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Original Research Article

An Investigation of the Golden Proportions and Geometric Principles Derived from Nature in the Structural Components of the Traditional Houses (Case Study: Qajar Houses in Ardabil)

Mahsa Javadi Nodeh[1], Azadeh Shahcheraghi[2*], Alireza Andalib[3]

1. Ph.D, Department of Architecture, Science and Research Branch, Islamic Azad University, Tehran, Iran.
2. Associate Professor, Department of Architecture,Science and Research Branch, Islamic Azad University, Tehran, Iran.
3. Associate Professor, Department of Urban Development, Science and Research Branch, Islamic Azad University, Tehran, Iran.

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Abstract

Problem statement: The use of proportions derived from nature in vernacular architecture is one of the principles that govern the interactionsbetween the built environment and nature. The existence of the formal relationship between the built environment and nature can lead to optimization,order,and stability in the built environment.In fact,structures in nature have become stable over time in terms of form and combination and can create reproducible principles regarding the continuity and beauty of spaces.Nowadays,such principles have been neglected in the proportions and numeric relationships employed in the geometry of spaces.The sample of this study contains twenty-four traditional houses in the Qajar era in Ardabil because most of these buildings have been built in this period.

Research objective: The present study aims to determine the compatibility of common geometric proportions used in the traditional houses of Ardabil with Iranian proportions,golden ratios ,and approximate ratios derived from nature to identify the most common nature-friendly layout in the region.

Research method : This study isapplied and mixed-methods research in which both quantitative and qualitative methodsare employed**.** First of all, the data related to the dimensions, sizes, and computational ratios were obtained via field observations. After that, the geometric proportions employed in halls, rooms, and main facades were identified using frequency diagrams. Then their compatibility with the proportions derived from nature was analyzedto determine which spatial ratios and standards derived from nature had the highest frequency in the buildings.

Conclusion: The results showed that the architecture of the traditional houses was consistent and compatible with nature in terms of formal characteristics.in addition to using Iranian proportions, golden proportionsin laying out the elements and architectural spaces from plans to façades,the architects of the buildings have also made use of ratios close to simple arithmetic proportions. This shows the relationship between the spatial patterns and the combination of data received from nature,which have been integrated intothe construction of the buildings.

Keywords: *Geometry, Nature, Golden Proportions, Traditional Houses, Ardabil City.*

* *Corresponding Author: +989123290241، Shahcheraghi@srbiau.ac.ir

Introduction

Traditional architecture has been formed within the limits of nature and in interaction with it. Therefore, nature is the basic foundation of this type of architecture (Neghabi, Hashempor & Asefi, 2020, 114) Accordingly, each aspect of traditional architecture is rooted in some covert features of nature (Lafafchi & Jahandar, 2017,85). Since the primary purpose in nature is to optimize structures and putthemin the most effective order (Mehdinezhad, Siroos Sabri, Ebrahim Damavandi, Abbaspoor, 2012,60) thearchitectural designs derived from nature are also optimized and orderedin their basic patterns, proportions, and regular geometry. The application of these geometric principles has linked Iranian architecture with various aspects of nature, and this close connection with naturehas made it sublime. Therefore, the architecture of the traditional houses in Iran best represents the coordination of the built environment with nature based ongeometric principles (Daneshdoost, 1995, 4-45). In fact, the architects of these traditional structures have selected and applied a logical proportional pattern based on their knowledge of various factors includingthe available materials, climate conditions, geometric and mathematical calculations, technical and executive issues, and the dominant culture (Balilan & Hasanpour, 2019, 49).Hence, the geometric principles derived from nature have served multiple functions in traditional architecture. Today, however, less attention is paid to the proportions and numerical relationships in the geometry of spaces. Such geometric principles can be reproduced to achieve aesthetic effects. They can be revised, altered, and adapted to the needs of today while maintaining the consistency and harmony of good architecture. Furthermore, the analysis of basic geometryin traditional buildings makes it possible to identify the geometric principles employed in designing and constructing main spaces, connecting various spaces inside the building, determining the location of each architectural element, and the relationship between beauty and stability of the structures. The recognized principles can then be used torepair and rebuild traditional structures.

In fact, the structures in nature have undergone various changes and alterations over millions of years to get to a stable condition (Mehdinezhad et al., 2012, 65). Many scientists and philosophers like Plato, Euclid, Kepler, Aristotle, etc. consider the golden ratio and its approximations (proportions obtained from Fibonacci sequence) as the most important geometric and proportional principles derived from nature. In addition to them, we have Iranian proportions, which have been recognized by Pirnia, Bouzjani, etc. The Iranian proportions are based on the regularities that exist in the system of the world and are all inbalance with nature (Pourahmadi, Yousefi & Sohrabi, 2011, 70) Various studies have alluded to the existence of proportions and geometric patterns in the structure of thetraditional houses in Iran. However, detailed studies on the geometric properties of the traditional houses, especiallythe use of golden proportions and their approximationsare scant. There are many valuable architectural structuresin the historical texture of Ardabil, typical examples of which are traditional houses. However, less attention has been paid to these structures and their architectural properties. Bearing these in mind, the current study aimed to identify the nature-related geometric principles employed in the spatial-structural elements of traditional houses in Ardabil to determinethe mostcommonly used proportions in different parts of the buildings. More specifically, the present study was an attempt to identify the geometric patterns and proportions employed in the construction of halls, rooms, and the main façades of the traditional houses via the use of drawing methods and computational ratios.

To obtain more precise data and determine the most common nature-related proportions used in these houses, almost all of the registered traditional houses in Ardabil (24 houses) were investigated. These houses, which have been registered as cultural heritage, mainly belong to the late Qajar Era. The geometric proportions used in the main spaces ofthese buildings were studied using drawing methods and frequency figures so as to determine the most common ratios. The analyzed spaces consisted of 28 halls, 95 rooms, and 28 main façades.

Literature review

After investigating various instances of historical buildings, many researchers have emphasized that there is a relationship between golden proportions and the structure of historical buildings (Najiboglou, 2010) The first application of golden ratios can be traced back to the primitive engineers who built Egyptian Pyramids and Parthenon Temple (Bemanian, 2002, 7). These ratios were also widely employed in architecture, painting, sculpture, etc. during the Middle Ages, Renaissance, and other eras to achieve balance and beauty (Mollazadeh, Mohammadian Mansor, Javanmardi & Khodabande, 2017, 82)For instance, Le Corbusier developed his modular system based on golden proportions (Noghrekar, 1999, 122). Iranian proportions can be observed in various historical buildings such as Persepolis, ChoghaZanbil Ziggurat, Jame'a Mosque of Isfahan, Sheikh Lotfollah Mosque, NiasarChaharTaq, etc. as the guiding and regulating principles in their construction (Mahdipour, 2012, 98).

To date, several studies have been conducted on historical textures in Iran. These studies have indicated that geometric patterns and proportions have been employed extensively in the construction of many artistic works and architectural buildings in this country. In keeping with the purpose of the present study, some of these studies are touched upon below.

In aresearch study, Pourahmadi, Yousefi&Sohrabi (2011, 60) used statistical methods to investigate length to breadth ratio of courtyards and rooms in the traditional houses of Yazd with reference to Pirnia's principles for Iranian proportions. They found that although these houses did not follow Iranian proportions, their dimensions were close to simple arithmetic ratios. In their study, besides the hot climate of the region, only the compatibility of the structures with Iranian proportions was investigatedbased on Pirnia's principles. In the current study, however, besides climatic and regional conditions, further details including the golden ratios derived from nature and the covert geometry of elements have been considered in the analysis of the proportions used in various spaces.

In another study, Balilan & Hasanpour (2019, 45) made an attempt to identify the geometric patterns employed in the art and architecture of the historical region of Abyaneh. They observed golden proportions in all of the artistic and architectural samples under investigation.However, via defining the limits of research, the present study formally investigates the proportions used in the structural components of traditional houses. In so doing, the frequencies of proportions in the design of plans and façades are determined, the covert geometry used in structural components and elements is explored, and spatial similarities and proportional patterns are examined.

In an analytical study, HashemiZarjabad, Ziaee Nia & Ghorbani (2016, 207) investigated geometric principles and golden proportions in the plan, façade, and section of Shokatieh School and observed that golden ratio was used more frequently than Iranian proportions. Similar studies have also been conducted on the proportions employedin the courtyards and façades of Safavid-Era mosquesin Isfahan, Timcheh Bazaars, and other architectural structures.The difference between these studies and the present one is in the period to which the structures belong as well as in the number of samples and the types of spaces being investigated. There are very few traditional structures belonging to the Safavid Era. However, in the present study, more samples from the Qajar era have also been investigated to obtain more detailed and dependable results. This canlead to more comprehensive information on the historical architecture of different eras.

In a descriptive-analytical study, Najafgholi Pour, Etessam & Habib (2017, 477) explored the geometry and proportions used in the traditional houses of Tabriz. They observed golden proportions in the structure of symmetrical buildings andanother type of proportion in other traditional houses of the region. In their study, merely golden proportions used in the façades of some traditional houses were investigated. Details concerning other structural components were not considered. In the current study, however, halls, rooms, façades, and other components have been investigated in a relatively large number of traditional houses belonging to a historical era in terms of the use of golden proportions.

In another study, Zakeri, Ghahramani, Shahnazi & Bazyar HamzeKhanie (2016, 27) analyzed the application of 'Iranian Golden Rectangle' and 'Gaz and Module' in five-door spaces, three-door spaces, and courtyards of 10 traditional houses in Shiraz via the use of various statistical tests such as normal distribution tools, coefficient of variations, etc. Their results revealed that the investigated spaces mainly followed 'Gaz and Module' ratios rather than the Iranian golden rectangle. In the current study, in addition to analyzing a larger statistical population, various research methods like frequency graphswithdifferentnumbers of classes and lengths have also been used. The aim was to determine the compatibility of vernacular architecture with the geometric and proportional principles derived from nature and their approximations.

A review of studies conducted to date reveals that although geometric and proportional principles have been investigated in the houses of various regions, studies on the houses located in the cold regions of Iran are limited. Only the façades of the houses in such regions have been investigated. Therefore, the present study aimed to focus on the components of plan and façade, especially in the architecture of the traditional houses belonging to the Qajar Era in Ardabil so as to identify geometric and proportional patterns in various components of the spaces. This study is the first one addressing such detailed components in this region. Previous studies have mainly focused on vernacular architecture in a limited number of buildings exploring only Iranian proportions. In those studies, the plan or façade of the buildings has been investigated as a whole and no detailedinformation has been provided. In the present research, however, all of the geometric proportions derived from nature together with their approximations have been investigated in detail in the structure of halls, rooms, façades, and some Orosi windows. Considering such details in the analysis of the buildings is the innovative aspect of the current study. We believe that byrecognizing the predominant geometric patterns in the traditional structures of the region and using them in designing new houses, we can establish sustainable architecture. The present study was a type of mixed methods research in which both qualitative and quantitative methods were employed. The predominant geometry in the spaces was indicated in a frequency graph with specific classes and length so that data analysis could be performed inductively and the applied geometric principles and their functions could be identified. To do so, first of all, a theoretical framework for geometry and golden proportions wasadopted. Then using computational, drawing, and analytical methods, the common geometric patterns were identified.

Methodology

In the present study, the required data were collected from the analysis of bibliographicstudies and existing plans as well as from various field observations. As can be seen in Fig. 1, after reviewing previous studies and deciding upon the theoretical foundations of the study, the proportions employed in 123 rooms and 28 main façades in a total of 24 traditional houses in Ardabil were investigated via the use of drawing and computational procedures. Then the proportions used in the visible structures of plans and façades were identified. After that, the quantitative data obtained from the experimental investigations were analyzed to obtain frequency graphs.Sturges Rule was used to calculate the number of data classes and their length for the halls, rooms, and main façades. Finally, the compatibility of these components with geometric patterns and proportions derived from nature was examined. In this study, the regularity of geometric structuresand geometric systemshas been analyzed via the use of drawing methods and computational proportions.

Theoretical foundations of the study

In the present study, the interrelationships between geometry, architecture, and ratios derived from nature as well as golden proportions, Fibonacci sequence, and the geometric principles employed in architecture were investigated. In the sections below, these concepts are introduced in greater detail.

• Ratios derived from nature in geometry and architecture

The ratios existing in different shapes that have been formed in nature follow the abstract rules of geometry. On the other hand, architecture and geometry have a close relationship with each other. Therefore, they can be considered as a kind of natural phenomenonand reflect natural proportions (Hejazi, 2008, 17). Particularly in traditional architecture, all of the dimensions and patterns have their roots in nature, and nothing in this type of architecture has been the result of whim or coincidence (Pirnia, 1999, 159). Geometric regularity is essential for any dynamic and organized system. For instance, all of the dimensions in an architectural structure, both in their entirety (height, length, and breadth) and in their constituent components (including surface patterns) are intertwined with geometry (Nasr, 2000, 114-118). Geometry itself has developed via modeling the sacred patterns formed and evolved in natural shapes (Najafgholi Pour et al.., 2017, 482). Then, it has been used to generate balance, coordination, harmony, order, beauty, innovation, creativity, structural form, climatic function, etc. in architecture (Ozkan & Dogan, 2013, 170). In other words, traditional architecture has produced harmonious structures and created architectural spaces via modeling the geometry that exists in nature (Ahmadi & Habib, 2020, 137). Based on this general approach, traditional architecture has been able to create attractive environments with stableidentities (Heidari & Ghasemian, 2019, 88). One of the first applications of natural phenomena in architecture is the use of the geometry derived from the golden ratio in plans and façades (Ghyka, 1977, 88-91). This proportion is concordant with Euclidean geometry, which is rooted in the mathematics of dots and lines (Roustayi, 2016, 43). Thus, geometric order can be derived from nature, mapped onto architecture, and result in multidimensional coordination with the architecture on the basis of the rules of nature.

- Golden proportions and Fibonacci sequence

Since ancient times, the golden ratio has attracted many scientists and artists as the most beautiful symmetrical ratio in nature. This ratio has been employed in various geometric structures such as rectangles, helixes, triangles, and regular pentagons.

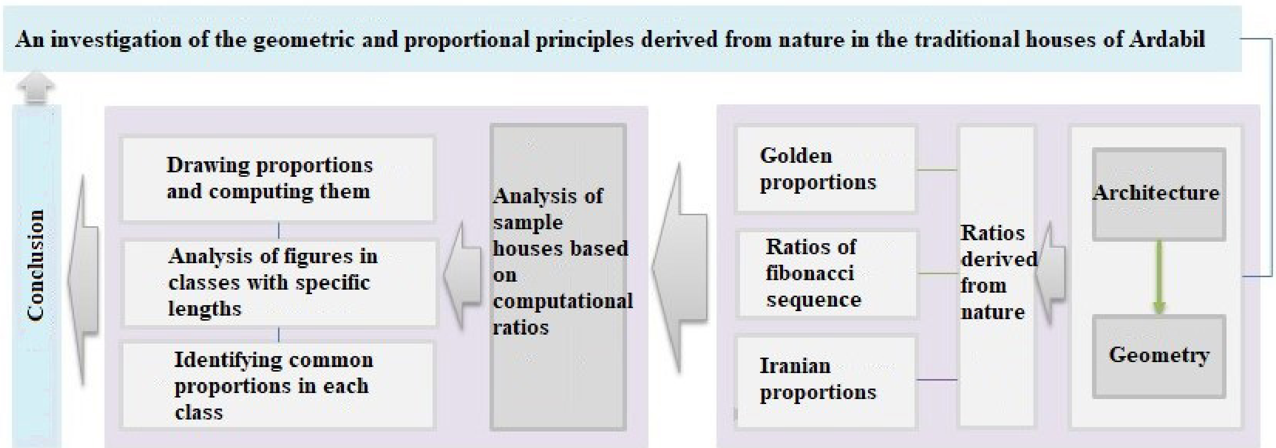


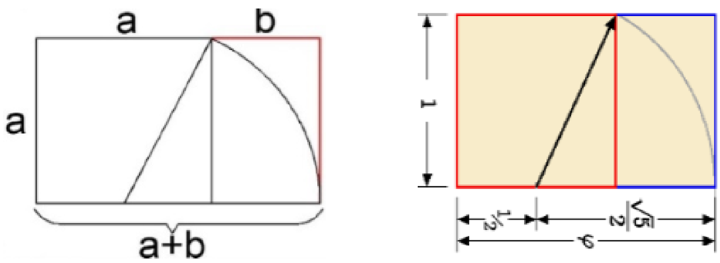
Fig. 1. The diagram of the research process. Source: Authors.

A rectangle whose length to breadth ratio equals phi number (Φ) and is derived from a regular pentagon with the related proportions is called the golden rectangle (Moosavi, 2017, 40). The details are illustrated in Figs. 2 & 3. Also, as is shown in Fig. 4, a helical form turning around at a specific angle is created via dividing the rectangle, which is called the golden helix. This helix is formed based on phi-factor or golden division (Madden, 2005, 14-16). This helix resembles the trend of energy radiation in nature. It looks as if energy is distributed from the center outward in a helical form as the result of a natural process. The growth patterns of animals, the patterns of planets in space, etc. have been shaped following this rhythm (Moosavi, 2017, 42). Phi ratio has also been used to create a rectangle whose short side is a unit of the long side and each time a square is truncated from the rectangle, the remaining rectangle still maintainsthe original ratio. This ratio is observed to exist all over nature (in oysters, snails, petals, etc.) (Golparvarfard, 2008, 39).

Leonardo Fibonacci is a 12th-century mathematician who introduced the Fibonacci sequence. He figured out the deep relationship between this sequence and the golden ratio and believed that both are derived from nature (Akhtaruzzaman, 2011, 15). Fibonacci sequence, which is an approximation of the golden ratio, can be found everywhere in nature from the arrangement of leaves and petals in plants to the structure of space. In other words, due to its mathematical and geometric features, this ratio can be observed in various forms in a wide variety of natural structures from galaxies to crystal molecules, plants, animals, and the human body. In fact, the traces of the Fibonacci sequence and golden ratio can be detected in all aspects of nature from atoms to cosmos. It can be said that these proportions have always been a pathway to get to a better condition and reducepossible problems (Moosavi, 2017, 39-51). Although mathematics and geometry have been two distinct areas of science, they have had exchangeable methodsto focus simultaneously on a given concept. One has relied on the language of numbers in describing a concept and the other has used geometric shapes (Najiboglou, 2010, 188) Fig. 5 below shows the relationships between the Fibonacci sequence and golden rectangle.

In the traditional architecture of Iran, some proportions concordant with nature have been applied. In addition to Pirnia, other scholars like AbolvafaBouzjani, Abu EshaqKoubanayi, etc. have also talked of Iranian golden ratios (Pourahmadi et al., 2011, 71).The rectangle whose length to breadth ratio equals 1. 73 is the Iranian golden rectangle. Moreover, as is indicated in Fig. 6 below, 1. 41 is also one of the proportions used in drawing this rectangle (Attarian, Momeni & Masoudi, 2016, 71) The ratios of the golden rectangle can also be surrounded in a regular hexagon. As can be seen in Fig. 7, rectangles surrounded by regular hexagonshave always attracted the attention of Iranian architects (Pirnia, 1999, 155-159). In addition to 1. 41 and1.73, the ratios of 1. 15 and 2. 31 have also been obtained from the rectangle surrounded bythe hexagon.

The limitedness of this geometry to just rectangular ratios not only is not indicative of its perfection but shows a lack of dynamicity in this type of architecture. The connection between architecture and geometry is not something accidental. Issues beyond formal shapes are involved in parts and



$$\varphi = \frac{1+\sqrt{5}}{2} \sim ۱.۶۱۸$$

Fig. 2. Drawing a rectangle based on the golden ratio and its mathematical equations. Source: Posamentier & Lehmann, 2012, 8.

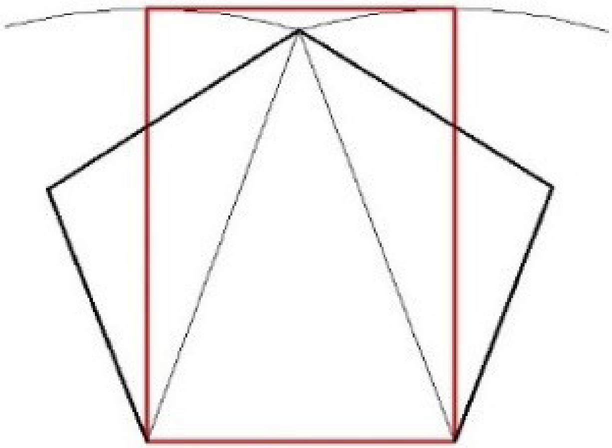


Fig. 3. The golden rectangle obtained from a pentagon with a diameter to side ratio of 1.61. Source: Navai & Haji Ghasemi, 2011, 117.

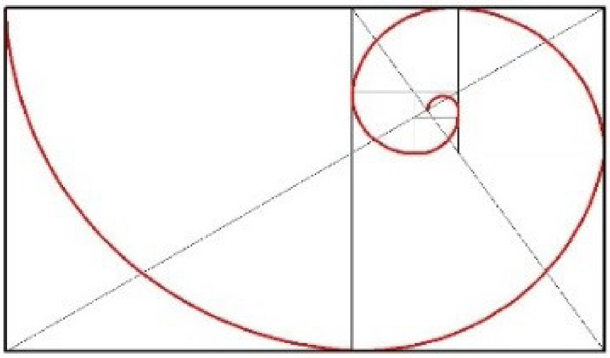


Fig. 4. The helix obtained from dividing the golden rectangle. Source: Posamentier & Lehmann, 2012, 8.

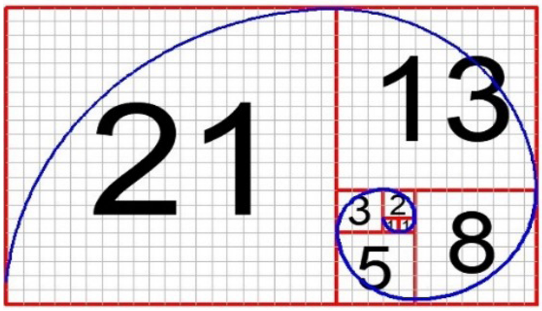
whole of this connection. Geometry is, in fact, the mathematical language of architecture, which seems to be simple but is complicated and multi-functional deep down (Pourabdollah, 2010, 9-11).

- Principles of applying geometric proportions in architecture

As a mathematical science thatis used for detecting proportions with its qualitative and quantitative dimensions, geometry is the substance and foundation of architecture. Therefore, if an architect wants to create a desirable architectural structure, he/she must follow the principles of this science (Rosental, 1970, 7-188). The relationship between architecture and geometry can be observed both in the visual combination of a building and in the practical aspects of its components (Taheri & Nadimi, 2014, 5) Geometric principles of nature have beenapproached and imitatedfrom different angles, through different methods, and in various surfaces (Falahat, 2017, 167). Following such principles and patterns can lead us to sustainable achievements (Lafafchi & Jahandar, 2017, 102). In fact, the application of geometry in architecture deals more with the rational world rather than the sensible world and is a skill founded on a combination of structural and perceptual factors (Najiboglou, 2010, 181). Geometry is not merely a symbolic entity; it is an organizing factor in the whole building (Abbasi, Valibeig, Saedvandi & Ghasemi, 2019, 96).and seeks to respond to the functional, structural, and aesthetic needs in architecture. The geometry of each region followsproportional patterns in different ways (Bemanian, Akhavat & Baqaei, 2010, 15-16) Therefore, an overt form of this geometry is used in the whole structure of the buildings and a covert form of it is hidden in the buildings and affects structural shapes (Tabataba'i Zavareh, Valibeig, Azimi & Shahbazi Chegeni, 2018, 105). In traditional architecture, in addition to golden geometry, a module has also been a tool for creating regular-sized components in buildings. The use of Peymoon has reduced divergence in sizes, facilitated the arrangement of different parts, and created new spaces without any need for substantial changes in the other spaces (Zakeri et al., 2016, 16).

Data analysis

As mentioned earlier, the geometric proportions applied in the structure of traditional houses can be detected through drawing methods and the analysis of numerical data obtained from computational ratios. Accordingly, after exploring the city and the historical area under investigation, samples were selected and the proportions existing in the spaces were checked. Then each of the samples was analyzed via the use of drawing methods. Traditional houses consist of various spaces such as 3-door room, 5-door room, hall, guesthouse, vestibule, atrium, kitchen, stable, warehouse, etc., which are generally divided into 3 categories: main spaces, service provision spaces, and communication spaces (Moosavi, Tabassi & Mehdizadeh, 2020,



$$f(n) = \frac{\varphi^n - (1-\varphi)^n}{\sqrt{5}} = \frac{\varphi^n - (-\varphi)^{-n}}{\sqrt{5}}$$

$$\varphi = \frac{1+\sqrt{5}}{2} \sim 1.618$$

$$n{=}k \rightarrow f(n) = \frac{(\frac{1+\sqrt{5}}{2})^n - (\frac{1-\sqrt{5}}{2})^n}{\sqrt{5}}$$

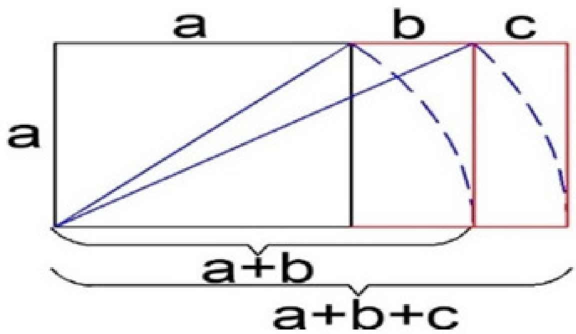
$$f(1) = 1\,,\ f(2) = 2\,,\ f(3) = 3\,,\ f(4) = 5\,,\ f(5) = 8$$

$$f(6) = 13,\ f(7) = 21,\ f(8) = 34,\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

=4.25

$$\frac{f(7)}{f(6)} = 1.61 \qquad \frac{f(7)}{f(6)} = 2.62 \qquad \frac{f(7)}{f(4)} = 4.20$$

Fig. 5. Golden rectangle and its relationship with Fibonacci numbers and the related ratios. Source: Posamentier & Lehmann, 2012, 8.



$$\frac{a+b}{a} = 1.41$$

$$\frac{a+b+c}{a} = 1.73$$

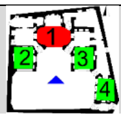
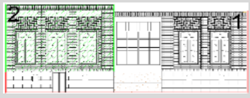
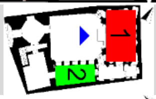
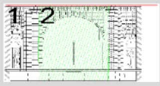
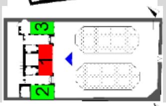
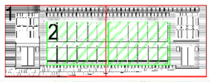
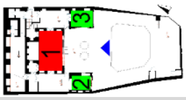
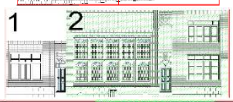
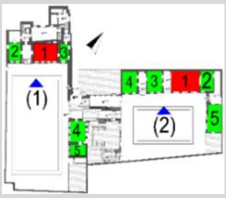
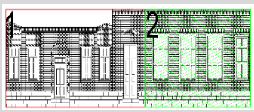
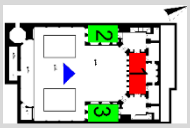
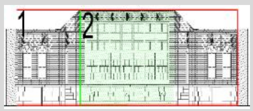
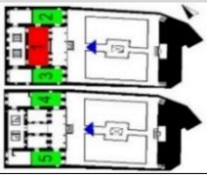
Fig. 6. Steps of drawing Iranian rectangle and the resultant ratios. Source: authors based on Posamentier & Lehmann, 2012, 8.

32)In the present study, the geometry of the main spaces including rooms and halls were investigated. Furthermore, in addition to the plan of the buildings, theirmain façades were also separately investigated.

Location of the study and samples

Ardabil is one of the ancient cities in Iran. It has a historical texture that follows the typical patterns of Iranian cities. Many valuable architectural structures exist in this city, including traditional houses. This region has a cold winter/ mild summer climate and is situated at analtitude of 1350-1500 meters above sea level (Zohuri, 2016, 215). The old texture of the city is in the form of a spider web. Considering the climate of the region, most of the traditional houses in the city face the sun so as to receive the highest level of sunlight and heat during the day (Javadinodeh, Shahcheraghi & Andalib, 2021, 22). Hence, the orientation of the main façades of the house is usually towards the southwest to the southeast. In the present study, to determine the most commonly used geometric proportion derived from naturein the traditional buildings of the region, almost all of the local traditional houses registered as cultural heritage (which mainly belong to the late Qajar Era) were selected to be investigated. The names of the selected houses are Ebrahimi, Arbabi, Ershadi, Asef, Aghazadeh, Hekmat Hall, Taghavi, KhademBashi, Khalilzadeh, Rezazadeh, Raiesi, Shari'at, Sadeghi, Sadr, Samadi, Ghaseminezhad, Mobasheri, Mojtahedi, Mostafavi, Manafzadeh, Mon'em, Mir Fattahi, Namazi, and Vakil. They werelabeled with a number from 1 to 24 as in Table 1 below. Of these traditional houses, Manafzadeh follows the patterns of the Qajar Era but belongs

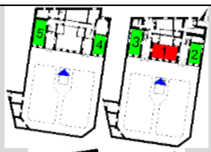
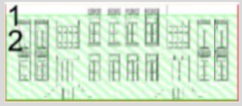
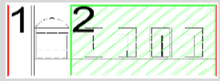
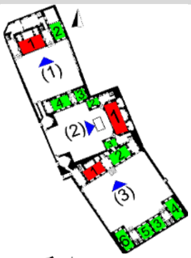
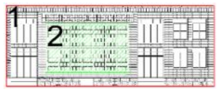
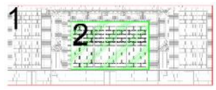
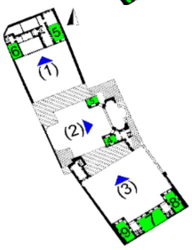
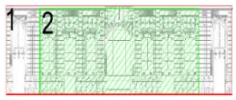
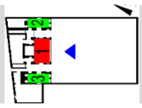
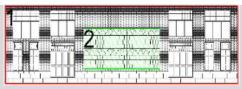
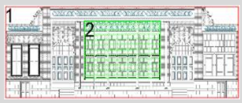
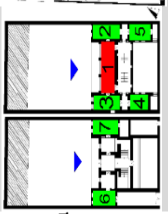
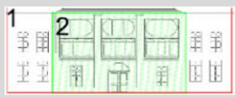
Table 1. Proportions of plans and façades in the traditional houses of Ardabil. Source: Authors.

Code of the Houses	Name of buildings	plans	Proportions of plans		Main façade	Proportions of façades	
1	Ebrahimi		1 2 3 4	1.57 1.14 1.18 1.35		1 2	2.65 1.73
2	Arbabi		1 2 3 4	1.40 1.75 1.10 1.60		1 2	2.60 1.40
3	Ershadi		1 2	1.75 2		1 2	1.44 1.35
4	Asef		1 2 3	2.30 1.63 1.71		1 2	4.20 1.61
5	Aghazadeh		1 2	1.65 1.66		1 2	2.62 1.95
6	Hekmat Hall		1	2.64		1 2	1.61 1.61
7	Taghavi		1 2 3	1.94 1.18 1.18		1 2	2.30 1.67
8	KhademBashi (1)		1 2 3 4 5	1.61 1.38 1.68 1.16 1.68		1 2	2.09 1.01
	KhademBashi (2)		1 2 3 4 5	1.62 1.36 1.25 1.18 1.60		1 2	3.75 1.61
9	Khalilzadeh		1 2 3	2.65 1.61 1.62		1 2	3.85 1.63
10	Rezazadeh		1 2 3 4 5	2.55 1.63 1.60 1.64 1.68		1 2	2.61 1.60

to Pahlavi Era. However, due to its similarity to the patterns of houses belonging to the Qajar Era, it was included in this study. The proportions in this table have been obtained bycalculating the length to breadth ratio of the plansof halls, rooms, and main façades.

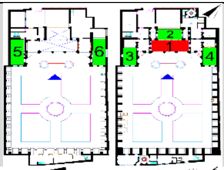
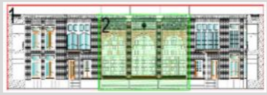
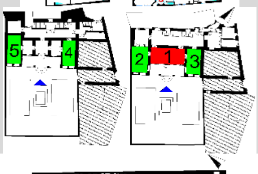
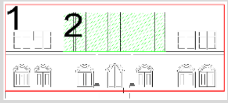
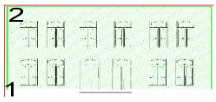
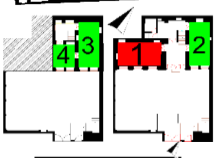
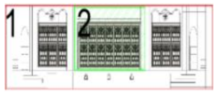
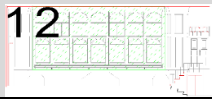
Based on the studies conducted on the selected houses, rooms with different usages are mainly in the form of a rectangle. Moreover, halls are usually situated at the center of the plan. They are also in the form of a rectangle with the long side facing south and south-east so as to receive the most sunlight. As can be seen in Table 1, the main façades, at the centers of which halls are located, follow specific proportions. However, in none of the houses is there any relationship between the largeness of the rooms and halls and the number of doors (or windows) installedin the main façade. For instance, the 3-door hall in Ershadi House is bigger than the 5-door hall in Taghavi House. Furthermore, analysis

Rest of Table 1.

Code of the Houses	Name of buildings	plans	Proportions of plans		Main façade	Proportions of façades	
11	Raiesi		1 2 3 4 5	1.75 1.77 2.30 1.78 2.29		1 2	3.10 1.63
12	Shariat (1)		1 2 3 4 5 6	1.18 1.74 1.71 1.60 2.62 1.65		1 2	2.40 2.67
	Shariat (2)		1 2 3 4 5	1.74 1.78 1.61 1.65 1.65		1 2	2.80 1.61
13	Sadeghi (1)		1 2 3 4 5 6	1.75 1.60 1.14 1.62 1.63 1.70		1 2	2.40 1.61
	Sadeghi (2)		1 2 3 4 5	2.60 1.60 1.62 1.60 1.58		1 2	2.61 1.61
	Sadeghi (3)		1 2 3 4 5 6 7 8 9	1.72 1.75 1.14 2.28 1.13 2.17 1.71 2.29 2.28		1 2	3.62 2.60
14	Sadr		1 2 3	2.25 1.65 1.65		1 2	3.70 2.32
15	Samadi		1 2 3 4	1.75 1.51 1.65 1.60		1 2	3.14 1.61
16	Ghaseminezha d		1 2 3 4 5 6 7	2.65 2.60 2.62 1.58 1.80 2.31 2.58		1 2	1.60 1.61
17	Mobasheri		1 2 3 4 5	1.61 1.60 1.64 1.65 1.64		1 2	4.25 1.61

of the main façades reveals that covert geometry has been used in various parts of the façades. The use of such geometric proportions has also affected the whole façade. In the houses with symmetrical façade, that is, in 4, 9, 10, 11, 15, 16, 17, 18, and 22, golden proportions have been used at the center

Rest of Table 1.

Code of the Houses	Name of buildings	plans	Proportions of plans	Main façade	Proportions of façades
18	Mojtahedi		1 2.59 2 1.73 3 1.62 4 1.65 5 2.60 6 2.68		1 4.10 2 1.61
19	Mostafavi		1 1.93 2 1.75 3 1.98 4 2.25 5 2.31		1 1.12 2 2.29
20	Manafzadeh		1 1.85 2 2.32 3 1.56 4 1.54 5 1.97 6 2.06		1 1.51 2 1.61
21	Monem		1 1.76 2 2.25 3 2.30 4 1.10		1 2.04 2 1.63
22	Mir Fattahi		1 1.85 2 2.30 3 2.29 4 2.27 5 1.12		1 3.57 2 1.61
23	Namazi		1 2.61 2 1.25		1 2.58 2 2.30
24	Vakil		1 1.95 2 1.15		1 2.20 2 1.73

of the façade. Also, in the houses with asymmetrical façades, namely in 8, 12, 20, and 21 as well as in the Orosi windows of 6 and 13, golden proportions have been employed. To obtain more precise and accurate information on the use of such proportions, the collected data wereanalyzedstatistically.

Data analysis

To obtain dependable results regarding computational ratios, the data must be analyzed based ona logical order. It is in this way that they can be interpreted meaningfully.Classifying the data requires a step-by-step calculation of the number of classesand their length via the use of specific formulas. To do so, the following formula, which is known as Sturges Rule, was used (Nasiri, 2005).

K=1+ (3. 3 logn)

K= the number of classes

N= total numbers

Log= logarithm with base 10

Therefore, to identify the geometric proportions used in[28] halls of the total 24 traditional houses in Ardabil, their plans were divided based on the coding system described in Table 1 and Fig. 8 (in terms of being Three-door, four-door, five-door, seven-door, nine-door, and twelve-door). As can be seen in Fig. 8, the obtained data were categorized into[6] classes each with alength of 0.25. The frequency percentage of each class is also represented in Fig. 9.

As can be seen in Fig. 8, the collected data cluster more around Iranian proportions and approximations of golden ratios. In Fig. 9, it is further indicated that the classes of 1.67-1. 91 (especially the ratio of 1.73), 2.40-2. 65 (especially the ratio of 2.61), and

1.42-1. 67 (especially the ratio of 1.61) have the highest frequency percentage, respectively. Thefrequency percentages are,respectively, 32.14%, 25%, and 17.85%.

Rooms were another part of the main spaces which were investigated in this study. In so doing, the geometric proportions used in 95 rooms of the total 24 traditional houses were investigated (Fig. 10). Since the number of rooms under investigation was high, the ratios were divided into 8 classes with alength of 0.2. Fig. 11 below indicates the frequency percentage of each class.

As can be noticed in Fig. 10, the observed ratios in the rooms mainly cluster around Iranian proportions and golden ratios. In Fig. 11, it is indicated that the classes of 1.69-1. 42 (especially the ratio of 1.61), 1.10-1. 29 (especially the ratio of 1.15), and 1.69-1. 89 (especially the ratio of 1.73) have the highest frequency percentages, respectively. Their frequency percentages are,respectively, 40.43%, 15.95%, and 13.83%.

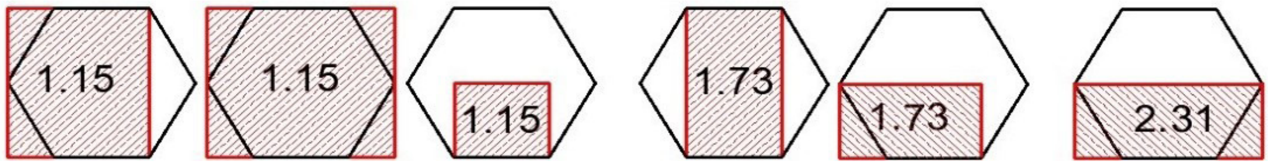


Fig. 7. Iranian rectangle surrounded in regular hexagon and some of the resulting ratios. Source: Authors based on Pourahmadi et al., 2011, 70.

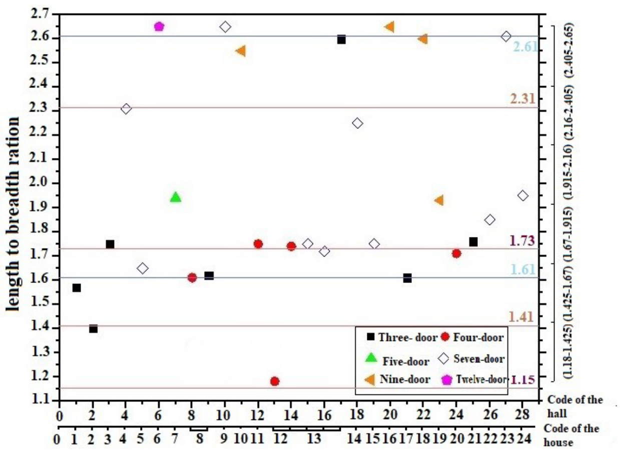


Fig. 8. Length to breadth ratios in the traditional houses of Ardabil. Source: Authors.

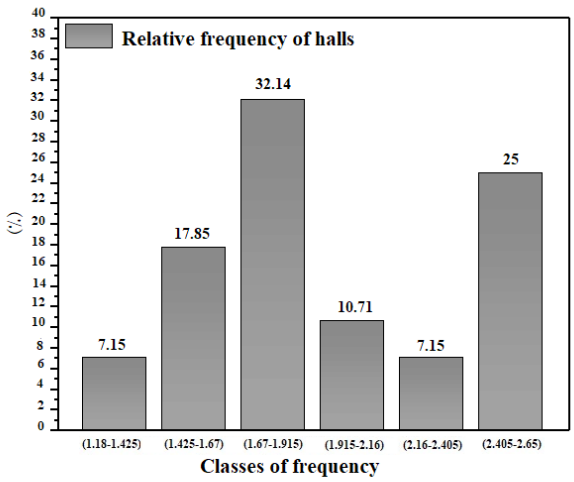


Fig. 9. Relative frequency percentage of the halls in the traditional house of Ardabil. Source: Authors.

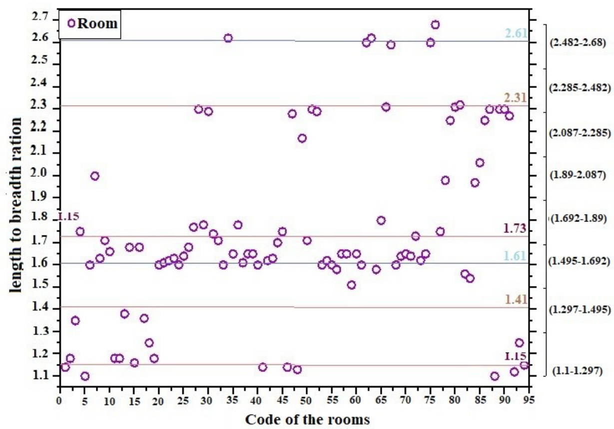


Fig. 10. Length to breadth ratio of rooms in the traditional houses Ardabil. Source: Authors.

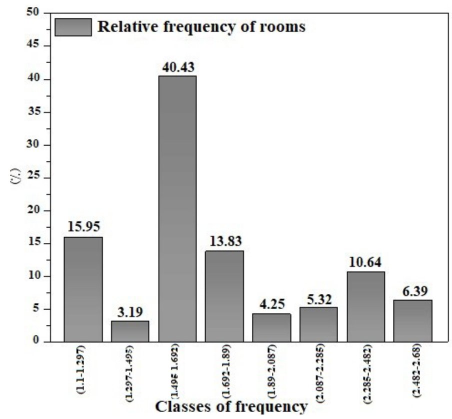


Fig. 11. Relative frequency percentage of ratios used in the rooms of traditional houses in Ardabil. Source: Authors.

For the analysis of proportions used in the main façades of the 24 traditional houses under investigation (Fig. 12), the gathered data were divided into 6 classes with alength of 0/52. The frequency percentage of each class is represented in Fig. 13.

As can be seen in Fig. 12, the observed ratios in the façades mainly cluster around golden ratios and Iranian proportions. Based on Fig. 13, the classes of 2.16-2. 68 (especially the ratio of 2.61), 1.12-1. 64 (especially the ratio of 1.61), and 3.72-4. 25 (especially the ratio of 4.23) have the highest frequency percentages, respectively. Their frequency percentages are, respectively, 35.71%, 17/85%, and 17.85%. On the other hand, according to Table 1 (proportions of the façade – the 2nd case) and the highlighted pictures of the façades, parts of the symmetrical façades (especially the center of the façade and the Orosi window), as well as some asymmetrical façades, often follow the golden ratio.

The general principles dominating the spatial organization of traditional houses in Ardabil have taken into account cultural considerations, climate condition, construction principles, location, etc. Using a wide variety of rectangles with different dimensions hasmet the requirements of design, and using just one specific proportion has not been useful enough. For example, as can be seen in Table 1, rooms in the northern front of the houses, which are situated near the hall with roughly the same perimeter zone depth and have the least breadth compared to other spaces due to the larger breadth of the hall, can be used in the cold seasons of the year to receive more sunlight. Based on the frequency diagrams and Table 2, it can be concluded that the ratios of 1. 73 and 2. 61 in halls, 1. 61 and 1. 15 in rooms, and 2. 61 and 1. 61 in façades might have been of paramount importance for architects as compared to other ratios. Furthermore, the use of compressed dimensions, which are areaction to the cold climate of the region, can be observed in various spaces that follow the common ratios of 5 to 3, 8 to 5, 8 to 3, and even 13 to 3, which allbelong tothe Fibonacci sequence. Therefore, approximations of the golden ratio can also be observed in the design of halls, rooms, and façades. Proportions of the Fibonacci sequence are more frequent in halls and main façades. However, the proportions obtained from the golden rectangle have a relatively high frequency, which is indicative of the fact that most of the computational proportions are derived from the proportions that exist in nature.

Conclusion

In this study, 24 traditional houses in Ardabil were investigated in terms of the use of geometric principles derived from nature. The analysis of the collected data including the shapes, sizes, and ratios of

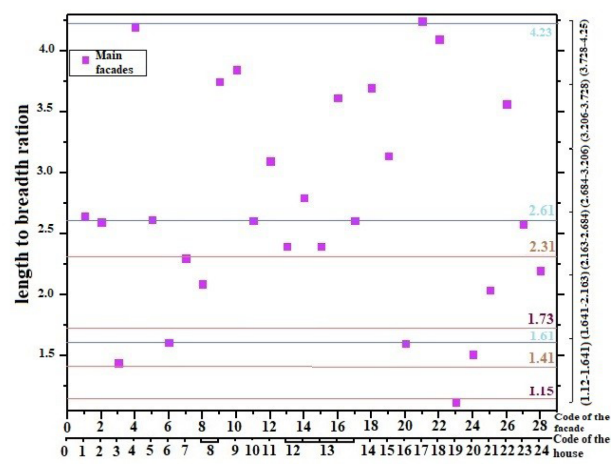


Fig. 12. Length to breadth ratio of the main façades in the traditional houses of Ardabil. Source:Authors.

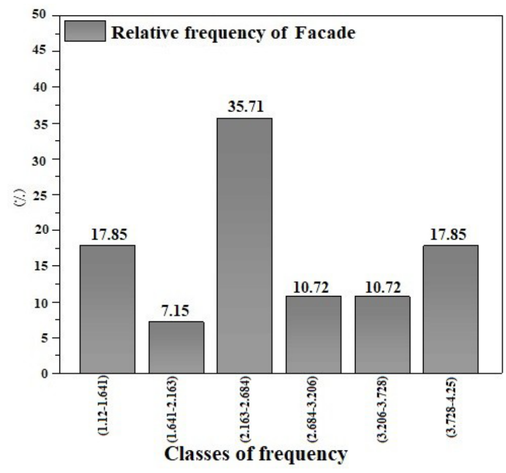


Fig. 13. Relative frequency percentage of proportions in the main façades of the traditional houses in Ardabil. Source: Authors.

Table 2. Frequency percentages of the proportions derived from nature in the structural components oftraditional houses. Source: Authors.

Name of the space	Sample size	Iranian proportions	Golden proportions	Approximations of the golden proportions
Hall	28	32.14	17.85	25
Room	95	13.83	40.43	15.95
Main façade	28	17.85	17.85	35.71

the spaces indicated that the common proportions in the construction of these houses were a combination of Iranian proportions, golden proportions, and the ratios derived from the Fibonacci sequence, which are themselves approximations of golden ratios. As can be seen in Table 2, the highest frequency belongs to Iranian proportions in the case of halls and golden proportions in the case of rooms. In the main façades, the most frequent proportions are covert geometric patterns, which have mainly been used in the central part of the façades and theOrosi windowsof the symmetrical buildings. Furthermore, parts of the asymmetrical buildings also follow covert geometry via the use of golden proportions (Table 1). Proportions derived from the Fibonacci sequence and the approximations of golden ratios are generally more prevalent in the main façades (Tabel 2). Therefore, considering the requirements and the general dimensions of the façades, it can be understood that the architects of these buildings have been able to use golden proportions as visual elements in the details of the façade (the central part and the Orosi) to create aesthetic effects. The architects have also used the proportions derived from arithmetic numbers in the general view of the façades to create visual attractiveness.

In this study, the construction patterns employed in the structural components of the traditional houses in Ardabil were investigated to understand their functions and identifythe most appropriate geometric patterns and proportions for the contemporary architecture in this region. One of the important factors in this regard is the climate. It was observed that the cold climate of the region affected the dimensions of the spaces and theirproportions. The spaces are usually small and compressed in the houses of this region. The frequent proportions in the dimensions of the rooms are 5 to 3, 8 to 5, 8 to 3, and even 13 to 3, all fromthe Fibonacci sequence. In addition, the dominance of Iranian proportions in the main halls, which havebeen used as winter rooms and centers for collective activities,indicates the lower depth and considerable width of these spaces to receive and save the highest possible level of sunlight. Also, the dominance of golden proportions in rooms indicates the considerable depth and lower width of the rooms as compared to the halls. These proportions have made it possible for the rooms to save heat in the compressed spaces. Part of the heat for the rooms has been provided by the halls and kitchens. In some cases, similar proportions have been used in the construction of two buildings. However, the resultant buildings are not similar and each has its own distinctive features. Moreover, in all of the houses under investigation, there is no relationship between the largeness of the space and the number of doors or windows.

The information provided in this paper on the use of geometric principles and proportions taken from nature in the architectural structure of traditional houses in Ardabil gave a new picture of them regarding the application of specific proportions in plans, main façades, Orosi windows, and the central part of the façades. It also demonstrated the effects of geometric patterns taken from nature on the architecture of the visual, climatic, and spatial aspects of traditional houses in this region. The results indicated that in some cases, various aspects of the house from Orosi to the hall follow specific proportions. In addition to the use of Iranian proportions and golden ratios in the arrangement of different architectural elements and spaces from plans to façades, ratios obtained from the Fibonacci sequence have also been employed in various parts of these houses. In fact, the stability of the structures resulting from the use of specific proportions has given distinguished features to these traditional houses and has made them sustainable as unified wholes. The findings of this study can help reconstruct, repair, and reproducetraditional houses. They can also supplement our architectural information on the traditional houses and help us understand the vernacular architecture of the region in previouseras.

Endnote

1. Two numbers with the ratio of 1.618 are called golden numbers (Lu & Steinhardt, 2007, 1108). They are also known as phi number, golden section, divine ratio, Fibonacci number, and Phidias ratio (Huntley,1970).
2. In the numerical sequence, which was offered by Fibonacci based on the growth pattern of the population of rabbits in nature, the following numbers are known as Fibonacci numbers: 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89. In this progression, each term is the sum of the previous two terms. Also, the result of dividing a term by a preceding term is close to the golden ratio (Omotheinwa, 2013, 634). Moreover, dividing a term by 1, 2, ... terms before it results in approximations of the golden ratio.
3. The number of doors is one of the fundamental units in Iranian architecture. It is usually believed that a space with a higher number of doors is big and has high quality. For example, 5-door spaces with five openings (doors or windows) have mainly been used as the hall while 3-door spaces have been used as rooms for different purposes.

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