.00
	max	209.00	6.74	0.38	9.89	5.75
2	min	22.00	1.83	0.15	1.83	0.20
	mid	32.92	2.74	0.31	3.53	1.00
	max	48.00	4.00	0.54	6.60	2.83
3	min	22.00	1.83	0.15	1.65	0.16
	mid	34.46	2.87	0.34	3.34	1.00
	max	52.00	4.33	0.60	6.60	4.33
4	min	42.00	2.33	0.15	2.21	0.20
	mid	65.68	3.64	0.31	3.48	1.00
	max	87.00	4.83	0.45	6.37	4.00
5	min	32.00	2.13	0.16	1.98	0.20
	mid	47.75	3.18	0.31	3.56	1.00
	max	68.00	4.53	0.50	6.17	3.66

4.2. Functional Efficiency

Calculations show that in sample one, the highest amount of integration (9.89) and the lowest mean depth (2.51) is related to the yard, surrounding living, and service spaces. As a communicational node, the central yard has reduced the depth of its adjacent spaces, providing the possibility of functional diversity in the spaces and the ease of spatial circulation.

Table 6- Space syntax parameters in studied sample (justified plan graph with input space as source)

studied sample	K	L	TD	MD	RA	i	cv	RRA
1	32	9	159	5.12	0.27	3.63	0.33	0.793
2	13	6	40	3.33	0.42	2.35	0.33	1.092
3	13	8	52	4.33	0.60	1.65	0.50	1.420
4	19	8	87	4.83	0.45	2.21	0.50	1.532
5	16	7	51	3.40	0.34	2.91	0.20	1.088

Accessibility of spaces is also effective in functional efficiency. In the first and second samples, the spaces of types c and d are observed in the Justified Plan Graph as loops. The existence of these spaces increases the variety of movement paths, increases access, and improves functional efficiency. Spaces have responded to different functional capabilities at other times, depending on the degree of connectivity with their adjacent spaces. A loop between the rooms allows these spaces to be used simultaneously when necessary for more people.

Table 7- Comparison of the depth of spaces in the studied sample

studied sample	1	2	3	4	5
depth	Number of spaces				
1	1	1	1	1	1
2	2	4	1	1	4
3	2	3	1	1	2
4	5	1	2	3	5
5	7	2	5	4	2
6	6	1	1	7	1
7	7	-	1	1	-
8	1	-	-	-	-

The lowest amount of RA in Table 6, equal to 0.27, is in the first example, which indicates a tendency for greater integration and better performance of the spaces concerning each other. This amount increases in other cases. The index of integration and separation is a sign of spatial efficiency and the type of functional usage of spaces by inhabitants. RRA amounts are from 0.79 to 1.53, and the higher rate shows the functional separation of spaces in recent buildings.

Table 8- Types of spaces based on the accessibility of spaces in the studied sample

studied sample	1		2		3		4		5	
Type of space	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
a	17	%53	2	%16	6	%46	10	%53	8	%50
b	8	%25	1	%7	3	%23	9	%47	5	%31
c	5	%16	6	%46	4	%31	0	0	3	%19
d	2	%6	4	%31	0	0	0	0	0	0

Chart2 - Types of spaces based on the accessibility of spaces in the studied sample

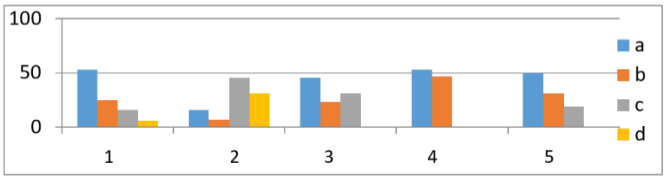


Table 8 and chart2, show that in older homes, the variety of activities in the spaces and the more accessibility have improved the Functional efficiency. spatial relationships have gradually decreased in homes in recent decades and often have spaces of type a and b due to reduced functional diversity and functional separation of spaces. In the third sample, the central hall is a closed space for family life that organized other spaces instead of the yard. This space is the most important in increasing integration and improving functional efficiency. The following samples have reduced the loops by assigning functions and creating special filters. However, in sample five, we see a loop between the communication corridor, living room, and guest space, reducing the length of the access path to the private sector. This feature has been used in the spatial layout of apartments in recent decades. Therefore, creating spaces with large numbers of the shortest communication paths with other spaces increases the functional efficiency of the spaces.

Table 9- Space – link ratio in the studied sample

Studied Sample	1	2	3	4	5
Space – Link Ratio (R)	1.03	1.15	1	0.95	1

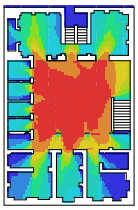
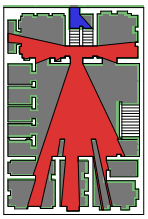
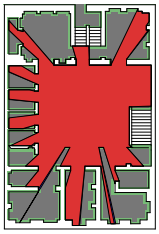
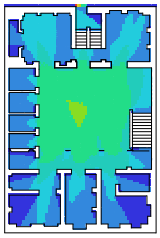
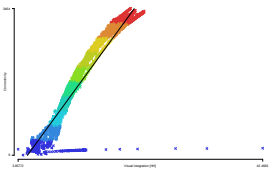
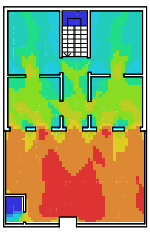
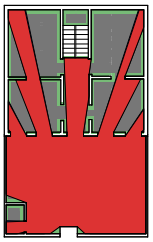
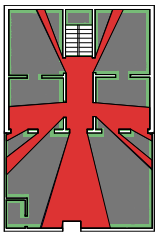
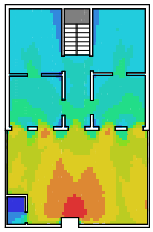
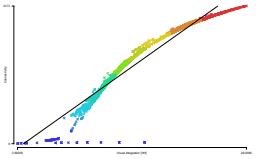
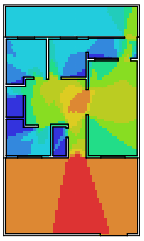
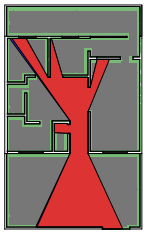
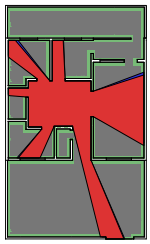
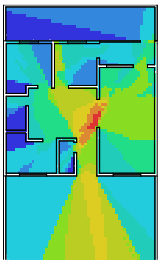
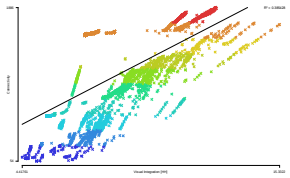
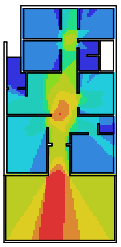
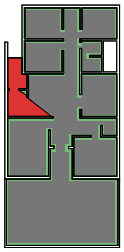
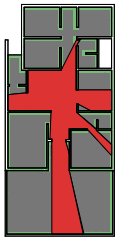
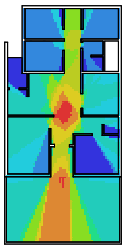
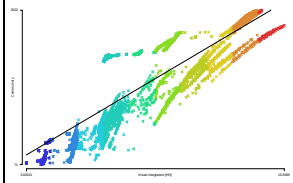
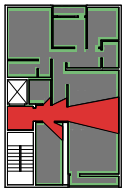
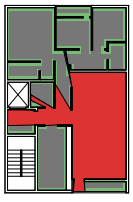
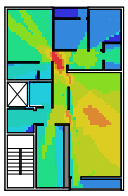
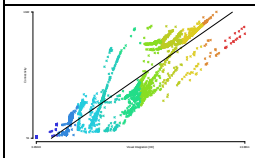
In the case of the space-link ratio (Table 9), values that are more than one indicate a higher spatial distribution due to the existence of loops in the spatial structure that cause spatial flexibility. Amounts less than one are due to more spatial separation. Amounts "R" in samples 1 and 2 indicate the possibility of more significant motion variation and spatial distribution. It is approximately equal to one in other cases, so there is more functional allocation. It is noteworthy that although recent houses have less spatial relation and diversity of space efficiency, in general, the proximity to number one for this feature indicates that Spatial organization is effective in responding optimally to functional needs.

4.3. Spatial Legibility

spatial readability and proximity to evaluate the visual capabilities are considered. The isovist technique and the visibility Graph have been used in this case. In Table 10, each sample is presented with; the legibility graph is based on the connectivity of spaces with each other, the VGA is given according to the integration parameter, and the legibility diagram of the spaces with R^2 index, which is

related to integration and connectivity parameters. R^2 has an amount between zero and one. If it is closer to number one, it shows the better connection between the spaces and the more legibility. It tends to zero, the less proper routing and less spatial communicational. In these graphs, warm colors (red, orange, etc.) mean more connection and less depth and indicate the most visible points. Cold colors (blue, etc.) indicate points that have less connectivity and more depth, in other words, are less visible.

Table 10 - Analysis of studied sample using Visibility Graph and Isovist techniques

	Space legibility	Isovist (view from the entrance)		VGA	visibility diagram
1		enterance 	Center of yard-Hall 		R^2:0.927893 
2					R^2:0.96503 
3					R^2:0.385428 
4					R^2:0.649908 
5					R^2:0.792886 

The isovist technique checks the view from the desired points to other parts. The shape and dimensions of the isovist depend on the geometry of the space and the observer's location. The entrance, the center of the yard, and the central hall were selected as observation points in Depthmap has checked and360 degree view to other spaces. Isovist from the entry point indicates that in the main yard sample if there is a hashti, the view from the entrance to the yard and other spaces is limited. This feature has been created in recent examples by creating an entrance filter. The isovist area of the yards has also been gradually reduced from the old sample to the present.

5. Finding

According to Tables 5 and 6, in sample one, the spaces used by the inhabitants have less integration and more depth than the average. In older homes, the depth of the guest space relative to the entrance was medium due to the inhabitants' privacy. In some cases, such as sample one, a space with easy access to the house entrance is reserved for the stranger guest (related to the Landlord's job). In general, the average depth in older houses is higher than in others. Creating depths and complex spaces, especially in traditional housing, has been desirable for creating privacy. This feature has diminished in the process of house configuration changes. These include the combination of living space and guest space in recent decades or the use of open kitchens. Thus, the hierarchy of access to guest space is gradually reduced. In recent examples, the reduction of integration between spaces is due to the decreased area and fewer spaces. Gradual separation of private and public spaces assign the function to spaces and how they are located in the entire structure of the building, which tries to relative separate the functional areas by increasing the number of divided spaces. Partition spaces have less average depth and high spatial integration than other spaces. In sample 5, the spaces are divided into private, semi-public, and public sectors, and for each space, a specific function is considered. This feature reduces the flexibility and functional diversity of the spaces. According to calculations and analysis, the private filter with high control value indicates the separation of the private sector from other spaces and less access to these spaces. After entering, the communication corridor with a lower control value defines the access path to the living room and the private filter. The highest control value (3.66) among all spaces is in the entrance, which covers access to other spaces well. Also, the path to the guest space is close to the average (3.33), which is relatively easier and faster than previous examples. In the studied samples, the A value varies between a minimum of 0.10 and a maximum of 0.54, which indicates that the different spaces in this spatial structure are functionally related to each other despite the functional zoning.

The proximity of RA values to zero (maximum and minimum 0.38 and 0.10) in sample one indicates spatial communication in this sample. Proper and optimal function of spaces leads to the organization of individual activities and the efficiency of the spatial structure. In sample two, placing the mass on one side reduces the yard's role as a connecting space. The main feature is the existence of a relatively wide communicational corridor that, based on quantitative calculations, has a minimum mean depth (1.83) and a maximum degree of integration (6.60). This corridor is the most integrated interior space with the most connection with other spaces. It can be said that its role is similar to the yard in the previous example. Creating paths and circular rings between the spaces causes better spatial distribution and facilitates the movement system in the spaces, which reduces the mean depth and increases the degree of integration. Of course, due to living conditions and family structure, the functional separation of spaces had not been done concretely in this category of buildings.

According to chart1, the maximum degree of integration between the spaces can be seen in the first example, which has a central yard and porch. These two spaces increase spatial relationships' configuration and functional efficiency by creating ease of movement and spatial circulation. In other cases, the wide corridor or the central hall plays a similar role to the yard and, as a middle joint, organizes the different spaces around them.

The legibility graph defines the spatial hierarchy according to the view of other points. The warm and cold colors spectrum shows that the yard has more visibility than other spaces. After entering the interior space, the guest spaces and the main hall have a warm

color in the next step. The spaces related to the private area of the house have a cool color. These spaces are less visible and have less contact with other spaces. As the colors tend to be a darker blue, this feature intensifies. The R^2index in the legibility diagram has a higher value for sample 1and 2. (R^2>0.75) and means visual communication and ease of routing in spaces. In comparison, lower numbers indicate more separation of the private sector from other spaces, which can be seen in recent patterns. A specific point that can be considered in the third sample is reduced R^2 due to the presence of the backyard and the addition to the end of the house's private spaces, which indicates less legibility to access and view the final part of the plan.

6. Conclusion

In this research, to understand the topological structure of Mashhad houses from the late Qajar eras until now, the features of spatial organization, functional efficiency, and spatial legibility have been evaluated and analyzed by space syntax. Based on the results of quantitative analysis a suitable solution has been presented in each era for the optimal function of spaces, the hierarchy of access and privacy, organization of social roles, and providing human needs, following living conditions. Findings indicate that in older houses, the yard, porch, and hashti (entrance), also communication corridors, respectively, have the most integration and less depth than other spaces. It can be said that these spaces, by spatial circulation and ease of access, improve the functional efficiency of different spaces. The porch has also been effective in spatial distribution and increasing spatial relationships. Gradually, the porch space has changed from a functional space in the past to the terrace space in today's houses, which has largely lost its connectivity and functionality. The hashti and yard have separated the public spaces from the private spaces by creating a hierarchy of entry and increasing the depth of access. The yard's role as an open space has gradually diminished over time. By removing the yard from the functional spaces, it seemed that the depth of the space would increase considerably. To solve this problem, a central communication space (central hall) reduces the depth in the whole building and, as a result, higher circulation and proper integration in the spaces. In older samples, the guest space has a medium depth number, creating a kind of access hierarchy. The spatial depth and hierarchy of access to guest space in recent houses have been reduced. Also, assigning functions to spaces has reduced spatial circulation. The private spaces have a lower degree of integration, are more segregated, and have more depth in access hierarchy. Although some functional and social features have been forgotten in the process of changes in the Mashhad houses' topological structure. It is hoped that the results of this study will pave the way for future studies in related research.

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