Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 7 July 2021: 11651 – 11663

Study the architecture of earth shelter and its role in underground habitat formation (Case Study: Iranian Shavadans)

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Abstract

In recent decades, the world's environmental pollution crisis has been broadly raised and led to human society concerns. Architects as an important part of community that are involved in environment must reflect on their constructions and take advantage of new ideas in reducing energy consumption and its pollution, given the continuing decline in non-renewable energies as well as availability of suitable sustainable energy resources (solar, geothermal, wind, etc.). Earth shelter architecture is one aspect of architecture where the thermal mass of earth behind the outer walls is taken into consideration in order to reduce heat loss and maintain the internal temperature within comfort zone of man. Studies on earth shelter construction typology in Iran can be considered as a model for today's innovative designs with an energy saving approach through introducing various Iranian samples of this kind. Erath shelter architecture of world is classified into three categories: Land enclosed with accumulated soil, rock shelter, and underground shelter. Most of these self-support architectures have been formed as they enter into depths of earth including sunken courtyard in warm and arid climates and Shavadan as an underground shelter in warm and humid climates. "Shavadan" is one of the underground spaces with special uses and features in depth of 6 to 12 meters, which has been a suitable shelter for escape from severe climatic bottlenecks since ancient times, and has been common in the cities of Dezful and Shushtar in southwestern Iran until modern times. A Shavadan has been dug in every house. The present study is a descriptive-analytic one and aims at expressing the patterns of Dezful and Shushtar traditional architecture, especially Shavadan (which has an important role in energy saving). The results of this study show that Shavadan has been a successful example of sustainable architectural principles in responding to environmental conditions of region.

Keywords: Warm and humid climate, Underground habitat, Terrestrial architecture, Shavadan

1. Introduction

Native architects tried to find solutions for better human life in anywhere of world. Although dealing with natural disasters is not an easy task, they benefited from every opportunity in order to realize their dreams. Chinese stockpiled ice for thousands of years B.C. The ancient Greeks and Romans cooled their drinks with snow that was covered with straw in holes (Imam, 2002).

Ample evidences of Iranian architect's ingenuity and creativity can be seen in examining Iranian sustainable architecture:

- Special windscreens for hot and dry areas
- Warehouse water scattered in many parts of Iran
- Deep-sea refrigerators for storing and preserving ice during summer

Meanwhile, Shavadan was built under special circumstances, which is characteristic of Dezful and Shushtar cities in southwestern Iran. The factors of Shavadan formation in Dezful include warm and semi-humid climate of Dezful city, its proximity to Dez River, having cool water of river and high elevation of city compared to river'; so, Dezful architects have been able to take advantage of river cool water and mild temperate of earth depths and create favorable living conditions at temperatures above 50°C prior to electric cooling devices invention (Safa'i, 2: 2013). The presence of people in these basements, not only has been duo to physical comfort, but also due to implications of people morale in this area. The paper aimed to clarify these concepts in local architecture of region and study bio-climatic solutions, especially shavadans in order to use Shavadon's cooling energy for architectural spaces optimization and get sustainable solution for current and future architecture using past experiences. We will study the effective factors on Shavadans, introduce this climatic element and then examine its components for home applications and architecture self-sufficiency from natural airflow ventilation perspective, which is consistent with indigenous and sustainable biodiversity patterns. Sarbanqoli, 2013: 1_2)

2. Warm and humid climate

The southern shores of Iran form the warm and humid climate of country, which are separated from central plateau by Zagros Mountains. The climate is characterized by warm, humid summers and mild winters. In summer, the maximum air temperature reaches 35 to 40 degrees Celsius and maximum relative humidity reaches 70 percent. The air humidity of this climate is high all year round, so temperature of different seasons between night and day is low. The cities of this climate differ in terms of heat and rainfall based on different coasts and distance from sea (Kasai, 2008: 160).

3. Sustainable architecture

Climate-friendly buildings or buildings based on climate have better quality in terms of human thermal comfort. The environmental conditions of these buildings are healthier and better, and daily and seasonal variations of light, heat and air flow of these buildings create varied and pleasant spaces. On the other hand, coordinating buildings with climatic conditions will save fuel consumption in order to control the environmental conditions of such buildings (Kasmai, 2010: 1).

4. Earth shelter architecture

Earth shelter architecture uses adjacent ground floors as its walls in order to prevent heat transfer to outside and maintain a constant temperature inside. This architecture style, known as the first man-made housing, is studied in parallel to contemporary styles known as sustainable solar energy architecture. After energy crisis of 1970s, the concept of earth shelter architecture has entered housing architecture trend and has been evolving ever since. Energy conservation is a top priority of shelter architecture. In the case of such structures, it must be acknowledged that a number of non-residential buildings have been built underground for non-energy saving reasons, but it does not imply that energy-saving is not possible in non-residential buildings. It is clear that such applications can be limited and effective tools in future. (Wendt, 1982)

Biological studies on this field in Iran provide examples that can be considered as a model for today's innovative designs with an energy-saving perspective. This type of construction appeared in response to human needs when modernity was not so advanced. (Khodabakhshian, 2012)

4.1 The advantages of underground development

Study the architecture of earth shelter and its role in underground habitat formation (Case Study: Iranian Shavadans)

The cities growth and increased demand for more spaces have resulted in cities with towers, skyscrapers and dense fabrics. We do not reject this method in general, but we should not overlook the urban landscape and horizon. Of course, there is another vital option underneath these buildings. Fortunately, underground development is one of the great opportunities that we can use in order to solve the problems related to our city's sustainable development.

Underground parking lots, freeways, and shopping malls can be created in order to use surfaces for other uses and enhance the urban environment. The benefits of underground structures are directly influenced by underground surfaces quality. (Khodabakhshian, 2012)

The advantages of underground space are summarized in Table 1.

Table1: The Advantages of using underground spaces

Aspects	Advantages
Energy	**Reduce wastage of energy conductivity** **Create heat storage capacity** **Earth temperature stability** **Air intrusion control** **Reduce thermal gain** **Residential Patterns effects on energy-related advantages**
Use land and space	**Limited visual impact** **Protect surface spaces** **Optimal use of land** **Protect land vegetation** **The possibility of creating denser urban structures** **Prevent traffic and parking on ground floor, use instead side lands for work, housing and recreation centers** **Protect against very hot and very cold weather** **Protect against noise and vibration** **Provide security** **Protect against natural disasters** **Affordability of underground construction**
Urban landscape	**Help preserve natural landscapes and urban areas** **Turn streets into underground tunnels enhances quality of life in city centers** **Less visual impact than surface buildings**
Protect environment	**Helps hide sensitive equipment** **Durability of building materials** **No need to use exterior facades** **Underground construction does not affect the shape or structure of rocks or natural conditions of the area** **Environmental stress factors such as noise pollution are reduced by underground construction** **Help to preserve environmental and cultural values**
Protect citizens	**Stability and resistance** **Food preservation** **Protect against aircraft noise pollution** **Protect against disasters and hazards caused by certain facilities and equipment**

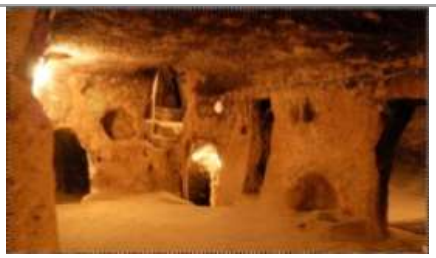
Security and protection advantages

(Source: Authors)

4.2 Collection of old (historic) earth shelter buildings around the world

Despite overall similarities between different earth shelters buildings in different parts of world, they have differences in space, number of floors, accessibility, and harmony with nature. There are still many rock shelters in Europe, and especially in south, places like Spain (region of Minorca), Atruria in Italy, Greece alongside a spring in Castelli and Delphi,. There is a populous stone village with a population of about 4,000 in Tripoli area. There is a densely populated rocky village about 200 kilometers southeast of Ankara in Göreme Valley. There are more rocky shelters in stable condition of ancient regions such as Pentus, Frigia, and Lydia. There are cities of earth shelters that are occupied by indigenous people in mountainous areas of Qaryan, Nalut, and Qadamis in northwest Libya (Golani and Ojima, 1996).

Table2. Collection of shelter buildings around the world

Places	Jeographical aspects	Sample document
China	Forty million people live in such homes in Shanxi and Henan districts, in eastern part of Gansu and Ningxia Autonomous Regions of present China. According to Chinese researchers, some samples have a life span of 3,000 years. In Gansu that is an eastern province, 83 percent of population lives in underground shelters. (Golani, 1986) There are two main types of land shelters in these areas, including central courtyard and stone shelters as homes. (Golani and Ojima, 1996)	 (Khodabakhshian,2012)
Tunisia	Most of high-density land shelters are built in North African country; Tunisia has only underground and rock shelters. Roman-style shelters are found in Boulargia area, north of Tunisia, with warm and dry Mediterranean climates in summer and humid and cold winters. This region was the center of wheat production in North Africa under ancient Roman rule. (Golani, 1986)	 (Khodabakhshian,2012)
Turkey	The city was called anciently Catalan Hoyuk, dating back 10,000 years. The city is located 400 km southeast of Ankara, Turkey; it has a warm and dry climate and a total of 42 underground shelters. Using underground and rock style shelters dates back 4,000 years. The surface of this area is covered with melt and sharp surfaces eroded and cone-shaped over time by dry desert winds. These conical shapes form a	 (Khodabakhshian,2012)

	communication network between buildings. These buildings were used as churches in addition to residential purposes during Byzantine period, when Christianity was considered an underground activity. (Golani, 1986)	
Mesa Verde	Another ancient example of rock shelters is found in Mesa Verde near Cortez, Colorado. The area is made up of indigenous habitats known for its numerous rock formations created in not-deep caves and in rocky hills along valley gorges. The front walls are made of internal rocks and mortar that attach to the main trunk. The internal structure of these buildings is generally made of hard sandstone cliffs connected by brick (Figure 10). The largest complex of region has an area of 40 acres and 1200 rooms, 135 prayer rooms and 19 towers. As vertical holes of 15 m height are found in specific sections, it can be seen that some of its residential buildings have 5 floors which are connected by ladders installed on façade. (MofidiShemirani et al., 2012)	 (Khodabakhshian,2012)

(Source: authors)

4.3 A Case Study on earth shelter architecture in and out of Iran

5. Shavadans

Shavadan derived from Shutapuata root that is mentioned in Iranian cities book related to Parthians and Sassanians periods (Bina, 2008: 37-39).

5.1 History of Shavadan

There is no enough information about the time of Shavadan applications. Given the early formation on Dezful and Shushtar cities core and part of Sasanian period's historic buildings, especially the historic bridge of city dating back to 1263, it seems that Shavadan application history is 1500 years; city's Jama mosque is related to 7th century AH and has Shavadans that supports this theory (Saremi, 1996).

5.2 Shavadan definition

According to “Sustainable values of Iranian Architecture” by Dr. Ali Akbar Saremi, “Shavadan is an underground and long road that often leads to Dez River and reaches a basin with six-meter depth on its way which is called Minamand Shabestan” (Saremi, 84: 1997). Shavadan is a space that is drilled under Dezful and Shushtar old cores at depth of 6 to 20 meters. (Figure 1) Air flow in Shavadans is made possible through vertical channels that are called Darize. Also, other materials are scarce due to type of soil that is conglomerate. (Saremi, 1997)

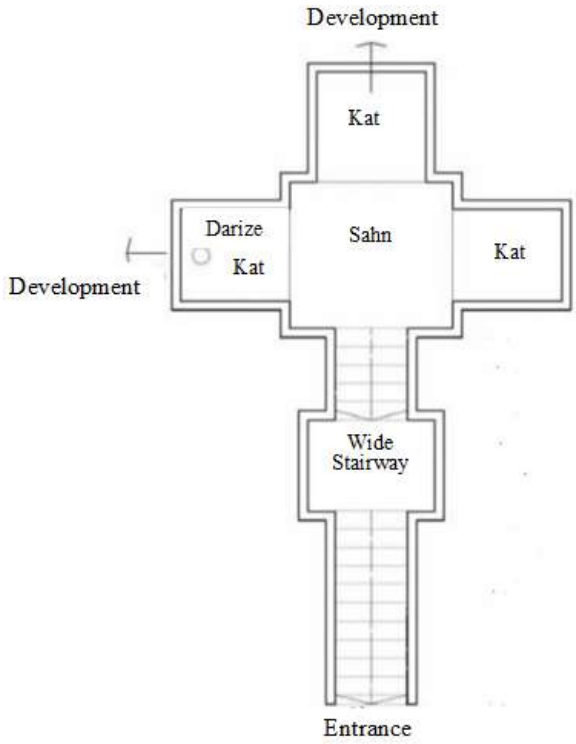


Figure1. The General Plan of Shavadan (Sattari Sarbanqoli, 2013: 2)

Mostly, Shavadans are used in hot summer days. In other words, there is another way of living under city besides living in city. In fact, the plan of using lower levels of earth and spaces such as Shabestan and Shavadan was provided due to adverse climate factors and neglect heat factor and its containment in this area.

Shavadan was used not only as cool and quiet space in summer, but also had a significant impact on ventilation and cooling of building so that cool air was often distributed through channels in various parts of building. Temperature of hot and overwhelming summer weather sometimes exceed 50 degrees Celsius, but Shavadan temperature is stable between 22 and 25 degrees Celsius and this cool atmosphere has been the best shelter for citizens in order to enjoy daily living. People worked and lived in tents and under trees shadow in other cities or villages that were deprived from having Shavadan. (Figure 2) (Kazempour, 2013: 3 to 5)

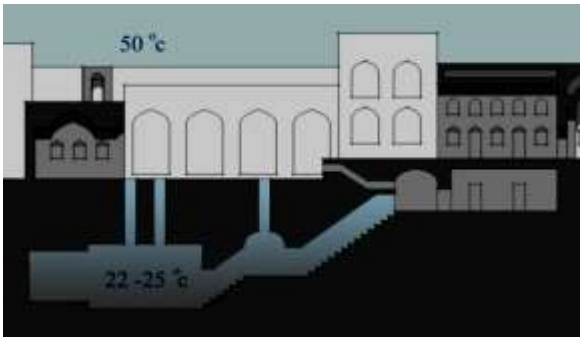


Figure2. Cross section of Shavadan and temperature difference of inside and outside (Safa'i, 2013: 4)

5.3 Shavadan architecture

Deep penetration and more favorable environment creation have two forms. Firstly, there are Shabestans that half of their height is below ground and under part of building. In some cases and buildings one can observe separate Shabestans in inner and outer parts of building with depths of about 7- 10m. It reaches up to 10 meters. The lighting and ventilation of Shabestans were

mostly through courtyard and exhaust pipes. Generally, Shabestan is part of building body and structures and was built along with building main body. (Figure 3) Secondly, underground was constructed as a result of deeper penetration into ground and was called Shavadan. Unlike Shabestan, Shavadans are mainly built beneath the courtyard and have free access to air through Cisara and Darize and their depth is about 20 meters. Shavadan is an element that is separate from overall structure of building and accessed by various forms, such as Shabestans or directly through courtyards. Shavadans are formed independent of yards in cases where houses are separated from courtyards and include semi-enclosed spaces or arches (Kats) which are used as living spaces (Mashoudi, 192 - 193: 1995). So, Shavadans are relatively large and deep rooms with stairs reaching up to 50. Shavadans are relatively warm in winter and cool in summer, with temperatures varying up to about 20 degrees Celsius. Shavadans entrance corridors are different; this means that in some cases there is a maze tunnel with continuous stairs facing bottom from entrance to center of Shavadan, and in other cases the stairs are extended directly from ground to the bottom. Generally, no material is used in constructing Shavadans except for stairs. Shavadans are drilled deep into earth and their roofs are formed naturally, flat or diagonally (Nouri Saghaei, 5: 2016)

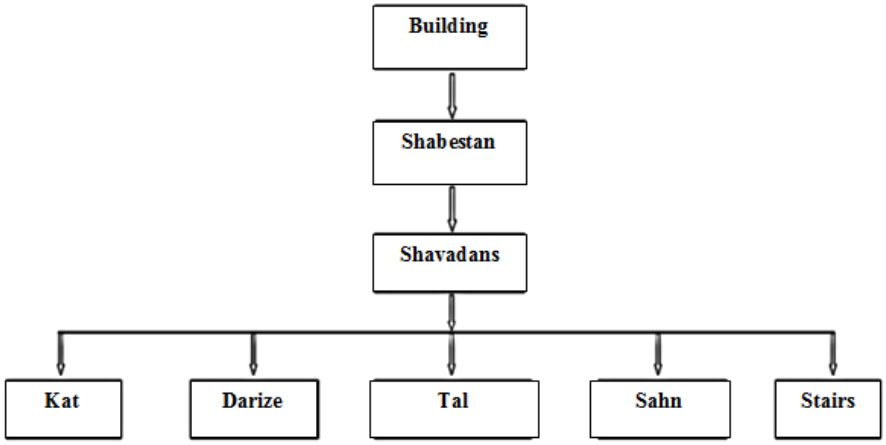
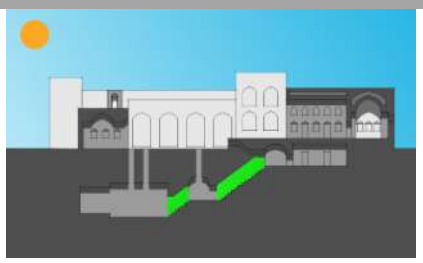
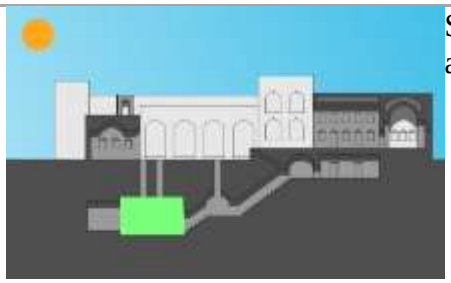
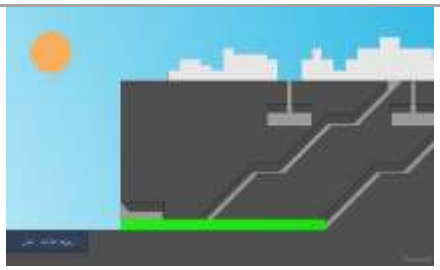


Figure3: Hierarchy of Shavadans in Shushtar and Dezful (Source: Authors)

Table 3: The main components of Shavadan

Row	Component name	Explanations	Image	Image source
1	Carstairs	The staircase is part that connects building to Shavadan and in some Shavadans the number of stairs reaches 40. Stairs are connected to Shavadan through courtyard, main room, rooms, or porch. Shavadan staircase has been implemented in different ways. Property size is the most important factor affecting staircase form. Direct, rotating and two-way staircases have been common forms of access to lower floors of earth. (Safa'i, 2013: 6-7). Stairs and floors of		Source: authors

		Shavadans were covered with bricks, and even rich persons painted walls and ceilings with white plaster slurry (Imam, 2003: 91)		
2	Wide staircase	Wide staircase is a wide plate or surface that was built after main stairs and then there were other stairs that reached the bottom of Shavadan. Large Shavadans could have two or three wide staircases. In some wide staircases, another outlet was built into underground spaces (Safa'i, 2013: 6-7).		Source: authors
3	Sahn	All Shavadans have a main space. This main hall is called Sahn. Sahn was the center of life's main activities in Shavadan and subdivisions were attached to it. It is possible to excavate land without arching in Dezful due to specific nature and strength of soil, and this has led to the freedom of action in Kats space (Safa'i, 2013: 7).		Source: authors
4	Tal	They are horizontal narrow canals that provide underground communication between neighboring Shavadans. These tunnels caused air flow as well as access. Occasionally, these tunnels provided links between several neighborhoods and led to margin of river through last adjacent river unit. Cool air flew into Tals and then into Shavadans by Kats. In some cases, they netted Tals for limited area (Figure 6) (Safa'i, 2013: 8_8).		Source: authors

5	Darize	A cylinder hole, about 1 m in diameter was used in order to provide light and vertical ventilation. The canal connected the home spaces to Shavadans and transmited cool air flow from Shavadans to home space. Also, Darize was dug in yard, which provided light as well as was used in order to transport soil during construction. In some instances, Darize gates have been linked to alleys, passages and even to roofs of homes. In this way, the air was always moving (Figure 7) (Safa'i, 2013: 7).		Source: authors
6	Kat	Kats are troughs into soil. The term Kat is used in two ways: A. Kat includes the troughs of Dez River shore that connects to Shavadans through Tals. In other words, connected Shavadans enter into Dez River shore wall. These calm paces are called Kat. B – Kats are numerous rooms or troughs that diverge from main Sahn. Kats are more private spaces in Shavadans. Each Shavadan had more Kats depending on its size (Safa'i, 2013: 8-9)		Source: authors

(Source: authors)

Table 4: Sample earth shelter architecture in Iran

Historical positions and aspects	Physical features	Functional systems	Documents
	Kariz		
Kish's old Qanat is 15 km long and extends along two branches of Saffin area and airport to current site of Kish's cultural and	Kish Qanat is not comparable with other Qanats of Iran in terms of Qanat branch length and wells depth. Given the low	Kish Qanats date back over two thousand years and are among the oldest Qanats of Iran. These Qanats have changed to entertaining and fascinating complex for visitors through refurbishing and improving one of these Qanats in the form of extensive tunnels with	

tourism complexes. The underground city of Kariz is remnant of Kish's main Qanat. This Qanat is over 2500 years old. The Qanat is used in order to supply fresh drinking water of islanders. Kariz city is 16 meters underground with a height of 8 meters and is mostly covered with fossils and corals; according to experts, they are 270 to 570 million years old; their components have been identified and certified.	slope of island, the groundwater way to Kish island surface is important and shows that island's inhabitants have used the most advanced methods of drilling in their time. Qanat use has changed over time and has become a fascinating underground space that has over 10,000 square meters area; it is called Kish Kariz. (Taghvaee, 2014)	unique architecture. In recent years, many efforts have been made in order to rebuild, preserve and renovate these historical fabrics. Some changes have enhanced Qanats' functional aspects including create new uses such as Iranian and world handicraft stands, classic and modern restaurants, museums, amphitheaters, conference hall, and art galleries. (Taghvaee, 2014) 
Noshabad		
Noshabad is located on suburb of Aran and Bidgol cities and is one of the five small ancient settlements in Isfahan province. Noshabad is the capital of Sassanid and Anushirvan dynasties and has 1500 years old. The underground city of Noshabad is known as "Auvi". In old tales on Kashan Silk, there is a saying on Noshabad "a myth is under skin of this city and breaths". Surprisingly, the dream of Noshabad's	The underground Auvi city is excavated into three floors at a depth of 20 meters. The underground city entrance is as narrow as one person pass. The smell of wet soil is felt when you enter the city. This underground city was created on three floors with a depth of 4 to 21 meters. The city was built mainly for communication between neighborhoods and protection of people's lives and property against unsafe	The underground city's construction is based on three reasons: a place for worshipers of Mithraism, a place for protection against high heat of salt pan, or a shelter against attackers who targeted this part of Central Plateau. The complex has had a major impact on architectural design due to its defensive reasons and use as a shelter. Groundwater was supplied from Qanats and riffles for residents during insecurity times and shelter use. Auvi is connected to Qanat and riffles in some places. The underground city ventilation system includes channels that are built on first floor and reach the ground level. The wells connecting floors create a path and direct airflow to lower floors. (Taghvaee, 2014)

underground city came true in early eighties AH. (Taghvaee, 2014)	conditions. It was been expanded both horizontally and vertically. Some rooms were excavated beside underground city as shelter. The height of each room was 180 cm. Auvi people have done a great deal of works on resting places in order to keep their life safe against enemies, even at 18 meters. (Taghvaee, 2014)	
The Hidden or Underground City of Samen is located in Samen city and 15 kilometers from Malayer in Hamedan province. Excavation of an underground area in Samen city led to discovery of a hidden city that was based on man- made and granite bedrock. There is no information on exact age of this mysterious city. According to preliminary studies, it probably dates back to pre-Parthian dynasty. It is possible that the city was founded during Mehrdad I of Parthian time (from 160 to 130 BC) and for ancient Iranian rituals.	The city has an estimated area of more than 3 hectares and almost 25 rooms have been discovered up to date. The underground city is 3 to 6 meters deep, with canals that have benn drilled over time and surrounded by several rooms. According to archaeological studies, the city contains nested canals. This place has been expanded throughout the historical periods and its rooms and corridors have different lifetimes. (Taghvaee, 2014)	It is assumed that city was hidden before Parthian period and then used as a cemetery. It is likely that the place was first used for special religious rituals of Mithraism and worship of "Mithra" for sun god. Evidences suggest that religious ceremonies have been carried out in secret underground locations and some of its channels may have been used in to bury religious victims or important religious persons. Research show that city has been used historically for three periods. First Period: The reason of its creation goes back to first period. According to preliminary surveys, the city's core is older than its canals and rooms around it. It is likely that city was built for special Mithraism rituals. Second Period: This is a period when city was used mostly. The period goes back to the Parthian. The site was excavated much earlier than Parthians, but it has been in continuous use since Parthian period. Third Period: The third period relates to fall of this ancient site, which seems to coincide with fall of kings in Iran. This place has been used as a shelter and a place for burial of special dead people during this period. (Taghvaee, 2014)

(Taghvaee, 2014)

Source: Authors

5.4 Shavadan and social connections

Underground communications between neighboring Shavadans and access to riverbank from underground with coping intense summer heat as well as defensive and counter-offensive purposes have shaped an underground life in old Dezful. Some Shavadans had all necessities of life and people conducted their social transactions in Shavadans on hot summer days. Also, neighborhood's privacy was defined for underground. Tals defined neighborhood boundaries, as connecting Shavadans. In some cases, Tals were lined with brick, thus formed private spaces and only air passed. Everyday life, however, continued in underground as on ground through preserving privacy in Shavadans and connecting ways; Shavadans were like residential units and Tals were similar to alleys and passageways (Safa'i, 2013: 9)

5.5 Shavadans in future

Shavadan is one of the most prominent elements of Dezful and Shushtar native houses. Shavadans have saved thousands of lives due to their immunity against natural disasters, against climate and natural phenomena such as floods and earthquakes, and war hazards; they were used as a refuge even during Iran and Iraq war. Contemporary construction state and urban planning and architecture have unfortunately taken place without considering Shavadan spatial system. Former space system is disrupted by improper urbanization. Shavadans must be examined and preserved in order to preserve this cultural heritage. (Sattari Sarbanqoli, 2013: 7).

Conclusion

Land architecture as a genotype of land shelters consists of three shelters types including soil accumulation, rock and underground.

1. The first one is an innovative form that is made on flat grounds. This type is common in United States, Greece and United Kingdom for energy saving and has not been discovered in Iran.

2. Another type of rock shelter consists of two continuous and discontinuous types that are common in Iran, China and Turkey. Underground shelters of Iran are known as underground cities.

3. Since using underground spaces has a long history, then, concept of underground spaces and their planning is not new and has not been implemented in many countries, but it has been used to achieve sustainability in most developed societies .Although, underground spaces connected to structures have been identified at ground level, no fully underground residential shelters have been found in Iran.

Examples of this type can be seen throughout the world. Planning underground spaces presents new challenges for urban planners and designers. Using these spaces minimizes visual and biological damages due to harmony with nature and can be an effective tool in achieving energy saving, reduced noise pollution, reduced air pollution, reduced visual pollution, create climate-responsive spatially, physically goals. These spaces are usually warmer in winter and colder in summer and have generally good temperature stability. So, they can be suitable for construction in hot and dry climates with high temperature fluctuations. There are disadvantages in any unusual construction and earth shelter architecture is no exception. Today, given the growing population and

need for affordable housing, earth shelter architecture may not be a viable option due to high costs of construction, but standardization and pre-construction can be solutions for these problems.

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