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Research Article

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The Impact of Geometric Proportions on Daylight Performance and the Proportions Derived From Nature in Traditional Houses (Case study:Ardabils Houses)

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Abstract

The use of proportions derived from nature in traditional architecture is a constant principle in the interactions between structural and physical environments. It has been shown that having an intrinsic relationship with nature can lead to formal similarities. This study attempts to determine the compatibility of common geometric proportions used in traditional houses with daylight performance and natural proportions of the surrounding physical environment so as to recognize the most compatible structural layout with nature. To this end, 28 Shahneshin rooms were chosen from 21 traditional houses in Ardabil. The required data were collected via field observation and logical reasoning and then numerical analyses were conducted on them. After that, using frequency diagram and mean coefficient of variation, the distribution pattern of the proportions employed in the Shahneshin rooms were determined. Finally, the compatibility of geometric proportions and skylight characteristics with daylight perimeter zone was examined through numerical analyses. The results obtained from the most common structural layouts indicated that in traditional architecture, physical environment and structural environment were compatible and interacted with each other; 95% of the prevalent proportions in the traditional houses of Ardabil appeared to follow arithmetic ratios and many of them were found to follow golden proportions. Moreover, they were observed to have the highest level of overlap with the frequency distribution and perimeter zone of daylight. Furthermore, the analysis of no-sky line area showed that in all of the cases, sky was visible from the inner space of the rooms.

Keywords : Geometry; Nature; Proportions; Daylight Perimeter Zone; Traditional Houses; Ecological Architecture.

1 Introduction

There are two general approaches regarding the relationship between structural and physical environments: 'intrinsic and conceptual relation-

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ship' and 'formal relationship' [16] Oftentimes, intrinsic relationships can lead to formal similarities. Hence, nature is manifested in the main components of architecture in different forms [17]. Therefore, each of the components of traditional architecture is rooted in some hidden aspects of nature [29]. This phenomenon can enhance the quality of both structural environment and human life and, at the same time, maintain the harmony of ecological and environmental conditions. The architecture of the Iranian traditional houses corresponds the physical environment; lots of natural data and proportions have been employed in it affecting its whole structural system. These natural data together with all of the related factors have been established and organized based on a specific set of basic patterns, proportions, and geometric ratios. In fact, geometry is the means through which Iranian architecture has come to be interrelated with nature and its secrets; and it is this interrelatedness that has made the Iranian architecture so magnificent [15] since, in this way, any piece of architecture can enjoy a remarkable level of efficiency [26]. In the architecture of the Iranian traditional houses, the use of geometric order has not been limited to some superficial aspects [47]; rather, in many of them, these proportions have led to the efficiency and sustainability of the buildings [24]. Architects determine and implement appropriate proportions based on the information that they have about various factors such as the needed materials, climatic conditions, geometric and mathematical calculations, technical and executive resources, and the prevailing culture and lifestyle of the local people [6]. Therefore, geometry has a multidimensional function in architecture. Having a sensible knowledge about the characteristics of geometry, the kind of the relationships it has with natural elements, and the methods of utilizing it in an orderly manner is much more important than knowing its constituent components. Getting such sensible knowledge about geometry is facilitated when simple mathematical functions are used [46]. Structural proportions without functional qualities are ineffective perceptions from nature as the primary purpose of nature is the optimization of systems [33]. Natural structures have passed many different types of experiments and have reached relatively stable and robust conditions [33]. They have been selected and evolved by the physical environment over millions of years. Therefore, it seems that if they are employed in the structural environment, they can result in a balance between physical and structural environments and help solve the environmental problems. They can also facilitate the incorporation of optimal and functional geometric proportions into the modern architecture, and help the efficient transfer of features inspired by nature to the human-made structures via changing and adapting them to the needs of the contemporary community [12]. A review of the literature shows that a number of studies have been conducted on the intrinsic and formal compatibility of physical and structural environments in some of the cities of Iran. For instance, one study has investigated daylight quality and performance in the traditional houses of Kashan in which the impact of the shape and the position of skylights on the amount of daylight reception has been analyzed [48]. In another study, the formal characteristics of Yazd's traditional houses have been investigated to determine their compatibility with the golden ratios derived from nature [44]. Other researchers have analyzed a specific natural structure such as 'shell'using mathematical equations so as to determine the form ofits golden spiral curve based on the rectangular plane and identify its different possible forms [19]. Another group of studies have attempted to explore the intrinsic and formal relationships between some specific structures existing in the physical and structural environments. The present study attempted to investigate the compatibility of the geometric proportions used in human-made structures with natural laws. The aim was to provide visual and thermal comfort for human beings and to lower the consumption of fossil fuels via creating a balance between physical and structural environments. More specifically, the purpose of this study was to specify the formal and intrinsic compatibility of the structural space of Shahneshin rooms of Ardabils traditional houses with the characteristics of physical environment. In the analysis of formal compatibility, the geometric proportions utilized in Shahneshin rooms were compared with the proportions derived from nature while in the analysis of intrinsic compatibility, the relationships of geometric proportions and skylight properties with daylight distribution and perimeter zone were explored. These processes can help recognize the geometric pattern of these structures, specify the proportions employed in them, and determine their daylight performance. In the analysis of formal aspects, the compatibility of these structures with golden ratios and arithmetic proportions taken from nature was investigated while in the analysis of intrinsic aspects, daylight performance was examined based on the geometry and proportions of the rooms, the ratio of the skylight area to the floor, and the sky-view angle in the sections of the rooms as well as nearby areas. For the purpose of this study, 28 Shahneshin rooms were selected from 21 traditional houses in Ardabil. Then, the quantitative data collected via the experimental investigations were analyzed so as to obtain the scatter diagram of the arithmetic proportions as well as their normal distribution pattern in Shahneshin areas. After that, daylight perimeter zone of the samples under investigation were obtained via the use of drawing methods and numerical calculations. And finally, based on all of the obtained data, the compatibility of the structures with natural characteristics was assessed. In this study, the geometric system was explained using mathematical equations.

2 Research methodology

The recognition of optimized cases can help maintain the integrated relationship between geometric structures and sustainable characteristics of nature [25]. In order to create an optimal condition in relation to the physical environment, several factors in the structural environment should be taken care of simultaneously in an integrated manner. Therefore, in order to assess the compatibility of the traditional houses with nature, their geometric structure should be analyzed in terms of first the golden and arithmetic proportions and then daylight perimeter zone.

2.1 Compatibility of the geometric proportions of structures with the proportions derived from nature

In traditional houses, all of the measurements and designing patterns are based on geometry; none of the components of these pieces of architecture are the result of personal whim or coincidence [42]. Geometric order is indispensable for any dynamic and systematic structure. In a typical architectural structure, all of the dimensions (height, length, and width) are integrated and interrelated through geometry in terms of both the whole structure and the constituent components (including surface patterns) [39]. Geometry has developed following the natural structures that have been inherently sacred [36].Geometry has been used in structural environment for various purposes such as the creation of spatial proportions, balance, harmony, coherence, order, beauty [18], innovation and creativity, different structural forms, ecological functions, symbolic spaces, etc. [41]. Therefore, restricting geometry to just rectangular proportions not only is not indicative of its perfection, but, on the contrary, shows lack of liveliness, artfulness, and dynamism in geometric architectures. Thus, the connection between architecture and geometry is not a coincidence, and every aspect of it is based on well-thought foundations. In fact, geometry is the mathematical language of architecture which appears to be simple, but is complicated in nature [43].So, the order in geometry emanates from the physical environment and spreads through to the structural environment. As a result, a multidimensional balance is created between these two environments based on the laws of nature.

2.2 Golden proportions derived from the geometric system of nature

The use of golden ratios in the planes and facades of structures is among the first uses of natural proportions in architecture [22]. This ratio conforms to Euclidean geometry which is taken from the mathematics of point and line [46]. Although mathematics and geometry are completely distinct, they have interchangeable methods for the expression of a specific mathematical concept with the only difference being that the former uses numbers and the latter uses geometric shapes [37]. Golden proportions,whose geometric orderliness has been derived from nature,can be observed in various situations such as the growth shape of plants, the idea of the unity of body and soul, majority of proportions used in Ancient Greece and Egypt, patterns employed in architectural components, and the proportions of plan and faade in the architecture of structures belonging to the classical, ancient [46] and renaissance eras [8]. Also, Le Corbusier put forward his modular system based on golden proportions [40]. Furthermore, all of the proportions of bones in human skeleton are always a multiple of phi (ϕ) number in a way that any degree of deviation from that proportion signifies lack of complete health [23]. Therefore, the golden proportions in the realm of living beings mostly follow the phi number, that is 1.618 [22]. The mathematical equation for golden ratios is: $x^2 - x + 2 = 0$. In mathematics, the square root of this equation, which is $|\frac{(1\pm\sqrt{5})}{2}|$, is called the golden ratio Eq. (2.1), E. (2.2) and the rectangle whose length-to-width proportion is $|\frac{(1\pm\sqrt{5})}{2}|$ is called the golden rectangle Fig. 1. The golden ratio is 1.618 which can be expanded via the use of geometrically increasing series Eq. (2.3), Fig. 2. The proportions existing in AFGD rectangle are represented in Fig. 3.

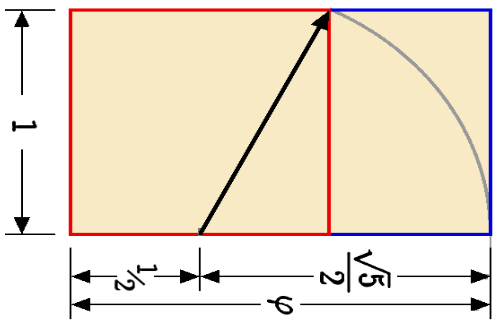


Figure 1: Proportions of the golden rectangle

$$BF = -\frac{1}{2}(1-\sqrt{5})AD = -5AD = \frac{1}{\tau}AD \quad (2.1)$$

$$AF = \frac{1}{2}(1+\sqrt{5})AD = \tau AD \quad (2.2)$$

$$\frac{AB}{BC} = \frac{BC}{BC+AB} = 1.618 \quad (2.3)$$

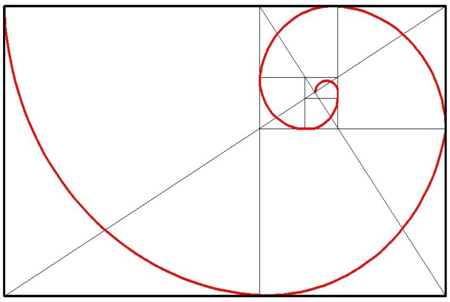


Figure 2: Divisions inside the golden rectangle cite10

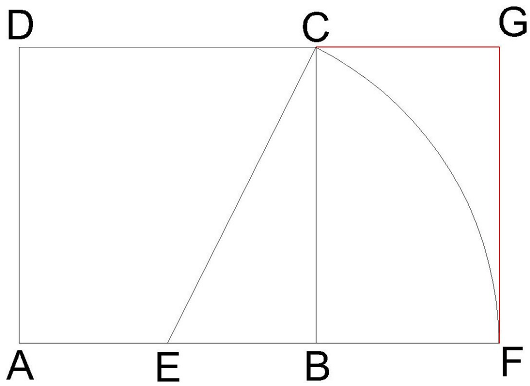


Figure 3: Drawing the golden rectangle

The phi ratio is used to create a rectangle in which the size of the long edge is a multiple of the size of the short edge, and each time a square is separated out from that rectangle, the remaining rectangle still follows the earlier proportion. This ratio is observed everywhere in nature (in shellfish, snail coils, petals, etc.) [23].

In addition to the aforementioned golden proportions, many Iranian traditional architects have put forward the proportions of a rectangle surrounded by a regular hexagon labelled as "Iranian golden rectangle".These geometric shape in which the rectangle has the ratio of 1.73 and the half-rectangles have the ratio of 1.15 have been reported to be quite common in the structure of Iranian traditional houses [42]. The Iranian golden rectangle has a precise geometric shape that includes six equilateral triangles. It determines the orientation of the houses in urban development and is derived from nature (follows the structure of beehives) [7]. However, the golden ratio and its related proportions in nature have mostly been realized as 1.723 [22] which are represented in Figs. 4 and 5 below.

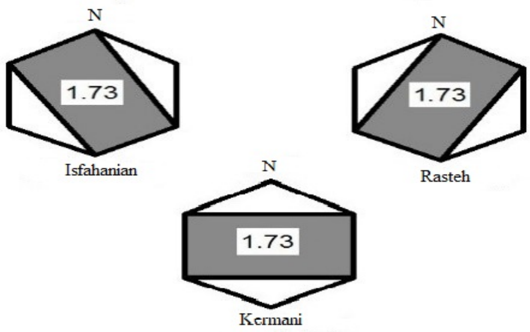


Figure 4: A rectangle surrounded by a hexagon according to Iranian golden proportions with the value of 1.73 to determine the orientation of structures

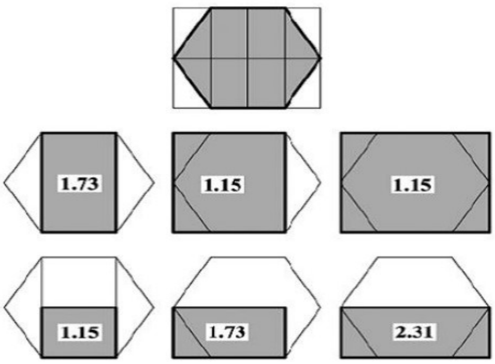


Figure 5: Regular hexagon and some of its drawing ratios, [44]

2.3 Compatibility of the geometric proportions of structures with daylight performance

Pattern-taking from nature is performed from different angles and surfaces through various methods [17]. When these patterns, in addition to following formal characteristics, follow the functions existing in nature (i.e., intrinsic characteristics), they become more stabilized [49]. Furthermore, nature is continuously reacting and resettling itself to respond to the physical and environmental changes in an economical manner. Therefore, the use of natural patterns leads to more stable attainments [29]. The first way for the interaction of structural and physical environments in architecture is to focus on the elements existing in the physical environment. The harmony between the structural environment and the characteristics of the physical environment or, put another way, the connection between architecture and the surrounding natural circumstances is a common feature through which every human being builds up a relationship with the physical environment [28]. A carefully planned interaction between structural and physical environments decreases the consumption of fossil fuels and other natural energy resources [9]. Therefore, architecture should start up from the ground so that it can be regarded as a coherent part of the surrounding physical environment [46]. Thus, the first step in making the structural and physical environments compatible can be the use of different natural forces and energies as well as other needed materials in integration with nature [3]. Compatibility with surrounding environment is essential in designing a structure that is meant to be harmonious with nature [46]. The most noticeable interaction with nature can be observed in Iranian structures, in which climatic conditions have carefully been taken into consideration [46]. One important factor that indicates the compatibility of a structure with the surrounding environment is making maximum use of the radiated sunlight and designing the structure in a way that receives the most sunlight possible. Therefore, the need for sunlight and solar systems is the most important factor to be considered in the construction of any structure [27]. Making use of sunlight seems essential for any structure as after entering the inner space of a structure, it can be used to control the environment and make it compatible with sustainability factors such as higher energy output, higher efficiency, and more desirable thermal and visual comfort [20], [21]. Moreover, daylight is one of the factors that plays an important role in making nature visible from both inside and outside of the structure [33]. It also has a significantly positive effect on the level of enjoyment, mental health, and physical health of the inhabitants [49].

2.4 The impact of the Length and width of the space on the degree and extent of daylight perimeter zone

One of the methods for the analysis of light based on its usage is the determination of its perimeter zone [45]. One of the main effects of daylight on architectural structures is the simultaneous creation of thermal, visual, and mental comfort for the residents [34]. Some of the factors that play an important role in the appropriate distribution of daylight in the inner space of a structure are the ratio of the Length of the room to the height of the window, the ratio of the window surface to the floor, and the height of the visible sky area from the inside. Therefore, in order to control the consistency of light inside the structure, the variables of no-sky line area and room index can be used [33]. the Length, width and other proportions of a room can be determined based on the position and dimensions of the skylight and the reflectance of the inner surfaces of the room. In the spaces lit up by wall-mounted skylights through which sky is visible, the proportion of Length, width, and reflectance in the room should follow the following equation so that the room can be lit up appropriately. This equation, which is called room index, is as follows Eq. (2.4) [13]:

$$\frac{L}{W} + \frac{L}{H} \leq \frac{2}{1 - R_b} \tag{2.4}$$

In this equation, L is the Length of the room from the window to the wall in front of it; W is the width of the room parallel to the window surface; and H is the height of the window measured from the top of the window to the floor of the room. These three variables are all expressed in meters. R_b, on the other hand, is the average reflection coefficient of all of the inner surfaces of the room [14]. Table 1 shows the average reflection coefficient of the inner walls, floor, and ceiling of a room in a building [13], [35].

In situations where the Length and width of a room is more than the specified value, the bottom half of the room will appear relatively darker and auxiliary lighting will be needed. Inner surfaces with higher reflectance and windows with higher caps make it possible to have deeper rooms. In broader rooms, more depth is acceptable. In a room with the width of 3 m, the height of 2.5 m for the window, and the reflection coefficient of 0.4, the maximum acceptable depth is 4.5 m [13]. Therefore, the geometric characteristics, size, layout, shape, and proportions of the skylight play a key role in the distribution of light across the inner space of a room [31]. Higher skylight-to-floor ratios will result in higher illuminance, which can cause dazzling effect. That is why, based on the analysis of various samples, this ratio should be lower than 50% [48]. One of the preconditions for using Eq. 1 is the visibility of the sky [30]. In one-sided, wall-mounted skylights in which radiation of daylight is not blocked by any obstacle and the sky is visible from within the room space, the useful perimeter zone depth of the room is almost double the height of the skylight. However, in traditional houses where sky is visible through the windows that open out to the central courtyard, the skyline area in front of the skylight determines the height of the visible sky at the bottom end of the room, or the useful perimeter zone depth (Figs. 6 and 7) [48].

Figure 6: Visible sky without a daylight blocker in front of the skylight, the section of Ershadi House in Ardabil

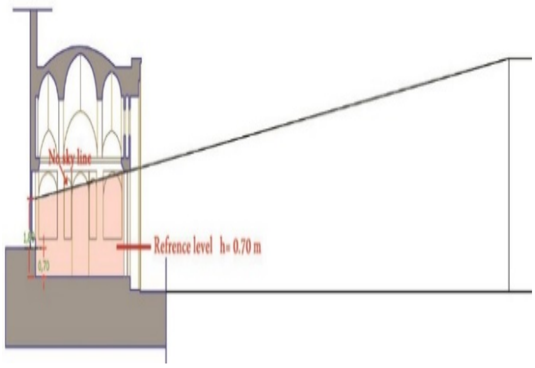


Figure 7: Visible sky without a daylight blocker in front of the skylight in the section, [11]

3 Methods

In this study,first the frequency of common structural geometric proportions in the traditional houses was determined.Then the frequency of daylight usage in them was investigated via the analysis of their maximum perimeter zone. Finally, the relationship between the structural proportions and the maximal exploitation of daylight was determined via the calculation of perimeter zone in Shahneshin rooms and comparing it with the frequency of geometric proportions. Based on this methodology, the most

Table 1: The relationship of the reflection coefficient with the proportions of the room and the daylight perimeter zone [13]

Reflectance R_b Room Width (m)	0.4 3	0.4 10	0.5 3	0.5 10	0.6 3	0.6 10
Window head Height (m)						
2.5	4.5	6.7	5.4	8.0	6.8	10.0
3	5.0	7.7	6.0	9.2	7.5	11.5
3.5	5.4	8.6	6.5	10.4	8.1	13.0

common layout of structural proportions employed in Ardabil's traditional houses for the purpose of daylight usage was identified. In order to obtain more accurate results and determine the most common structural proportion derived from the physical environment, almost all of the traditional houses inscribed on the cultural heritage list, mainly belonging to Qajar Era, were selected as the statistical population. The selected houses were Ebarahimi, Ershadi, Asef, Aghazadeh, Taghavi, Mojtahedi, Hekmat, Khadembashi, Khalilzadeh, Rezazadeh, Raiesi, Shariat, Sadeghi, Sadr, Samadi, Ghaseminezhad, Mobasheri, Moravvej, Managzadeh, Mirfattahi, and Vakil, which were respectively coded with a number beginning from 1 to 21 as is represented in Table 2. By measuring the width and Length of the rectangles depicted in Fig. 8 based on Table 2, the proportions of the Shahneshin plane as the central space of the structure was obtained.

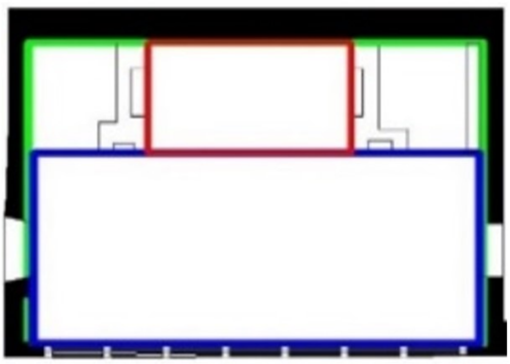


Figure 8: Proportions of the separated rectangles in the Shahneshin rooms of traditional houses

3.1 The location of the study

Ardabil is one of the cities in Iran which is situated at the latitude and longitude coordinates of 48° 2′ and 38° 25′, respectively [4]. The analysis of the topographic map of this city shows that it is situated at almost the middle southern area of the alluvial plain with the width of 80 km, altitude of 1200 m above sea level, and the total slope of lower than 0.5%. The city is situated in the range of Mount. Sabalan and its mean altitude in the plain area is calculated to be 1350 m above sea level. This plain is surrounded by a number of high hills and mountains and as we move away from the central parts to the outskirts, especially toward the west, the altitude increases [50]. Ardabil is situated in a short distance from Astara Port, which is located in the coast of the Caspian Sea. As a result, it is under the influence of the climate of the marine areas and, regarding the climatic conditions, is considered as one of the cold cities of the country [4] and falls into the group of areas having "very cold winter/ mild summer". In winter, the weather gets so cold that even when sunlight is directly radiated to the surfaces of structures, they are still quite cold [27]. However, in summer, they have proper thermal conditions even in the hottest hours of the day. Therefore, controlling coldness in this city is of paramount importance. The histogram diagrams of temperature variations in 2 hours as well as the range of thermal thresholds in Ardabil indicate that in 53. 77% of the time, the city is quite cold; about 34% of the time, the thermal conditions are appropriate when under sunlight, and only in 11.9% of the time are the conditions appropriate in shadowy areas. Furthermore, the sky is clear in 150 days of the year, and the sunshine duration is 2595 hours per year [4]. Therefore,

Table 2: Width-to- Length ratio of the rectangles derived from Shahneshin rooms of Ardabils traditional houses

Code of the room	1	2	3	4	5	6	7	8	8	8	9	10	11	12
3 * Main rectangle	1.57	2.19	1.72	1.73	1.94	2.70	1.56	1.59	1.87	2.48	1.51	1.77	1.18	
	12	13	13	13	14	15	16	17	18	19	20	20	21	21
	2.12	1.73	1.92	1.60	1.75	1.83	1.59	1.74	1.61	1.93	1.88	2.27	1.93	2
4 * Small rectangl	1	2	3	4	5	6	7	8	8	8	9	10	11	12
	1.45	0	1.07	0	1.93	1.30	0	0	0	1.07	2.11	0	1.47	0
	12	13	13	13	14	15	16	17	18	19	20	20	21	21
	0	1.39	2.45	1.96	1.44	1.52	0	0	0	0	1.56	0	1.10	2.62
4 * Large rectangle	1	2	3	4	5	6	7	8	8	8	9	10	11	12
	1.03	0	1.03	0	1.65	1.37	0	0	0	1.05	1.53	0	1.09	0
	12	13	13	13	14	15	16	17	18	19	20	20	21	21
	0	1.04	1.22	1.73	1.14	1.17	0	0	0	0	1.23	0	1.45	

the architecture of the region can be formed taking advantage of the climatic characteristics and considerations such as: orientation of the structure based on the reception of maximum sunshine (30° east), the east-west elongation of the structure, vicinity, and height of the structure based on the angle of radiation in winter [27]. Ardabil has an ancient historical texture that follows the pattern of other traditional cities in Iran and is home to several traditional places and many valuable religious and cultural sites [1]. Since the traditional texture of Ardabil has a defensive layout which is in the form of a spider web with different paths and streets having diverged from the central part of the city, there is no predominant orientation in the traditional houses of the city. However, in each residential building, the living space around the central courtyard has an appropriate orientation toward the sun so that the highest possible level of sunlight and solar heat can be received. Furthermore, the size and expansiveness of the glassy surfaces of the skylights are determined in a way that the skylights in the southern front can create greenhouse effect and trap the heat coming from the sun in a thermal cage to be used in the cold days of the year.

3.2 Structural proportions and geometric data of the spaces

In order to identify the geometric proportions employed in the main spaces of the traditional houses in Ardabil, first of all the frequency percentages of length-to-width proportions were determined in the 28 sample sunder investigation based on Table 2. In Fig. 10, the proportions employed in Shahneshin rooms have been classi-

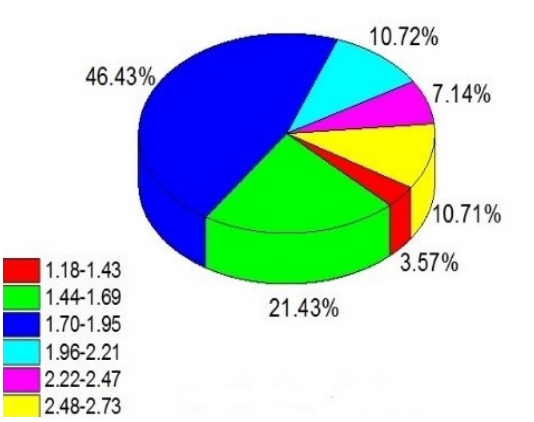


Figure 9: Relative frequency percentages of the proportions of the main rectangle (blue) in Shahneshin rooms

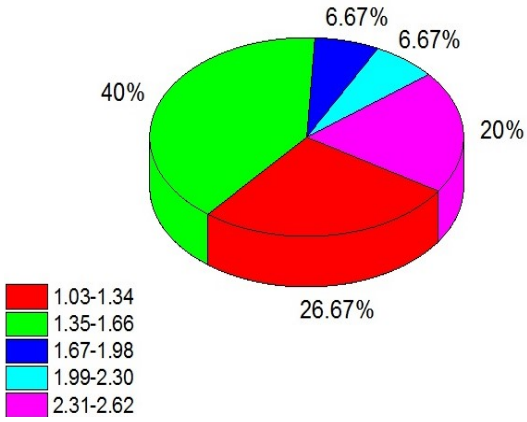


Figure 11: Relative frequency percentages of the proportions of the small rectangle (red) in Shahneshin rooms

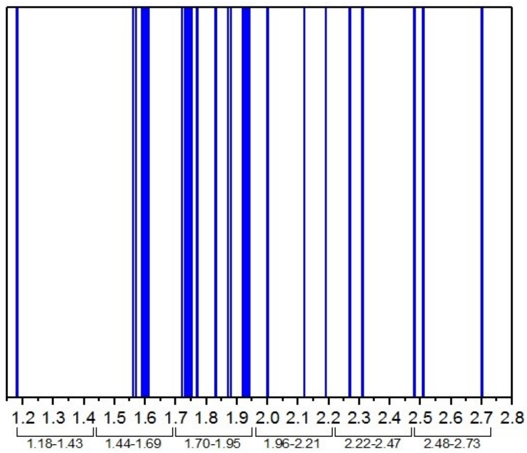


Figure 10: Frequency of the proportions of the main rectangle (blue) in Shahneshin rooms

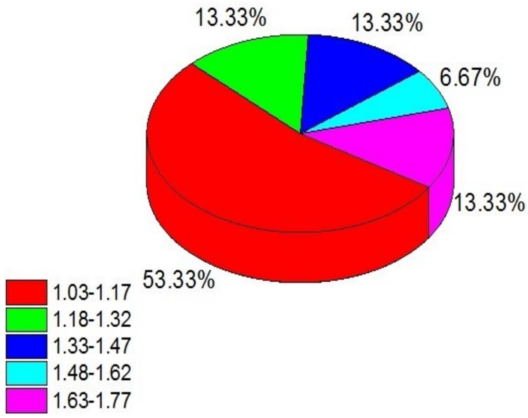


Figure 12: Relative frequency percentages of the proportions of the large rectangle (green) in Shahneshin rooms

fied using a frequency distribution table. To determine the frequency and length of each class of proportions,Estrogenic method was used [38] and the data were divided into 6 classes each with the length of 0.25. Based on these results, the set of proportions ranging from 1.70 to 1.95 was found to have the highest relative frequency percentage among the proportions of the main rectangle in Shahneshin rooms. As can be seen in Fig. 12, the set of proportions ranging from 1.03 to 1.17 was found to have the highest relative frequency percentage among the proportions of the large rectangle in Shahneshin rooms. Also, Fig. 11 shows that in the small rectangle, the highest relative frequency percentage tuned out to belong to the set of proportions ranging from 1.35 to 1.66. In order to determine dispersion in terms of the mean value of each class of proportions, the mean coefficient of variation in terms, which is obtained via dividing the standard deviation by the mean value, was used Eq.(3.5) [5].

$$C_\nu = \frac{\sigma}{\mu} \tag{3.5}$$

As can be observed in Fig. 13, the coefficient of variation is 17.48% for the main rectangle, 17.85% for the large rectangle, and 28.5% for the small rectangle. These findings indicate that the main and the large rectangles follow numerical proportions as their coefficient of variation was found to be lower. On the other hand, it seems

Table 3: Skylight-to-floor ratio, length, height of the window cap from the floor, and the room index of Shahneshin

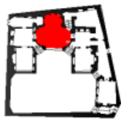
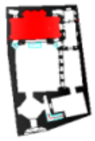
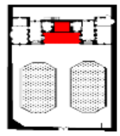
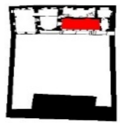
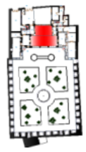
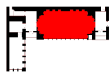
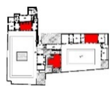
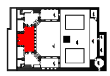
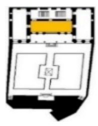
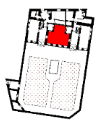
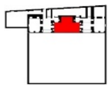
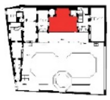
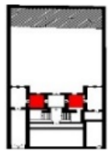
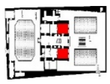
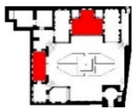
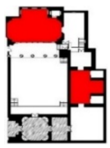
Orientation of the room	Height of the visible sky	Room Index	Width of the room	Height of the window cap	Depth of the room	Skylight to faade ratio	Skylight to floor ratio	Planes	Code of the room
S	4.70	5.5 3.3	6.75	4	6.5	52%	25%		1
E	4.60	7 1.97	9.94	4.10	5.72	32%	31%		2
SE	3.87	5 3.04	7.81	3.60	7.52	76%	39%		3
S	5.90	5 1.76	5.8	3.70	4	41%	84%		4
SE	4.50	6 1.90	8.55	4	5.18	45%	49%		5
SE	3.80	8 3.14	12.64	3.80	9.21	33%	43%		6
N	3.60	7 2.33	14.40	3.25	6.23	50%	36%		7
SE	5	5 2.77	7.26	2.12	4.57	33%	30%		8
SE	3.25	6 2.5	7.42	2.50	4.74	14%	35%		
SE	4.60	5 1.95	8.91	4	5.41	58%	41%		
SW	3.55	6 2.25	8	3.26	5.20	58%	57%		9
SE	4.62	7 1.37	9.37	4	3.86	37%	84%		10
S	3.37	6 3.65	8.09	2.70	7.4	27%	27%		11

Table 3. Continue

Orientation of the room	Height of the visible sky	Room Index	Width of the room	Height of the window cap	Depth of the room	Skylight to faade ratio	Skylight to floor ratio	Planes	Code of the room
SE	2.75	5 3.75	6.9	2	5.81	22%	21%		
SE	3.34	5 2.23	8.6	2.30	4.05	26%	26%		12
SE	4.85	7 2.37	5.80	3.30	5	51%	58%		
SE	4.15	6 2.27	10.90	3.70	6.30	69%	36%		
SE	2.80	5 3.73	10.05	2.80	8.19	15%	30%		13
S	4	6 2.90	8.15	3.50	7.13	41%	47%		14
S	4.55	5.5 1.98	5.33	4	4.55	30%	80%		15
NW	4	7 1.53	9.12	3.60	3.96	60%	74%		16
S	2.46	5 2.31	6.68	2.2	3.83	23%	39%		17
S	2.48	5 2.60	7.15	2.22	4.42	25%	32%		18
N	1.95	5 2.15	6.36	2	3.28	21%	29%		19
SE	4.20	6 2.54	8.53	4	6.93	60%	46%		
SE	2.70	5 2.16	8.03	2.50	3.53	28%	44%		20
SE	3.80	8 2.75	10.07	3.60	7.35	50%	38%		
SE	3.23	5 2.53	7.37	3.80	6.38	40%	25%		21

that the small rectangle has had a peripheral function of assigning a place for the chief member of the family to sit, and has usually been set in the house without any specific geometric pro-

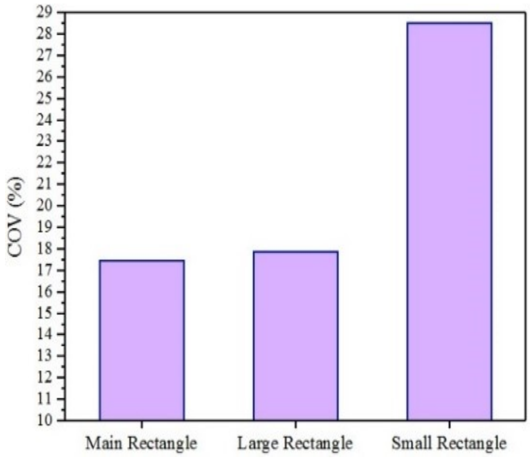


Figure 13: Mean coefficient of variation in terms of the percentage of rectangular proportions in the Shahneshin rooms of Ardabils traditional houses

portion. Therefore, according to Fig. 13, the reduction of the coefficient of variation in the main and large rectangles can be indicative of a performance compatible with the surrounding natural environment; hence, they can have the potential to be reproduced. Furthermore, the existence of the combinational performance in the spaces can also bring about geometric legibility in the structural environment [32].

3.3 Daylight perimeter zone

Based on the results obtained from the analysis of the selected samples, the Shahneshin rooms in most of the traditional houses were found to face south and south-east to get the most possible sunlight. They were also observed to have planes in the form of a rectangle or Tanabi. As can be seen in Table 3, the minimum height of the visible sky area from the bottom end of the room is 190 cm. This means that in the farthest distance from the window, a person sitting on the floor, sitting on a chair with the height of 80 cm, and even standing upright can benefit from the daylight. Since in all of the rooms, the height of the visible sky area was found to be more than 100 cm, we can conclude that quite sufficient daylight can reach the bottom end of all of the rooms. Therefore, the residents can easily take advantage of daylight and there is little need for artificial light. Due to the absence of the negative effect of nearby structures on the light influx, the perimeter zone can be even two times more illuminated. Furthermore, based on the explanations given above, Eq. (2.1) can be used to calculate the perimeter zone. Based on the results represented in Table 3, the spatial proportions, that is, the proportions of width and length to height are compatible with the equations presented above in the discussions related to the standards of room index. Therefore, we can conclude that in all cases, the spatial proportions are appropriate for the perimeter zone depth. The percentage ratio of the skylight surface to the floor in these houses varies from 25% to 84%. In many of the houses in which this ratio is higher than 50%, sunshades are used to adjust the amount of light pouring in.

4 Analysis of the results

To understand the relationship between the different sets of data obtained from the rectangular proportions of Shahneshin rooms, we need to determine their distribution and mathematical function. Only in this way is it possible to correctly analyze the nature of the distribution of proportions and perform the needed calculations. The distribution of the data around a fixed value led us to use a specific type of statistical distribution pattern called "normal distribution". As can be seen in Fig. 14, it seems that the data tend to cluster around the mean. This type of distribution is based on natural assumptions, and the variations of many different, unknown variables in nature on aggregate follow this pattern. Standard deviation (σ) is the most useful index to assess the dispersion of data. It shows the distance between each piece of the data and the statistical mean. Higher values of standard deviation suggest that the data are dispersed, while lower values indicate that they are more converged and tend to cluster together. The standard deviation of the variable$x$ is obtained through Eq. 4.6 below [38]:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}} \tag{4.6}$$

where n is the total number of data, X_i is the numerical value of the data, and $\bar{X}$ is the mean value of the whole data. Also, the mean value of

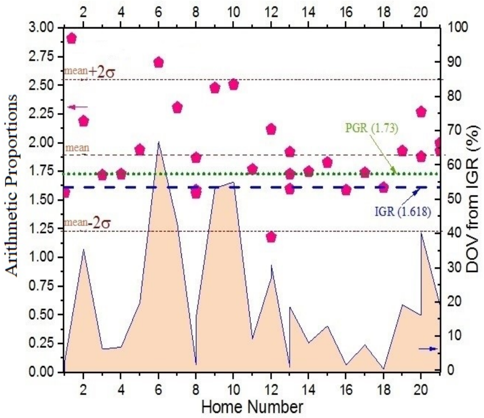


Figure 14: Normal distribution of proportions employed in Shahneshin rooms of Ardabils traditional houses

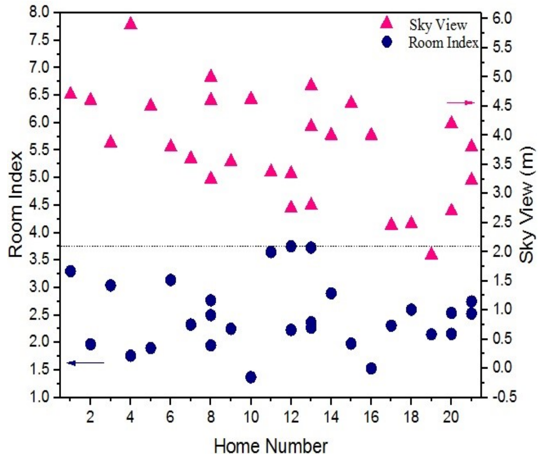


Figure 15: Room index and the height of the visible sky area in Ardabils traditional houses

the whole data is obtained from Eq. (4.6) below:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{4.7}$$

Regarding Fig. 14 and considering that 95% of the data are in the range of mean $\pm 2\sigma$, we can conclude that the obtained data follow normal distribution pattern. The use of the mean and standard deviation revealed that 95% of the proportions utilized in Shahneshin rooms were close to each other having a normal distribution around the mean value of 1.89 (Fig. 14). Furthermore, as can be in Fig. 14, most of the proportions used in the traditional houses were found to follow arithmetic proportions in addition to golden proportions. Still, 95% of the data in the specified range appeared to have normal distribution.

The upper part of Fig. 15 shows that the minimum height of the visible sky area in the bottom end of the room is 190 cm. Therefore, in all of the houses, sky is visible. According to the standards elaborated above, sky visibility is a precondition to using Eq. (2.1). Since this precondition was fulfilled in all of the rooms, the equation was sued to calculate the room index for all of them, which are presented in the lower part of Figure 15. The highest calculated room index was 3.75 which was lower than the minimum reflectance (i.e., 5) presented in Table 1. Therefore, for all of the Shahneshin rooms, the room index was found

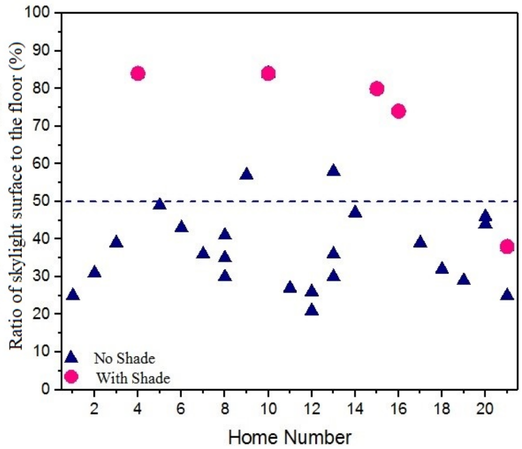


Figure 16: Ratio of skylight surface to the floor which indicates daylight distribution rate in Ardabils traditional houses

to be appropriate in terms of daylight perimeter zone depth. Fig. 16 shows the ratio of the skylight surface to the floor. According to the established standards, if this ratio exceeds 50%, the illuminance will be dazzling. Based on the results obtained, most of the houses had appropriate illuminance, except the houses coded as 4, 16, 10, and 15. However, all of these 4 houses with inappropriate illuminance had a porch with a sunshade that was used to protect them against the superfluous sunlight. In addition, Orosi windows, that are integrated in one piece, appeared to provide more consistent daylight and more integrated view from the outside as compared to the divided and disconnected windows [2]. They also reduced the probability of dazzling resulting from superfluous daylight. Moreover, colored glasses were found to provide more consistent daylight to the bottom end of the room spaces.

5 Conclusion

Analyses indicate that geometry and common spatial proportions in the structural environment have not only followed arithmetic proportions in various planes, but also have been able to provide sufficient amount of illuminance in an appropriate perimeter zone depth. Our investigations revealed that those houses which received excessive amounts of daylight tended to use horizontal sunshades to adjust the entering light. In fact, geometry and structural proportions have followed the data existing in nature not only in terms of the formal characteristics, but also in terms of the functional aspects. This effective interaction between physical and structural environments indicates that the daylight distribution rate and perimeter zone depth in the traditional houses of Ardabil are higher than the depth of the rooms. Via the use of common frames and decorations on the skylights, the distribution of daylight becomes uniform and overlaps with ideal conditions so as to respond to the human needs. In fact, 95% of the proportions used in the traditional houses have aimed to provide a consistent amount of daylight to the inner spaces of the structures. Besides these proportions, Orosi windows have mainly been adjusted based on the perimeter zone depth and the depth of the rooms so as to make the sky visible even from the bottom end of the rooms. That is why most of these windows appear to follow main rectangle proportions and the proportions related to the height of the room so as to ensure sky visibility from, and daylight penetration to the farthest ends of the rooms. The structural system has been designed in a way that follows specific proportions in planes and skylights with maximum efficiency and minimum error to make it compatible with an important characteristic of the physical environment. Therefore, the variables of the structural environment have followed the natural and have developed in accordance with its characteristics. The structures designed based on specific natural proportions are enduring due to not only following the standards of beauty, but also ensuring an appropriate and integrated performance. Therefore, the simultaneous and integrated consideration of the components of structural space and the natural characteristics of the surrounding environment can lead to an appropriate interaction between physical and structural environments in modern architecture.

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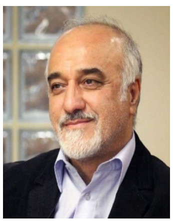

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