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Sustainability Features of Iran's Vernacular Architecture: A Comparative Study between the Architecture of Hot–Arid and Hot–Arid–Windy Regions

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Abstract: Vernacular architecture has evolved over time to reflect and sustainably comply with the environmental and cultural contexts in which it exists. This kind of architecture possesses a variety of original and clever practices and technologies to satisfy various necessities imposed by context. Iran's vernacular architecture has mastered the art of adaptation to context by developing different architectures in different regions of the country. Despite their different appearances, these architectures follow the same logic in spirit: sustainable adaptation to context. This original research work surveys this logic in two regions, one hot-arid and the other hot-arid-windy, in Iran (represented by the city of Yazd and the region of Sistan, respectively) through a comparative study. This paper studies different elements and techniques of sustainability in these areas, reasons for their existence and the factors that have shaped them into the specific way that they are. The main elements that were studied through this survey include: fabric and orientation, sidewalks, facades, materials, entrances, courtyards, basements and cellars, porches, roofs, wind-catchers, and openings. In conclusion, links that connect different specifications of context to different aspects of construction are discovered and their role in overall character of two region's architecture is illustrated so they can be used as guidelines for future designs and constructions.

Keywords: sustainability; vernacular architecture; context; adaptation; Iran; Yazd; Sistan

1. Introduction

Modern buildings consume 30–40% of the overall energy used all over the globe and experts predict this percentage will rise up to 50% by the year 2050 [1]. Due to such great energy consumption, buildings produce up to 30% of the greenhouse gases (GHG) released into the atmosphere every year, causing numerous problems around the world including global warming and climate change [2].

All the buildings must provide a proper indoor environment and they are mainly constructed to achieve this goal [3], especially the residential ones. A closer inspection on energy consumption issue reveals the fact that cooling and heating of modern buildings is the responsible factor for 10–20% of total energy use of buildings in developed countries and this ratio increases to 50% in less developed ones [4]. Meanwhile, traditional climate aware constructions known as Vernacular architecture (the main method of building for generations in different countries) has been able to consume much less energy and produce much less pollution compared to modern buildings and simultaneously provide a comfortable and sustainable living environment by adapting to different contexts' climates [5,6].

Human life is directly and indirectly affected by climatic conditions [7]. Vernacular architecture utilizes these conditions in order to provide dwellers with the comfort they seek. A vernacular building is a building built by local people using traditional technologies from locally available materials matching the environmental context to accommodate domestic ways of life [8]; it is a description that is completely in accordance with what is known today as sustainability. In this method of construction, cooling and heating of dwelling is mainly based on passive measures that maximize the use of natural resources such as wind and sunlight [9]. Different climates require different responses by architecture to meet different requirements [10]; therefore, variation in climate leads to variation in architectural responses in vernacular buildings.

Vernacular architecture shapes the greater part of Iran's traditional architecture, going back almost 8000 years [11]. As mentioned earlier, any form of architecture, including vernacular, is interdependently related to its local context [12]. As a result, according to different climatic contexts across the country, Iranian vernacular architects and masons have come up with different solutions and techniques to accommodate these climates. These solutions and techniques all together shape the overall character of different regions' vernacular architecture [13].

This paper attempts to depict these accommodations and shed light on the sustainable adaptation process of vernacular architecture to context in two regions, Yazd (hot-arid) and Sistan (hot-arid-windy), in Iran, through a comparative study between the two.

2. Literature Review

Numerous studies have been done on different aspects of Iran's hot-arid region's vernacular architecture in cities like Yazd and Kashan. These studies have surveyed the elements and techniques that masons have used in order to create a comfortable living environment within the confinement of vernacular houses.

Saljoughinejad and Rashidi Sharifabad (2015) [14] classified the climatic strategies used in Iranian vernacular residences based on spatial constituent elements. Keshtkaran (2011) [15] presented data to prove the harmony between climate and architecture of Yazd. Foruzanmehr surveyed different elements of Yazd's vernacular architecture, their performance and role in dwellers' lives through several studies [8,12,16–19] and concluded that vernacular houses provide a more comfortable living environment compared to modern apartments in most cases. Khalili and Amindeldar (2014) [13] studied the logic and performance of traditional solutions in low-E vernacular buildings of hot-arid regions in Iran and concluded that these buildings provide a sustainable environment. Moosavi, Norhayati and Norafida (2014) [20] researched the performance of atria, focusing on its natural ventilation role and presented some solution to enhance its performance.

Compared to the large body of research on vernacular architecture in hot-arid regions in Iran, studies that have been carried out on Sistan architecture are few. Perhaps the written report of "George Peter Tate", the British historian and archeologist who resided in Sistan between 1903 and 1905 is the oldest source available; he wrote: "*people in Sistan show great skills in adapting to environmental factors. Their homes are built in remarkable harmony with region's climate*" [21]. Davtalab (2003) [22] documented the Qele-no village in Sistan in order to introduce the vernacular architecture of this village to academic society. Fazelnia and co-authors (2012) [23] surveyed the harmony between the expansion pattern of Tombaka village in Sistan and the direction of sand storms in the region and suggested this pattern to be used in the design of new developments across Sistan. Sargazi (2014) [24] described different techniques used by native people in Sistan in order to achieve a sustainable environment in their vernacular houses.

Researchers have also used the comparative study approach to further investigate the differences in vernacular architecture in different regions in Iran. Khajehzadeh, Vale and Yavari (2016) [25] studied the differences between traditional courtyards in two cities of Yazd (hot-arid) and Bushehr (hot-humid) in Iran and investigated the reasons. Saadatian and co-authors [26] reviewed different wind-catcher technologies in different regions and compared their performances. Soflaei, Shokouhian and Zhu (2016) [27] compared the sustainability features in courtyard houses in Iran and China and concluded that, in both countries, the use of passive measures for heating and cooling provides an acceptable level of thermal comfort for the dwellers.

3. Methodology and Materials

This paper seeks to investigate the sustainable adaptation process which vernacular architecture has undergone in order to accommodate to necessities of two different regions of hot-arid and hot-arid-windy in Iran, in order to provide an insight for designers and constructors how to adapt their buildings to context. To do this, Yazd architecture as a city with the greatest untouched vernacular fabric in hot-arid region of Iran (the birthplace of this region's vernacular architecture [28]) has been illustrated and compared against Sistan's (Figure 1).

To reach its goal, this paper uses an analytical/qualitative research method to compare the elements and techniques utilized in two regions' vernacular buildings.

The research process is divided into five sections:

(1) Comprehensive literature review on Iran's vernacular architecture, concentrating on hot-arid regions (considering the large body of research available, there was no need for direct field studies).
(2) A series of field studies and documentations among thirty-two sample houses across Sistan supported with interviews with native masons. Sample houses were chosen based on the ratio of each district's number of villages to all the villages in the Sistan region (Table 1). These houses were chosen from the oldest and most intact buildings in each district and then documented by authors, using direct measurements to draft plans, elevations and sections (Figure 2).
(3) Study of climate, geography and geology in the two different regions' contexts.
(4) Investigation of differences between two regions' architectures caused by different contexts.
(5) Concluding the sustainable adaptations that vernacular architecture has undergone in order to accommodate to two contexts. (Connection and order of these sections are depicted in Figure 3.)

Table 1. Number of documented houses in different districts of Sistan.

District	Number of Villages	Percentage	Number of Sample Houses
Zabol	77	9.5%	3
Zahak	148	19.7%	6
Hamoun	160	19.8%	7
Hirmand	305	27%	12
Nimrouz	118	14%	4
All the region	808	100%	32

Figure 1. Location of Yazd and Sistan in Iran.

Different elements and techniques of Sistan's vernacular architecture were surveyed through a field study and documentations of thirty-two houses across the region as sample statistical population. In addition to documentation, direct wind speed and temperature measurements were carried out inside two sample houses, over a period of four months (June–August 2015), concurrent with 120-Days Winds, using a digital anemometer (Anemometer Kestrel 1000).

Figure 2. Thirty-two documented houses across Sistan as study sample.

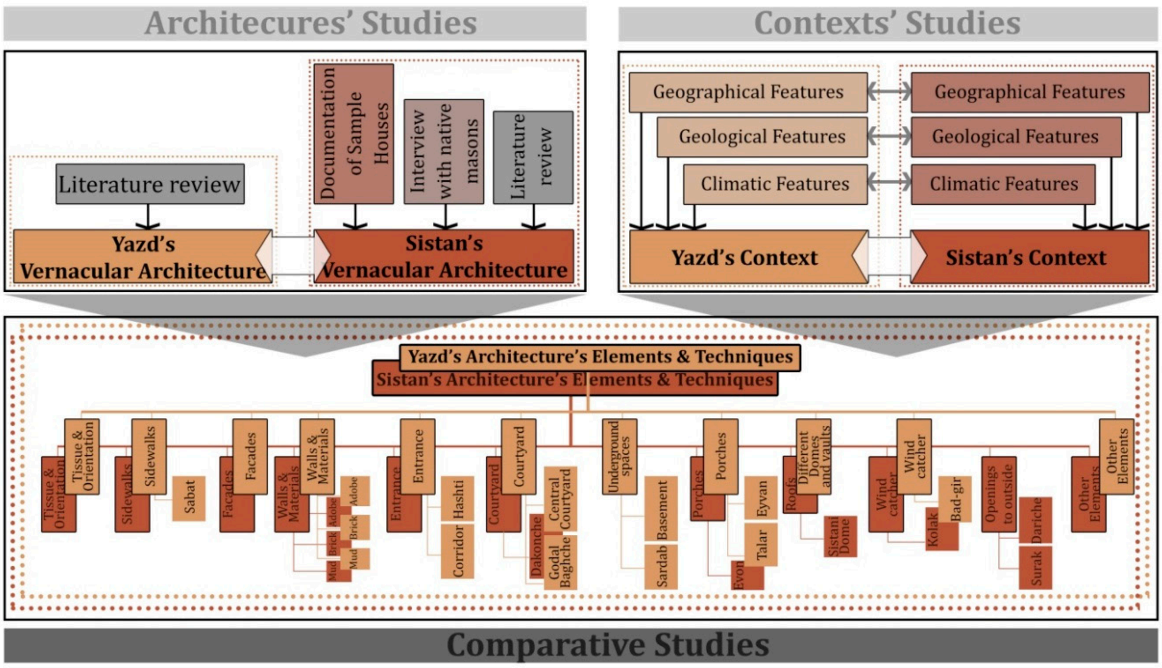

Figure 3. Research process.

4. Defining Features of Two Regions' Contexts

In different regions of Iran, as quoted earlier by Memarian and Brown (2006) [11], "*variation in climate led to variation in architectural response*." This variation is also due to different geographical and geological features in different regions. To conduct a better investigation, this paper has expanded the study domain on defining features of two contexts [29] and has also investigated the geographical and geological characteristics of the two regions in addition to their climate, which are described in the following sections.

4.1. Yazd's Context

4.1.1. Yazd's Geographical Features

Yazd (31.8974°N, 54.3569°E) is located in the central plateau of Iran, a large section in the central and eastern part of the country [14]. The city is situated in an oasis where two barren deserts, Dasht-e-Kavir and Dasht-e-Lut, meet (Figure 4).

The city resides in a valley between Shirkuh Mountain (the highest mountain in the region with a height of 4075 m) and Kharaneq. Yazd is 1203 m above the sea level and is the greatest city located in the central plateau [30].

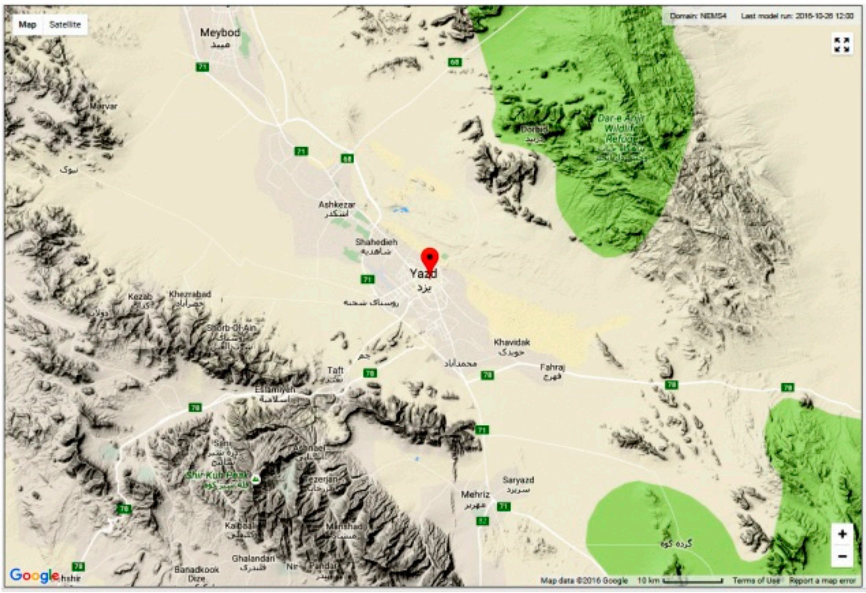

Figure 4. Yazd's geographical map [31].

4.1.2. Yazd's Geological Features

Iran's geological map shows that Yazd is surrounded by alluvium grounds. In the east and west of the city, districts covered with sand dunes are noticeable. Close heights are mainly made of limestone and, in the north of the city, there is a streak of upper red formation hills [32,33] (Figure 5).

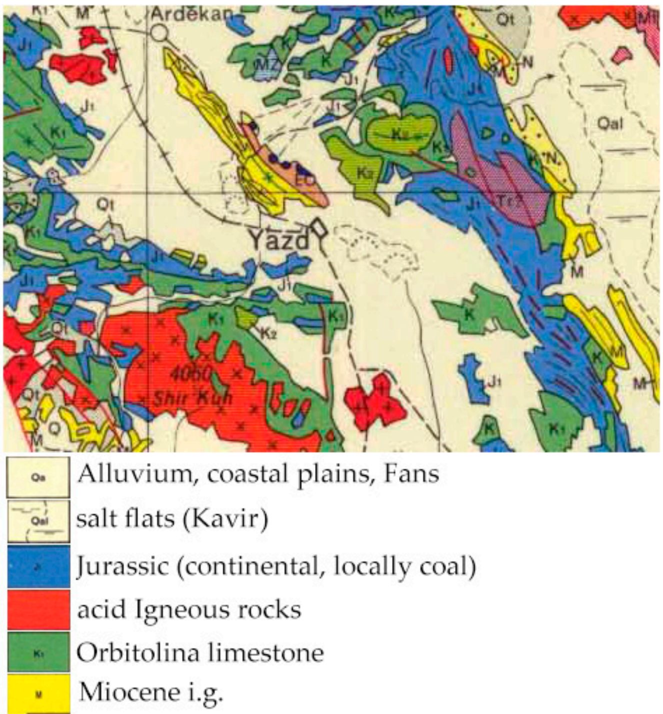

Figure 5. Yazd's geological map [32].

4.1.3. Yazd's Climatic Features

With an average annual rainfall of only 60 mm, Yazd is the driest major city in Iran and also the hottest one in the center and northern parts. The temperature of the city varies between +40 °C in summer (due to glazing sun and deserts surrounding the city) to below 0 °C in winter (due to the shortage of any significant body of water and scarce cloud coverage) [30,34] (Figures 6–8).

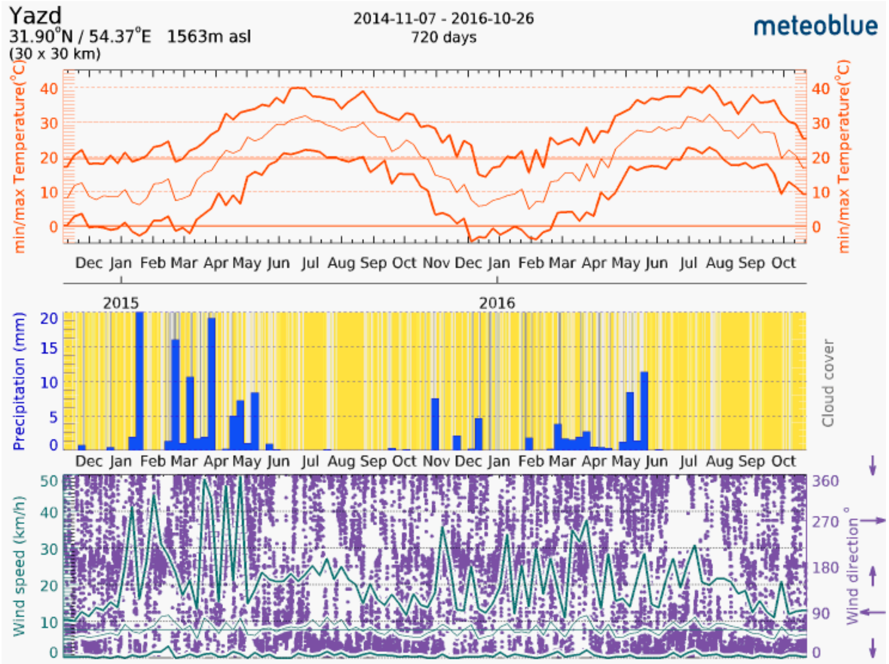

Figure 6. Yazd's weather [30].

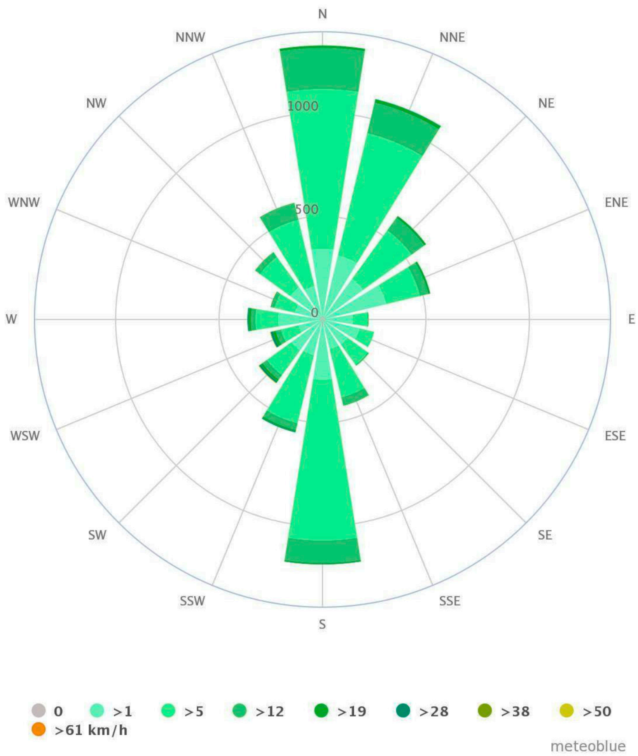

Figure 7. Yazd's wind-rose [30].

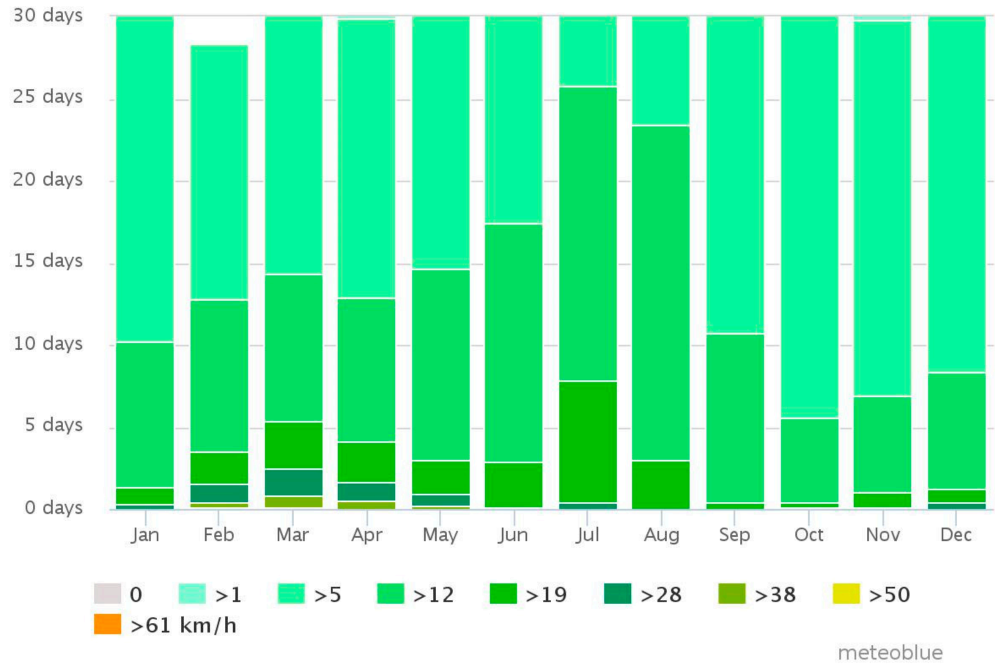

Figure 8. Yazd's average monthly wind speed [30].

Wind-rose diagram (Figure 7) of Yazd shows that different winds cross the city in different directions and a prevalent wind direction cannot be detected. Wind speed in the lower heights near the ground is so significantly low that tangible wind flows can only be noticed in heights of 10 m or more above the ground (Figure 9) [35]. Relative humidity varies from 6% in hot months of the year to approximately 70% in winter (Figure 6) [36].

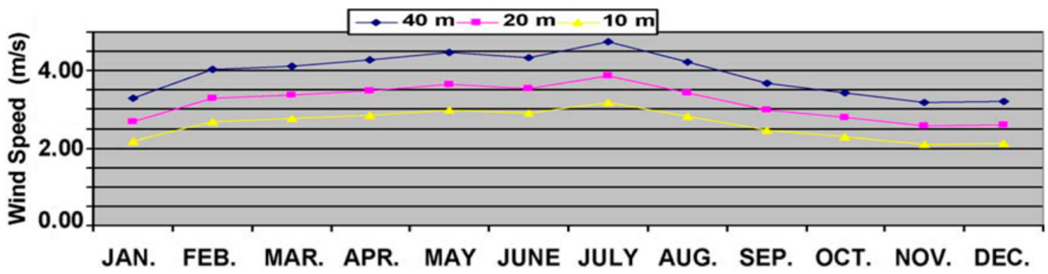

Figure 9. Yazd's wind speed in different heights [34].

4.2. Sistan's Context

4.2.1. Sistan's Geographical Features

Sistan region (31.032°N, 61.490°E) is located in the southeast of Iran [37]. It is a low-land, shaped by the alluviums of "Hirmand" river, the main watershed for Sistan basin.

Hirmand River (or as it is known in Afghanistan, "Helmand" River) drains into the natural swamp of "Hamoun" lake complex, consisting of three sections, "Hamoun-Poozak", "Hamoun-Saberi" and "Hamoun-Hirmand", located in the northern and western parts of Sistan region [38] (Figure 10).

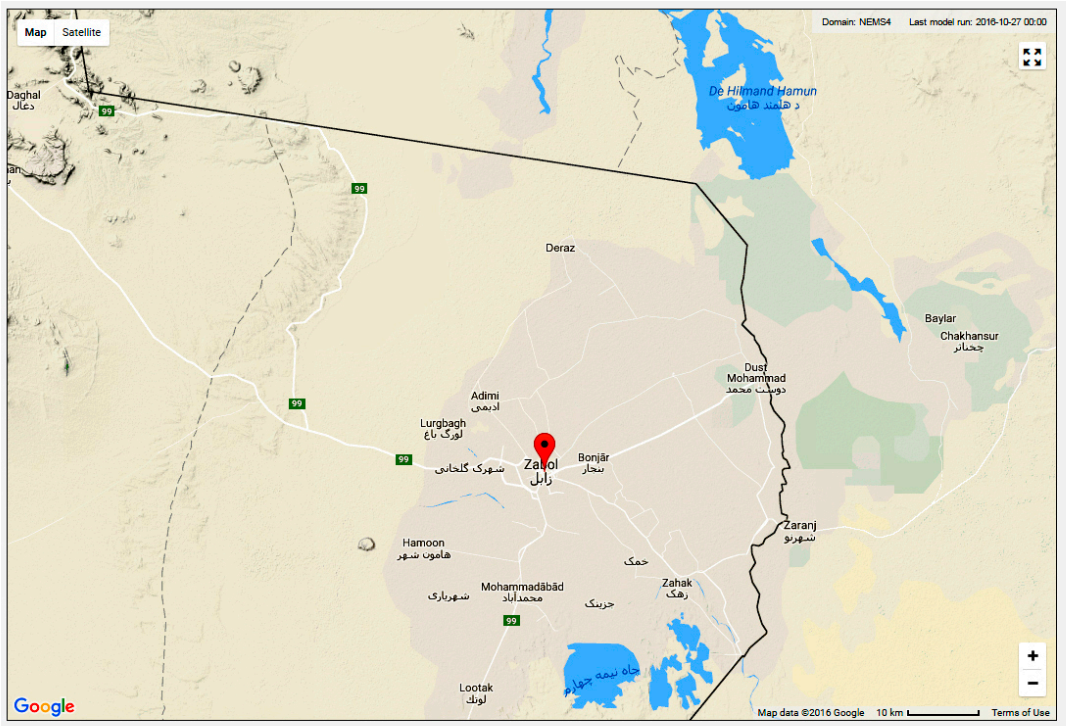

Figure 10. Sistan's geographical map [31].

4.2.2. Sistan's Geological Features

The geological map of the country shows that Sistan is mainly a shallow swamp made of alluvium covered with vegetation. In the east of the region and over the border of Afghanistan, there is a region covered with sand dunes. Dots of igneous rocks can be detected in and around Sistan but they shape a small area [32,33] (Figure 11).

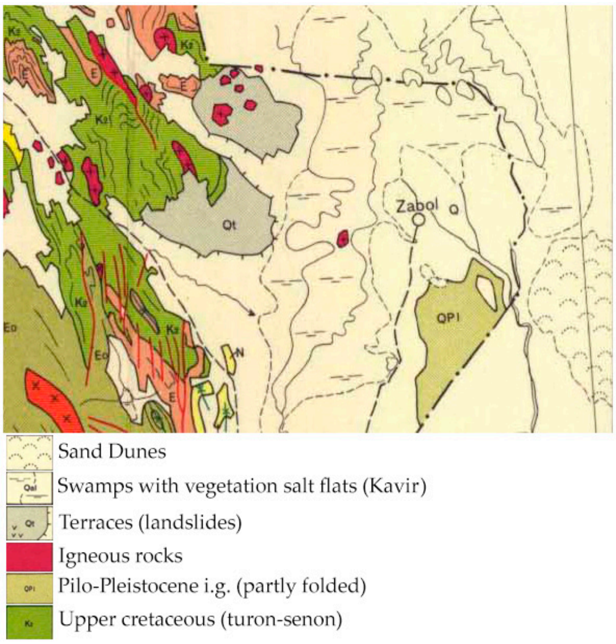

Figure 11. Sistan's geological map [34].

4.2.3. Sistan's Climatic Features

According to the weather information, Sistan has a hot-arid climate with an annual average precipitation of 55 mm occurring mainly in winter (December to February) while its evaporation exceeds ~4000 mm/year as a result of high temperatures and frequent winds [30,39] (Figure 12).

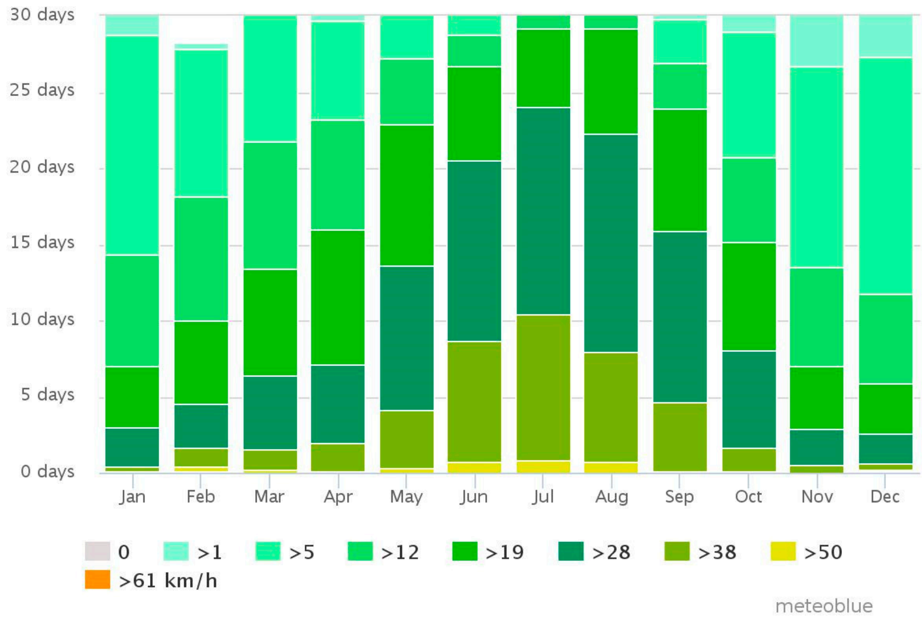

Figure 12. Sistan's average monthly wind speed [30].

In summer, especially in the 120-day period between June and September, strong northern winds known as "120-Days Winds" (Figure 13) [40] affect the region, passing Hamoun Lakes and spreading their humidity across Sistan [41]. These winds are the most important climatic feature of the region, blowing at an average speed of 9 m/s [42] pretty near the ground (Figure 14), conveniently passing the lakes on their way to the populated areas in the southeast parts of the region (Figure 11) [43] the direction of these winds is north-west to south-east (Figure 15).

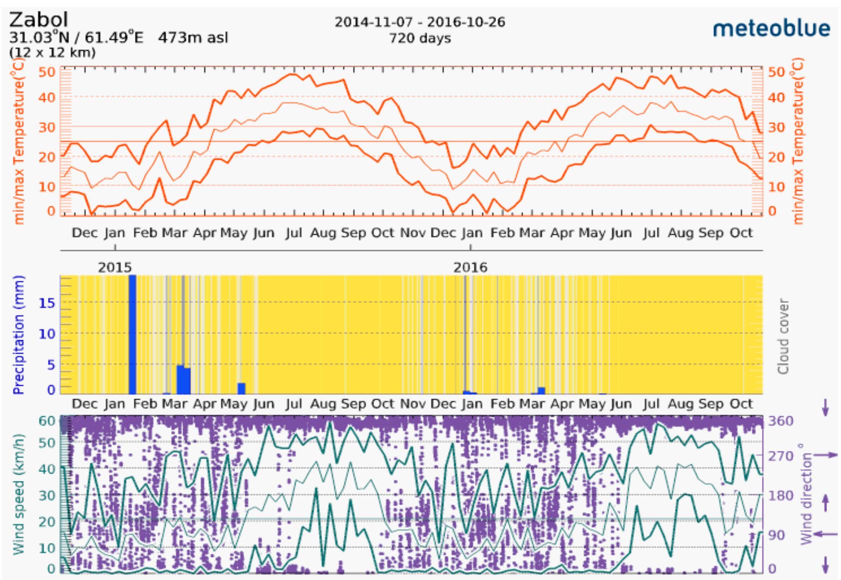

Figure 13. Sistan's weather [30].

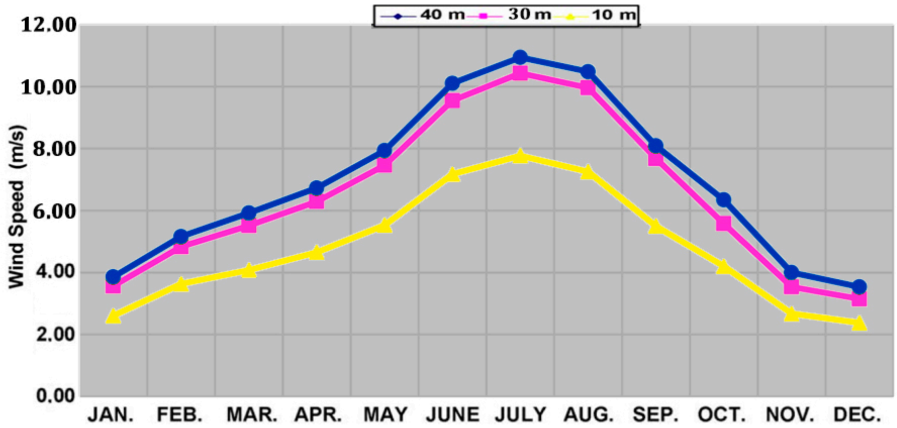

Figure 14. Sistan's wind speed in different heights [44].

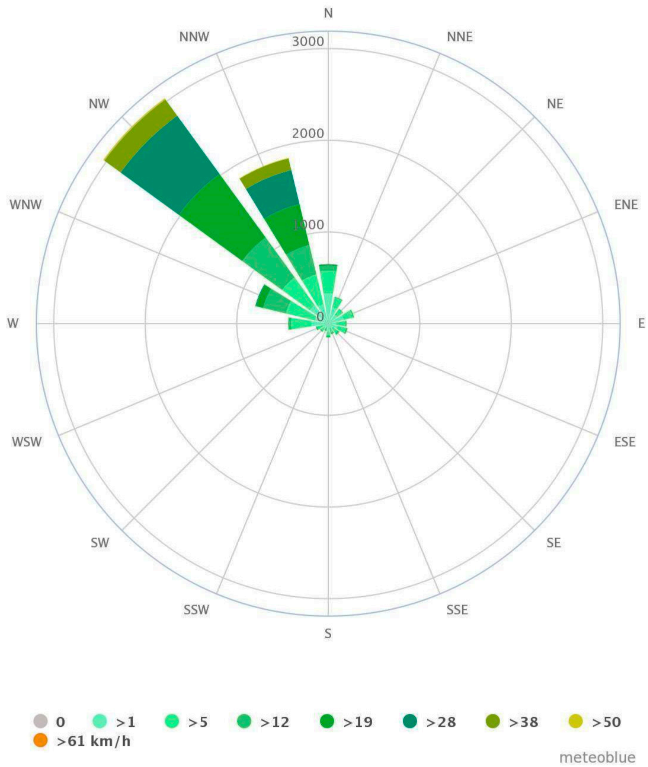

Figure 15. Sistan's wind-rose [30].

5. Comparison of Elements and Techniques

Vernacular architecture is believed to be the product of thousands of years of sustainable adaptation to environmental conditions and the outcome of people's experience through several generations [45]. This kind of architecture represents the expertise on how to use the locally available resources to accommodate cultural and environmental necessities of the context [46]. Iran embodies a variety of vernacular architecture styles consistent with different cultural and environmental aspects of different regions in the country [14]. These accommodations have led to diverse architectural representations in different regions, in the form of a diversity in elements and techniques that are used in different contexts [29].

For the two regions, Yazd (hot-arid) and Sistan (hot-arid-windy), differences in elements and techniques are as follows:

5.1. Fabric and Orientation

Fabric concentration and orientation in both regions is compatible with their respective contexts.

The aerial view of Yazd (Figure 16) is a dense urban development that has been built to reduce the direct sunlight exposure and maximize the shadow coverage in the alleys and urban spaces [14,15]. Studies estimate that about 60% of urban areas and pavements in this city are covered by roofs or Sabats [47] to protect the people from the excessive heat and sunlight (Figure 6). Prevalent orientation of the streets is east to west to create the most shadow coverage possible [48]. Secondary alleys in the heart of the Fabric are narrow, irregular, curved and in some parts covered canals, built to block the wind-flow in pedestrian level; as mentioned earlier, Yazd is surrounded by dune sand areas (Figure 5) and the winds in pavement level cause sandstorms, therefore tortuous alleys [11].

A correct building orientation that best employs passive measures to maximize the use of natural resources can save 20–50% of building's consumed energy [49]. Correspondingly, in a typical house in Yazd, long axis is rotated 30 degrees clockwise from the north and the smaller southern side of the courtyard faces Mecca (Qibla) [50] which is the main factor in shaping the city orientation; unlike Sistan that the orientation of the fabric is decided by the prevalent wind direction (Figure 15), Yazd lacks this factor and wind flows to the city in every front (Figure 7).

Wind is the most influential factor in Sistan's climate [23]. Unlike Yazd, the soil in and around Sistan is mostly alluvium and there is a significant distance between the region and the nearest dune sands (Figure 11); therefore, the risk of sandstorms is lower. Furthermore, the prevalent wind that blows in hot days of the year crosses Hamoun Lake on its way to the region (Figure 10), and turns into a humid cool breeze which is entered to the fabric by direct uncovered alleys parallel to it in a north/west–south/east direction [51].

Although the sunlight exposure level is almost as high as Yazd (Figure 13), in order not to block the wind from entering the fabric, Sistan people have refrained from covering the alleys and creating a heavily dense fabric; therefore, the coverage percent of the region is lower than Yazd (Figure 17) [52].

In the hot-arid region that Yazd lays, the population centers are few, heavily dense, significantly more populated and greatly distanced from one another (Figure 4) [28] because the people intended to block the outside factors by creating dense fabrics. In order to make these fabrics work, they have to be pretty large, so the central parts can be safe from outside unpleasant factors (Figure 18) [53].

In Sistan region, however, there are more but smaller population centers, less dense than the ones in the hot-arid region, in order to let the wind flow in the fabric (Figure 19) [54].

Figure 16. Yazd's fabric; aerial view.

Figure 17. Sistan fabric; aerial view.

Figure 18. Yazd fabric's orientation.

Figure 19. Sistan fabric's orientation.

5.2. Sidewalks

To protect the people against summer heat and glazing sunlight (Figure 6), the streets and sidewalks in vernacular architecture of Yazd are mainly curved and narrow canals with an overall east–west direction (Figure 18), surrounded by high adobe walls on both sides (Figure 20) to maximize the shadow coverage [48]. These narrow deep canals, filled with air that is cooled down by the shadows create an air-block in the pedestrian level and help keep the warm winds from descending to the houses' level near the ground [55] In some portions, the sidewalks are roofed or vaulted to increase the shadow coverage, shaping Sabats (roofed alleys) (Figure 20) [15]. Narrow sidewalks also help to create a dense fabric all over the city (Figure 18) [56].

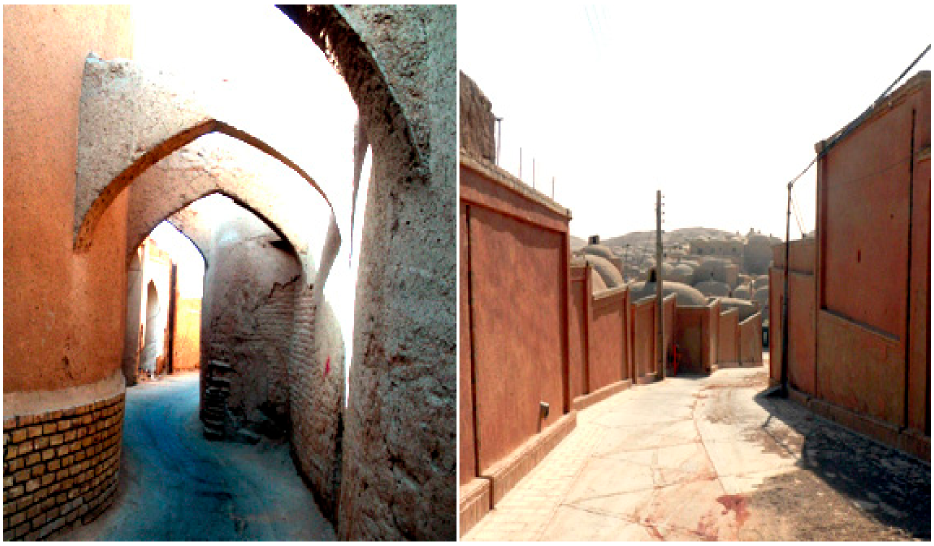

Figure 20. Yazd's sidewalks (**Left**); Sistan's sidewalks (**Right**).

Compared to Yazd, Sidewalks are straighter in Sistan and their overall direction is parallel to the prevalent wind direction which is north/west–south/east (Figure 19), allowing the wind to penetrate the fabric [51]. The height/width ratio differs in the two regions: Sistan sidewalks are wider and their surrounding walls are lower (Figure 20) because the prevalent cool breeze of the 120-Days Wind flows in lower heights near the ground (Figure 14) [44] and the need to shade the pavement—by covering it with vaults or roofs—to provide a comfortable path is less essential. As a result, the overall fabric is less dense comparing to the fabric of Yazd (Figure 19).

5.3. Facades

In Yazd, external facades are usually blocked by attached neighboring houses in order to reduce the area of external surfaces that face direct sunlight and hot winds. Openings are few, usually located in higher parts of the wall and sometimes the only opening to the outside world is the houses' entrance door (Figure 21) [25].

The walls in both regions are made of adobe, brick and mud without any further padding, resulting in exterior walls with light colors (Figure 20) a technique that has a significant counter-effect on the impact of solar radiation on buildings and reduces houses' indoor temperature [57]. External surfaces are built as smooth as possible to maximize the light reflection of outside walls [56].

According to field studies and direct observations, compared to Yazd, Sistan's architecture facades contain more openings in different levels (this issue will be further discussed under the title of openings). Due to the abundance of hay and straw in the region, which is a result of Hamoun Lake (Figure 11), the surfaces are sometimes padded by thatch (Figure 21) to increase the walls' thermal resistance [58], resulting in less smooth surfaces. As mentioned earlier, Sistan fabric is not as dense as Yazd's and, unlike that region, external fronts of the houses in Sistan are not usually blocked by neighboring houses. According to documentation of sample houses across Sistan, external walls in Yazd's architecture are far higher than the ones in Sistan, resulting in higher facades facing the alleys.

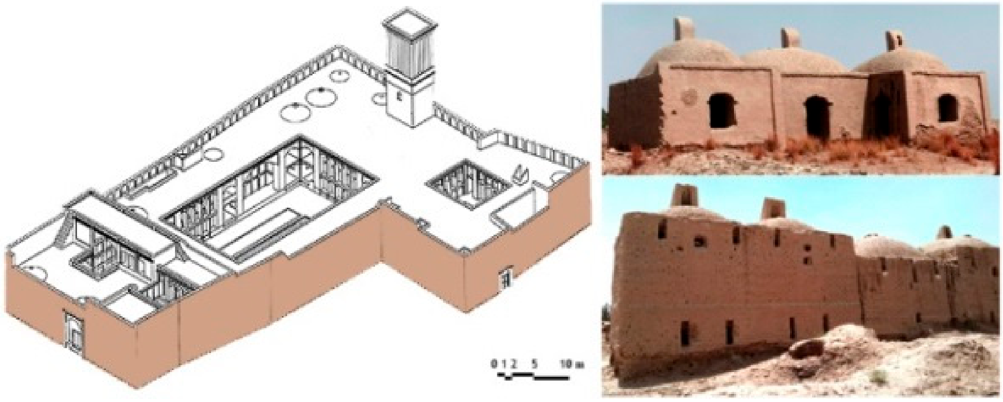

Figure 21. Facade of Mehraban house, Yazd (**Left**); and Facade of a typical house in Sistan (**Right**).

5.4. Walls and Materials

Both in Yazd and Sistan, a typical house is usually built by mud, adobe and brick; the only materials abundant and also cheap in both regions (Figures 5 and 11) [14]. These materials are used in all parts of the building, including walls, roofs, and foundations [45]. The materials used in Yazd's architecture are mostly made of clay that is excavated from the ground in the building process in order to dig the underground spaces [28], whereas, in Sistan, the required clay is obtained from Hamoun Lake basin [59].

The adobe walls are pretty thick in both regions: Yazd's walls are 40–100 cm (sometimes even more) thick and are mostly covered with mud plaster [25], while Sistan's standard adobe is a 22 cm $\times$ 22 cm $\times$ 5 cm block and its walls are made of three rows of adobes which are 66 cm thick (Figure 22) [60].

The walls are excessively thick because of their structural role as ceilings' supporters [61]; this group of materials possesses a high thermal capacity which delays the heat flow within the thermal mass of the walls and minimizes the temperature fluctuation between day and night [62].

Figure 22. Use of adobe and brick in construction Yazd (**Left**); and Sistan (**Right**).

Using thick walls is one of the most commonly used techniques in Iran's vernacular architecture of hot-arid regions; especially in Yazd where, according to Foruzanmehr and Vellinga (2011) [12], 90% of the houses utilize this technique. The thickness of these walls varies from 40^{cm} in south-facing fronts to 100^{cm} in the exterior fronts. The same percentage applies to vernacular houses in Sistan based on the field study and documentation of sample houses.

5.5. Entrances, Hashtis and Corridors

In Yazd, "entrance door" is the only opening of the houses to the public spaces [45]. Entering the door, visitors find themselves in a conjunctive space (usually an octagonal one) called Hashti [28]. This space works as a thermal filter against the outside's harsh climate (Figure 6) [47]. The link between Hashti and Central courtyard is usually a corridor with an indirect view to the yard. Hashti and corridor alongside each other prevent the cool air of the courtyard exiting the building (Figures 23 and 24) [13].

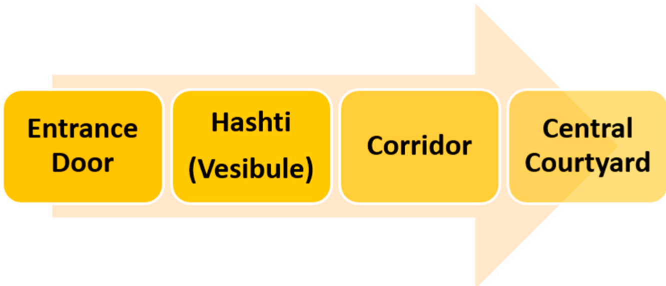

Figure 23. Entering sequence in Yazd's houses.

In Sistan, on the other hand, there are usually more than one entry, and sometimes equal to the number of rooms, each room having its own exclusive door [63]. This is because the prevalent wind in Sistan is a cool humid flow and, in contrast to Yazd architecture, which blocks the harsh outdoor climate, Sistan architecture welcomes the wind and utilizes it for ventilation (Figure 24b), which is the reason why it does not use Hashti or Corridor in its design. Compared to Sistan, Yazd has a higher temperature fluctuation between day and night due to the arid climate, whereas in Sistan the fluctuation is lower because of Hamoun Lakes' humidity (Figure 13) and there is no need to hamper it through Hashti and Corridor [52].

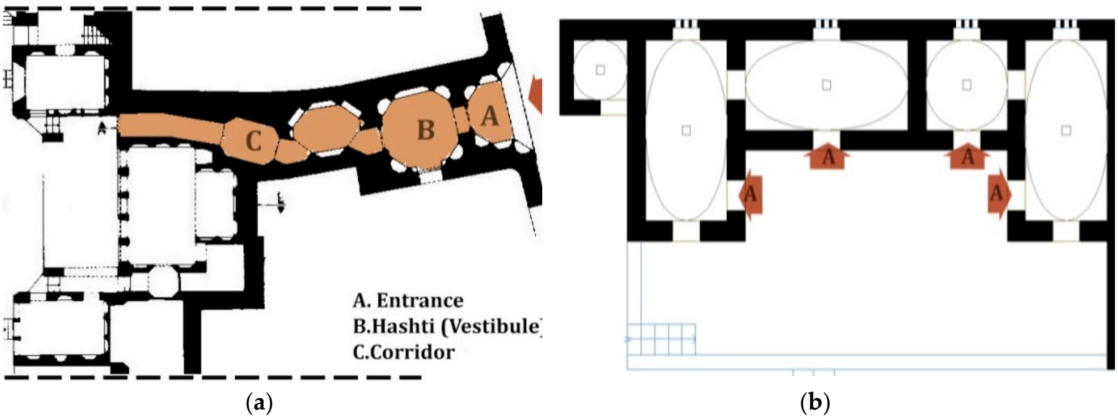

Figure 24. Entering sequences: Kashan (Borujerdiha house) (**a**); and Sistan (**b**).

5.6. Courtyards

Courtyards are one of the main points of difference in vernacular architecture of two regions. In Yazd, introversion design results in Central Courtyards and Godalbaghches (Courtyards that are dug in the ground) in the buildings which are surrounded by rooms in all fronts.

Central courtyards provide a small but effective cool and humid microclimate inside a building [29] that is completely separated from the hot-arid world outside by high non-porous walls (Figure 21). All the space in houses is organized around the central courtyard and all the openings are opened into it [28].

Hot-arid wind-flow of the outside world can hardly penetrate the central courtyard's microclimate, especially when the depth of the yard is greater than its width [64]. In some cases, the yard depth is as much as 3–4 m [53]. Yazd central courtyards usually contain shallow pools, trees and vegetation, which alongside each other reduce the temperature fluctuation inside the building and provide a cooler, more humid and consequently comfortable setting for the dwellers [27]. Almost 90% of Yazd vernacular houses have central courtyards [12].

In summary, central courtyards and Godalbaghches:

- Increase the shadow coverage of yards by increasing the surrounding walls' height [28].
- Increase the ability to keep the air that was cooled through the night in the yards during daytime [27].
- Provide and easier access to subsurface water canals (Qanat) passing below houses [15].
- Help to create airflow by making temperature difference in different parts of building [17].

In Sistan, on the other hand, according to the field studies and documentation of sample houses, courtyards are semi-open spaces attached to building mass and built at the same level as the building (Figure 1). Building mass does not surround Sistan's courtyard on all fronts (Figure 25) and, unlike Yazd, because of almost constant summer wind-flow (120-Days Wind) that becomes humid and cool by crossing Hamoun Lake along its way to the region, there is no need to create an isolated microclimate inside buildings to reach a more humid and cool living environment (Figure 11).

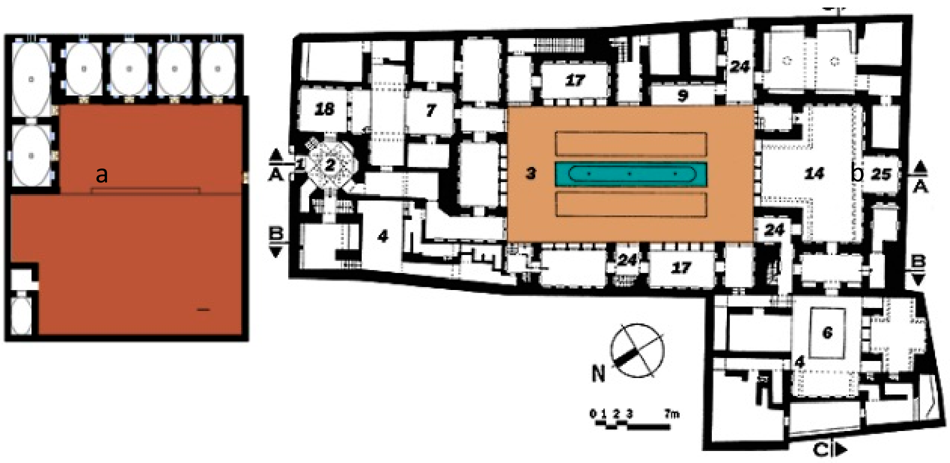

Figure 25. (**a**) Sistan's native courtyard (Dakonche); and (**b**) Yazd's central courtyard (Mehraban House).

The winds discussed above are the main factor for natural ventilation and are welcomed by making penetrable and almost open courtyards, called Dakonche (Dã kōn chá) (Figure 26) [58,65]. These courtyards are separated from public space by low walls with a maximum height of 100 cm, allowing the winds to easily enter, ventilate and exit the buildings. Due to the humidity of the winds, there is no need for shallow pools like the ones in Yazd, but trees and vegetation are similar features of yards in both regions (Figure 27).

Figure 26. Sistan's native courtyard (Dakonche) (**Left**); and Yazd's central courtyard (**Right**).

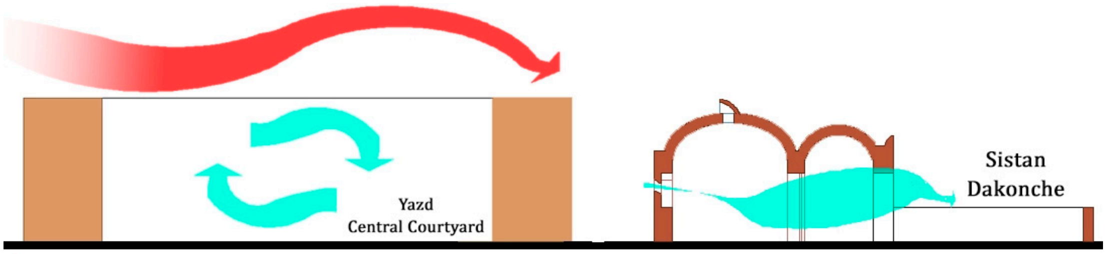

Figure 27. Courtyard ventilation performance in: (**Left**) Yazd; and (**Right**) Sistan.

5.7. Basements and Cellars

Basements and Cellars (Sardab) are two underground spaces of Yazd's architecture. The basement roof level is somewhat higher than the courtyard ground level allowing it to have openings towards yards, whereas "cellar" is completely underground and has no openings to outside [28].

High day/night and summer/winter temperature fluctuation has lead Yazd's masons to build these spaces underground, where, due to the high thermal capacity of the soil, fluctuations are subtler. These spaces are cooler than aboveground spaces in summer and are warmer in winter [66]. In some cases, these spaces have direct access to underground water canals called Qanats and sometimes Qanat water can enter Sardab space to humidify air and hamper its temperature [13]. According to Foruzanmehr and Vellinga (2011) [12], 97% of Yazd Houses have underground spaces.

Due to the high water table [34] and the region's soil texture (Figure 11), digging underground spaces in Sistan region is impractical. According to field studies and documentation of sample houses, only 18% of Sistan vernacular houses use underground spaces, which, in most cases, are created as a response to topography. In addition, as Hamoun Lake provides the whole region with sweet water, there is no need to dig Qanats and underground spaces to reach water [65].

Researches show that, in Yazd, none of aboveground rooms, even the ones supplied with wind-catchers, can provide a comfortable setting throughout an entire summer without the use of electrical devices [12], whereas, in Sistan, according to wind speed measurements (Figure 12), utilizing prevalent wind-flow in natural ventilation can provide this kind of environment, a statement that is certified by the lack of electrical devices in the studied houses across the region.

5.8. Evons, Eyvans (Porchs) and Talars

Eyvan and Talar are semi-open spaces, closed on three fronts and open in one, facing the central courtyard [28] (Foruzanmehr (2015) [8] has described the differences between these two).

North-facing Talars and Eyvans with their backs against direct sunlight provide a shaded space for dwellers to experience a comfortable setting on hot summer days. They are almost always combined with other climatic techniques such as domes and wind-catchers and also use water and vegetation to provide a cooler setting [67]. Where there is no significant airflow near the ground levels in the region (Figure 9), temperature difference between Eyvan and courtyard causes a mild airflow in the building and provides indoor spaces with favorable thermal comfort [14].

In Sistan, semi-open space of the house is called Evon (Eyvan in the native accent), which according to field studies and documentation of sample houses, is a stretched shallow vaulted space in front of the rooms, always facing south (Figure 28). Evon is similar to Yazd Eyvan but with vaulted roof instead of timber columned roof due to the lack of trees with structural woods in the region. Evon with its back against wind and its front facing direct sunlight, provides a warm pleasant space in front of the house against the cold winter winds which blow from the south (Figure 13). There are no north-facing Evons in Sistan's architecture because they would form an air-block that prevents the desirable northern wind-flow from entering the houses through ventilator openings (Figure 29).

One of the main functions of Yazd's Talars is to create temperature difference and cause airflow in the household, whereas, in Sistan, due to constant wind flow in summer, there is no need to stimulate airflow manually (Figure 13).

Figure 28. Sistan Evon (**Left**) and Yazd Eyvan (**Right**).

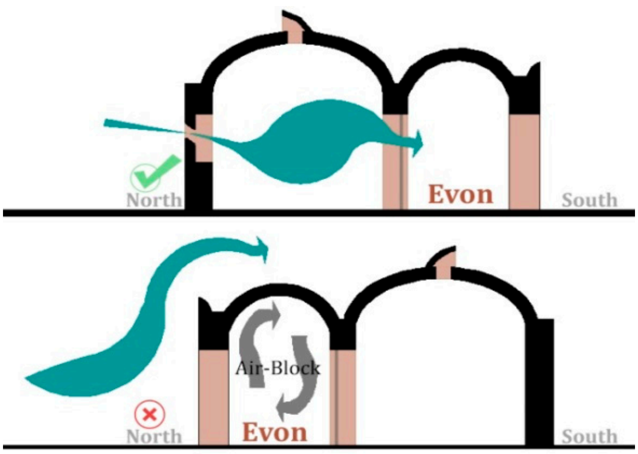

Figure 29. Sistan Evon, built south of the building.

5.9. Roofs (Vaults and Domes)

Both regions of interest face low precipitation level (Figures 6 and 13) and lack of structural timber due to their hot-arid climates. lack of timber prevents constructing flat roofs; therefore, available materials such as adobe and brick are used in order to cover the houses' spaces and create a comfortable indoor environment in the only way possible considering these materials' specifications, which is building Domes and Vaults (Figures 16 and 17) [28].

Domes and vaults are conveniently more suitable for both regions climates because:

- Compared to flat roofs, they receive less direct sunlight and a part of them is always shaded, thus decreasing the roof temperature (Figure 30) [15].
- Temperature difference in different sides of dome and vault creates a mild airflow underneath [14].
- Compared to flat roofs, domes and vaults are more exposed to wind flow which decreases the roof temperature [56].
- The extra space underneath the domes and vaults is where the hot air inside the room rises and accumulates, far from the level of dwellers, which helps to create a comfortable setting [60].
- The exterior surface area of domes and vaults is larger than flat roofs which lead to greater thermal exchange rate than flat roofs, causing vaults and domes to emit the absorbed heat of the day and cool down faster during the summer nights [68].
- Due to their thickness caused by the nature of their materials, vaults and domes act as thermal hampers, delaying the heat flow within their thermal mass and minimizing the temperature fluctuation between day and night (Figures 30 and 31) [62].

According to field studies and documentation of sample houses, there are three different roof types in Sistan architecture: Filpush, Barrel Vault and Sistani Dome. Among these three, Sistani Dome is the unique native roof of the region and has not been documented elsewhere in the country. Field studies show that 83% of living spaces in Sistan architecture are covered by this type of roof.

Sistani Dome is stretched in one axis, which leads the prevalent northern wind towards Kolak; unlike Yazd that wind blows from different direction and symmetric domes lead the winds towards several openings of Yazd wind-catchers. Compared to common domes of Yazd, Sistani dome provides a greater exposed area against winds. The volume underneath this dome is greater compared to Yazd's domes and can keep more warmed air far from dwellers level. Considering the orientation of houses and their roofs in Sistan, Sistani domes have greater shaded area compared to Yazd's Domes.

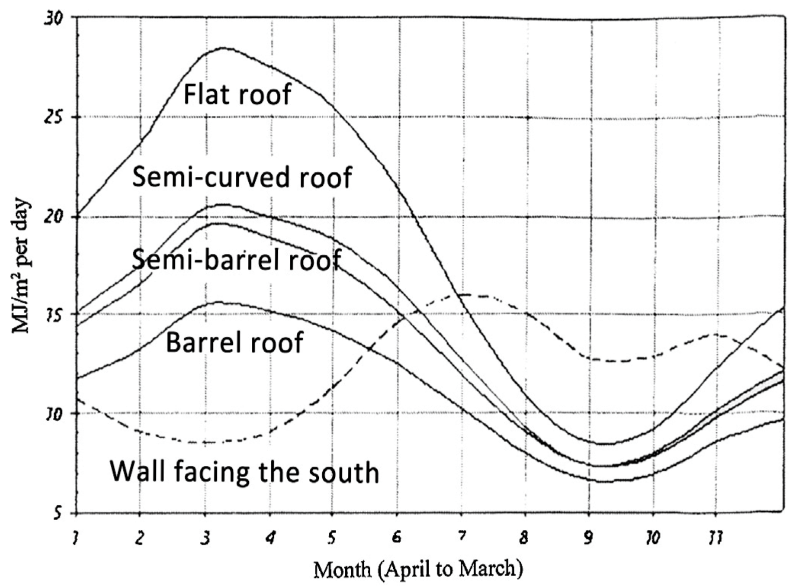

Figure 30. Total daily solar radiation of different roofs in hot-arid region of Iran [69].

Figure 31. Roofs' typology in: Sistan (**Left**), and Yazd (**Right**).

5.10. Wind-Catchers

Yazd's wind-catchers are normally tall structures over building roofs working as canals to direct the wind into buildings [28]. Facing the cool and favorable winds of the region, wind-catchers trap the wind at a certain height and guide it into the buildings [45]. Aside from direct wind-flow, wind-catchers ventilate the rooms by simulating chimney effect [70]. These elements are usually built for summer spaces or cellars in Yazd architecture [68].

Sistan wind-catcher or Kolak (Kō lak̗ in native language) (Figure 35) [58], on the other hand, are short, one-sided and face the prevalent 120-Days Winds [59].

Yazd wind-catchers are far taller than Sistan's due to the extreme dense fabric of the city and the lack of significant or cool winds in low altitudes (Figure 9 and Table 2) [36], whereas, in Sistan, according to field studies and documentation of sample houses, Kolaks are at most 100 cm tall due to the fact that winds blow in lower altitudes (Figure 14) (Table 2) and the fabric is less dense than Yazd. Yazd wind-catchers are built tall to increase the thermal exchanging surface area of the wind-catchers walls and cool the wind that is about to enter the room [71]. In Sistan, the winds are already cool because they have passed Hamoun Lakes on their way to the region (Figure 11).

Table 2. Yazd wind-catchers' height [72].

Height (cm)	Count	Percentage
0–120	141	21.3%
120–300	255	38.5%
300–500	157	23.7%
500–1000	103	15.5%
Over 1000	7	1.1%
Total	663	100%

Yazd wind-catchers are multi-sided (usually four) [69] because winds blow in different directions in the region (Figure 7). In contrast, Sistan Kolaks are one-sided because prevalent winds blow only in one direction (Figure 15). The economic success in mid-nineteenth century encouraged more elaborate wind-catchers in Yazd [16]; thus, different sizes and forms of Yazd wind-catchers also represent the socio-economic situation of the house owners (Figure 32). Sistan, on the other hand, did not experience the same economic boom and even today is one of the most destitute regions of the country with a feeble agricultural based economy [65]. Thus, wind-catchers in Sistan are all the same: small, short and unelaborated (Figure 32).

Figure 32. Wind-catchers of: (**top**) Yazd; and (**bottom**) Sistan.

Constructing huge wind-catchers in Yazd is expensive; therefore the number of wind catchers in each house is few, even for the houses of well-to-do families. In Sistan, it is cheap to build Kolaks and this fact has led to numerous Kolaks in each house to the point that even stables have their own Kolaks.

Based on the findings of Foruzanmehr and Vellinga (2011) [12], 40% of Yazd houses use wind-catchers. In the same questionnaire study in Yazd, they concluded that 33% of the comments depicted the wind-catchers as: unfiltered against dust, birds and insects; and ~12% believed that wind-catchers are expensive to build and maintain. They also concluded that one of the main reasons that almost 90% of Yazd population uses electrical devices for ventilation is that there is a lack of control in wind-catchers performance.

In Sistan, on the other hand, almost all the buildings use kolaks and according to field studies and direct observations, the use of electrical ventilation devices is as low as 10% because dwellers can control the performance of Kolaks by simply blocking it whenever needed due to its small size. It is also not expensive to build and maintain.

5.11. Openings

Openings in Yazd architecture are mostly located on the higher parts of the walls facing the central courtyards. These openings are equipped with decorative wooden frames and colored glasses that provide privacy, hamper the direct sunlight radiation and also do not disturb the ventilation and airflow between the rooms and courtyards [73].

As mentioned earlier, exterior façades of Yazd houses are shaped by tall non-porous walls and the number of openings is reduced to a minimum (Figure 21) to prevent dust and unfavorable hot wind from entering the houses [28]; as a result, the openings in Yazd architecture are mostly built on ceilings facing the sky (Figure 38) or on the interior walls, facing the central courtyards [53].

Rooms that are located in the north part of the houses (facing the south warm sunlight) are usually equipped with large door-windows (greater part of the door is made of glass within wood frames) to let in the most possible sunlight in order to provide a comfortable warm environment during winter [29]. Sistan architecture, on the other hand, utilizes openings in order to direct the favorable, cool and humid 120-Days Winds (Figure 13) into the living environment for ventilation. Unlike Yazd, the favorable prevalent winds blow at lower altitudes in Sistan (Figure 14), which is the exact reason why there are openings in Sistan's vernacular houses walls (Figure 33).

According to field studies and documentation of sample houses, three different ventilator openings are used in Sistan vernacular architecture: (1) Kolak; (2) Surak and (3) Daricheh (Figure 34), none of which has been documented elsewhere in the country. The fact that prevalent winds are constantly blowing during summer (Figure 13) has led Sistan masons to manipulate the winds through these special openings in walls and roofs [54,74].

Kolak (Kōlaḱ), the native wind-catcher of Sistan was discussed in previous title. Suraks (Sŭ rraḱ) are oblique opening canals, usually built in groups of three, located in higher part of the northwest walls of the houses facing the northwestern winds. Two lids of each canal in different sides of a wall are located in slightly different heights causing the wind enter the room obliquely (Figures 33–35) [54,74].

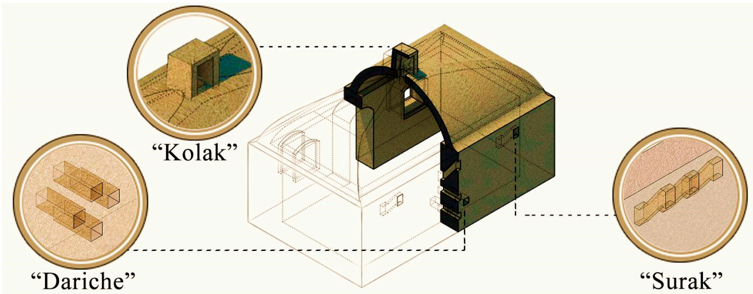

Figure 33. Distribution of openings in vernacular houses of Sistan.

Figure 34. Unique openings of Sistan's vernacular architecture.

Figure 35. Kolak: Native wind-catcher of Sistan.

Darichehs (Da ri cẖə) are straight canals, usually built in groups of four, in the lower part of northwest walls of the house facing the same winds (Figure 36) [58,59]. Two lids of each canal on two different sides of the wall are located at the same height causing the wind to enter the rooms directly (Figure 34). Dariche is located in the lower section of the walls near the ground, creating the opportunity to stack hay in front of it. The stack is sprayed with water, and when the wind passes through, gets cooled off causing a cool breeze to enter the rooms [58,75].

Sistan architecture also uses windows in its southern walls to let in the warm southern sunlight in winter. These windows work as exit points for interior airflow during summer and are a part of ventilation process in the houses (Figure 36) whereas in Yazd architecture, as mentioned earlier, decorative door-windows face the central courtyards (Figure 37).

Figure 36. South facing windows (**Left**); and Darichehs (**Right**).

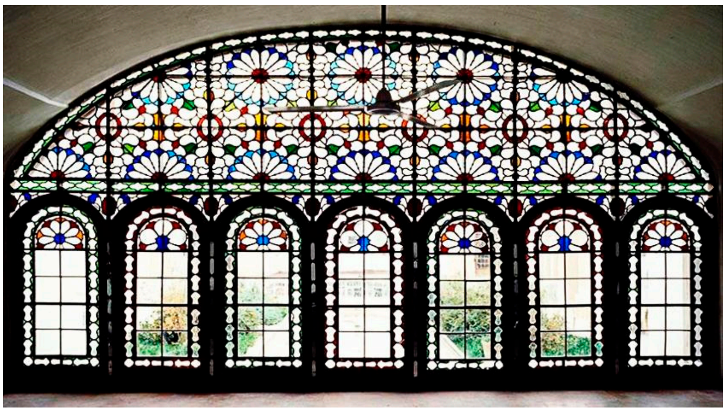

Figure 37. Door and windows facing central yard in Yazd architecture.

5.12. Other Less Significant Elements

In addition to the elements mentioned above, there are a number of elements that are not commonly used in the vernacular architecture of the two regions, and their adornment characteristic outweighs their climatic performance. Two of these elements are as follows:

5.12.1. Khishkhans

It is used in Yazd's architecture and is a hole in roofs with an additional small dome built on it. The dome is pierced and through its several openings, light can enter and the warm air inside can leave the room [13]. Kolaks play the same role in Sistan architecture, letting in both light and wind (Figure 38).

Figure 38. Light entering the room through Kolak (**Left**); Kolak's opening (**Middle**); and Yazd's Khishkhans (**Right**).

5.12.2. Shutters (Tabesh-Bands)

Tabesh-band is Yazd architecture solution to control the solar radiation. It is a set of thin louvers built with wood and plaster, attached over a window or door in order to shade it [28]. Due to the abundance of reeds in the region, Sistan architecture uses reed weaved shutters called Kholak (khō lák in native language) to control the sunlight [58] (Figure 39).

Figure 39. Native people of Sistan weaving Kholak shutters.

6. Conclusions

Vernacular architecture accommodates itself to its context through utilizing different solutions. Context is actually the major determinant in the techniques and elements of this architecture. In hot-arid and hot-arid-windy regions of Iran, vernacular architecture has sustainably adapted itself to geographical, geological and climatic specifications of the context. Native builders use their limited resources with clever and sustainable strategies to achieve maximum comfort. This sustainable adaptation has led to differences in vernacular buildings in two regions and caused them to utilize strategies that are similar in logic, but different in appearance. Both architectures have been able to provide a comfortable living environment for their occupants through ages and that is why the native people still keep on building their homes in almost the same way. Success of vernacular architecture in adapting to context and providing a comfortable living environment can be extended to future designs by comprehending its logic. To conclude, the differences between the architecture of hot-arid and hot-arid-windy regions of Iran and the reasons for their existences are explained in the following illustration (Figure 40).

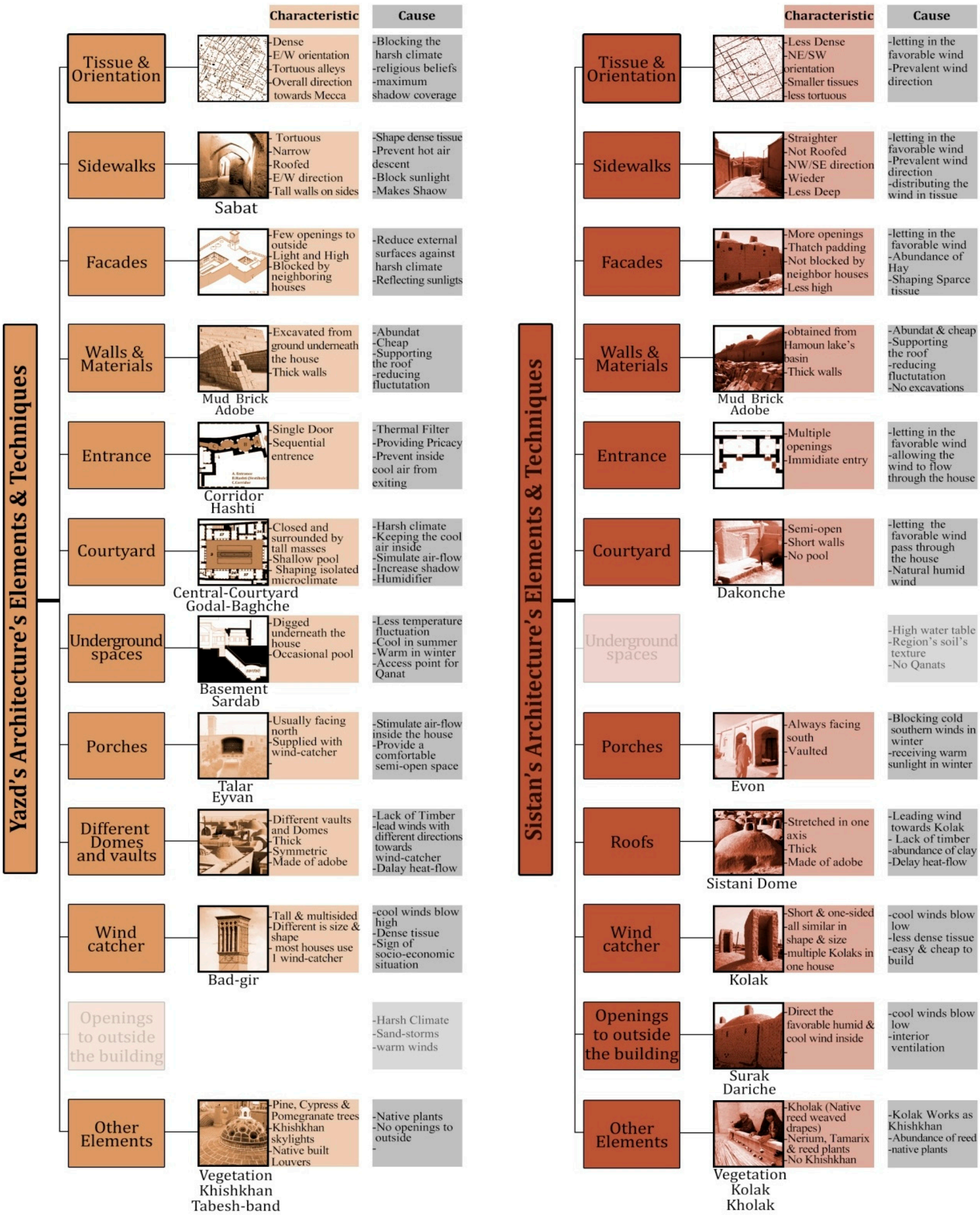

Figure 40. Sustainability Features and cause of their existence in hot-arid and hot-arid-windy regions of Iran.

Through understanding these characteristics and their causes, future construction can continue the sustainable adaptation in vernacular architecture and add their own innovations in order to accommodate to new ways of living and construction.

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