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A Comparative Study of Spatial Configuration Functional Efficiency in Three House Systems with Large, Small and Micro-Modules Using Space Syntax Method

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ABSTRACT

Amongst the spaces in which human beings attend, the house is the place where one affects and is affected by it on a daily basis. Each of the various spaces of the house possesses unique characteristics and various factors such as climate, culture, society, and others contribute in the formation of them. The establishment of these spaces at the side of one another gives rise to different spatial systems that lead to the formation of various types in this kind of architecture and influences the shape of the various patterns of using them in addition to bringing about shape differences. The present study aims at investigating and comparing the functional efficiency of the houses in three house patterns with large, small and micro modules using space-related mathematical relations. To do so, nine traditional houses have been selected for the aforementioned three spatial systems in the cities of Kashan, Isfahan, and Yazd as the case studies. The study method in this research is descriptive-analytical and the type of the inference applied herein is deductive of the comparative type. The initial data were extracted through drawing graphs related to the plans of each of the studied houses; then, these data were inserted into the mathematical relations of spatial syntax. This way, based on the indices "spatial value", "mean depth of the space" and "relative integration", the functional efficiency of each of the aforementioned patterns was extracted. The results signified that the houses with a large module have the highest spatial value, highest depth amount and highest relative integration rate that altogether eventually result in the increase in the functional efficiency of such a pattern of the house in contrast to the small- and micro-module house patterns. Moreover, the investigation of the spatial difference in the nine studied patterns indicated the existence of similarities in the configuration and spatial organization of the houses in Kashan and Isfahan and their differences from the houses in Yazd in this regard.

Keywords: Functional Efficiency, House, Large Module, Small Module, Micro-Module.

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1. INTRODUCTION

Houses are places for living not for watching; thus, their function are more important than their appearance unless both of the aforesaid concepts are summed up in them. Amongst the spaces in the periphery of human beings, the house is the most immediate space related to mankind who is influenced and influences it on a daily basis. House is the first space wherein the human beings feel and experience spatial belonging and it is the only place wherein the first immediate experiences of the space come about in solitude and among crowd (Ando, 2016).

Besides this issue, it has been shown in the theory proposed by Bill Hillier (2007) that, along with the apparent characteristics of space like form, shape, color, texture, and others, the thing that influences the users' experiencing of a space is the relationship between its micro-spaces that is generally termed as spatial configuration. He keeps on explaining that this style of attitudes towards space makes feasible the recognition of social behaviors that are usually in the qualitative form within the format of quantitative values. He also expresses that the spatial configuration of a building or a city can be explored using graphical instruments thereby to apply mathematical analysis for recognition. He calls this science as space syntax (Hillier, 2007).

Amongst the concepts that can be examined in the area of space syntax is the functional efficiency that is a concept widely applied in various scientific fields. In environmental sciences, it has been elaborated under the title of the environment's capability for satisfying various needs of human beings. In this regard, functional efficiency of an environment in the environmental psychology domain is the environment's ability for responding to the various physical and psychological needs of the users thereof; amongst these needs, security, comfort, vitality, sense of belonging and other cases of the like can be pointed out (Altman, 1976; Newman, 1972; Lang, 1987). In the energy and bioenvironmental area, as well, functional efficiency of a space has been defined as the extent to which the place supplies the individuals with their comfort conditions, including heating, cooling, lighting, ventilation and other cases of the like (Fanger, 1972; Humphreys & Nicol, 1998; De Dear, 1998). However, in space syntax science, functional efficiency has been introduced as the degree to which space is utilized by its users. In this regard, indices like establishment position of the intended space in the overall structure of the building, its bond and relationship with its adjacent spaces, the amount of access to the aforesaid spaces and others of the like influence the efficiency of the intended space (Mostafa & Hasan, 2013).

In the literature of Iran's traditional architecture, especially in the area of housing, the most important classification has been carried out by Pirnia (2008) in terms of spatial configuration; in this classification, various houses have been divided based on their floor area and the constituent elements into three systems, namely large module, small module and micro-module (Pirnia, 2008, p. 181). Based thereon, the current study intends to rely on the quantitative methods of space syntax in investigating and comparing the spatial structure of the houses in three systems of large, small and micro modules. Thus, the current research seeks to answer the following questions:

1) How can the spatial value and functional efficiency of the spaces be achieved using the spatial syntax's mathematical relations as well as based on the set of information obtained from the spatial configuration?
2) Can having quantitative spatial information enable the recognition of sociocultural patterns governing the house?
3) Amongst the three large-, small- and micro-module systems, which one is at the highest level in terms of the functional efficiency and spatial value?

2. STUDY LITERATURE

In this section, the role of the houses' configuration is analyzed in explaining the cultural-social patterns governing them as well as in examining the houses' functional efficiency.

2.1. Analyzing the Spatial Configuration in Line with the Explanation of the Socio-Cultural Patterns

This theory was founded in 1984 by Hillier and Hanson in London and it is based on research about the way the social and spatial forms are related. The theory is of the belief that space is the initial and primary core in the quality of social and cultural incidents. Although space is per se formed within the social, cultural and economic processes, it is usually recounted as a ground for social and cultural activities (Makrí & Folkesson, 2000). In line with this, the most original idea with which this theory has dealt is the spatial configuration wherein the relationships between the elements in the whole system are given high importance. In this regard, Hillier is of the belief that the spatial and social forms are so closely interlaced that the spatial configuration alone can define many of the social patterns. This way, the most important point in analyzing space and behavior of the addressees therein is the consideration of the relationship between the spaces in a macro system which is recalled in this article as the spatial configuration. So, from the perspective of this theory, the relationship between the activity and space, more than being definable in the characteristics of the space in individual form, can be discerned and defined in the relationships existent between the spaces or the very spatial configuration as well as the addressees' interrelationships (Hillier, 2007).

2.2. Interpretation of the Spatial Value and Functional Efficiency of Space in Space Syntax Method

"Space Syntax Method" is a developed approach in analyzing the spatial structure of the manmade environment. The goal of this method is describing the spatial models and displaying them within the format of numerical and graphical forms hence facilitating the scientific interpretations about the intended spaces (Mostafa & Hasan, 2013, p. 445). One of these methods investigates the structure of the spatial arrangement or the space syntax and gives the results in the form of graphical or mathematical data via exploring the relationships between the physical space and the spatial structure existent therein. Using the analysis of these data, the mutual relationship between the people's behavior and the environment's body can be investigated and their effects and/or changes can be predicted in the course of time. One of the goals in using the space syntax method is the perception of the social relations in space like privacy and the degree to which the spaces are private or public (Me'emarian, 2005, p. 339).

For example, in Iran's traditional houses, the increase in the amount of spatial depth causes a reduction in spatial access which per se leads to the increase in spatial privacy. This issue has been manifested particularly in the establishment of the house's interior part in the most distant point as well as in the access to the entrance spaces (Me'emarian & Sadoughi, 2011).

From Hillier's perspective, "the efficiency of space" includes the ability of a complex for adapting the functions and performances in proportion to each of the subspaces in the whole complex (Hillier, 2007, p. 247). Effective spatial factors include cases like the relationship between the space and its accommodated activities, existence of appropriate movement axes in the space, spatial flexibility, spatial proportions and security provided by the space and all of these cases are amongst the essential issues in designing an environment. These factors are completely related to the activities of the residing individuals and play a very important role in the success of an environment. Thus, it seems that the incorrect configuration severely influences the building's effectiveness. A building is considered to be effective when the users can take part in various activities feasible therein without any problem (Lang, 1987).

In a theory that was posited by Bill Hillier in 1986, various spatial values in a plan were for the first time evaluated based on the "spatial differences" through using quantitative methods (mathematical relations of space syntax). This is while the spatial value was recognized in Rapaport's theory only by taking advantage of the qualitative methods in the past. Next, Hillier investigated 17 types of rural houses in France by considering the spatial patterns of them and proposed that it might be possible to somehow classify the houses by observing their patterns in such a way that the order governing their spatial structure can be discerned (Hillier, 2007).

3. STUDY METHOD

As it was mentioned before, the present study's main goal is the investigation of the spaces' functional efficiency in nine house patterns with micro-, small- and large-modules. Based thereon, the spatial syntax's mathematical relations were used. In order to extract the required data for using in the mathematical relations of spatial arrangement, graphical system was used in such a way that the graphs related to each of the case studies will be drawn in separate in the first step from the building's main entrance section and the obtained information are utilized in a second step in the spatial arrangement's mathematical relations. In this step, three indices are employed for assessing the functional efficiency of the houses, including A) calculation of the spatial value; B) calculation of the index related to spatial depth and C) the relative integration index each of which will be explained in details in the forthcoming parts.

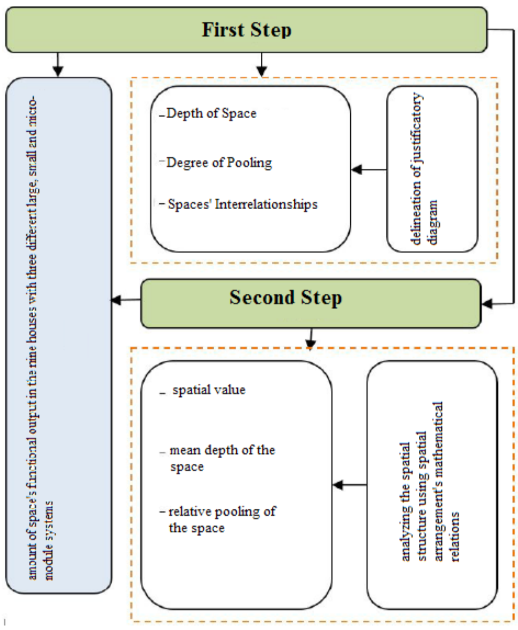


Fig. 1. Study Process

3.1. Step One: Extracting the Spatial Configuration Using Drawing Graph

Graphs or justificatory charts include charts that are drawn for showing the spaces as well as their interrelationships. The analysis of these charts enables extraction of information for the spaces' syntax structure, spaces' depth rate, the degree of their integration as well as their interrelationships. The results obtained in this step offer the information required for use in the second step.

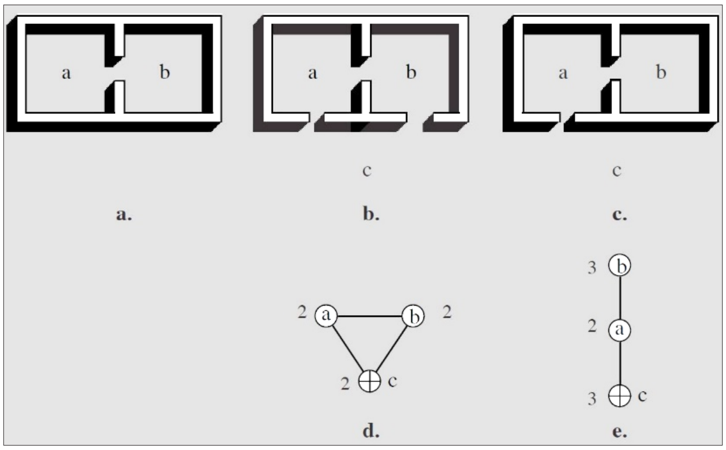


Fig. 2. Basic Concepts of Graph
(Hillier, 2007)

3.2. Step Two: Analyzing Functional Efficiency Using the Space Syntax's Mathematical Relations

As it was mentioned before, this section uses three indices, named "spatial value" factor, "spatial depth" and "relative integration" calculation indices, for investigating the spaces' functional efficiency. The following section explains each of them.

3.2.1. Calculation of Spatial Value

In order to calculate the spatial value, the spatial difference should be firstly investigated. The spatial difference is examined using the degree or the extent to which each space is related to other spaces. Space's degree of the bond (number of bonds) demonstrates the relative depth of space in relation to the other spaces in every spatial structure according to its justificatory diagram and also indicates the configuration's rate of permeability in quantitative terms. The investigations show that the values of bond predict the frequency of space's use to a large extent meaning that the lower bond designates the lower likelihood of use and higher bond shows the higher likelihood of use. The strong or weak point of this inequality between the bond rates expresses the degrees of the cultural importance set in the integration (bond) or separation and isolation meaning that its strong point (low values) reflects the maximum integration and its weak point (high values) indicate maximum separation (Hillier, Hanson, & Peponis, 1987, p. 365). In the following relation, spatial differences have been investigated:

(1) $$H = -\sum [\frac{a}{t}\ln(\frac{a}{t})] + [\frac{b}{t}\ln(\frac{b}{t})] + [\frac{c}{t}\ln(\frac{b}{t})] + \cdots$$

Where, H is the relative spatial differences for a, b and c and other spaces. The values of a, b and c and others are per se indicative of the number of bonds related to each of the spaces a, b and c and others and t designates the total sum of all the bonds in the intended spaces and it can be calculated as shown below:

(2) $t = \Sigma\,(a + b + c)$

After calculating the spatial difference, the spatial value should be calculated. In order to calculate the spatial value, use is made of the following relation:

(3) $$H^* = \frac{H - \ln 2}{\ln 3 - \ln 2}$$

In the above relation, H*[1] expresses the amount of spatial value; the higher the value of this factor, the more it is indicative of the separation hence the lowest spatial value. The lower the value of this factor, the more it is indicative of the maximum integration hence the highest spatial value. In other words, the lower the amount of H*, the higher the spatial value hence the higher the functional efficiency. However, the higher this amount, the lower the spatial value hence the functional efficiency of the space will be decreased.

In the above relation, H is the factor of spatial difference that can be extracted from relation (1). The values of ln (3) and ln (2) respectively show the minimum and maximum spatial differences of H that are fixed in the above relation (Hillier, Hanson, & Graham, 1986, p. 365).

3.2.2. Calculation of Spatial Depth

By depth, the distance from space to the entrance (basic or root space) is intended. In this regard, the mean spatial depth to the root space is the number of stages taken for reaching each space from the root space. In a spatial structure, the highest amount of depth is obtained when all of the spaces are placed in a linear sequence along the entry axis.

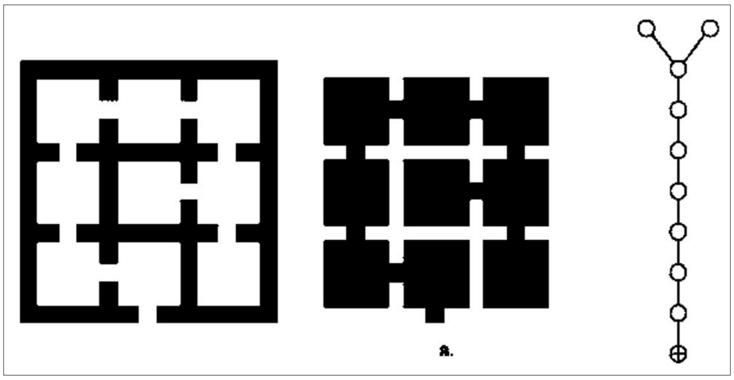


Fig. 3. The Highest Rate of Depth as a Result of Space's Linearity
(Hillier, 2007, p. 20)

This is while if the spatial structure is organized in a way around the basic space (entrance) that creates a uniform distribution in space's physical structure, therefore, the value of depth rate is created in the spatial structure.

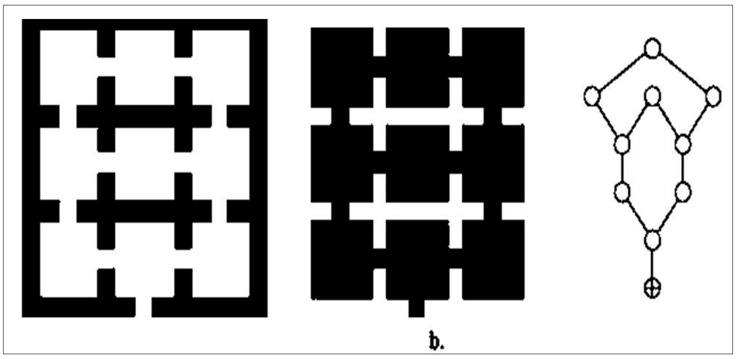


Fig. 4. The Lowest Amount of Depth as a Result of the Uniform Distribution of Space About the Basic Space
(Hillier, 2007, p. 20)

In order to compute the mean depth of the space, the following relation is used:

(4) $$\mathrm{MD} = \frac{\sum \mathrm{D}}{\mathrm{K} - 1}$$

In the above relation, M.D.[2] indicates the mean depth of the space to the root space, ΣD is the total modulus of depth for all of the spaces to the root space and K is the total number of all the spaces existent in a graph.

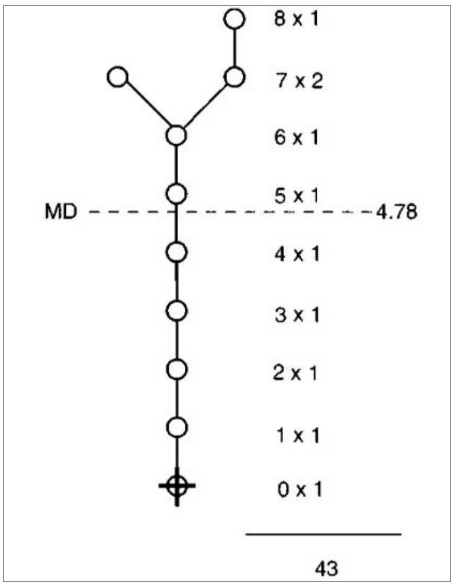


Fig. 5. Calculation of Space's Mean Depth
(Hillier, 2007)

It is worth mentioning that the more the mean depth of space in a spatial structure is increased, the more the functional efficiency in that space is decreased. On the contrary, the more the mean depth is reduced, the more the functional efficiency is increased in the intended space (Hillier, 2007, p. 22).

3.2.3. Calculation of Space's Relative Integration Index

By the relative integration of space, space's relative connection that describes the permeability of a building's spatial structure is intended. Lower values of this index indicate the maximum spatial integration and accretion; on the contrary, the higher values indicate the maximum separation of the spaces from one another. The higher the integration of a space (lower relative integration rates of the space), the more the functional efficiency of the space will be increased and, on the contrary, the more the spaces are separate and less connected to and from one another, the functional efficiency is more reduced (Manum, 2009, p. 4).
In order to compute the space's relative integration rate, the following relation is used:

(5) $$R.R.A = \frac{R.A}{DK}$$

In the above relation, R.R.A[2] denotes the space's relative integration rate. R.A is the relative symmetry of the space and DK shows the number of spaces created in the largest loop existent in the graph extracted from the intended space (Hillier, Hanson, & Graham, 1986, p. 227).
- Space's relative symmetry is indicated by R.A. Space's relative symmetry means the visual depth of the various spaces in a spatial structure of the main space (for instance, the gate or the main entrance). If the depth of space in a building is lower than the depth of the same space in another building, space is called symmetrical. In this state, separation and isolation of space are increased and the increase in the visual stages between the existent spaces leads to the weakening of the functional relationship (output and efficiency). Therefore, plans wherein the spatial depth is maximized are functionally more inappropriate for various patterns in comparison to the plans with lower depth (Hillier & Hanson, 1988, p. 147).
In order to calculate the space's relative symmetry, the following relation is used:

(6) $$R.A = \frac{2\,(M.D-1)}{K-2}$$

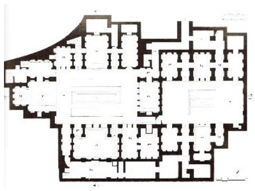
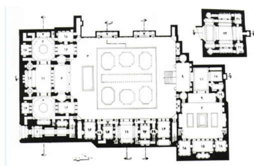
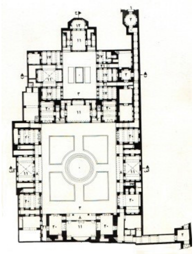
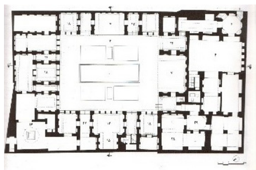
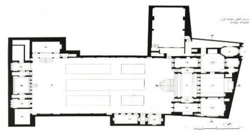
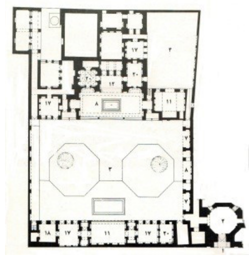
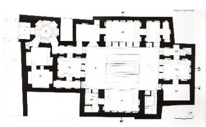
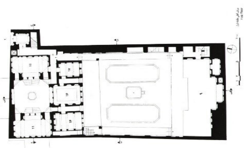
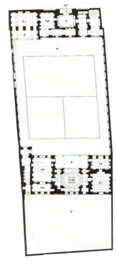
In the above relation, M.D is the mean depth of the space the amount of which can be computed according to relation (4) and K is the total number of the spaces existent in the graph. It is worth mentioning that the amount of R.A. ranges between zero and one, unity with the former indicating maximum integration meaning that there is no depth (high functional output) and one indicating maximum separation and isolation meaning maximum depth (low functional output).

4. INVESTIGATION OF THE STUDY CASES

Based on the viewpoints of Pirnia (2008), Iran's traditional houses have been designed and constructed in three configuration systems called large module, small module, and micro module. Accordingly, all of the spaces of a house, including the interior, exterior, rack, yard, garden, various kinds of rooms (three- or five-door or windowed rooms), Tehrani hall, guest room, corridors and other spaces in each of the above systems were implemented in each of the abovementioned spaces with a special scale with the scales and the interrelationship of these spaces following the specific pattern of that module which is a means for easing the work and directing the entire sizes in designing process that causes an architect to use a special size and scale in the construction of the building. It has been in this way that module brought about diversity in the architecture and this is why no trace of imitation is seen in any of the traditional buildings (Pirnia, 2008, p. 180).
-In houses with a "large module", the combination of the spaces was in such a way that the house consisted of two interior and exterior parts. The spaces include exterior space, dining room, guest room, interior space, Tehrani, hall, and summer stay, bathroom and kitchen. The dimensions of the house in the large module are 48×48 and the yard is obtained in the house with a large module based on golden proportion.
-In "small module", the house is cheap and comfortable. Its composition is something like the house with a large module with two three-door rooms, one five-door room, hall and kitchen being in its interior space with the guest room being in the exterior part of the house. The dimensions of this house are 32×32 and the yard is, as well, obtained based on the golden proportions.
-In the micro-module, the house is small and simple and comprised of two to three rooms and, in the meanwhile, containing interior and exterior parts, as well. In these houses, the three-door rooms have been transformed into five-door rooms and they also have hall and Tehrani, as well. In the exterior space of the house, hall and guest house are located and the five-door or Shekam-Darideh room, hall and kitchen are situated in the interior space. These houses are more beautiful than houses with a large module, and every inch of the house is put into maximum use (Pirnia, 2008).
In this study, nine houses with different configuration have been investigated as case studies with three of the houses being in Yazd, three houses in Kashan and three other houses in Isfahan. Various configurations have been selected based on the type of module in the houses in such a way that, out of these nine houses, the first three patterns have been selected with a large module,

the second three houses with a small module and the third three patterns with a micro-module spatial system. Each of these houses has spaces like entrance, exterior yard, an interior yard and numerous and diverse semi-open spaces and covered spaces. In order to achieve the study goals, amongst the various spaces existent in the houses' configuration, spaces should be selected that are firstly present in all of the aforementioned samples; secondly, they should play a functionally significant role in the formation of the house's configuration in such a way that the change in their places in the house's structure results in the change in the relations between all of the spaces dependent on that space and influences the spatial structure of the entire house. According to the above-presented materials, three spaces, namely "exterior yard", "interior yard" and "guest house" have been considered as the sample spaces.

Table 1. Study Cases in Three Large Module, Small Module, and Micro-module Systems

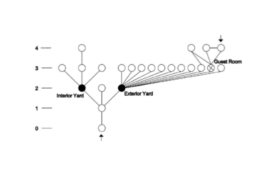
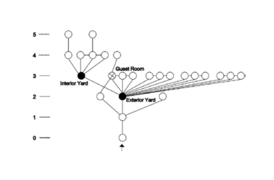
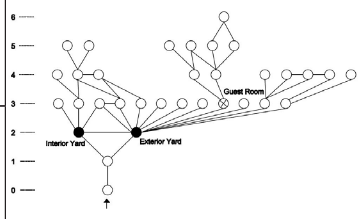
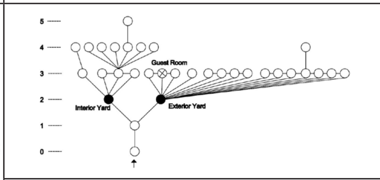
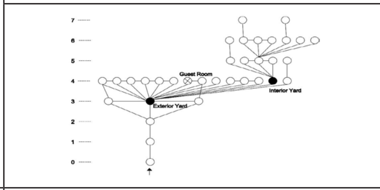
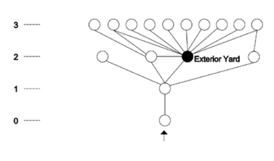
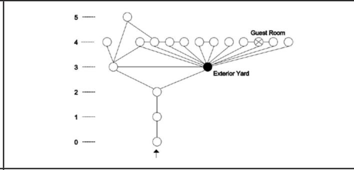
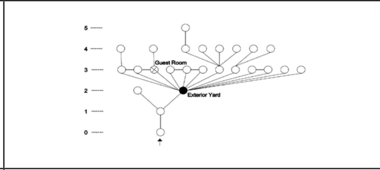
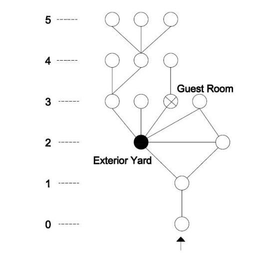
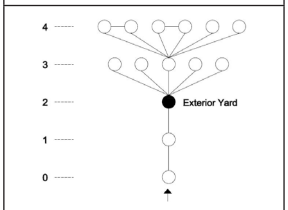
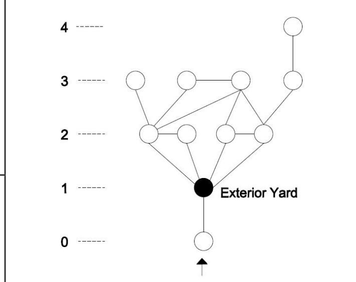
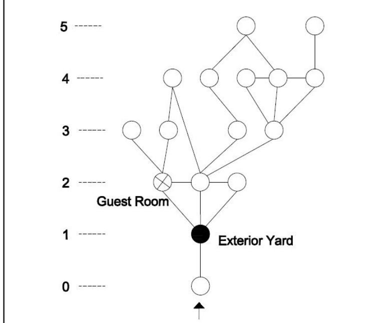
	Yazd's Houses	Kashan's Houses	Isfahan's Houses
Large module			
	Pattern 1: Gerami House (Hajighasemi, 2009, p. 154)	Pattern 2: Tabataba'ei House (Soltanzadeh & Mosavi Rezvati, 1996)	Pattern 3: Akkafzadeh & sharif House (Mola Asadallah, 1998)
Small module			
	Pattern 4: Meshkiyan House (Hajighasemi, 2009, p. 202)	Pattern 5: Khayriyeh House (Soltanzadeh & Mosavi Rezvati, 1996)	Pattern 6: Sheikh Al-Islam House (Mola Asadallah, 1998)
Micro-module			
	Pattern 7: Arab House (Bibi Roqayyeh) (Hajighasemi, 2009, p. 84)	Pattern 8: Bakuchi House (Soltanzadeh & Mosavi Rezvati, 1996)	Pattern 9: Sukiasiyan House (Mola Asadallah, 1998)

5. DISCUSSION AND ANALYSIS

In this section, the study structure is designed based on the steps defined in the section on the "study method".
A) Step One: Extraction of the spatial configuration using graph drawing:

In this step, the spatial relationships of each of the intended houses are extracted within the format of the graph. In drawing the graphs, the entrance spaces are considered as the base space.

Table 2. Graphs of the Study Cases in Three Systems of Large, Small and Micro Modules

	Yazd's Houses	Kashan's Houses	Isfahan's Houses
Large module	 		 
	Justificatory chart related to pattern 1	Justificatory chart related to pattern 2	Justificatory chart related to pattern 3
Small module			
	Justificatory charts related to pattern 4	Justificatory charts related to pattern 5	Justificatory charts related to pattern 6
Micro-module	 		
	Justificatory charts related to pattern 7	Justificatory charts related to pattern 8	Justificatory charts related to pattern 9

B) Step Two: Analyzing the functional efficiency using the spatial syntax's mathematical relations:

As it was mentioned before, use is made in this section of the mathematical relations for extracting the functional efficiency of the house's spaces. To do so, three concepts of "spatial value", "depth rate" and "space's relative integration" are respectively calculated.

C) Calculation of the Spatial Value: In order to extract the spatial value for the three spaces, namely interior yard, exterior yard, and guest room, in each of the case studies, mathematical relations (1) and (2) are used. The results have been offered in Table (3).

Table 3. Investigation of the Spatial Value in the Three Various House Systems

		H^a (Guest Room)	H^b (Exterior Yard)	H^c (Interior Yard)	H*	H Ratio
Large module	Pattern 1	0.19	0.33	0.35	0.31	$H^a<H^c<H^b$
	Pattern 2	0.38	0.29	0.32	0.32	$H^a<H^b<H^c$
	Pattern 3	0.23	0.31	0.36	0.52	$H^a<H^b<H^c$

Small module	Pattern 4	0.2	0.34	0.27	0.39	$H^a<H^c<H^b$
	Pattern 5	0.31	0.36	0.37	0.87	$H^a<H^b<H^c$
	Pattern 6	0.27	0.32	0.37	0.67	$H^a<H^b<H^c$
Micro-module	Pattern 7	0.22	0.36	0.32	0.46	$H^a<H^c<H^b$
	Pattern 8	0.34	0.37	0.39	0.95	$H^a<H^b<H^c$
	Pattern 9	0.30	0.33	0.35	0.72	$H^a<H^b<H^c$

According to the results given in the above table, the following points can be made:

D) It is observed in an investigation of the three indices (H^a, H^b and H^c) that the amount of H^b is larger in all the three houses in the city of Yazd (pattern 1, pattern 4 and pattern 7) followed by Hc and then Ha which has acquired the lowest rate whereas the values of these three indices have been obtained different in all three intended houses in the city of Kashan (pattern 2, pattern 5 and pattern 8) as well as in all three intended houses in the city of Isfahan (pattern 3, pattern 6 and pattern 9) in such a way that the amount of Hc is the largest in all three houses followed by Hb and finally Ha for which the lowest value has been attained. Considering such a notable rhythm in the values of spatial difference in the nine studied cases, the existence of a special sociocultural pattern can be discerned in the formation of the spatial structure of the intended three spaces in the aforementioned houses meaning that the socio-cultural pattern that has been influential in the formation of the configuration in Yazd's houses is different from the pattern applied in the construction of the houses in Kashan and Isfahan while the existence of an identical pattern in the houses in Kashan and Isfahan indicates the existence of a special sociocultural similarity amongst the residents of these houses. This can be perceived with the observation of the apparent shape of the plan pattern of these three cities (Table 3).

E) According to the materials presented in the study's theoretical section, the more the obtained numerical value exceeds the index H*, the more the spatial value is reduced therein hence the functional output of that space is decreased; conversely, the lower the aforementioned index, the more the spatial value of the intended space is increased hence the functional output of the space is augmented (Hillier et al., 2007, p. 365). Thus, it is observed in a comparison of the data obtained from H* values in all nine intended houses that the highest amount of spatial value (H*) goes to the houses with micro-module in all the three cities of Yazd, Kashan, and Isfahan. On the contrary, the lowest value has been obtained for houses with a large module. As has been explained in the literature, this finding signifies that the houses with the large module have the highest spatial functional efficiency and, contrarily, the houses with micro-module have the lowest functional efficiency.

F) Based on what was mentioned before, the high values in spatial difference show the lower functional efficiency and, contrarily, the low values in the spatial difference show higher functional efficiency; thus, it can be understood accordingly that the functional efficiency of each of the spaces, namely interior yard, exterior yard and guest room, is in the separate highest for the houses with the large module and lowest for the houses with the micro-module. On the other hand, the number of the bonds in each of these three spaces in the corresponding graphs is reflective of the idea that the number of bonds in the three aforesaid spaces is the highest in the houses with large module and that the number of bonds in the three spaces, namely interior yard, exterior yard and guest house, with their adjacent spaces is in the lowest possible rate.

G) Calculation of the Mean Depth and Relative Integration of the Space:

In this section, use is made of mathematical relations (3) and (4) for calculating the depth and relative integration of each of the nine study cases. The obtained data have been summarized in the following table.

Table 4. Investigation of the Depth and Relative Integration Indices

		MD	RRA
Large module	Pattern 1	3.29	0.03
	Pattern 2	3.72	0.021
	Pattern 3	3.81	0.022
Small module	Pattern 4	3.02	0.04
	Pattern 5	3.65	0.053
	Pattern 6	3.29	0.042
Micro-module	Pattern 7	2.6	0.09
	Pattern 8	2.5	0.066
	Pattern 9	3.25	0.048

The results obtained from the above table are as explained below:
H) In regard of the depth index (MD), as was mentioned in the section of "study method", the low values indicate the lowest depth and, contrarily, the high values indicate the highest depth. The lower the amount of depth, the easier the access to space hence the higher the functional efficiency (Hillier, 2007, p. 22). It is observed in a comparison of the data obtained from the depth index values for the nine studied patterns that the houses with large module have the highest depth which is reflective of the lowest functional efficiency of them and, contrarily, the lowest depth and the highest functional efficiency belongs to the houses with micro-module.
I) As for the relative pooling index (R.R.A), as it was mentioned above, the lower the amount of relative integration, the higher the functional efficiency as a result of which the space would have maximum integration (Manum, 2009, p. 4). Therefore, the houses with large module have the highest integration and the highest functional efficiency and, contrarily, the houses with micro-module have the maximum separation and the lowest functional efficiency.

6. CONCLUSION

The primary goal of the present study is the investigation of space's functional efficiency in the nine house patterns with the spatial system of micro-, small and large modules in three cities of Yazd, Kashan and Isfahan. In order to achieve this goal, spatial syntax's mathematical relations were used. The first study step included the extraction of the spatial configuration by drawing the graph corresponding to each of the studied cases. In the second step, the functional efficiency analysis was conducted using spatial syntax's mathematical relations and relying on the results obtained from the graphs; three indices of "spatial value", "mean depth of the space" and "relative integration of the space" were calculated in separate for each of the aforementioned samples. It is worth mentioning that each of the analysis instruments, including graphs and mathematical relations of the spatial syntax, has capabilities that can be utilized in line with proving the functional efficiency's rate. Based thereon, the followings can be pointed out in response to the questions raised in the section on the "Statement of the Problem":

1) In the science of syntax, efficiency means the frequency in which space is used by the users. This concept is directly associated with the spatial value meaning that the increase in the spatial value from the perspective of the space users leads to an increase in the usability thereof. In this regard, indices like the establishment position of the intended space in the overall building structure, the amount of their connection and relationship with their adjacent spaces, the amount of access to the aforesaid spaces and other cases of the like are influential in the amount of spatial value hence the efficiency of the intended spaces. On the other hand, instruments like justificatory charts as well as the mathematical relations that are used for quantitative analysis of the concepts related to space's syntax are amongst the tools that are also employed in the space syntax method. Application of these instruments enables the offering of the qualitative and descriptive concepts related to space in the form of numerical and graphical models that eventually lead to the offering of the scientific interpretations regarding the intended spaces. In line with this, the extraction of indices like "depth of spaces", "degree of space's mean depth", "relative integration of the space" hence "spatial value rate" is carried out using mathematical relations that eventually make the elucidation of the intended space's functional efficiency possible.

2) In this study, cultural-social patterns of space mean similarities in the construction and use of the space. One of the present study's goals is the extraction of the similarities in the spatial system of the three spaces of the interior yard, exterior yard and guest room as viewed by the residents of the houses in Kashan, Isfahan and Yazd. Based thereon, the study findings indicated that the existence of a certain rhythm in the amounts of the spatial difference in the houses studied in each of the aforesaid cities is reflective of the existence of a specific sociocultural pattern in the formation of the configuration in all the three aforesaid spaces in the system of the houses from each of the intended cities. However, the existence of similarity in the values obtained for the three foresaid spaces in the two cities of Isfahan and Yazd and the differences between these numbers and the values obtained for the city of Kashan are suggestive of the similarities in the construction typology as well as the pattern of using the spaces in the two cities of Isfahan and Yazd. Thus, it can be accordingly stated that the use of quantitative values of the spatial arrangement enables the discernment of the socio-cultural similarities in the residents of an urban system in terms of the construction pattern and space-using styles.

3) In the evaluation of the functional efficiency rates and spatial values of the three spaces, namely interior yard, exterior yard and guest room, in the three house patterns with large, small and micro-module systems, the study findings indicated the followings:

-Houses with micro-module have the least spatial value in comparison to the other two patterns and this is reflective of the existence of more separation between the spaces of the house that eventually leads to the reduction in the functional efficiency of the house with micro-module. On the contrary, the houses with the large module have the highest spatial value and this is reflective of the highest functional output in this type of house.

-The factor "spatial difference" is lowest in the houses with a large module or the spaces of the interior yard, exterior yard and guest room and, contrarily, it is highest in the houses with micro-module. As it was mentioned before, the high values of spatial difference show the lower functional efficiency and the low values indicate the higher functional output; thus, it can be perceived that the functional efficiency is in its highest amount in the houses with a large module and in its lowest amount in the houses with micro-module.

-Houses with large modules have larger depths in contrast to the houses with micro-module for such a reason as the sequence and numerosity of the spaces but they generally have better functional efficiency in contrast to the other patterns of houses due to their higher spatial connection to the other spaces.

-In houses with a large module, larger depth has been obtained as compared to the other studied samples due to the numerosity of the spaces as well as due to the existence of spaces that are sited one behind the other in a consecutive manner. Due to the existence of appropriate spatial connection and formation of numerous spatial loops in this style of houses, the level of the spaces' connection with one another is increased hence more flexibility and permeability is created in the space and this eventually leads to the functional facilitation of various spaces in such types of houses hence formation of the highest amount of functional efficiency for this type of houses in contrast to the other two patterns.

It is worth mentioning that although the amount of the functional efficiency obtained for the large module system is higher than that obtained for the other two patterns, it appears that this issue is due to the maximal existence of substructure and existence of numerosity in the spaces in the construction system of this house pattern. This is while the two small and micro-module systems, as well, have in themselves a proper efficiency rate due to the substructure and number of spaces in them. However, the thing intended in the current research paper is the comparison of the outputs of the three spaces, interior yard, exterior yard and guest room shared by all three patterns. Thus, the study findings show in this regard that, out of the three intended modules, the amounts of outputs obtained for these three spaces are larger in the large module than the other two patterns and this issue is per se caused by the mean distance of the three spaces to the root space (mean depth of space), the amount to which the aforementioned spaces are connected to their peripheral spaces (relative pooling of the space) and finally the value rates of the intended space.

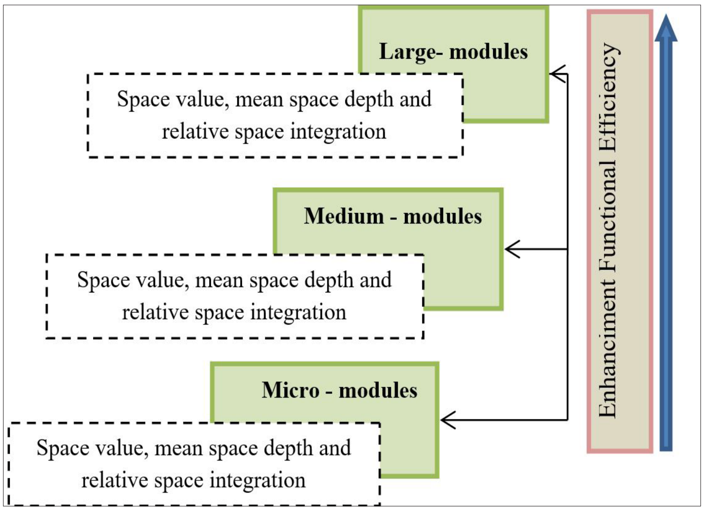


Fig. 6. Analytical Diagram of Functional Efficiency in Three House Patterns with Large, Medium and Micro-modules

It is worth mentioning that although the amount of the functional efficiency obtained for the large module system is higher than that obtained for the other two patterns, it appears that this issue is due to the maximal existence of substructure and existence of numerosity in the spaces in the construction system of this house pattern. This is while the two small and micro-module systems, as well, have in themselves a proper efficiency rate due to the substructure and number of spaces in them. However, the thing intended in the current research paper is the comparison of the outputs of the three spaces, interior yard, exterior yard and guest room shared by all three patterns. Thus, the study findings show in this regard that, out of the three intended modules, the amounts of outputs obtained for these three spaces are larger in the large module than the other two patterns and this issue is per se caused by the mean distance of the three spaces to the root space (mean depth of space), the amount to which the aforementioned spaces are connected to their peripheral spaces (relative pooling of the space) and finally the value rates of the intended space.

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END NOTE

1. It should be noted that in comparing H* values, each sample should be considered with respect to its city. That is, the space value (H)* in the pattern house 1 belongs to the city of Yazd; should be compared with values of patterns 4 and 7, and in this way, the values of * H in pattern 2 should be compared with patterns 5 and 8 which belong to Kashan, and pattern 3 should be compared with pattern 6 and 9 which belong to the city of Isfahan.
2. When comparing MD and R.R.A values, each sample should be considered according to its city. It means this That is, these values in Pattern house 1 belong to the city of Yazd, and should be compared with the values of Patterns 4 and 7. In the same way, the values in Pattern 2 should be compared with patterns 5 and 8 that belong to the city of Kashan, and pattern 3 should be compared with patterns 6 and 9 that belong to the city of Isfahan.

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