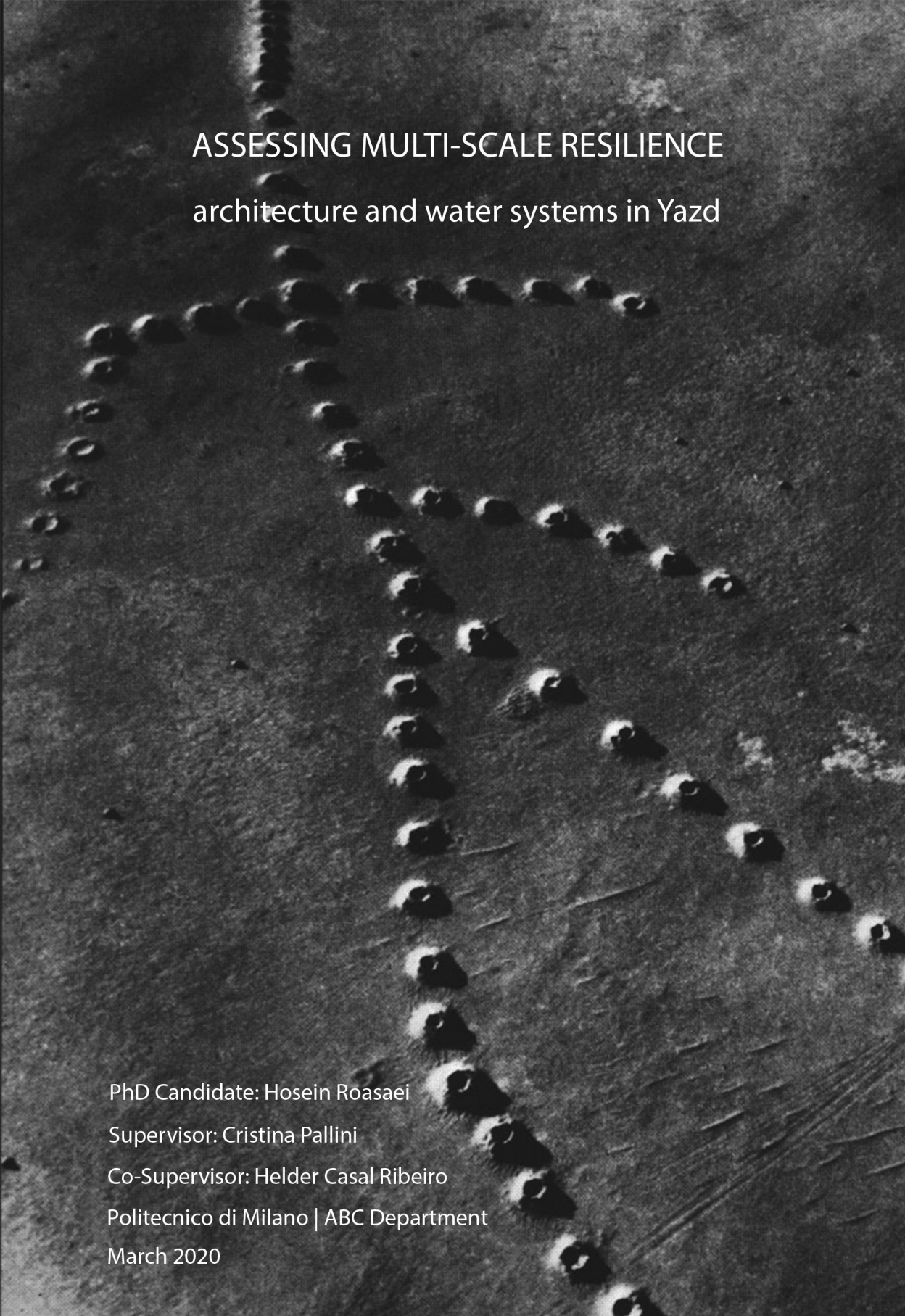

ASSESSING MULTI-SCALE RESILIENCE

architecture and water systems in Yazd

PhD Candidate: Hosein Roasaei

Supervisor: Cristina Pallini

Co-Supervisor: Helder Casal Ribeiro

Politecnico di Milano | ABC Department

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Abstract

Over the last 40 years, many disciplines have summoned the term "resilience" that is the intrinsic ability of a system to respond, adopt and evolve to different forms of pressure, and applied it to various systems.

Although the resilience approach is quite new in the built environment studies, traditional building types, whose functional performance, and key urban role, have proven successful for centuries, may be regarded as intrinsically resilient. In addition, resiliency is context-based concept and it might differ in various circumstances.

This research, to clarify this point, focuses on Yazd, included among World Heritage Sites in July 2017, as its main study case. Yazd is the driest major city in Iran, the world largest inhabited city made of adobe. The distinguishing features of Yazd built environment result from a long-term interaction of natural and social orders. Namely the efforts undertaken by subsequent generation to supply water to the fields for agriculture and to the city for survival and to establish and exploit focal points for long-distance trade.

Natural order signifies climatic considerations, geography, water bodies and etc. while social order represents cohesion of the social fabric to which trade was given an economic drive.

The intrinsic resilience of Yazd relied on the balance

between its water based infrastructure (qanat), plugged-in artefacts and urban pattern. This required a project for the extension and upkeep of a water infrastructure at the regional and urban level, brining to the fore the multi-scale dimension of resilience. Thus, in order to assess multi-scale resilience of architecture and water systems in Yazd, these three notions must be broken down into their essentials.

To clarify these notions, we need to adopt a multi-scale approach, that is focusing what might be confined to the realm of architecture into a broader rationale, entailing elements of geology, hydraulic engineering, energy efficiency, urban studies, social and economic studies and etc. Interpreting a discipline, philosophy, structure, text, and so on through a distinctive language is actually a case of de-constructive rereading (Durmus, & Genccan, 2017) . By de-constructive rereading of Yazd, we may understand more clearly the role of its architecture and water system and their relation to natural and social order.

Assessing multi-scale resilience of architecture and water systems in Yazd, will make it possible to understand resilience as a concept based on dialogue, adoption, evolution and equilibrium between various disciplines.

Thus, the thesis intends to interpret and breakdown the structural themes and design topics in order to set design concerns and guidelines/priorities that will help calibrate the architects intake on contemporary planning and city management where cross-disciplinary / multidisciplinary vision is embraced as an undeniable factor for future design in all its scales and social meaning and significance.

Keywords: resilience, architecture, water system, Yazd

Figure 1: *Street in Yazd, photo by Oeil-et-Plume*

Figure 2: *Street in Yazd,*
photo by Saham Boorghani

Figure 3: *Covered street in Yazd, photo by Bulent Ozgoren*

Figure 4: *Street in Yazd, photo by Xavier Allard*

Figure 5: *Covered street in Yazd, photo by Mansur Alam*

Figure 6: *Street in Yazd, photo by Mansur Alam*

Figure 7: *Covered street in Yazd, photo by the author*

Introduction

Today a rising number of domain-related resilience concepts exist with their peculiar definitions. As a design principle, resilience was an implicit aspect of construction before the 19th century (Schon, 1983). However, over the last 40 years, various disciplines have embraced the term "resilience" and applied it to ecological, psychological, social and physical systems (Kohler, & Hasller, 2014).

Resilience may be defined as the ability to respond, adopt and evolve to different forms of pressure. However, dealing with built environment, the resilience approach focuses on the long-term evolution of the built environment and on its interaction with multiple natural and social demands and sometimes threats.

Yazd, the driest major city in Iran, helps clarifying our point. Located at the centre of the Iranian plateau 1200m above sea level, and surrounded by mountains, Yazd has a desert climate: large diurnal temperature variation, extreme seasonal change and humidity rate less than 20 percent. Nevertheless, Yazd is the world largest inhabited city made of adobe, so much so that traditional crafts have survived to the present time.

From the 1930s onwards, several policies were established to modernize the city. This led to the creation of a few wide commercial streets and provision of easy access to modern housing, mostly outside the historic

Figure 8: *Alley close to Jame Mosque, photo by Naderi*

city. Apart from changes occurred throughout the 20th century, the property boasts plenty of well-preserved buildings and public spaces.

In arguing the need to pay particular attention to a context-based notion of resiliency -tested over the long term span- this research focuses on the historic core of Yazd as identified by UNESCO in July 2017.

The intrinsic resilience of Yazd relies on the long term combination and integration between water-based infrastructure (qanat), plugged-in urban artefacts (payab, watermill, ice house, water reservoir and houses) and urban pattern. Somehow the location of plugged-in artefacts resulted in a non-isotropic space, which imposed some basic hierarchy criteria to the urban topography.

Yazd therefore may well exemplify how resilience may be considered as a long-term, constant project requiring a thorough understanding of specific physical features and a social structure responsible for keeping the "territorial machine" alive.

Obviously, this balance is not given once for all, entailing as it does a constant process of adaptation. Variables can be both natural and social. Namely, variability of the climate, geography, population, economic necessities and etc.

As a result, to get an in-depth understanding Yazd architecture and its water system, must be broken down to its essential constituting elements. Uta Hassler and Niklaus state that resiliency is a interdisciplinary bridge, while the difficulty is in controlling those disciplines. Thus, this process of reading Yazd through its essentials demands a multi-scale approach.

To clarify these notions, we need to adopt a multi-scale approach, that is focusing what might be confined to the realm of architecture into a broader rationale, entailing elements of geology, hydraulic engineering, energy efficiency, urban studies, social and economic studies and etc. Serap Durmus and Hatice Genccan suggest that interpreting a discipline, philosophy, structure, text, and so on through a distinctive language is actually a case of deconstructive rereading (Durmus,

& Genccan, 2017) . The re-reading efforts arguably serves producing new knowledge, and remembering and bringing into focus what is forgotten, all through a new perspective (Durmus, & Genccan, 2017).

In this respect, the research has implied collecting historical maps from Cultural Heritage, Handicrafts and Tourism Organization of Yazd (HCY), Cultural Heritage, Handicrafts and Tourism Organization of Iran, Municipality of Yazd, International centre on Qanats and Historic Hydraulic Structures (ICQHS), UNESCO, and historic records and etc. at different scales.

At the territorial scale to understand the role of Yazd along the long distance trade routes across Iran and to recognize the physical features based on which the qanat system was originally established and periodically extended.

At the city scale historical maps became tools to identify moments of change, and to map the course of qanats across the city and their relation to major public buildings for example Jame mosque complex. To understand and map access points from long distance trade roads and trade related areas such as bazaar. To recognise and map ethno-religious neighbourhoods, residential areas, productive ones and city walls. In addition to historic maps, the detailed survey on Zarch qanat and Vaqf Abad qanat produced by Semsar Yazdi and on site survey by the author were used to cross-check the course of qanats across the city.

Aerial photographs of the historic area of Yazd since 1950s and old photos gathered from various sources such as Yazd municipality, Iran National Cartographic Centre, Yazdnegar archive and their comparison with recent photos taken by the author and others, used to show the original situation of historic parts of the city which has changed a lot after the demolition of walls and the opening of new roads.

Interpretative maps done by Nikolai Vladimiovich in 1861 and Michael Bonine in 1984 and Cultural Heritage, Handicrafts and Tourism Organization of Yazd, together with interviews done by the author and literature

review helped in creating an interpretive map of Yazd. This map was produced by the author through a process of cross-checking all the above mentioned materials and superimposing the layers in one unified map.

Schemes, diagrams and technical data provided by various scholars from different disciplines together with literature review and translation of original materials in Persian into English and site survey on plugged-in artefacts provided the understanding of how these individual buildings work and what is their role in the bigger system.

In addition, the author participated in various workshops and conferences such as "Crisis and Rebirth of Cities, Naples, 2017", "Water and City Hydraulic Systems and Urban Structures, Yazd, 2018" and "First International Workshop on Earthen Architecture, World Heritage: Conservation Problems and Challenges, Yazd, 2019".

By de-constructive rereading of Yazd we may understand more clearly the role of its architecture and water system and their relation to natural and social order.

Natural order signifies climatic considerations, geography, water bodies and etc. while social order represents cohesion of the social fabric to which trade was given an economic drive.

Assessing multi-scale resilience of Yazd architecture and its water system, and the constant challenge of redefining the equilibrium requires understanding the reason or reasons of its existence, its development and its constituting elements through various disciplines.

The research is organized into three main bodies: the first is devoted to the "Geographic Theatre" or in other words, the combination of natural and artificial features as a scenery in its broader sense, which both the individual and society played their part in daily life and over long period of time.

The second section entitled "Composition of the Habitat" explores the qanat infrastructure and its combination with urban framework. The third is devoted to "Plugged-in Artefacts" arguing that qanat related buildings marked focal points of the urban layout fulfilling

fundamental social role.

The chapter "Geographic Theatre" intends to set the contexts for the following chapter. It deals with fundamental trajectories that were the initial cause of establishment of the settlement in Yazd region: natural order and dynamics of trade. To get a general understanding of these notions, historical texts and in particular travellers' reports will be the first material in hand.

Travellers' viewpoint is at up-most importance in reading the characteristics of a city. Travellers' reports are valuable windows for looking into the past. Many letters and diaries demonstrate shared life events inside a physical environment. Conceivably more than any other kind of historical text, reports tell us how people both embraced and resisted the time and place in which they lived. Their personal motives suggest much about how people in the past made their cultures, but made them from the materials at hand (Jaffee, 2012). Yazd has been privileged in this matter and since 10th century there have been many travellers who mentioned it and described its physical and social aspects.

Those reports as well as the research's initial premises characterize and describe Yazd through natural and social disciplines. Thus, this chapter is followed by the description of the environmental characteristics of the Iranian plateau and specifically the province of Yazd. These characteristics are derived from geological, hydrological, atmospheric, and biological processes. They include land forms, bodies of water, climate, soils, natural vegetation, and animal life.

As the research brings to the fore the notion of extreme climate condition in Yazd, its characteristics need to be well defined. The term "extreme" proposes an intransigent judgement against some norms (Cook, 1996) and relatively, according to "Climate System Science", the language used in climate science is not precise and extremes in one location could be normal in another (WCRP). Although most climates have unpredictable flashes or in other words, are entitled to have extreme climate conditions, our intake stands for those who share these moments over the long period of time.

Drought, high variation in day and night temperature, thunder and sand storms, quakes constitute the criteria that define extreme climate conditions.

Among other important factors affecting the formation of the city, its strategic position and its relation with long-distance trade routes has strengthened commercial activities. Consequently, dynamics of trade may be understood as a common ground for different ethno-religious groups to which long-distance trade was allowing a condition for survival and a perception for the future.

This chapter also puts a detailed attention to the history and moments of expansion. Intuitive relation with history and time problems alongside the differences and similarities in the moments of expansion become a tool and facilitate the process of in-depth understanding of the city. Since Yazd architecture and its water system evolved in a considerable amount of time for its planning and construction, this process clearly show how deeply human settlement implies an understanding of nature. In addition, a long-term project or in this case Yazd may provide a palimpsest for the adaptation of landscape and the transformation of the built environment. Thus, by analysing and reinterpreting the historic maps and texts and reading the moments of growth, we may grasp a better understanding of this adaptation.

The second is devoted to "Composition of the Habitat". Firstly, qanat the vein of the system, operating as "hydraulic infrastructure[1]" , would be demonstrated in different disciplines: its origin, distributing, evolution, construction and typology.

Among four sources of water, i.e., rivers, springs, lakes, and ground-waters, in Iran's desert, groundwater has

1 In response to the significant question regarding why qanat system could be rendered as the hydraulic infrastructure, and correspondingly to 1987 US National Research Council's adaptation the term "public work infrastructure", which defines "a comprehension of infrastructure spans not only these public works facilities, but also the operating procedures, management practices, and development policies that interact together with societal demand and the physical world", we shall bring to the fore qanat construction, its operation, its economy and social order which is articulated around the system.

always been life giving. Qanat is an ancient system of underground water collection and distribution; largely used in arid and semi-arid climates and has evolved through time adapting to different geographical and anthropological contexts. Since ancient times, water in the desert has always been considered as a sacred entity, and the foundation of an ancient civilization in Iran has been established on artificial irrigation (Tavassoli, 2016). In areas with low yielding aquifer, where digging deep wells is not a feasible choice, qanat could well serve the irrigation needs. As such qanat is a resilient water supply system that could indefinitely provide water by preserving subsurface water tables (Motiee et al. 2006).

This chapter follows by analysing the urban framework and rural area of Historic city of Yazd that illustrate the body of the system and its townscape. Architectural notions together with ideas articulated by the rereading of city such as typology, pattern, density and scale together with qanats courses would become apparatus to challenge the long-debated notion of "Islamic city" which derives its initial idea from the influential article "morphogenesis of Iranian cities" (Bonine, 1979).

American geographer Michael E. Bonine states that Iranian cities have an orthogonal network of streets which does not conform to the maze of irregular, twisting lanes postulated for the ideal Islamic city. "*The grid system did not develop from an outgrowth of streets around rectangular religious buildings or from the orientation of Iranian houses to maximize seasonal usage, but rather it is due to irrigation systems. The orthogonal network of water channels corresponds to the slope of the land*" (Bonine, 1979). Passageways follow these channels to reach various plots of cultivated land. Cities have expanded along the existing streets and water channels. The basic morphology of traditional Iranian cities was created fields and orchards.

By challenging the notion of Islamic city this research tries to prove that the urban texture of Yazd is based on a grid and not a maze that is described by ideal Islamic city. The grid that is formed through an answer of the

built landscape to the extreme conditioning of the environment. Consequently, the urban texture of the built landscape is hinged on a water based infrastructure at various levels such as social, economic and environmental.

The third chapter is entitled "Plugged-in Artefacts". Radical climate conditions of Yazd, have aroused requirements for shelter, have influenced local cultures and also have stimulated people to present unique solutions to the problems of survival and to create innovative works of art (Tavassoli, 2016). This solutions have made human existence or in other words, life possible through the invention of "plugged-in" system of "artefacts".

The plug-in notion is derived from Archigram movement in 1960s."Plug-in City" was proposed in 1964 by Peter Cook. It presented an enthralling new approach to urbanism, rethinking of traditional perceptions of infrastructure's role in the city (Merlin, 2013).

Our point is that Peter Cook's provocative idea may help us define the interrelationship between built environment and water infrastructure in case of Yazd. Consequently, this chapter closes with the in-depth investigation of plugged-in artefacts or qanat based structures (windcathcer, payab, windcatcher, water reservoir, water mill, ice house and courtyard houses) from qualitative and quantitative perspective comprehending the way the qanat system manifests itself in a townscape.

In order to fully understand this prototype plug-in city, this research benefits from a series of drawings and cross-scale sections: from the territorial level to the architectural scale. Confronting the multi-city and complexity of Yazd built environment and its relation with its natural landscape, cross-scale sections helped us representing this relationship in comparison to Cook's plug-in city.

Relation between hydraulic system, urban structures and architecture is currently gaining momentum for scholar from many disciplines and many areas of the

world. Since 1980, this ancient know-how about hydraulic system (qanat) has been a subject of close attention by many scholars like archaeologists, geologists, civil engineers, geographers, experts of social sciences and economics, hydrogeologists, architects, urban planners and etc. (Semsar Yazdi & Labbaf Khaniki, 2013).

The importance of Yazd is also proven by many conferences held all over the world: in fact the city emerged as a key term of reference / case study in the following conferences : "qanat, kariz and khatara, traditional water system in the Middle East and North Africa", London, England 1987, "international conference on karez irrigation", Urumqi, China, 1993, "sceitific conference", Paris, 2001, "les galleries de captage en Euope Mediterrananeene, une approche pluridiciplinaire", Madrid, Spain, 2001, "international frontinuis conference", Luxemburg, 2003, "international symposium on qanats", 2000, "IWA workshop on evolution of qanat and relevant hydraulic technologies", 2015, Yazd, Iran, and "water and city; hydraulic systems and urban structures", 2018, Yazd, Iran.

Although, this witnesses that the recognition of qanat system and the fact that its coexistence with nature is a global concern and how scholars from different disciplines look at Yazd, observing deeply, we recognize that, Yazd architecture and its water system are mostly considered as a subject of interest for some scientific fields and with the hope for preservationists to revitalize it and its production system (Semsar Yazdi,& Labbaf Khaniki, 2013).

The former concerns historians whose approach towards the system is similar to their view towards historic monuments. However, the latter emphasis on the issue that the qanat system is in danger. 100 percent of Yazd water usage was provided by qanat system and fountain in 1940 while this number drops down dramatically to 19 percent in 2015 and deep wells with 54 percent and semi-deep wells with 27 percent of share replaced the qanats (Semsar Yazdi, 2018).

Today the historic city of Yazd and its qanat system are

at stake for various reasons. The drought undoubtedly has caused a great impact on the level of water in the aquifer. Annual precipitation of Iran is 293 millimetres and this number is 50 millimetres for Yazd while this number is 840 millimetres in the world (Semsar Yazdi, 2018). Although Iran has been in drought for the last thirty years (Ahmadi, 2018), this phenomenon has been emphasized by different factors such as social changes (Shah's white revolution) , new development of city and other natural hazardous. For instance, 100 percent of Yazd water usage was provided by qanat system in 1940, while this number drops down dramatically to 19 percent in 2015.

Since most of qanat based cities are still inhabited and Yazd is the largest inhabited city made of adobe in the world, the need to understands the risks and prospects rises dramatically before any intervention is posed into the system.

Investigating and mapping the city of Yazd with an interpretive eye, we shall bring to the fore how in the past resiliency depended on a long-term investment made by the subsequent generation on the interaction between natural and built environment. Architecture was crucial for the success of this interaction, as its most significant products -qanat related buildings- provided the environment for the different moments of human life and activity.

Thus, the thesis intends to interpret and breakdown the structural themes and design topics in order to set design concerns and guidelines/priorities that will help calibrate the architects intake on contemporary planning and city management where cross-disciplinary / multidisciplinary vision is embraced as an undeniable factor for future design in all its scales and social meaning and significance.


15′
30′
45′
32°00′
31°30′
54°30′
UTM GRID ZONE DESIGNATION 40S
UTM GRID ZONE DESIGNATION 40R
Firūzābād
Zarch
Āb Anbār-e Now
KHARDUNEH
KUH-E KHORASAN
PUZEH-YE SORKH
CHAKHEKI
KAMAR-E BUBAK
KUH-E OSHTORI
YAZD
NDB
YAZD
Textile factory
Power plant
Brickyard
Transformer station
Masts
Tower
Station
Water tower
Underground pipeline
KUH-E SAMGTARASH
KUH-E BON-E CHAH
KUH-E CHELTASH
KUH-E GULFARAJ
KAMAR-E JENN
TAPPEH-YE
Mohammadabad
Farm
Fort
Taft
Watchtower
KUH-E GALU BADAM
KUH-E AHUR
SHIR KUH
KUH-E SIAH
PUZEH-YE DAMEH
GODAR-E ZARU
KUH-E HAFT ADAMIN
Watermill
DEH BALA
Hud-e Pelta Dar
Baghdadabad
KUH-E GIG
CONSTRUCTION
Towers
Darreh
KUH-E KHEYBAR
KUH-E ADDROSH
KUH-E LAKHOSH
KUH-E MAZHAR
Numerous farms
Water tower
PUZEH-YE NISH KUH
KUH-E SANGAB KHUNI
KUH-E TANG-E HONZAKI
KUH-E TANG-E CHENAR
KALMAND KUH
KUH-E AMRI
APPROXIMATE ALIGNMENT
KUH-E DAST-E PASAND
KUH-E KAMAR-E ZANJIREH
KUH-E ZEYN OD DIN
Zeyn od Din (fort)
KUH-E HALVA Y
KUH-E DAH MARDE
KUH-E KERMANSHAH
KUH-E SEFID
KUH-E ERMAN
KUH-E GODAR-E SEYKHOWRI
TALE GODAR-E BADH
KUH-E TANG-E CHENAR
KUH-E TALL-E SHEKARGAH
KUH-E TOBISH
Hummocks
KUH-E CHAHAN KAMAR
KUH-E SHAKH-E BID
KUH-E KAMAR-E HAJJI ZAMANI
KUH-E CHAH-E ZARD
KUH-E CHAH TOROSH
KUH-E KOTAHSARAN
KUH-E KAMAR-E SANGAB
KUH-E BAZORGAN
KUH-E GELRANG
KUH-E DO CHAHI-YE CHAH MIL
OSTAN-E YAZD
OSTAN-E KERMAN
10⁷
13⁸
12⁵
6⁰
8⁹
7³
11⁵
13²
10⁰
8⁵
8⁵
8⁹

1. Geographic Theatre

This chapter identifies Yazd in its "geographic theatre"[1], examining the natural features of its geographical location and the breath of its territorial relationships.

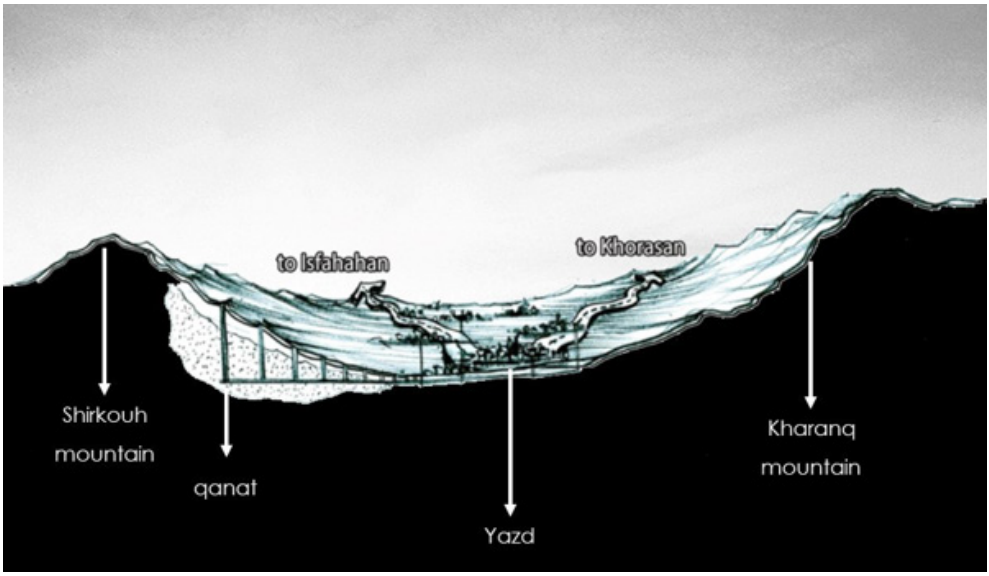
This chapter focus on the integration of natural and artificial features as a scenery in its inclusive dimension, where individual and society played their part in daily life and over the long period of time.

Thus, this chapter puts emphasis on two main notions concerning Yazd geographic theatre: natural order and dynamics of trade. Natural order signifies climatic considerations, geography, water bodies and etc. while dynamics of trade represents cohesion of the social fabric to which trade was given an economic drive.

Since resiliency is associated with ability of system to adopt and evolve in a long term span of time, this research used historic texts and travellers' reports that provided valuable information about natural and social order of their time. Thus, investigation and comparison of those materials became an apparatus of in-depth understanding of Yazd resiliency.

Figure 9: *Geographic Theatre of Yazd, map from Directorate of military survey, Ministry of Defence, England, 1988*

1 The notion of "geographic theatre" as a key reading frame is taken from Cristina Pallini, la composizione nei progetti di ricostruzione per le citta scambiatrici del Mediterraneo orientale: Alessandria e Salonicco (Architecture and City Reconstruction in Eastern Mediterranean Ports: Alexandria and Thessaloniki), PhD dissertation, IUAV, Venice, 2001.



1.1 Natural Order

The term "natural order" refers to the order generated by non-human-made surroundings and conditions in which all living and non-living things exist on Earth. The concept of the natural order encompasses two different components (IHBC , 2019):

- Ecological units that operate as natural systems (such as soil, vegetation and so on).

- Universal natural resources (such as air and water)

Yazd is situated in the watershed plain of Yazd-Ardakan which is bordered by the Shir-kooh Mountains to the west and southwest and to Kharanaq Mountains to the east (Figure 10). The plain contains scattered and short mountain chains; characteristics which have resulted in the relative security and a milder weather for the area. The annual precipitation of Yazd is around 100 mm; formerly most of its water was supplied by either mountain snows thawing or from qanats running underground.

The movement of surface waters in Yazd is under the

Figure 10: *Left: Tower of silence in Yazd, photo by Abedi*

Figure 11: *Yazd placement between mountains from Heritage Organization of Yazd [modified by the author].*

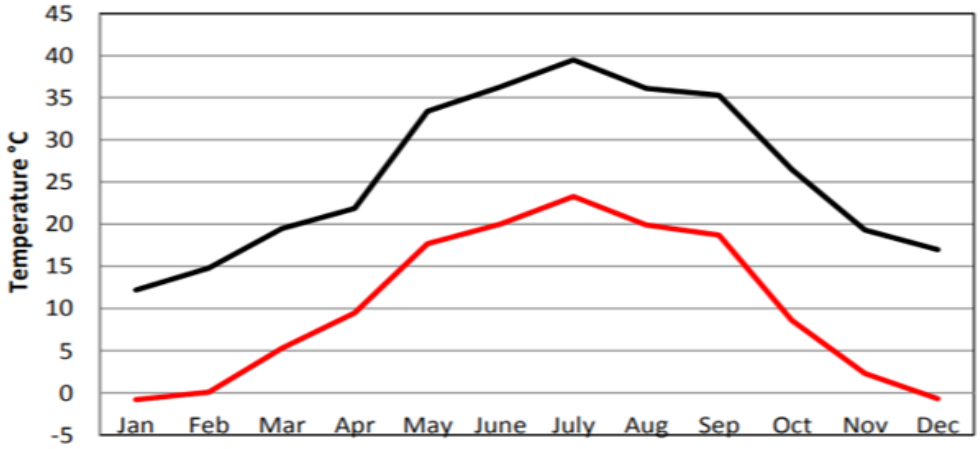


Figure 12: *Temperaturevariations of Yazd city; the red line illustrates the minimum; the black one shows the maximum, (Abedini, 2014)*

influence of the topographic state of its south-western heights Shir-kooh. Water resulted from precipitation flows through Yazd Plain in a southeast to north-west direction. On the whole, among climatic factors having a huge effect on the formation of the specific architecture of Yazd, mention can be made of: low precipitation together with intense evaporation, distance from high seas, proximity to the vast dry salt desert of Iran (Kavir-e Namak), low relative humidity, intense heat, seasonal winds and storms as well as huge yearly and daily temperature oscillations.

Wind speeds vary from a calm breeze, 0 m/s to 7 m/s, to, on rare occasions, to a strong breeze greater than 12 m/s. The highest average wind speed of 3 m/s (light breeze) happens in June, when the average daily maximum wind speed is 6 m/s (moderate breeze); the average number of hours of sunshine is 11; and the average precipitation is approximately zero. The lowest average wind speed of 2 m/s (light breeze) occurs in December, when the average daily maximum wind speed is 4 m/s (gentle breeze), the average number of hours of sunshine is 6 and the average precipitation is 8 mm (Weather Spark, n.d.).

In a year, the wind direction is from the west, 16% of the time, similarly from the north-west, almost 16% of the time and from the southeast, 13% of the time. The wind direction from the northeast is the least often: 2%

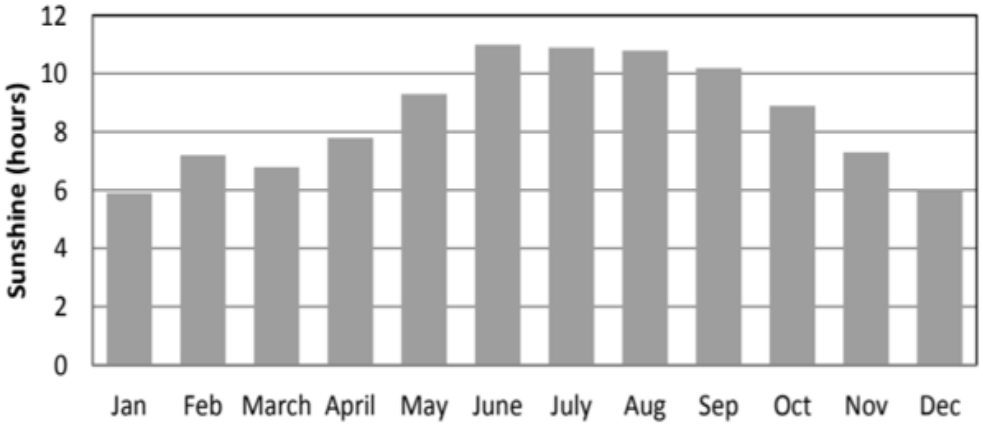


Figure 13: *Monthly average number of hours of sunshine per day (Abedini, 2014)*

of the time. The Koppen-Geiger climate classification for Yazd is BWh, which puts it in desert city class, and as it is common in desert regions, its climate is hot and arid.

All above mentioned characteristics qualify Yazd natural order in the present time. However, since the notion of resiliency is accompanied by long term adaptation to natural environment, it is essential to understand natural order of Yazd through history.

One of the earliest description of Yazd by Arab geographer Ibn Hawqal[1] dates back to the 10th century. He notes that large areas of province were either infertile or mostly infertile. They have been deserted due to low amount of rainfall or the presence of salt in soil. In addition to those features, he mentions that sand storms were often and moving sands invaded city frequently (Ibn Hawqal, 2011).[2]

Ibn al Balkhi[3] , a Persian geographer in 12th century, mentioned the extreme climate of Yazd by mentioning that Yazd is located on the edge of desert. He stated that the summers were extremely hot and there was

1 Muhammad Abul-Qasim Ibn Hawqal (born in Nisibis, Upper Mesopotamia; travelled 943-969) was a 10th-century Muslim Arab writer, geographer, and chronicler.

2 The face of the Earth originally written by Ibn Hawqal in 977.

3 Ibn al-Balkhi was a Persian geographer, mathematician, physician, psychologist and scientist. He was also the founder the "Balkhi school" of terrestrial mapping in Baghdad.

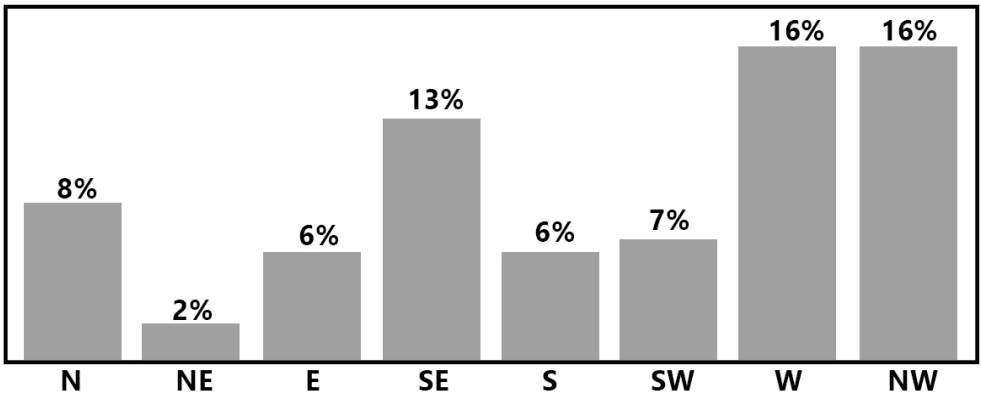


Figure 14: *Various percentages of wind direction over the entire year (Abedini,2014)*

hardly any rain (Nicholoson, & Strange, 1952). Hamd Allah Mustawfi Qazvini who visited Yazd around two centuries after Ibn al Balkhi confirms the latter concern and states water in Yazd was a scarcity (Afshar, 1992).

Henry Bathurst Vaughan[1] and Edward Browne[2] provided a detailed climatic data on Yazd in 19th century. "*The climate is very healthy and, as a rule, dry and bracing. During the coldest month of the year, December, the thermometer ranges from 30 to 37 Fahrenheit (-1 to 3 C), but at the beginning of June, it rises to 90 (32 C), which is the maximum temperature*" (Browne, 1893).

The water scarcity consequently affected agriculture and vegetations. Rashid al-Din Tabib, a historian from the 13th century, mentions that the return they got from the land was rarely comparable with other places (Morgan, 1999). Another report from 14th century by Abil Rida Awi reinforces this fact. Abil Rida Awi also adds that planting tamarisk was common to stabilize moving

1 Henry Bathurst Vaughan was born on February 27, 1858 in Britain. As a young man, he joined the British Indian army in Bengal region as an infantry soldier. As well as being a soldier, he was also a painter artist.
At the age of 30, when he was lieutenant in the intelligence branch, he was sent to a secret mission in Persia. During the year of 1888, he had a long journey through Iran from south to north, and gathered information about the country. Then he printed its confidential report, entitled Report of a journey through Persia, in Kolkata in 1890.
2 Edward Browne, British Orientalist, who came to Yazd a month after Vaughan.

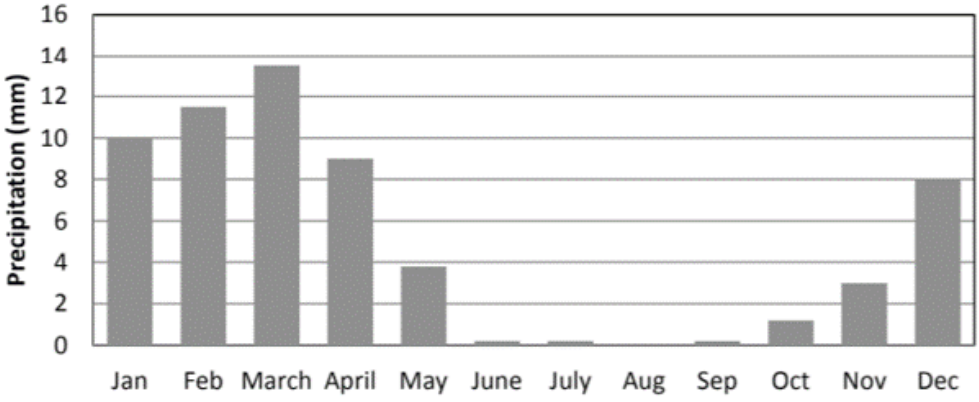


Figure 15: *Different kind of precipitation, including drizzle, rain, hail, sleet or snow (Abedini, 2014)*

sands (Iqbal, 1950).

Despite the fact that there were hardly any rain, reports mention the presence of underground water channels for agriculture or domestic use. The report of Qazvini in the 14th century states that water was scarce in the region but it was brought by channels from hills and each house had its storage tank.

This underground water channels (qanats) have been mentioned in different historic records. Zarch qanat for example has been noted in "History of Yazd" by Jafari in the 16th century: "*Qanat of Zarch is one of the oldest qanats, which enjoys two branches running inside and outside of the city. This water is always flowing into the city even when the enemy army besieges the city and ceases water. One should climb down seventy steps to get access to its water which is a little bit salty but still refreshing when cold*".

Browne lays emphasis on the presence and importance of qanat in the 19th century and mentions not only the quality of water, but also its amount and source:

"*The water, which is good and sufficient to meet the requirements of the town, as well as to irrigate a large number of gardens, is obtained from near the foot of the Shirkuh, whence it is brought by qanats starting at a depth of 100 feet (30 m). The qanats approach the town from the south and south-west. There are said to be at least 70. It would be difficult to cut off the water supply from the city altogether, as some of the streams*

*run at a great depth below the ground, and passing on, supply suburbs to the north. These subterranean streams are reached from the city by long flights of steps descending towards them through subterranean passage*s" (Browne, 1893).

But more importantly the effect of natural order has been noted in the built environment and in particular its materiality. Being located on the edge of desert provided mud and mud brick as the first material in hand. Hamd Allah Mustawfi Qazvini stated in the 14th century that Yazd was built of sun-dried bricks which lasted as long as burnt bricks elsewhere.

Browne's observation in the 19th century shows that the same technique and use of material was still present at that time. "*Yazd is built almost entirely of mud or sun-dried bricks. A few of the better houses as well as some of the mosques and other public buildings being faced with burnt bricks*" (Browne, 1893).

In Vaughan description of the urban framework, he states that the city is like an interior inside the walls and it is filled with mass of houses. In-between them narrow winding streets run. Some are roofed and so low that is impossible for a horseman to ride through. In his remarkable sketch of Yazd skyline, he tries to depict the main elements of the city (Figure 16 and Figure 17). The dominance of wind-catchers and domes is clear together with his effort to show a dense urban pattern. The fort and its gates, Jame Mosque and the telegraph routes alongside with natural environment are bold components in his drawing. He also explains various aspects of the city such as its materiality and construction techniques : "*wood being scarce, the roofs of the houses are built of sun-dried bricks, which are made into numbers of small domes"* (Browne, 1893).

Thus, natural order is an inseparable aspect of Yazd built environment. Artificial is interwoven with natural in such that the constant dialogue and adaptation have created a unified entity. In this fusion, materials, construction techniques, urban pattern, urban artefacts and water systems are architectural expressions of natural environment.

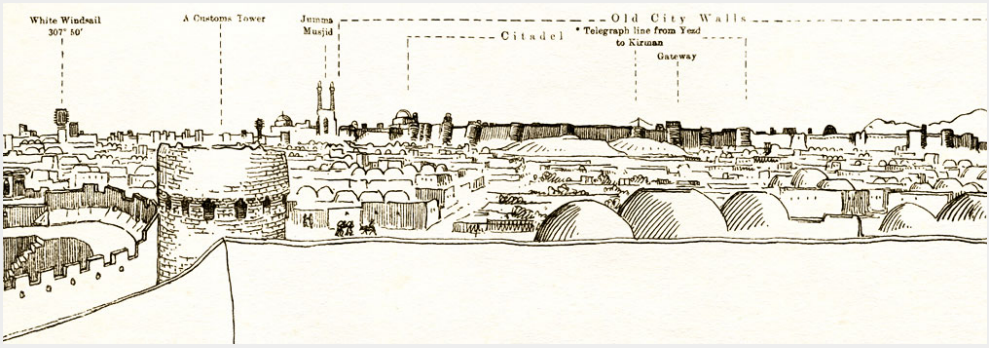


Figure 16: *Skyline of Yazd drawing by Vaughan in 1893.*

Figure 17: *Yazd's gate, ,wall,fort tower and ditch drawing by Vaughan in 1893.*


Ardakan
Maïbout
Maïmoun
Achkizar
YEZD
Mohammedabad
Taft
Ser-i-Yezd
Tizardjan
Mahriz
Cochk
Sakhv

Figure 18: *Left:1884 Perron map ,Yazd and vicintity, from La Nouvelle Geographie universelle, la terre et les hommes, 19 vol. (1875-94), drawn by Elisee Reclus. Cartographer is Charles Perron.*

Figure 19: *Top: The dessert near Yazd photo by Hasan Alamsi*

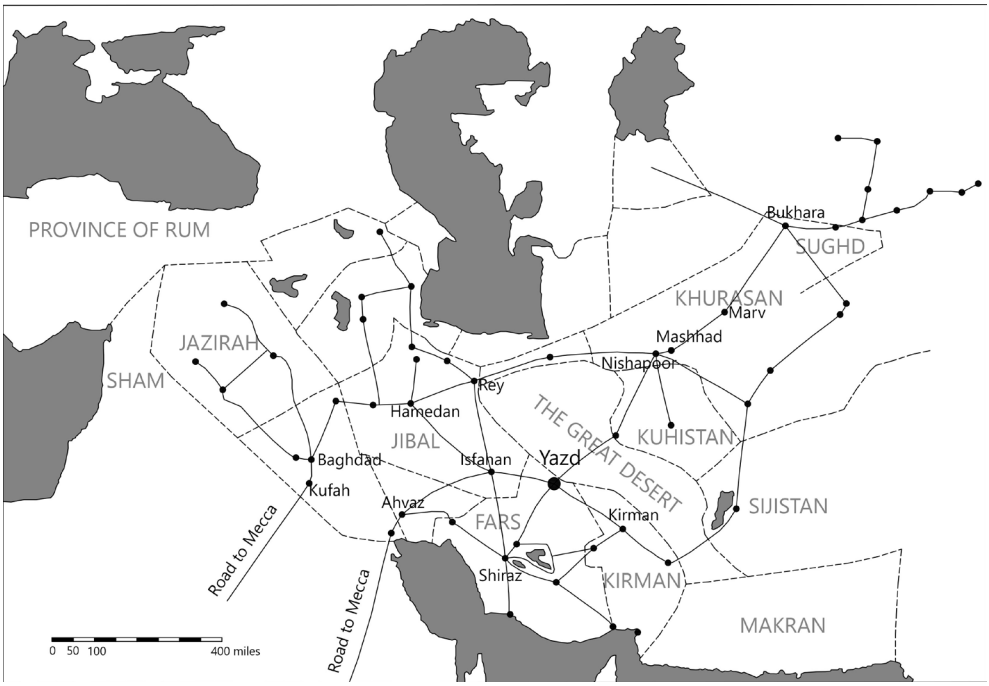


Figure 20: *The province of Abbasid era, showing the main trade routes [modified by the author] (Sykes, 1963)*

1.2 Dynamics of Trade

The momentum towards establishing many cities starts from a spot which is deemed fit in providing access to other human settlements (UN- HABITAT, 2017). Existence of these roads and their relation with other cities has not only maintained the social-cultural and economic life of the city throughout its history but also has had a direct effect on it.

The central position of Yazd as a confluence of various cities was an advantage. In fact, Yazd has always been identified as the intersection of Iran because it was located on the major commercial routes such as the Spice Road, the Kerman-Rey and the Khorasan-Fars roads. Even today, these roads play a major role in the trade and commerce of Yazd.

- The Spice Road: Following the advent of an economic flourishing in the Persian Gulf, the spice road was built in order to enable direct trade between Indian and

Muslim merchants in the 10th and 11th centuries. Its flourishing continued until the 15th century which coincides with the invasion of Mongols (Razavi, 2003). The road was one of the most popular trade routes starting from India and ending in the Mediterranean Sea. At first it was only used for exchanging spices but later became a vehicle for trading other merchandises too. Aside its commercial use for exchanging goods, it also served as a way for transferring culture and civilization to other places so that even today Yazd Zoroastrians communicate with India via this road. Therefore it can be claimed that the route is still viable but has a different function compared to its past.

- The Fars-Khorasan Road: The new road connecting Fars and Khorasan provinces and passing through Yazd, roughly corresponds to the ancient route which has been in use from the beginning of the 10th century until present day (Mirhoseini,2000).

- Karbala Road: The main road from Rey to Fars had been of utmost importance in various episodes of time because it connected the vast territories of eastern and central parts of Iran to its western provinces and to Mesopotamia. During the pre-Islamic period it was used for traveling to Ctesiphon (Madayen), the ancient capital of Persia, and during the post-Islamic era it connected the Iranian inland to the holy city of Mecca as well as to the holy pilgrimage cities of Iraq. The strategic location of Yazd allowed it to be connected to Fars via the Rey-Kerman road. Even today Yazd enjoys a strategic position for those who want to go to Karbala from eastern provinces of Iran (Pooya,1991).

Moreover, the bazaar is regarded as one of the most important and most prominent thoroughfares of Yazd. Not only major urban functions are accumulated within bazaars but also bazaars act as connectors between them. Intra-city streets and bazaars provide relation with the outside world by linking to long-distance roads.

During the course of history, trading and commercial activities as well as industries such as textiles have been the main subsistence channel for inhabitants of Yazd and its outskirts.

Many reports from travellers confirm these facts. Marco Polo, the Venetian explorer, stated in 13th century that Yazd had a great amount of trade. He added that the inhabitants weave their quantities of a certain silk tissue known as Yasdi, which merchants carry into many quarters to dispose of (Yule ,1871).

This continued until the 14th century as well, since Rashid al-Din Tabib and Friar Odoricus have described quite similar situation and stated that silk is one the main export product of Yazd (Morgan, 1999 and Schefer, 1890). Pedro Teixeira who visited Yazd in 17th century provides a more detailed explanation of Yazd's export product: "*the richest and finest carpets came from Yazd from which place I saw some, each of which, on account of its workmanship and perfection, was valued at more than a thousand ducats, while the fabric known as al-qatifa was the best, the nest and the most perfect*" (Sinclair, 1802).

Yazd continued its role as a trade hub in the following centuries. Edward Scott Waring on his tour to Shiraz in the early 19th century passed through Yazd and reported that the city was a centre of commerce for all trade of Persia. "*Coarse prepets were sent there and sold to Uzbeks and people of Khurasan, the merchants taking on their return journey silks, carpets, felts and Kashmiri shawls*" (Scott Waring, 1807).

Capt. Christie brings into the fore the amount of trade in Yazd with respect to its geographic placement: "*Yazd is a great mart between Hindoostan [India], Khorasan, Baghdad and Persia and was said to be a place of greater trade than any other place in the latter empire. He mentions that there were over 50,000 camels in the city, which is an indication of the extent of the trade*" (Pottinger, 1816).

Having understood the importance of trade, it is fundamental to note the relation of trade on dwellers lives and particularly their occupation. Major Euan Smith confirms that in the 19th century there were 18,000 silk workshops in Yazd, employing probably 9,000 hands and that the silk was considered by some to be the best in Persia (Goldsmid, 1871). The importance of

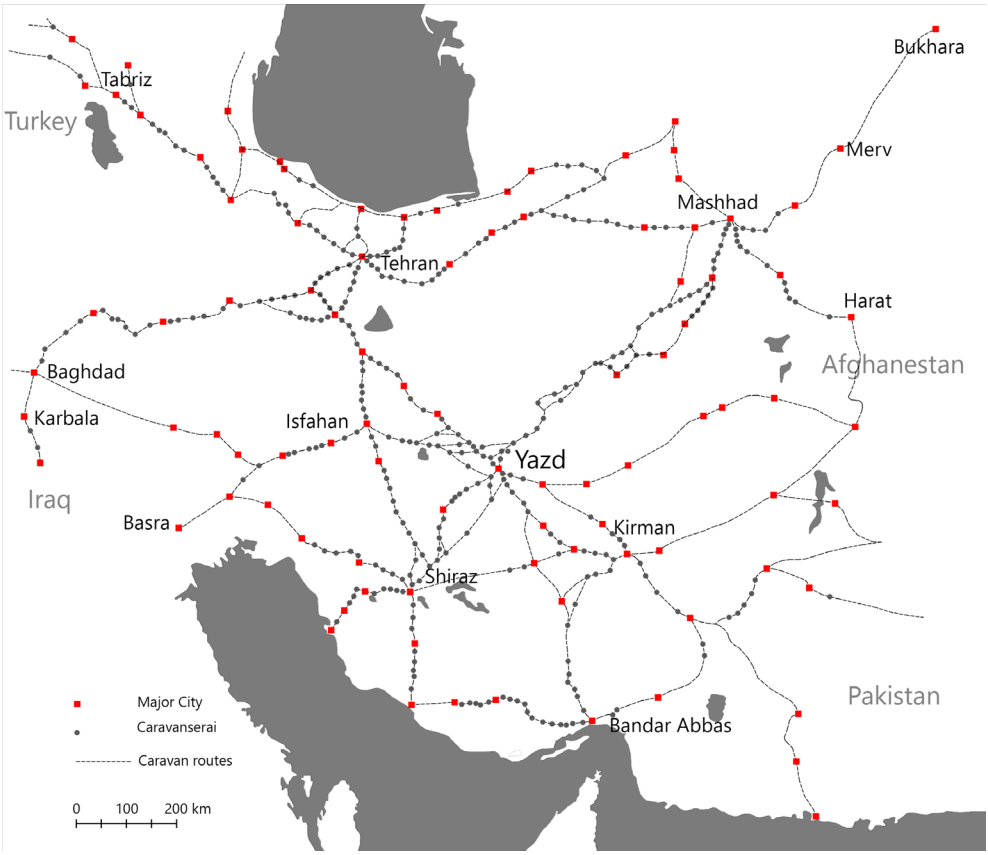
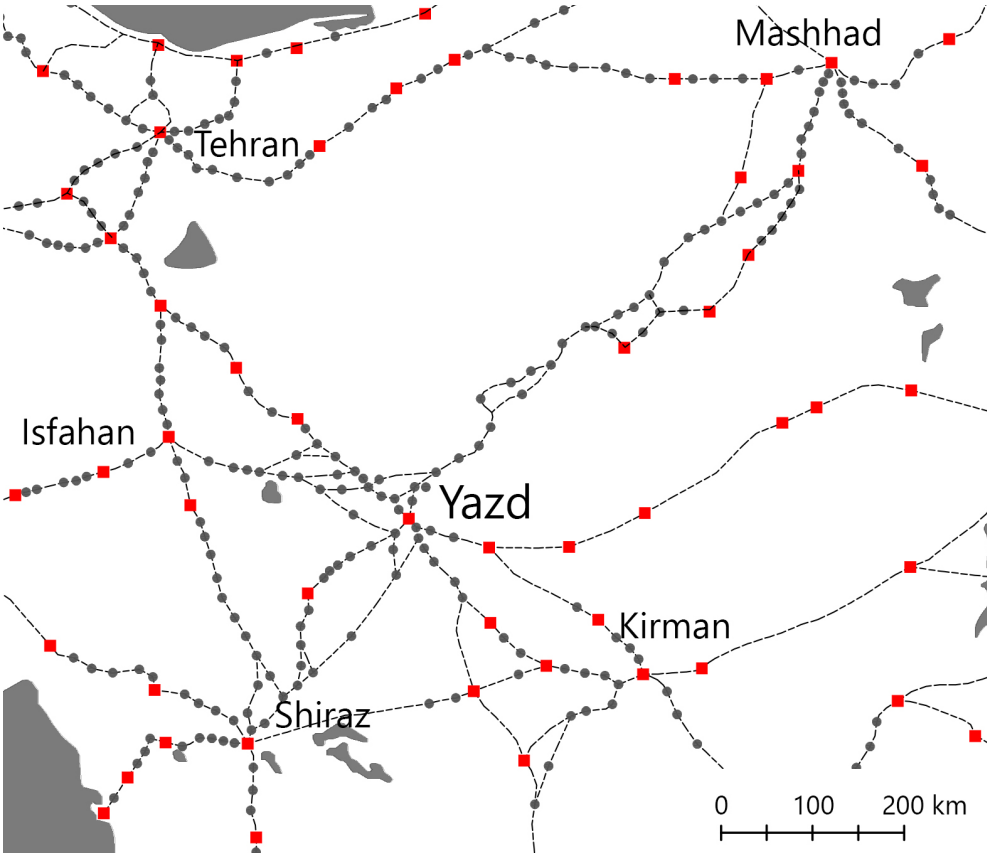


Figure 21: *Caravansaris of Iran from Iranian Cultural, Heritage handicrafts and tourism industry [modified by the author].*

these figures needs to be analysed with respect to the number of inhabitants on the same period. Fortunately Browne provides such figures. He states that the population was about 65,000 to 100,000 in the late 19th century (Browne, 1893). Thus, in relation to number of inhabitants trade had a great impact on people lives and occupation.

In a climate that land is not generous enough, trade has played an important role: "*Yazd being simply an emporium of trade situated in the middle of an unproductive plain, does not contain supplies sufficient for the consumption of her own inhabitants. Consequently, sheep are imported from Shiraz and grain from Isfahan. It is only during the months of October, November and December that the city subsists on its own grain raised in the neighborhood. Special arrangements would have to be made for the supply of any large force halting*



here" (Browne, 1893).

Located at the crossroads of caravan routes, Yazd included at the crossroad of caravan routes, Yazd included important bazaars. Many caravanserais were to be found both outside and inside the city walls. A caravanserai was not built just a place for merchants/travellers to rest in safety, it was also a meeting point.

The safety of a road depended by the presence of caravanserais, each set a one-day journey from the other. Despite many formal differences, all caravanserais shared a similar spatial layout.

Many of them house spaces and elements like inner courtyard, hall, cells, stable, well, Ivan, and staffs space. Some other have other services and spaces such as bath, mill, store, pray room, water cistern, and the security infrastructures.

Figure 22: *Caravansaris of Iran from Iranian Cultural, Heritage handicrafts and tourism industry [modified by the author].*

Zein O'din caravansari can be mentioned as an example. It has a unique circular footprint and located outside of Yazd (Figure 23). Inside its portal lies a broad vestibule, like a cross road facilitating access to different spaces. The central courtyard surrounded by niches. There is an elevated platform at the centre of the courtyard for passengers to unload their merchants and belongings. The ivans are linked by a line of shallow arched porches each of which leads to a small room for sleeping. Stables can be reached by a by passages that run around the perimeter of the building behind the sleeping quarters. Zein O'din caravansari is surrounded by towers and high tick walls in order to protect the travellers and their belongings.

The urban caravansaris have some minor differences in their spatial organization. They do not accommodate large areas for stables and often the rooms are bigger in respect to caravansaris outside city walls. In addition, the may include some spaces for trade activities or are conected to bazaar. Examples could be mentioned of Moshir caravanserai and Golshan caravanserai that are built close to bazaar.

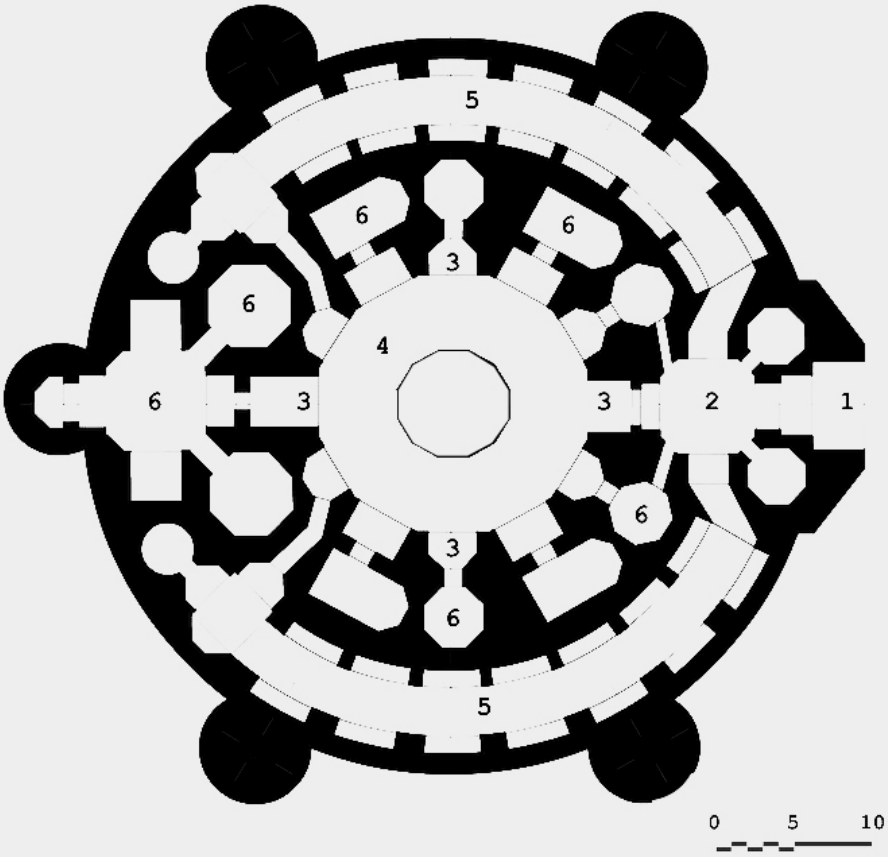


Figure 23: *Zeinodin Caravanserai, Plan, 1. Entrance, 2. Vestibule, 3. Porches, 4. Courtyard, 5. Stable, 6. Chambers, 7. Platform, 8. Tower mapping by Hosseni [modified by the author]*

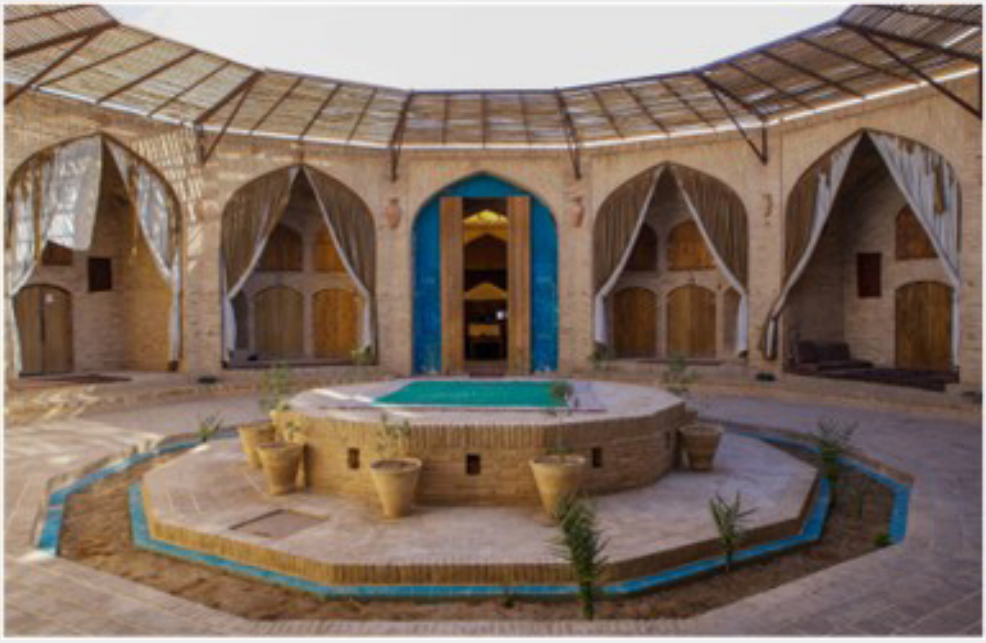
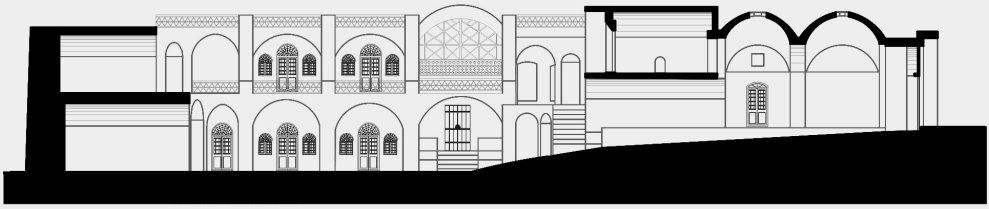


Figure 24: *Zein O'din Caravanserai in Yazd, photos by Abdi*

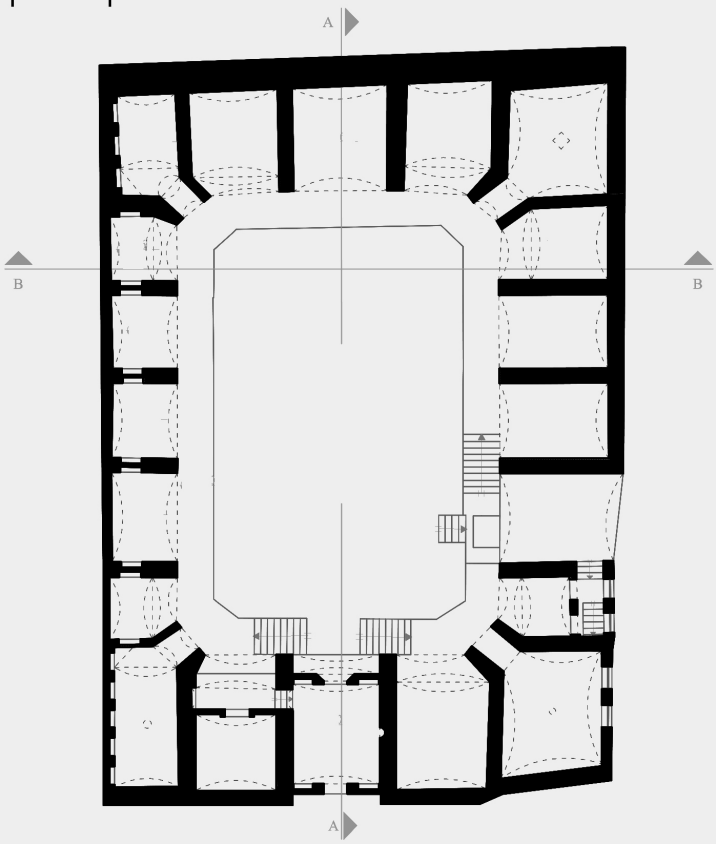
Figure 25: *Moshir Caravanserai in Yazd, photo by Diba*

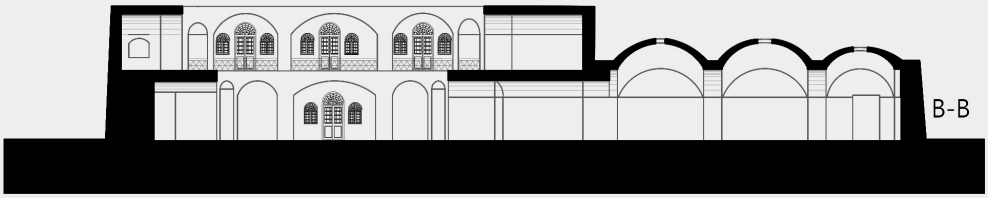
Figure 26: *Moshir Caravanserai in Yazd, drawing by Hosseini, [redrawn by the author]*



A-A

0 1 5 10m





B-B

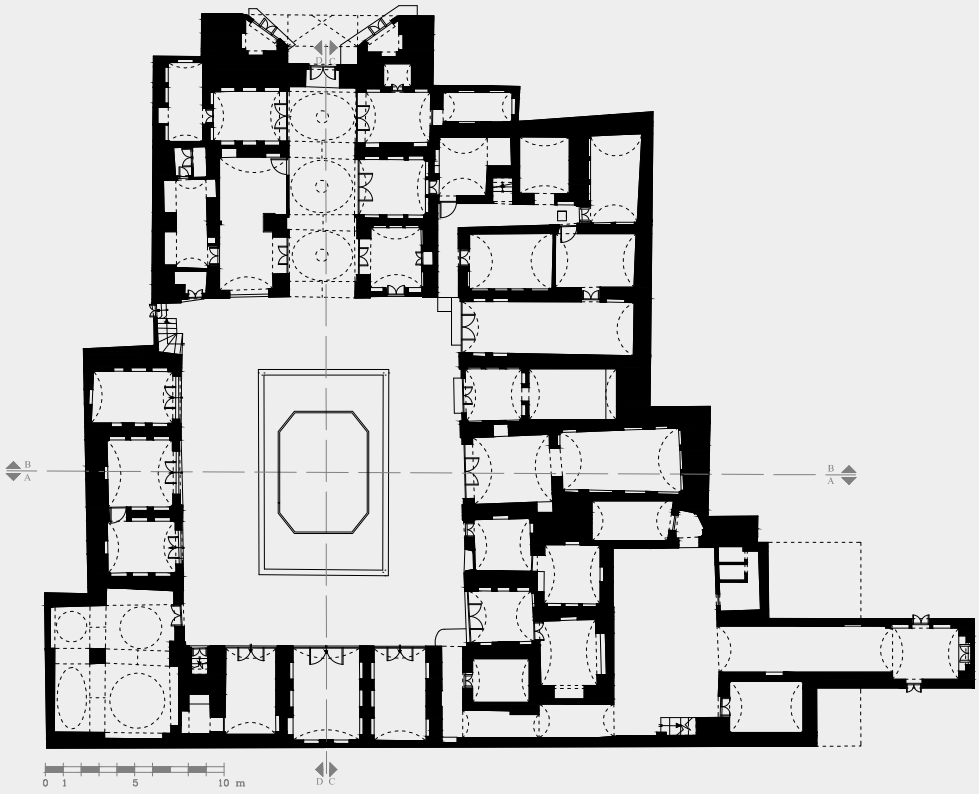


Figure 27: *Golshan Caravanserai, plan and sections, drawing by Hosseni, [redrawn by the author]*

A-A

C-C

0 1 5 10 m

D-D

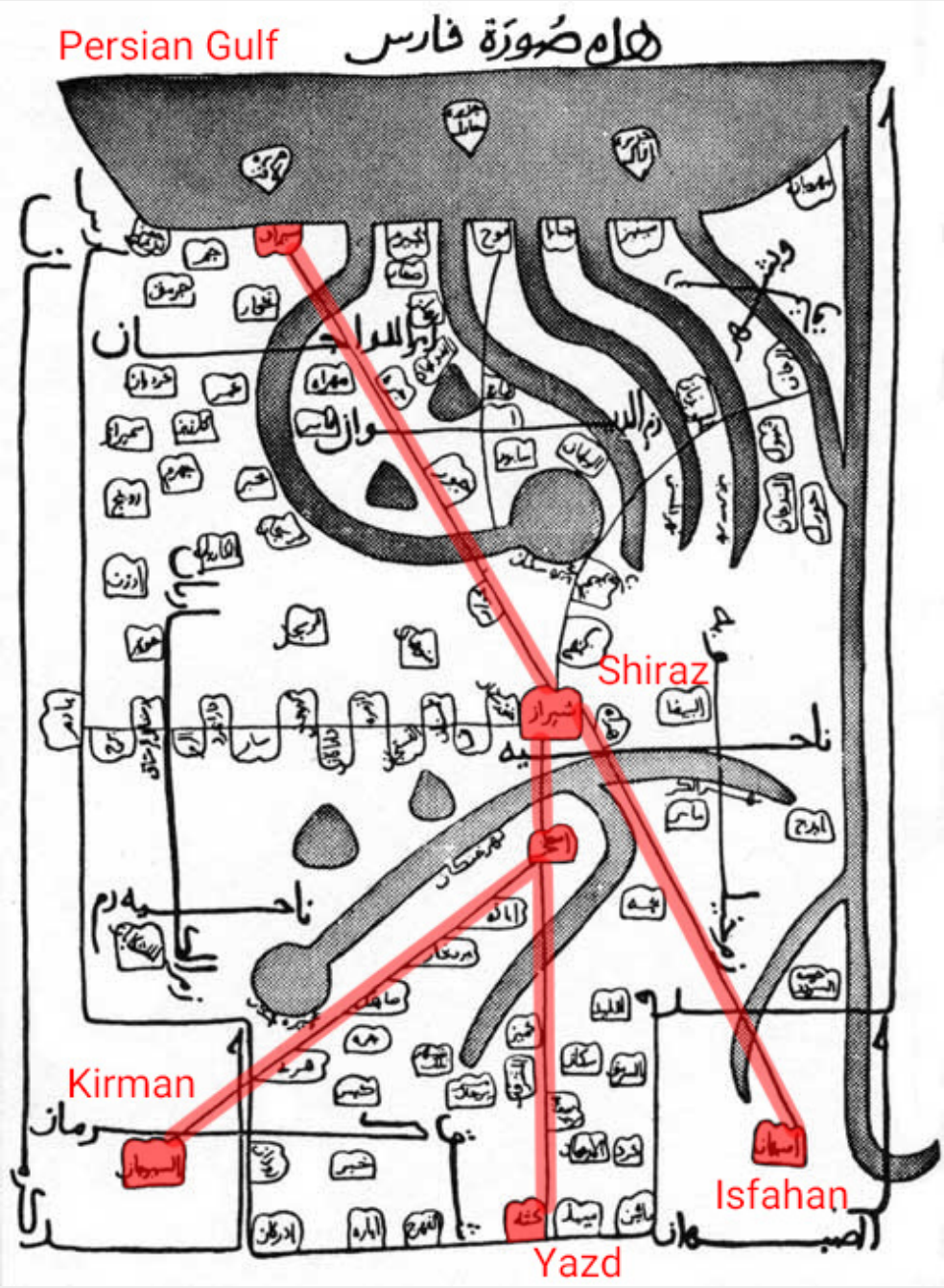

Persian Gulf
هذه صورة فارس
Shiraz
Kirman
Isfahan
Yazd

Figure 28: *Left: Map of Fras Province in Persia, Ibh Hawqal, this map shows the importance of Yazd in long-distance trade routes in 10th century. From bh Hawqal,The Face of Earth [modified by the author]*

Figure 29: *Top: A view of Khan square in Yazd in 1902 photo by M. E. Hume-Griffith.*

Figure 30: *Down: A commercial caravan introducing goods into the Khan square of Yazd in late Qajar era, photo from Yazdnegar*

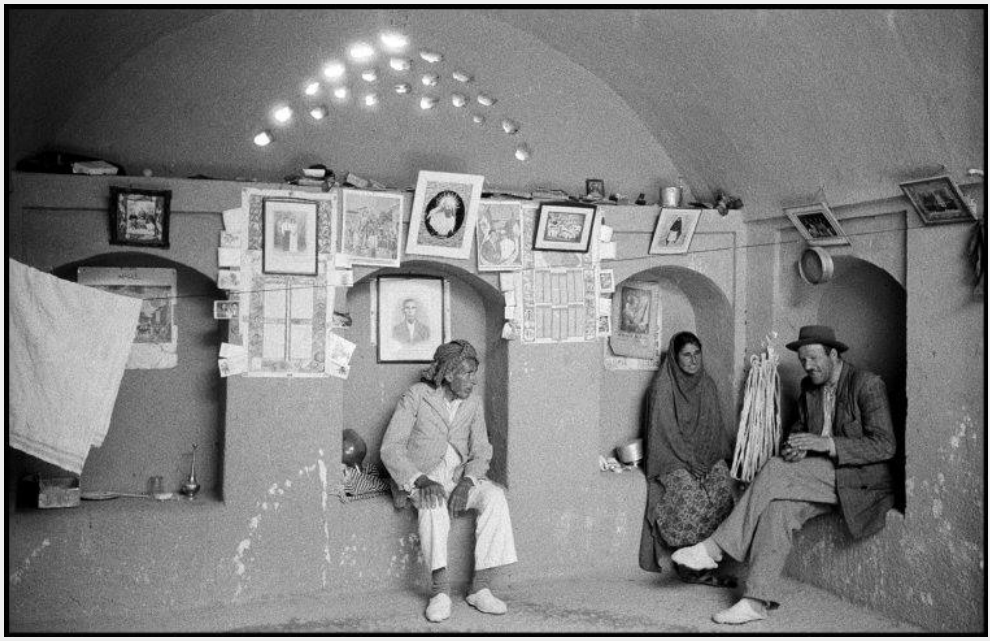
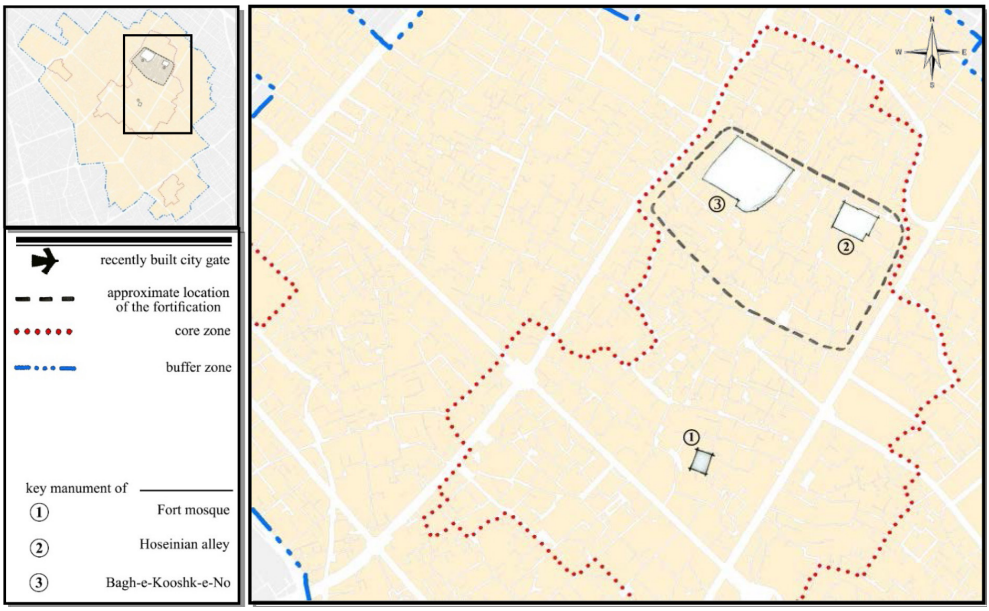


Figure 31: *Left top: Zoroastrian women of Yazd in 1946, photo from Shokoohepars*

Figure 32: *Left down: Zoroastrians of Yazd in 1946, photo from Shokoohe pars*

Figure 33: *Top: confectionery in Yazd in 1944, photo from Mashregh news*



1.3 Evolution of Yazd

Figure 34: *Left: City wall, from O.C.N.R.C Monde Iranian*

Figure 35: *Changes in the formation of the city and key monuments of the early Islamic era from HCY base Archive*

Oral history has it that Yazd was one of the major cities of the Achaemenid Era (550BCE-350BCE) with its own road maintenance and courier systems. It was located on the route, connecting Rey to Kirman and Isfahan and it was also on the road of Pars to Khorasan.

Pre Islamic era

Historical books mention the names of important cities in the Yazd Region at the beginning of Islam, cities such as Naein, Keseh, Meybod and Fahraj. Most historians claim that Yazd founded on the ruins of Keseh and gradually replaced it.

Early Islamic era (7th to 10th century)

During the Umayyad rule (662 -749), Yazd was under the rule of Ala' Tufy who demolished the palace of his predecessor and built a new garden with a palace next to it which was named "Kooshk-e-no". This garden and palace were later turned into a community which was called "Mad-abad Kooch-e-Bagh". Hosseinian and Taziyan are two other communities which were established during this era, however, the later was completely destroyed by the flood of 1455.

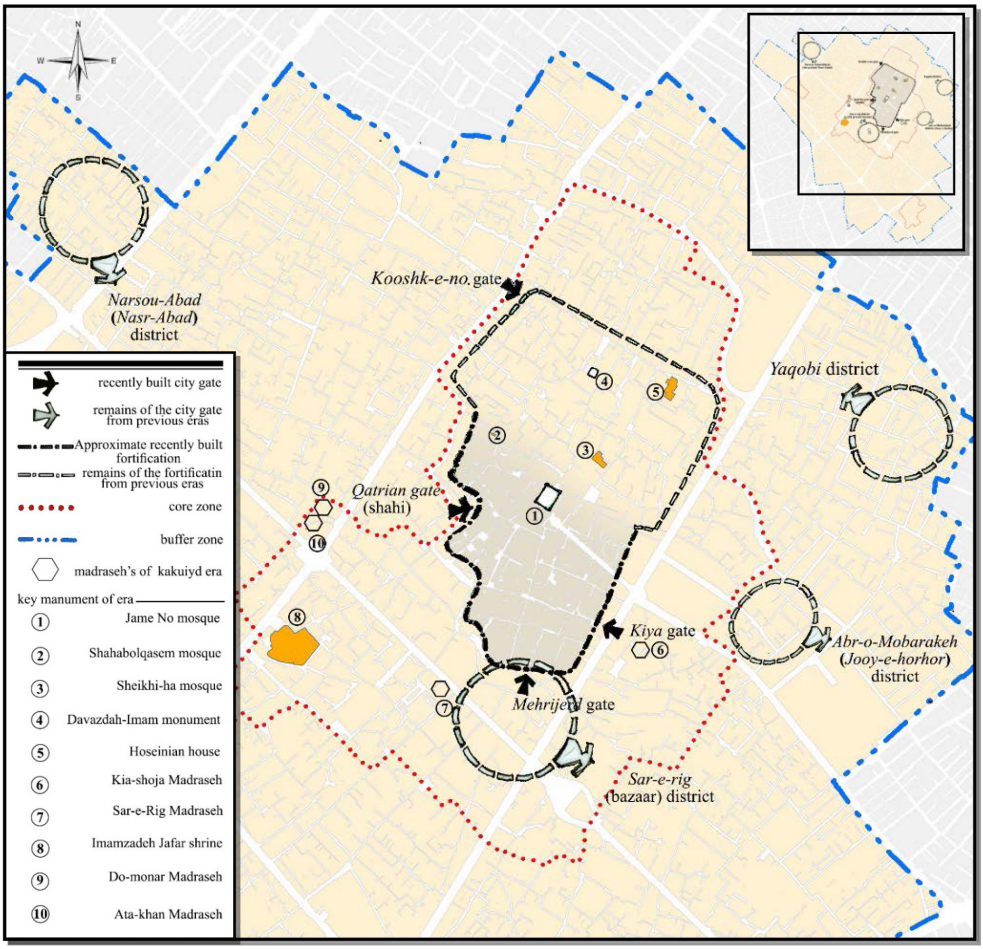


Figure 36: *Changes in the formation of the city and key monuments of the Kakuyid era (10th to 12th centuries), from HCY base archive*

Kakuyid era (10th to 12th centuries)

Historical texts mention the construction of a mosque near Gate of by Ahmed Zamaji (7th century) some historical references refer to this mosque as "Fort". This mosque is still known with the same name in Yazd.

"In the 11th century A.D., Yazd under the local rulers Al-i Kakooya grew into a large and prosperous city. In 1053, a wall and four gates surrounding the city were built" (Afshar, 2004). Today, a trace of the northern wall exists, although all the gates have been demolished, but can still be recognized. Under the Kakuyid rulers, many urban elements were built.

"Yazd owes its flourishing, in the fifth century A.H, to the flowing of numerous qanats in there such as Yaqoobi, Abr-o-Mobarakeh, Savab or Absava and

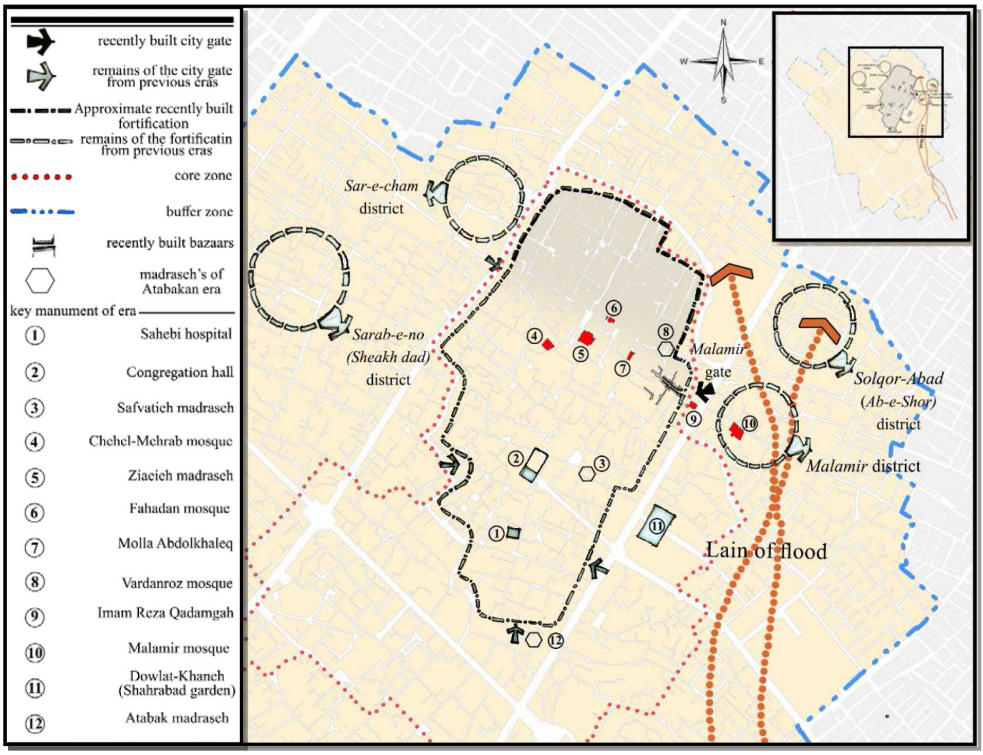


Figure 37: *Changes in the formation of the city and key monuments of the Atabeg era (12th century), from HCY base archive*

Mahmood-abad. Ala'o Dole Kalanjaar also ordered a payab to be built near "Dar-e-deh Mosque" on Zarch Qanat" (Afshar, 2004).

The development of Yazd during this era can be observed in the fortification around it with four main gates named "Qatrian", " Mehrijard or Darvazeh Shahi", "Kooshk-e-no" and "Darb-e-Kia", the expansion of gardens and farms in the western and southern parts of the city, the construction of few mosques and madrasehs, and the addition of new communities. By considering Yazd's expansion patterns in that time, there are some divisions in residents related to the social class, occupation and religion. In general, during the Kakuyid Era, the city expanded in three different directions: south, west and east. Topography, soil quality, accessibility

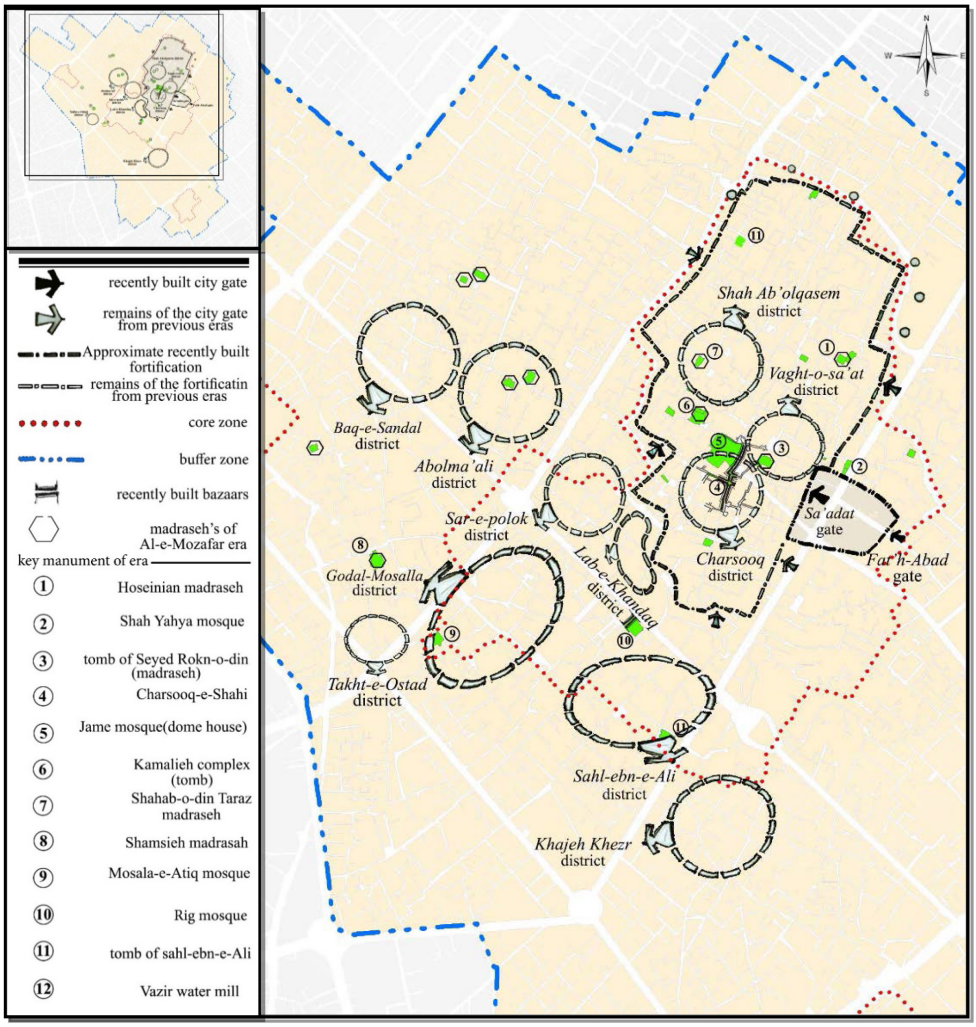


Figure 38: *Changes in the formation of the city and key monuments of the Muzaffar-id era (14th century), from HCY base archive*

to water (qanats) and location of trade routes were the main factors behind this expansion.

"The city fortifications were restored in 1289 during the reign of Toqa Shah, however, it has been mentioned that his predecessors, namely Sultan Qotb-o-din and Aboo Mansoor had a new fortification built around the city and added some districts which were situated outside the fortification" (Bafghi, 1963).

Atabeg era (12th century)

Four communities were developed during this era including new Ezz-abad, Maryam-abad, Solqor-abad and Sar-e-cham in the outskirts of Yazd.

Historical documents mention the construction of

several Qanats in Atabeg era, three of which were designed to supply water to the newly established districts. These qanats included: "Ezzabad", "Moriabad" and "Solqorabad". *"During the reign of Ala-o-Doleh Toqa Shah, a devastating flood stroke Yazd which caused heavy damages and destroyed rig-e-Firoozi district and parts of the city wall"* (Dossier of Yazd, 2017).

The economic axes of the city or bazaars were formed along the former bazaars, namely the north-south direction, as a result of which the city expanded towards Mehrijard Gate. Atabeg rulers gave priority to agricultural, industrial and commercial businesses in order to earn more income. The construction of "Malamir Gateway" and the annexation of Fahadan community as an East-West Route- played a vital role in the city development and new Bazaarche such as Malamir, Fahadan and Qadamgah were formed along it.

Muzaffarid era (14th century)

Historical documents mention the construction of a new fortification from Qatrian gate up to Malamir. As a result, the number of gates increased to seven (Mehrijard, Qatrian, Ilchi Khan, Kooshk-e-no, Malamir, Sadat and Darvazeh-No), the construction of six separate towers and digging a moat in the northern section of the city wall to protect the city and adding a watch tower by each gate, replacement of the gates doors and addition of "Dar-e-no". The damages which occurred by floods can be the main reason for restoration and reconstruction of the fortifications.

In this era the city kept expanding southwards, an administration citadel was established at the eastern edge of the town, and a new commercial centre around Jame Mosque. It seems that the damages caused outside Kakuyid fortification had a significant impact on the urban development patterns, based on previous remarks, simultaneous with the developments, within and next, to the city wall, the city was developing in other districts. Since, most of the Madrasehs of the 11th and 12th century were built outside the city walls. But after the destructive flood, the development of city is mostly focused within the city walls.

As the city kept expanding southwards in this era,

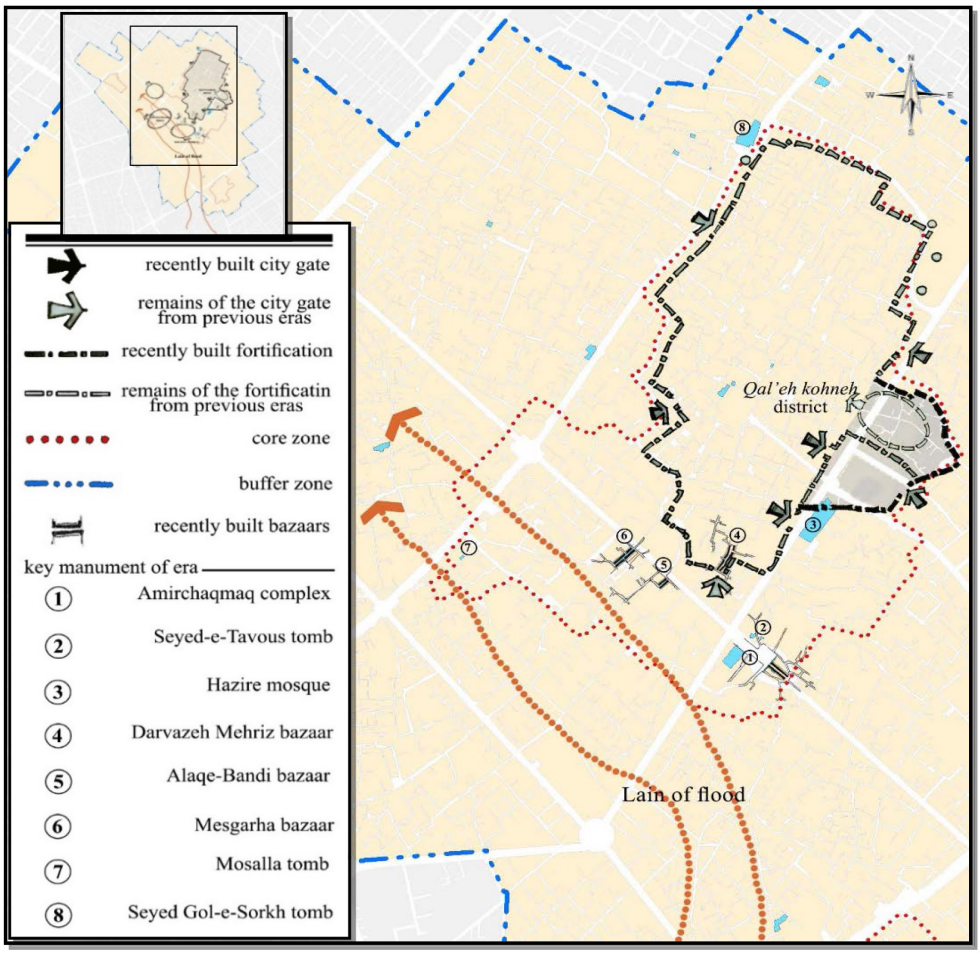


Figure 39: *Changes in the formation of the city and key monuments of the Timurid era (14th to 15th centuries), from HCY base archive*

Bazaars were formed alongside this direction up to Mehrijard gate, Bazaars such as Dallalan Bazaar and Khatoon Bazaar developed along one of axis of the Jame Mosque up to Qatrian gate. These new developments decreased the role of the northern Bazaars and boost the economy and social mobility concentrated in the new centre. Along the pass of Fahadan, Bazaars were developed around the fortification. It can be said that the Bazaars were organized on the basis of a single profession criterion in Yazd at this era.

Timurid era (14th to 15th centuries)

The trade and business of the city flourished in Timurid era. *"During the reign of Amir Jalal-o-din Chaqmaq and his wife, Bibi Fatemeh Khatoon, about 1000 houses, Madrasehs, Khaneqahs, public baths, and caravanserais were repaired and reconstructed"* (Dossier of

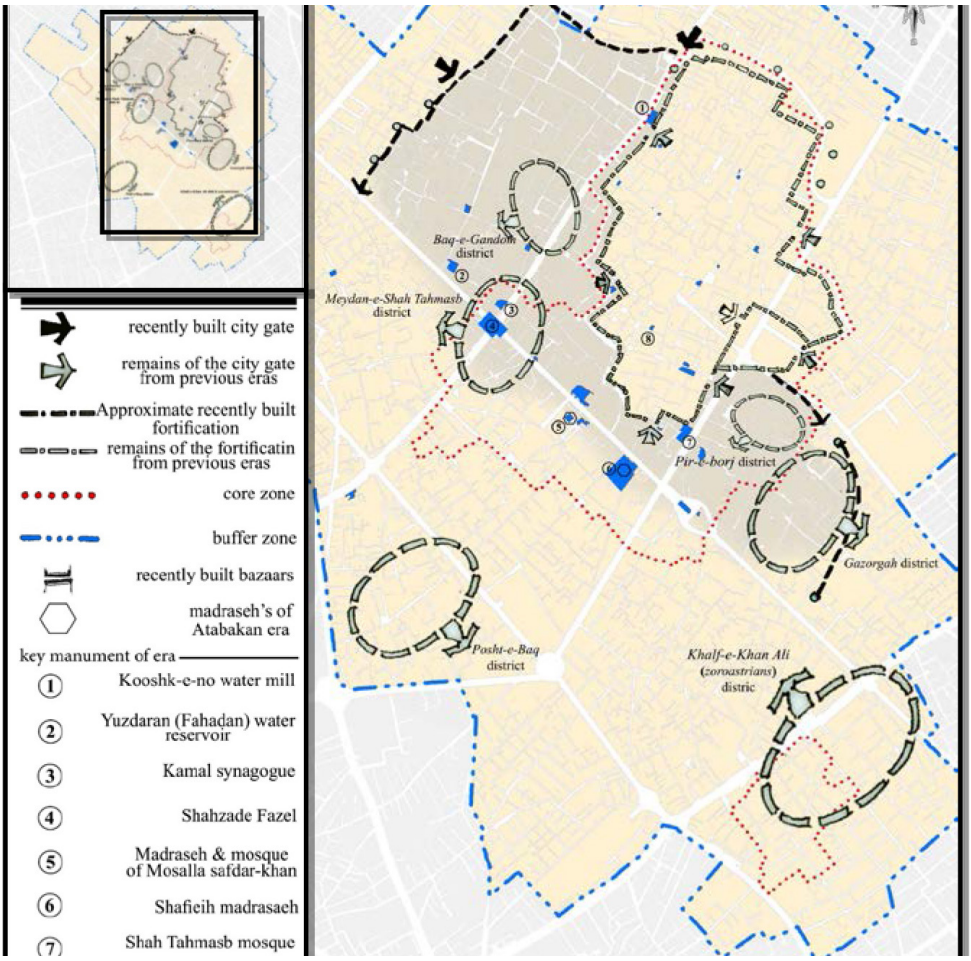


Figure 40: *Changes in the formation of the city and key monuments of the Safavid era (16th to 18th centuries from HCY base archive*

Yazd, 2017). The Bazaar, which still exists in Yazd and origin of contemporary bazaar goes back to, was built outside the city walls, next to the gate of Mehriz. *"This Bazaar consisted of 50 shops, each having two entrances. Later on, Amirzadeh Shams-o-din Mohammad, son of Amirchaqmaq, also added 30 shops which were used by tailors"* (Bafghi, 1963).

The citadel had two gates, one opening to the outside of the city and the other toward the inside. There was a moat all around the city. Later on, in Timurid era, not only another part of city was included in the fort, but also a tower was added to the main gate of the city and the interior garden outside the gate was turned into a square and finally was integrated the castle fortification to the city wall.

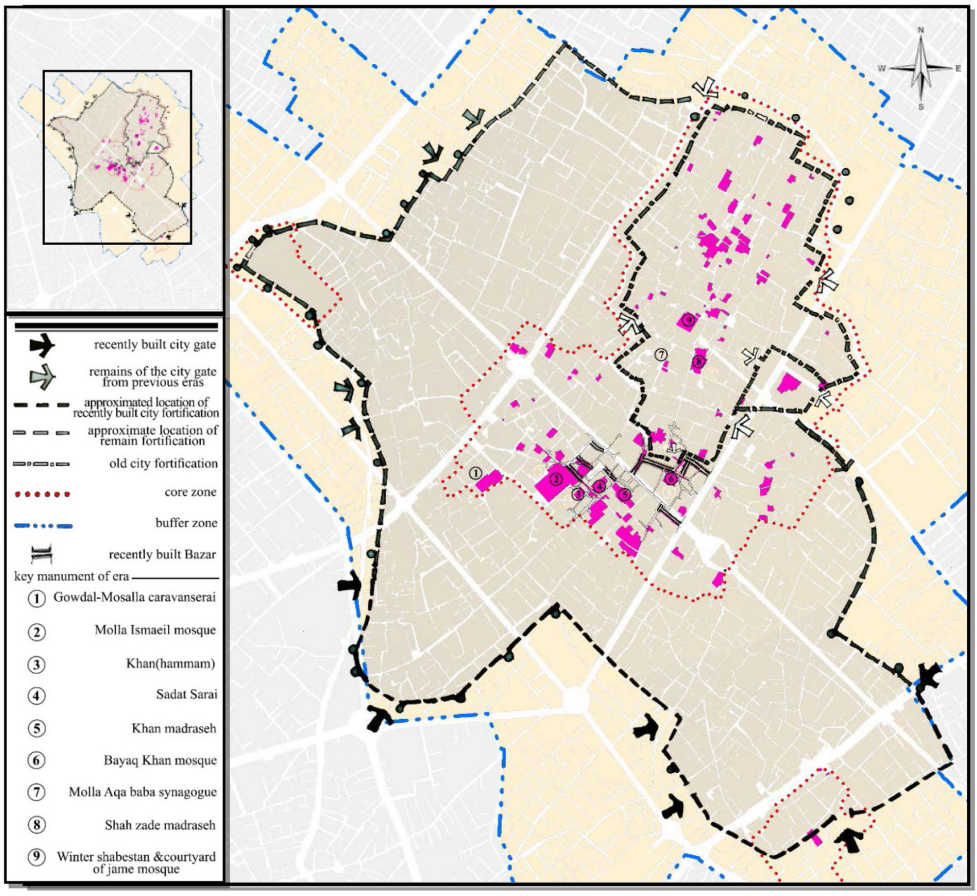


Figure 41: *Changes in the formation of the city and key monuments of the Qajar era (18th to 20th centuries), from HCY base archive*

Safavid era (16th to 18th century)

In the Safavid era, new gates were built including: Kooshk-e-no, Shahi, Malamir, Mehriz or Mehrijard, Hazireh Molla, Shahzadeh Fazel, and Seyed Gol-e-Sorkh Gate. Building new caravanserais such as "Robat-e-Khargooshi" on the way to Isfahan, "Robat-e-Zein-o-din", on the way to Kirman, and repairing some of the old caravanserais of Yazd such as "Robat-e- Anjireh" on the way to Khorasan and "Robat-e-Yaqmish" on the way to Isfahan, all show that Yazd has been an important spot for trading relations.

"Yazd reached its highest trading position during the reign of Shah Abbas I. As a result of its welfare amenities and secure conditions, the city achieved a desirable

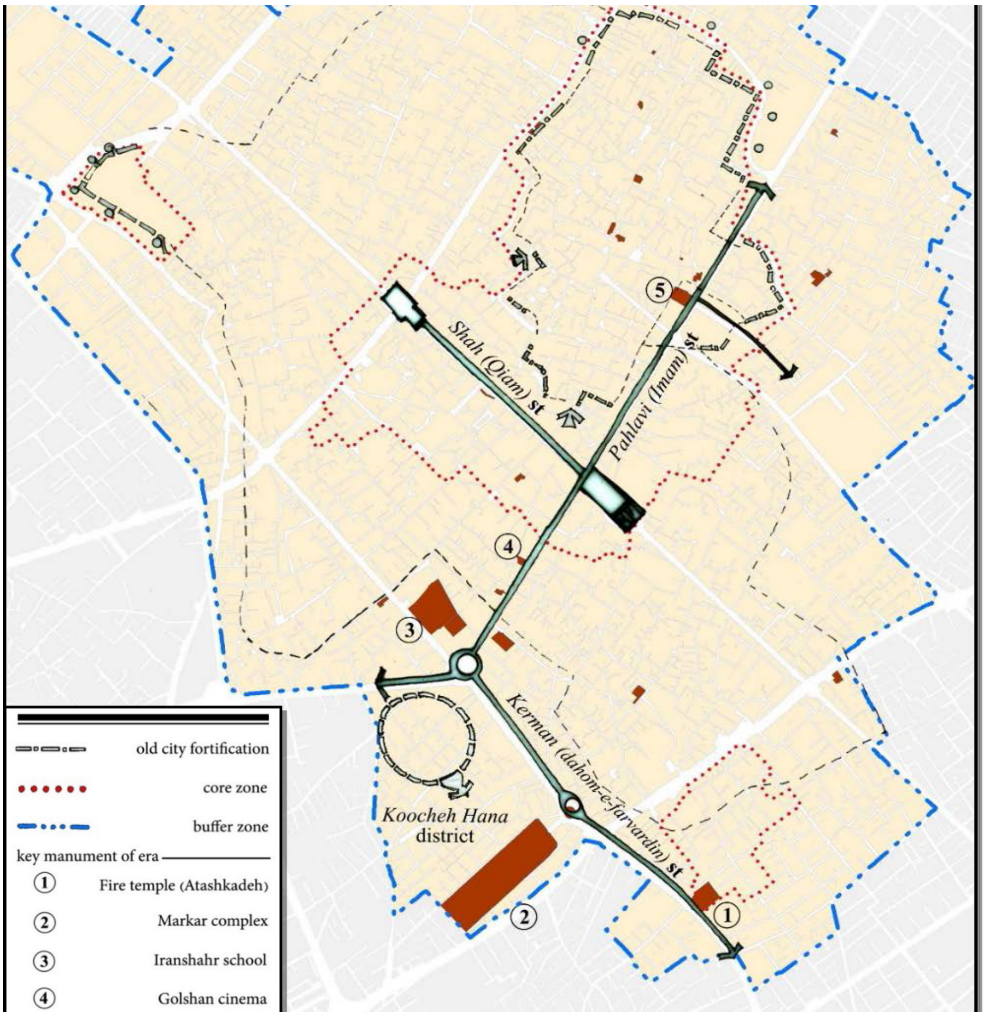


Figure 42: *Changes in the formation of the city and key monuments of the Pahlavi era from (20th century), from HCY base archive*

level of agricultural and industrial development" (Dossier of Yazd, 2017). During Safavid era, the commodities of Yazd such as silk and other fabrics were well known to merchants. Jean-Baptiste Tavernier writes: *"In this city, there are three caravanserais and several covered Bazaars like a covered alley. These Bazaars are full of merchants and craftsmen chambers"* (Tavernier, 1686).

Qajar era (18th to 20th century)

Most of Yazd present historic communities belong to Qajar era. The newly-made buildings in 19th century demonstrates the importance of Yazd and the growing inclination in renovation. On the other hand, the emergence of new buildings such as cinema and bank

changed the view of the city; and replaced the old concept of the city with the new western style. In the Qajar era, the constructions of the urban elements consisted of: numerous green areas and commercial spaces such as Vakili complex, Sa'adat square, Panje Ali Serai, Ali Aqa Serai, Kermani Serai, Golshan Serai, etc. The religious buildings included Bayaq Khan Mosque, Molla Ismail Mosque, etc. which were built around and among the other architectural constructions, and consequently a vast and interwoven complex of bazaars and squares was created.

Pahlavi era (20th century)

Pahlavi era was the time of universal development and modernism and there were certain urban changes compatible with the modern time and the lifestyle of the people. However, Yazd was able keep its historical and traditional form along with the new changes. So, the boundaries of the communities did not change considerably. Despite the arrival of cars, the spatial and continuity of the fabrics managed to preserve their old characteristics and functions and also the relationship between the historic areas of the city are preserved up until present. The new contemporary circumstances, the changes of the modern life led to the establishment of streets and taking other measures. With the prevalence of cars, the growth of Yazd City was stopped from inside and the city kept expanding outwards, because there was an intention to keep its traditional and historic style. In the last years of the Pahlavi Era, the first master plan for Yazd was prepared by University of Tehran. After Islamic Revolution, a new revision plan was prepared. In both cases, the most significant part of the plan was to preserve and keep the historical zone intact from the changes.

Being a living dynamic city, Yazd has evolved gradually with some inevitable changes. From the 1930s onwards, several policies were established to modernize the city. That led to the creation of a few wide commercial streets. This occurred mostly outside the historic city. Contrary to those interventions, large zones of the historic city still remains intact and they possess a large number of excellent examples of balance between artificial and natural.

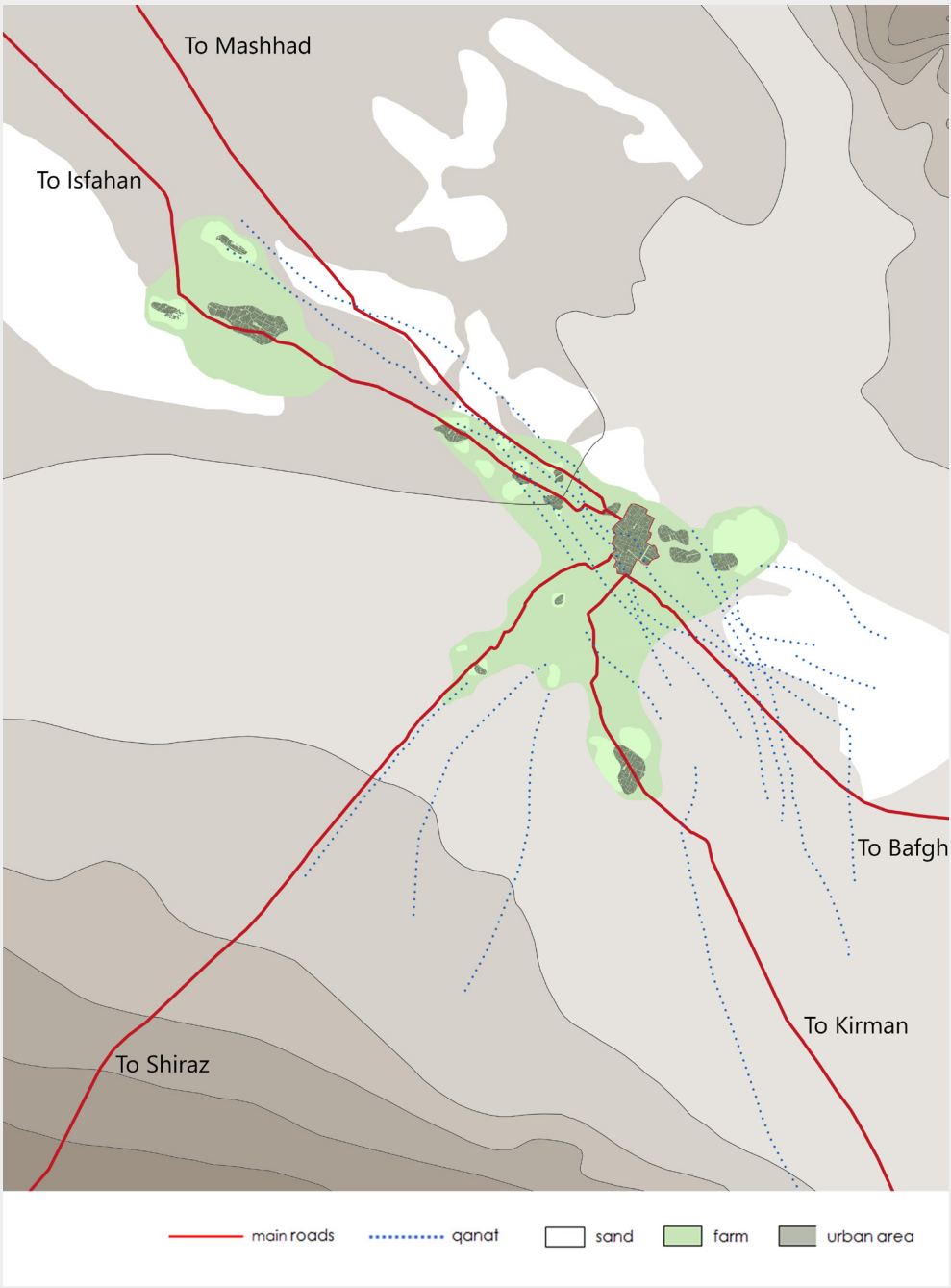


Figure 43: *Development of Yazd from 11 to 14 centuries from HCY base archive with [modification of the author]*

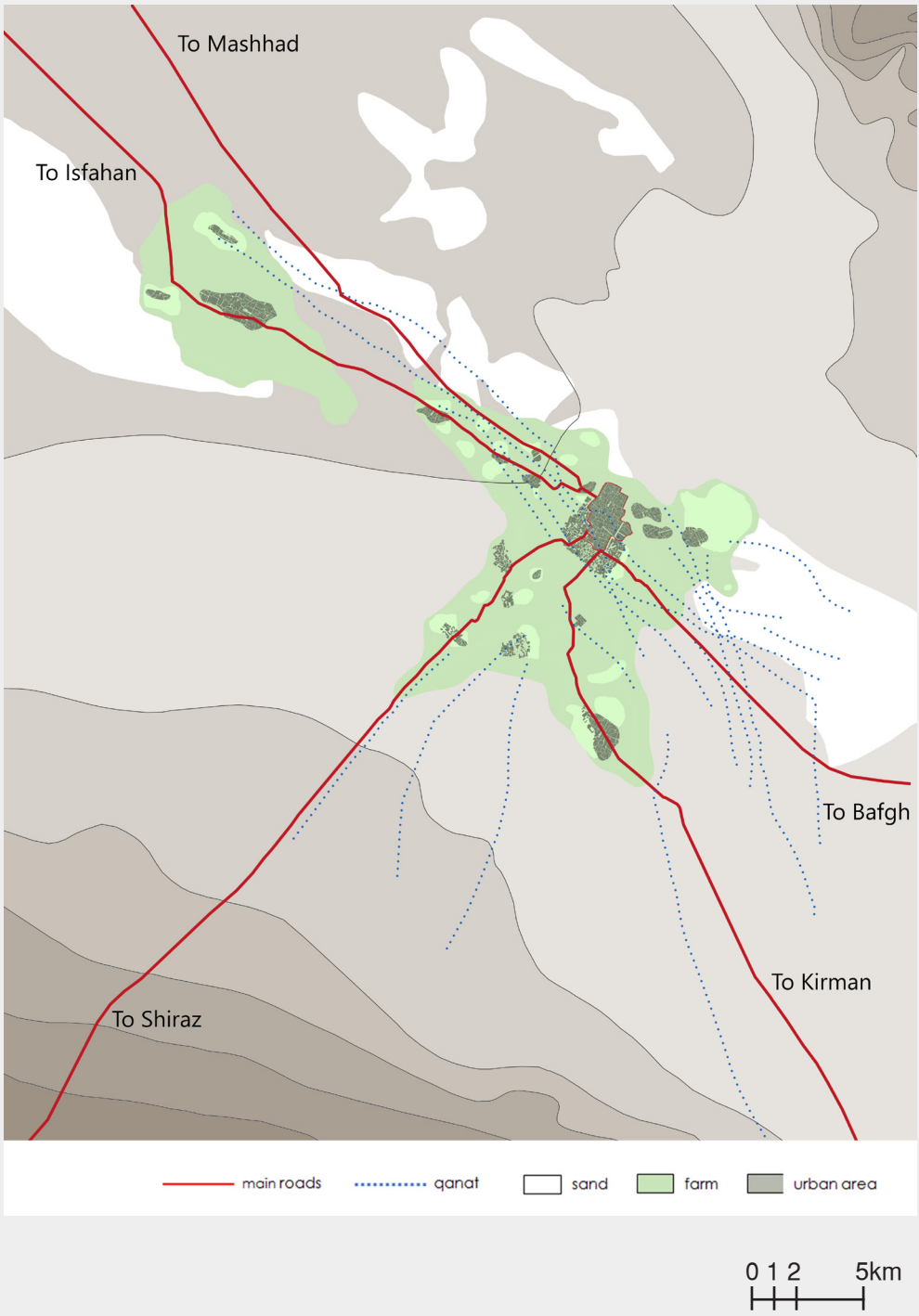


Figure 44: *Development of Yazd from 14 to 16 centuries from HCY base archive, with [modification of the author]*

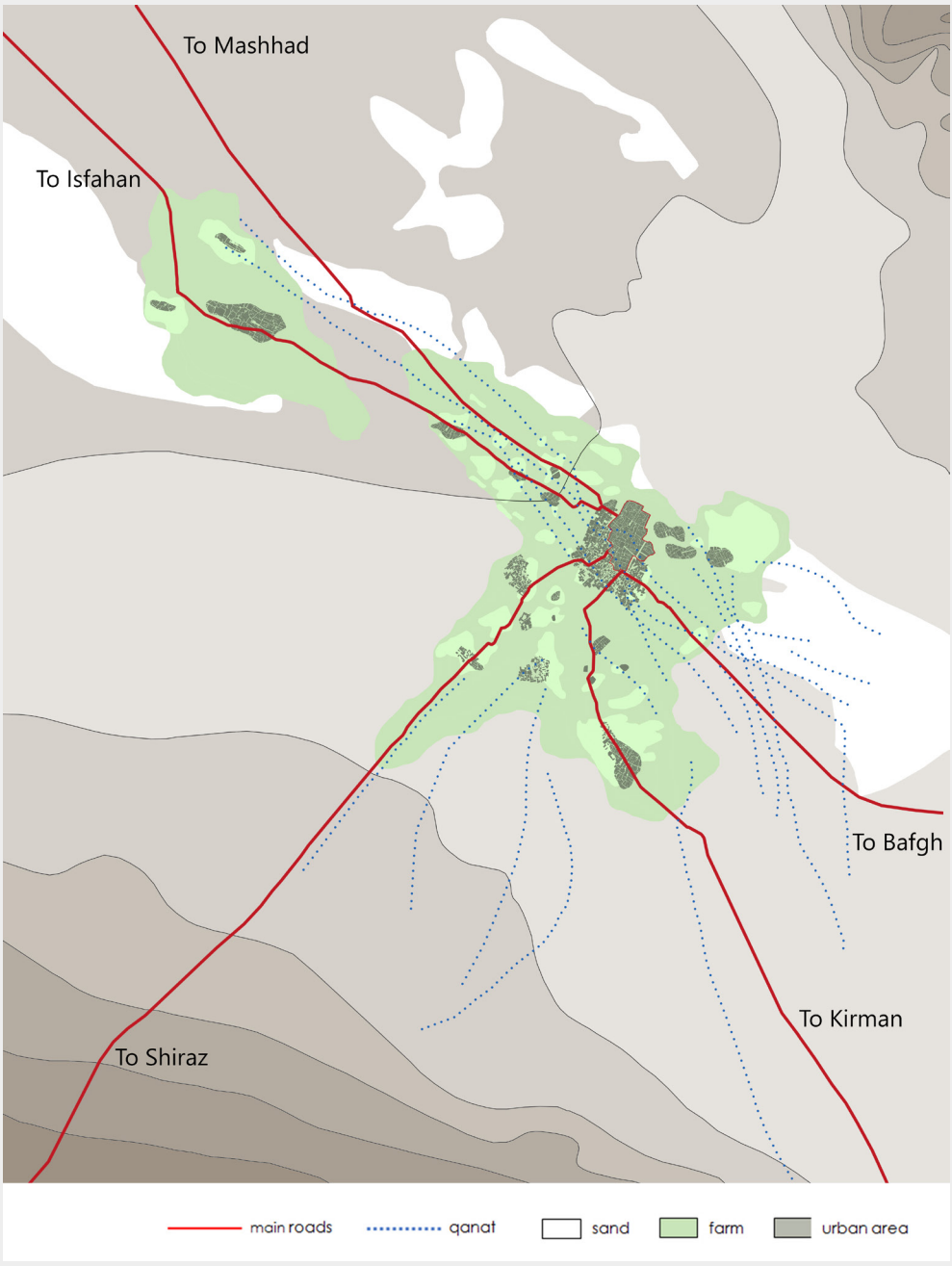


Figure 45: *Development of Yazd from 16 to 18 centuries Map from HCY base archive, with [modification of the author]*

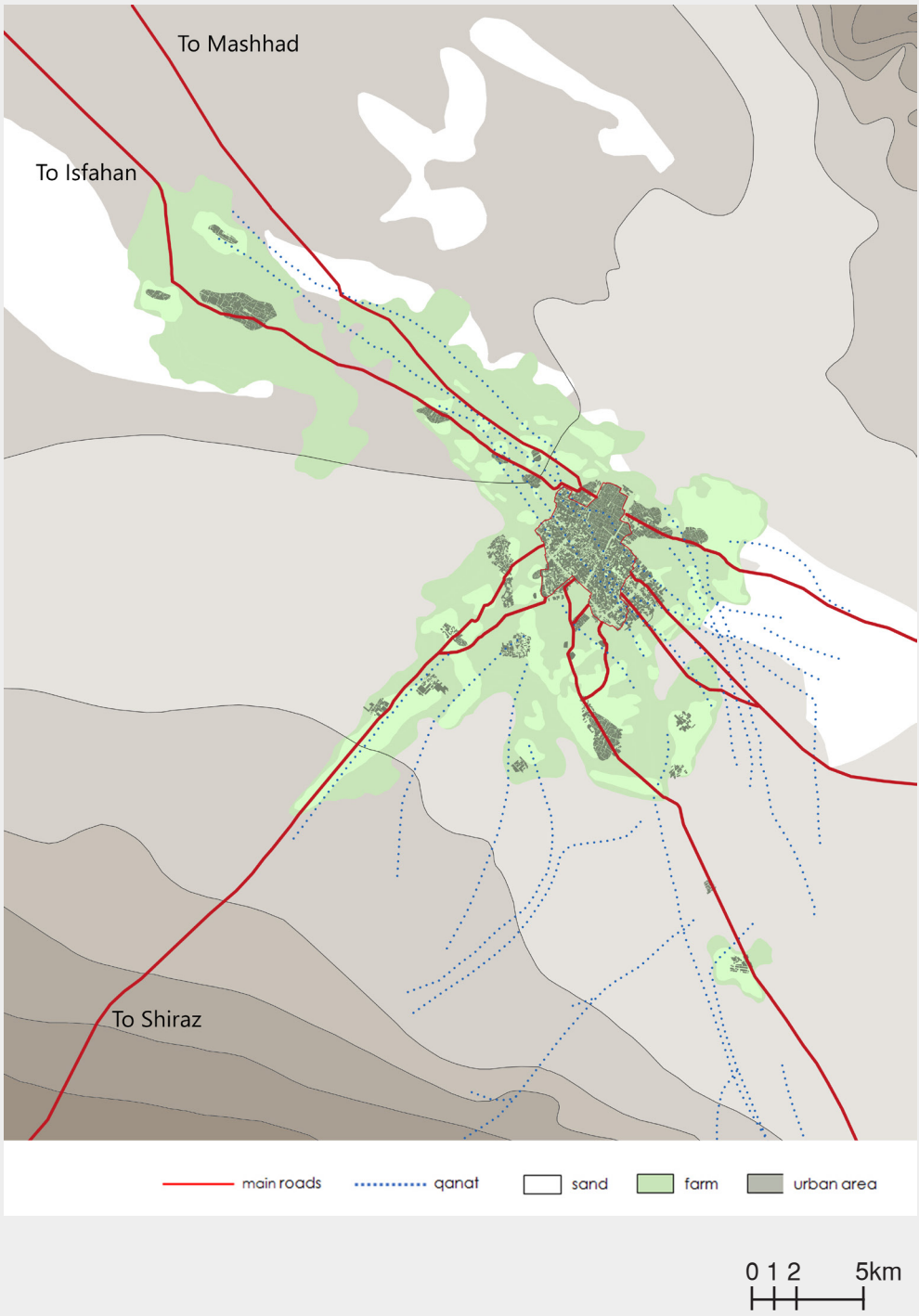


Figure 46: *Development of Yazd from 18 to 20 centuries from HCY base archive, with [modification of the author]*

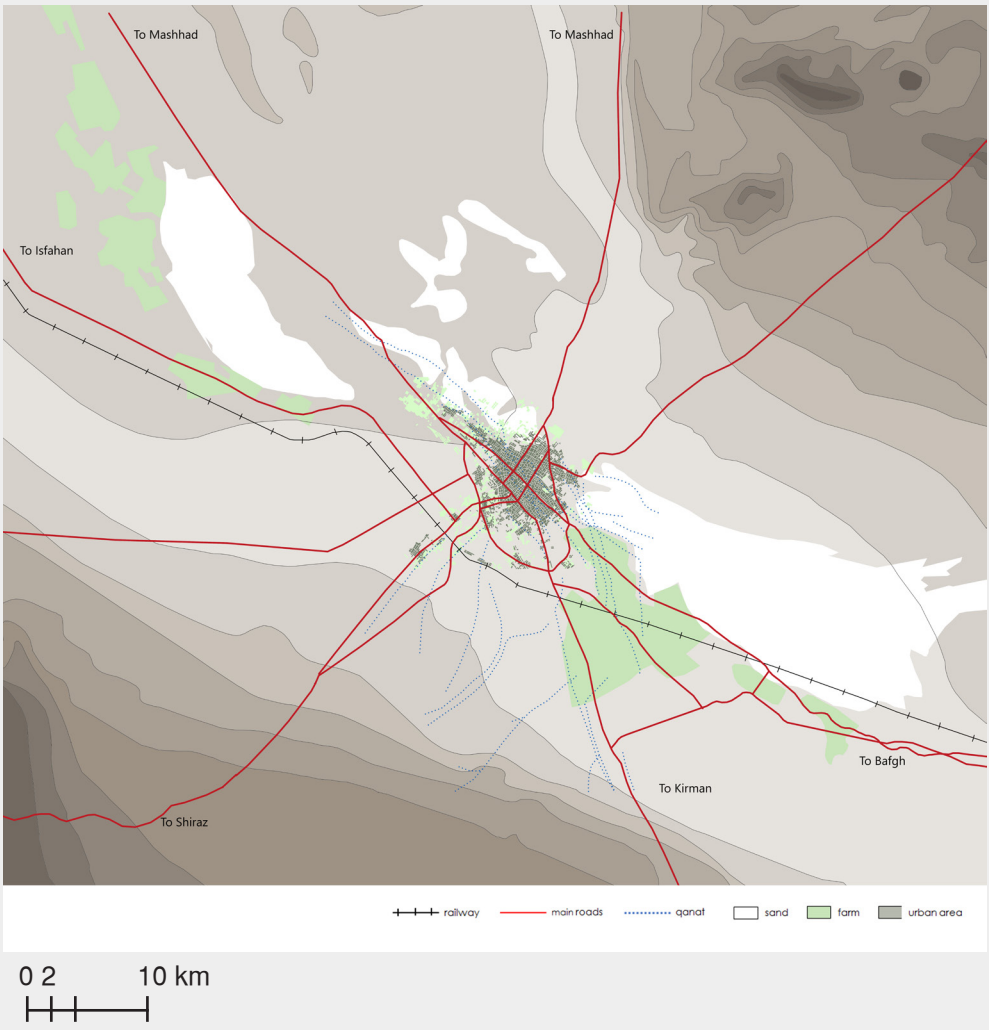


Figure 47: *Development of Yazd before Islamic Revolution in 1979 . from HCY base archive, with [modification of the author]*

2. Composition of the Habitat

"Composition of Habitat" refers to the artificial made to provide the setting for human activity, ranging in scale from buildings to cities and beyond. Habitat in the realm of architecture may be defined as the man-made spaces in which people live, work and recreate on a day-to-day basis with a vision for the future progress.

Qanat, a man-made hydraulic infrastructure, creates the essential settings for liveable spaces. It operates at different scales. At the building scale, it provides water for daily activities; at the city level, it defines the framework of the city and at territorial scale, it determines the placement of the settlements.

This chapter explores the qanat infrastructure and its combination with the urban framework of Yazd. Urban Frameworks connects the social, artificial and environmental aspects of built environment and provides frameworks for a long-term process of understanding, adapting and responding to diverse challenges, with a focus on creating resilient city.

In Yazd, the interaction between qanat infrastructure and urban framework manifested itself in the physical features such as street layout, and in the non-physical characteristics in form of social hierarchy.

Figure 48: *Dowlat Abad Garden, photo by Maryam Felidae*

2.1 Qanat Infrastructure

Absence of surface water has constituted the urge and motive for people to search for ways and means to inhabit the dry-land, and to extract its hidden waters. It pushed people to seek, imagine, create, and reverse obstructions to new possibilities throughout their history. The qanat system is a clear example of this dynamic. To build a qanat, one must have a all-inclusive understanding of where and when one lives. French scholar, Henri Gablot who studied qanat system and its origins, considered the qanat system to be one of the most imaginative engineering works in the history of humankind.

"In fact, the extraction of hidden waters and construction of oases and gardens, the life-filled Pardis or Paradise within a landscape that is a seeming tabula rasa, could not occur without the presence of rich imagination" (Sanaan Bensi, 2019).

The genesis and geographic distribution of qanats have been investigated from various aspects and different

Figure 49: *Left: Aerial view of qanat infrastructure, photo from Iran Tourism*

Figure 50: *Aerial view of qanat infrastructure, photo by Rashedi*

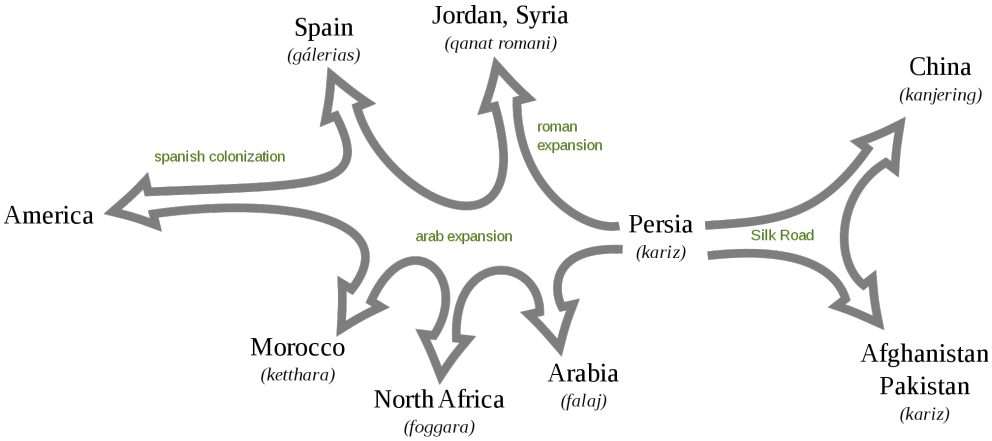


Figure 51: *Qanat's diffusion (Salaban, 2009)*

viewpoints. German scholar Haupt studied the qanat system in lake Van in Turkey (Haupt, 1925). French archeologist Chauveau has done some research on the oasis of Kharagha in Egypt (Chauveau, 2001) and Mirjo. Salvini has studied the hydraulic structures in Urartu, which Henri Gablot considers the birthplace of qanat. (Salvini, 2001), (Gablot, 1995).

Having lived for almost 20 years in Iran, and studying the qanat system and its origin, Gablot on the basis of Sargon tablet[1] and other evidences introduces a theory: He claims that the origin of qanat could be the Urartu surroundings (Western Azerbaijan province in Iran and Eastern Turkey) and related to the second millennium BC (Gablot, 1995).

Roman Ghirshman, one of the early archaeologists who studied the Central Plateau of Iran, who excavated of Sialk and Cheshmeh Ali, states that in regard to the Iranian irrigation technique and the significance of water in Iran, artificial irrigation methods have been used

1 The three fragments of clay tablets, contain inscriptions of the Assyrian king Sargon II who, towards the end of the 8th century BCE, built an empire in the Middle East, the Fertile Crescent, conquering Samaria, Damascus, Gaza and, in 717. These are self-celebrating sentences, emphasizing the military victories and the measures in favour of the population.

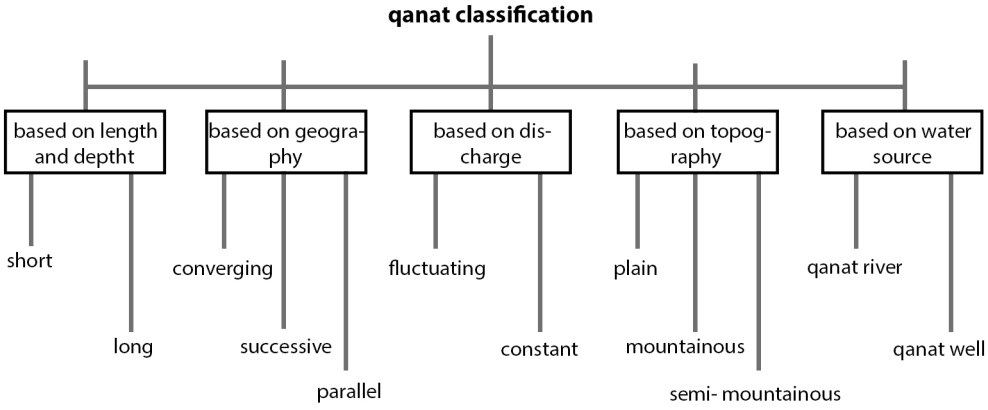


Figure 52: *Qanat's classification from Semsar Yazdi, & Labbaf Khaniki (2013), [redrawn by the author]*

from prehistoric times (Ghirshman, 1985). There are other palaeontologist such as Diakonov and Richard Frai who believe the qanat technology is an Iranian "export product" distributed all over the world. (Diakonov, 2001), (Frai, 1994).

The qanat system is called differently in different countries. (Lum,1965), (Beaumont,& Bonine, 1989), (Aghasi,& Safinejad, 2000). There are more than 27 terms for qanats being used in these countries such as "Qanat" and "Kariz" in Iran, "Ain" in Saudi Arabia, "Aflaj" in Oman, "Kanerjing" in China, "Galleria" in Spain and "Inuguttati" in Sicily (Semsar Yazdi,& Labbaf Khaniki, 2013).

In general, the qanat system spreads out between the latitudes 15 and 45N. Many of countries between these latitudes benefited the system and some still exploit this technique such as Japan, China, Iraq, Syria and Iran (Semsar Yazdi,& Labbaf Khaniki, 2013).

Among four sources of water -rivers, springs, lakes, and groundwater- in Iran's desert, groundwater has always been life giving. Qanat is an ancient system of underground water collection and distribution, largely used in arid and semi-arid climates has evolved through time adapting to different geographical and

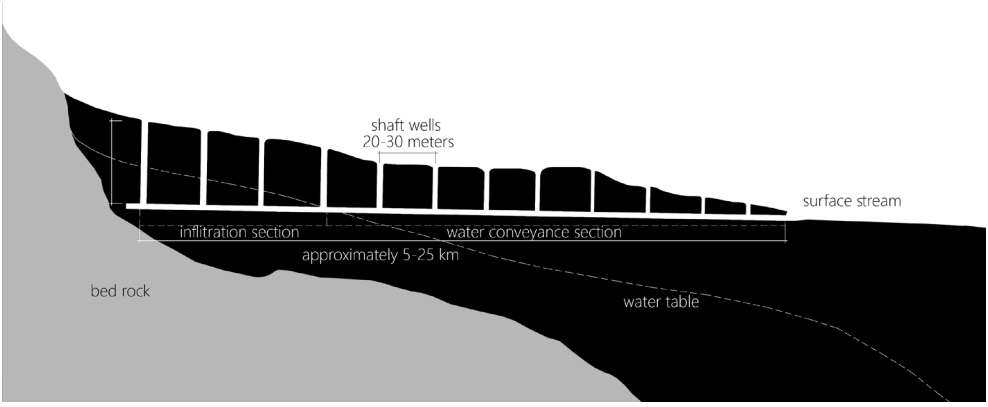


Figure 53: *Cross-section of qanat infrastructure from the mountain to the plain, originally drawn by Ward English in 1968 with [modification by the author]*

anthropological contexts. Since ancient times, water in the desert has always been considered precious, and the origin of civilization in Iran depended on artificial irrigation (Tavassoli, 2016). In areas with low yielding aquifer, where digging deep wells is not a choice, qanat could well serve the irrigation needs. As such the qanat is a sustainable water supply system that could indefinitely provide water by preserving subsurface water tables (Motiee et al., 2006).

The geographer Paul Ward English helps us visualize a qanat as a sloping subterranean tunnel dug into water-bearing sedimentary soil, far enough to pierce the water table and penetrate the aquifer (Figure 53). Filtering into the upper reaches of these channels, water from the aquifer emerges as a surface stream where needed (Ward, 2015).

Qanats are categorized on the basis of their length, discharge and depth (Behnia, 1988). However, Iranian engineer Ali Asghar Semsar Yazi and Iranian geographer Majid Labbaf try to add topography, geographic

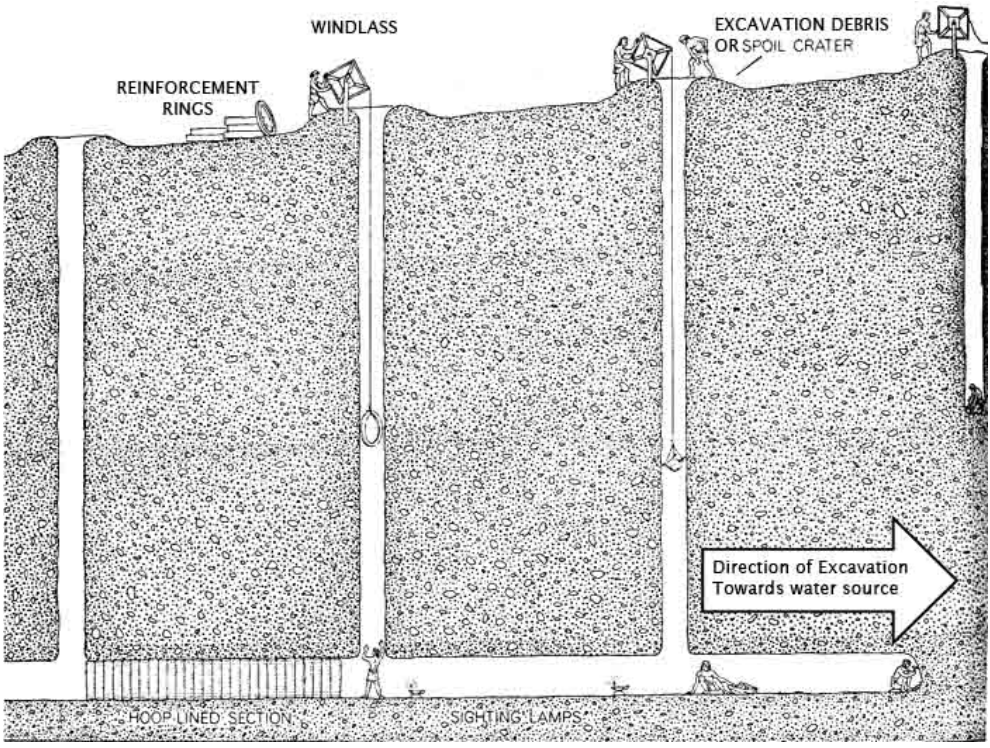


Figure 54: *Excavation of a qanat (Wulff, 1968).*

situation and source of qanat flow to Behnia's classification (Semsar Yazdi, & Labbaf Khaniki, 2013). Thus, we could interpret that the qanat system is a underground infrastructure that give access to the hidden water at the foot of mountains.

Vertical shafts with sequential increase in their depth are connected by a horizontal underground tunnel where water is directed from aquifer down a slight slope to gardens, farms, and settlements.

"However, the vertical shafts are not themselves used for accessing water. Rather, they are important, first, for calculating the right direction and proper angle of slope for the horizontal tunnel. Later, during excavation, they are used for faster removal of dug materials, as well as for regulating pressure and oxygen for workers. Finally, after the completion of construction, these shafts are used for maintenance, providing workers an easier way to get at the underground horizontal tunnels for repair" (Sanaan Bensi, 2019).

H. E. Wulff describes excavation of a qanat: *"Excavation of a qanat begins at the downhill end after a trial well (right) has successfully tapped the uphill water table. Where the gradually sloping tunnel passes through zones of loose earth (left) hoops of tile support the walls, but a tunnel generally lacks masonry except at the discharge point.*

Ventilation shafts are dug at intervals of 50 yards or so; earth and rock excavated from the tunnel face are winched to the surface through the shafts. Sightings over a pair of oil lamps help to keep the tunnel diggers' progress on a straight line. A lamp flame that burns badly also gives warning of bad air. Before the tunnellers break through to the head well, men at the surface hail it dry" (Wulff, 1968).

The placement of mother well, distance between vertical shafts, appropriate slope for the horizontal tunnel, and length of the qanat were thoroughly inspected during the process of construction.

According to Gablot, the slope of the underground tunnel must be around 0.5/1000 to minimize the erosion of the inner surface of the horizontal tunnel. This is an important technical issue, as slope directly affects the point where water emerges on the surface.

Most qanats in Iran were constructed by muqannis with primitive tools: a broad-bladed pick, a shovel, and a small oil lamp (Ward, 1968).

These man-made tunnels running for several kilometres are among the earliest achievements of hydraulic engineering. Qanats are expensive to build and expensive to maintain, nonetheless, their diffusion in dry areas results in the most economical water supply in regions where water is critical scarcity.

It has been estimated that qanats costed around 10,000$ per kilometre to be built and considering the fact that some of them are more than 20 km long and it took between 5 to 25 years for each to be constructed, it had been a long term investment(Ward, P. 1968, Kazemnejad, 2018). Construction costs have increased in recent years as the quality of life of Iranians has

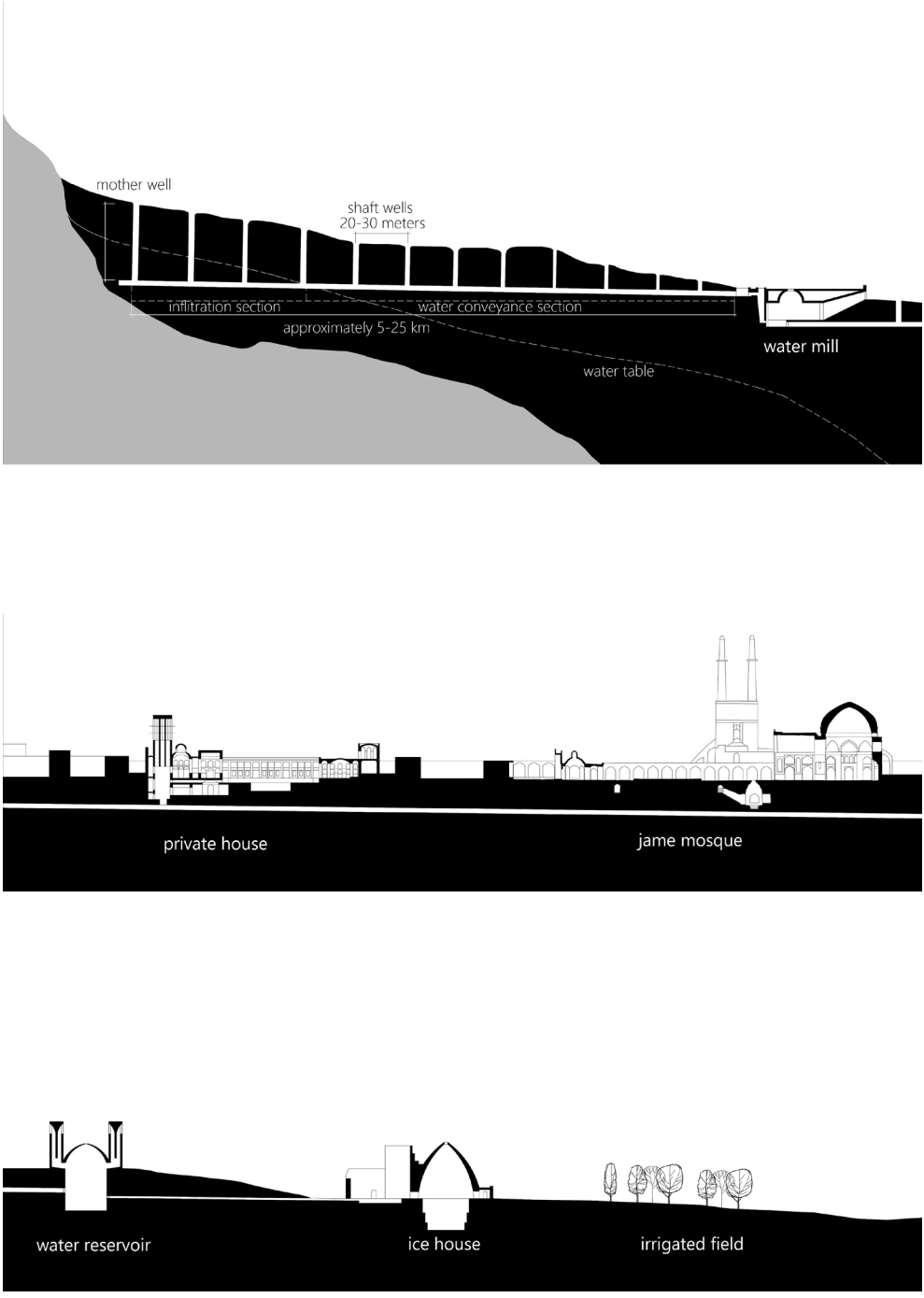


Figure 55: *Schematic cross-scale section from the mountain to the plain [drawn by author]*

Figure 56: *Qanat construction in Qajar era (20th century), photo from Media Gallery of Fouman*

improved and labour costs have increased. Additionally, the division of large landholdings into smaller ones under the new land-distribution policy, as well as the introduction of expensive modern machinery has made it difficult for the individual landowners to afford the expense of constructing new qanats or maintaining old ones.(Wulff, 1968).

The importance of the qanat system lays in the way in which it organizes territory through a process of revealing water to surface and, thereby, providing the possibility of habitation (Sanan Bensi, 2019). This system can be presented in a schematic cross-scale section from the mountain to the plain including plugged-in urban artefacts such as watermill, water reservoir, payab, ice house and house (Figure 55).

The complexity of this territorial system becomes clear when we consider the treatises that collected and organized the know-how knowledge of water management and the construction of qanat.

"Inbat al-miyah al-khafiya", by the Iranian Muslim mathematician and engineer of the late 10th and early 11th centuries Abu Bakr Muhammad Al-Karaji, is one of the oldest surviving manuals on hydraulic and water

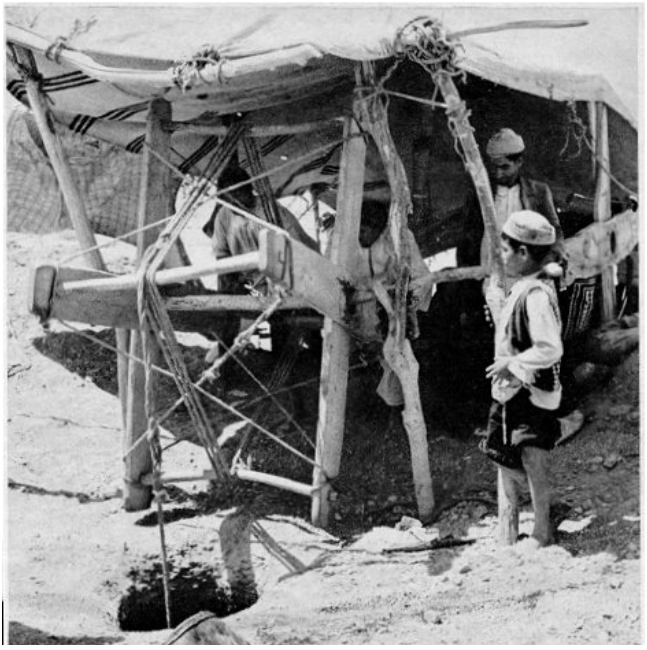


Figure 57: *Qanat construction in Qajar era(20th century), photo from Zoroastrians Heritage*

supplies (Sanaan Bensi, 2019). In his book, Al-Karaji illustrates the principles of the hydrological cycle, classification of soils, description of aquifers, and the search for groundwater (Abattouy, 2014).

He observed these processes and practices during his lifetime and organized them scientifically and according to his educational background in the form of a treatise. Karaji himself wrote, in the introduction, *"I know no profession more beneficial than the extraction of hidden water, as it gladdens the earth and makes life possible"* (Al-Karaji, 1674).

The book assembles a substantial knowledge on the methods of finding and treating water as well as the instruments used in construction and preserving qanats.

Al-Karaji explains the way to find underground water sources: the geological conditions that affect where the water is naturally stored underground; the topography, type, and colour of soil and stone; vegetation in the proximity; and other indicators.

In the following chapter, he mentions various kinds of water, their sources, use, and ways of cleaning and purifying them. Then, he focuses on different subjects

related to water, such as how earthquakes affect underground water or how to verify whether a well still contains water or not. The relation that he describes is fundamental since he is directly tackling the issue of resilience and risks.

In the last chapters of his book, Al-Karaji concentrates on the legal aspects of water management. Ownership of qanats is complex, since the land surface and its underlying section where houses the infrastructure can belong to different people. That is to say, he reveals a legal situation in which different ownership systems overlay and superimpose each other.

Al-Karaji states that these legal standards vary if the hydro-infrastructure is a qanat, well, or canal and if they are constructed for the use of a farm, animal, or a city.

What is the legal and ownership status when a qanat constructed by someone for the use of a city or settlement passes underneath the farm belonging to someone else?

And what happens if the qanat system needs to be repaired or even accessed?

These are the more fundamental questions. Moreover, different territorial ownership principles apply to different geological conditions, for example, if a qanat or well is constructed in a soft porous soil or muddy or hard soil .

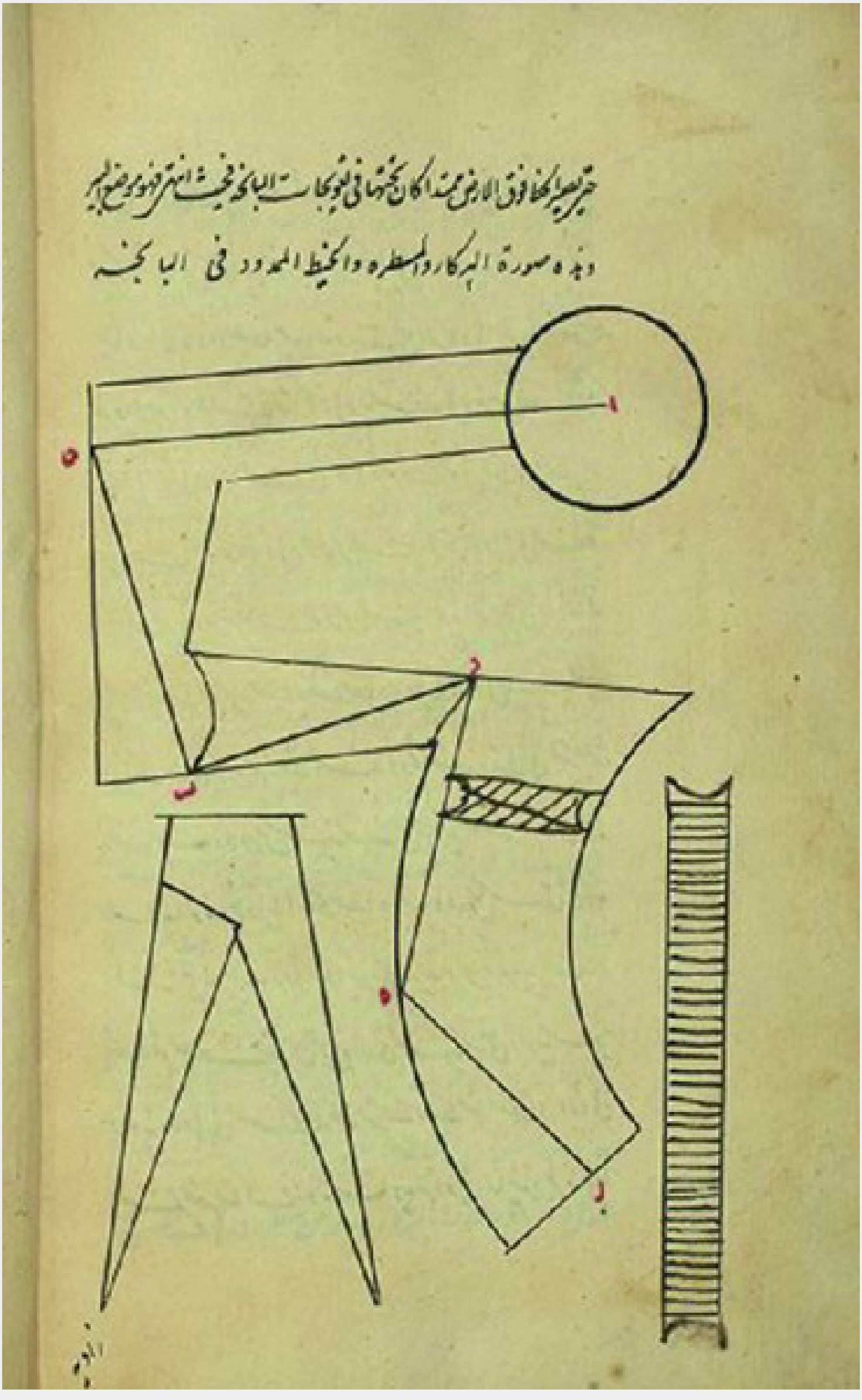
Sanaan Bensi states that *"in this way, geometry measures not only the surface or the landscape, as its etymology literally says (geo, earth + metry, measure); it also encompasses the whole complexity and contradiction of the act of measuring. Indeed, measurement is tightly related to the management of land"* (Sanaan Bensi, 2019).

One of the fundamental legal aspects concerning the qanat system is the law of harim or borders, which has given an owner protection over a territory surrounding a qanat and prohibited the sinking of new mother wells or any other construction within a defined distance of an existing qanat (English 1968). The border law does not itself establish this distance and it may differ in

Figure 58: *Diagrammatic plan of underground tunnel. Showing how to project it on the surface to be able to site and dig the well. The drawing shows a compass and a ruler (Al-Karaji, 1674).*

Figure 59: *Levelling tools. These figures are included in a chapter which explains the levelling tools and techniques for surveying the ground. This surveying process for understanding the topography and height differences along the qanat path is crucial in the construction process (Al-Karaji, 1647).*

Figure 60: *Levelling tools. These figures are included in a chapter which explains the levelling tools and techniques for surveying the ground. This surveying process for understanding the topography and height differences along the qanat path is crucial in the construction process (Al-Karaji, 1647).*


وهذه صورة البركار والمسطرة والخيط الممدود في ا ب ج ه

في تمام الآلة ان المقدر بها في كل موضع يجب ما يراه صوابا واذا كان الموضع كبيرا الخ

والصورة ترتيب صاحب الخشبة من صاحب الميزان يعير الخيط وجعله مقدارا لما يجب

رجل من جبل بعد ان يكون البعد بين الوتد الذي معه الميزان في اول الوتد الواحد

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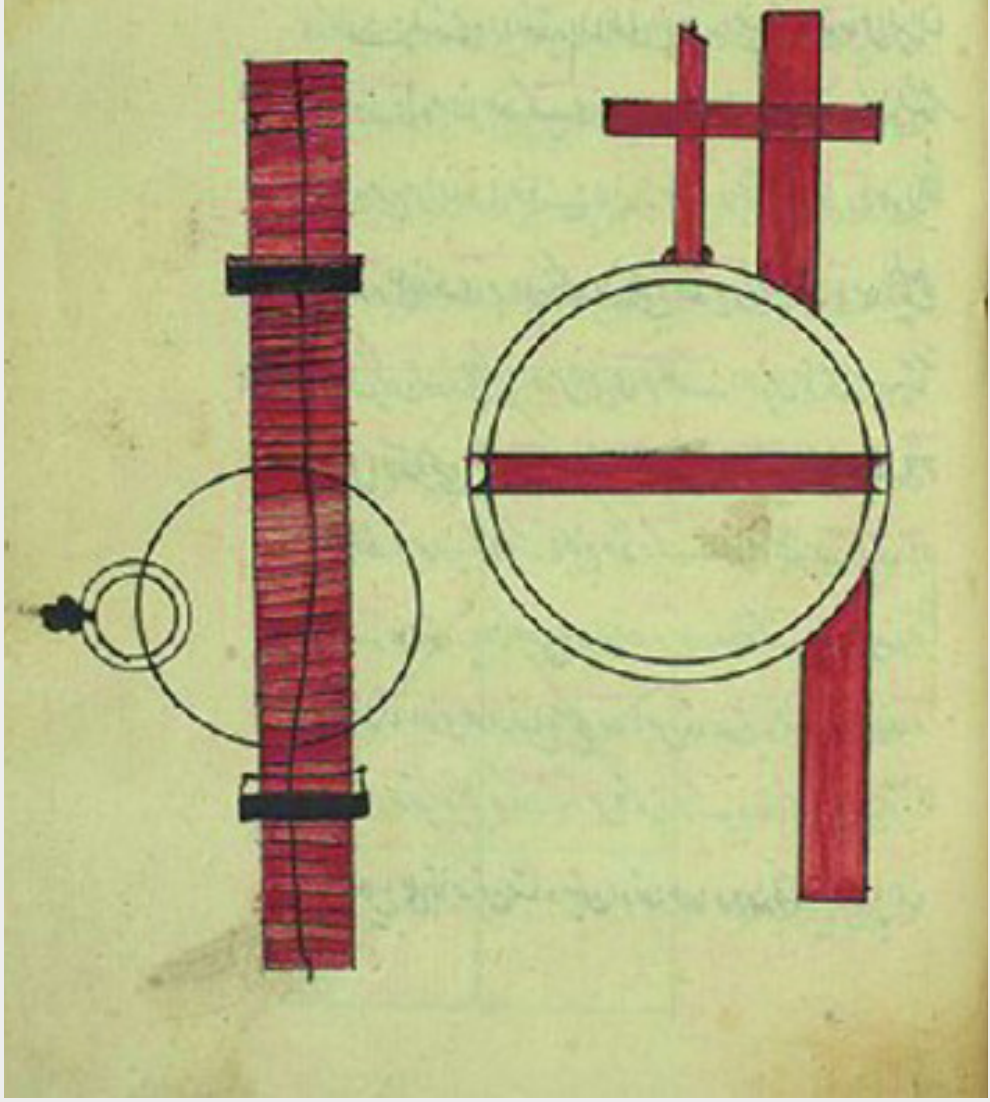

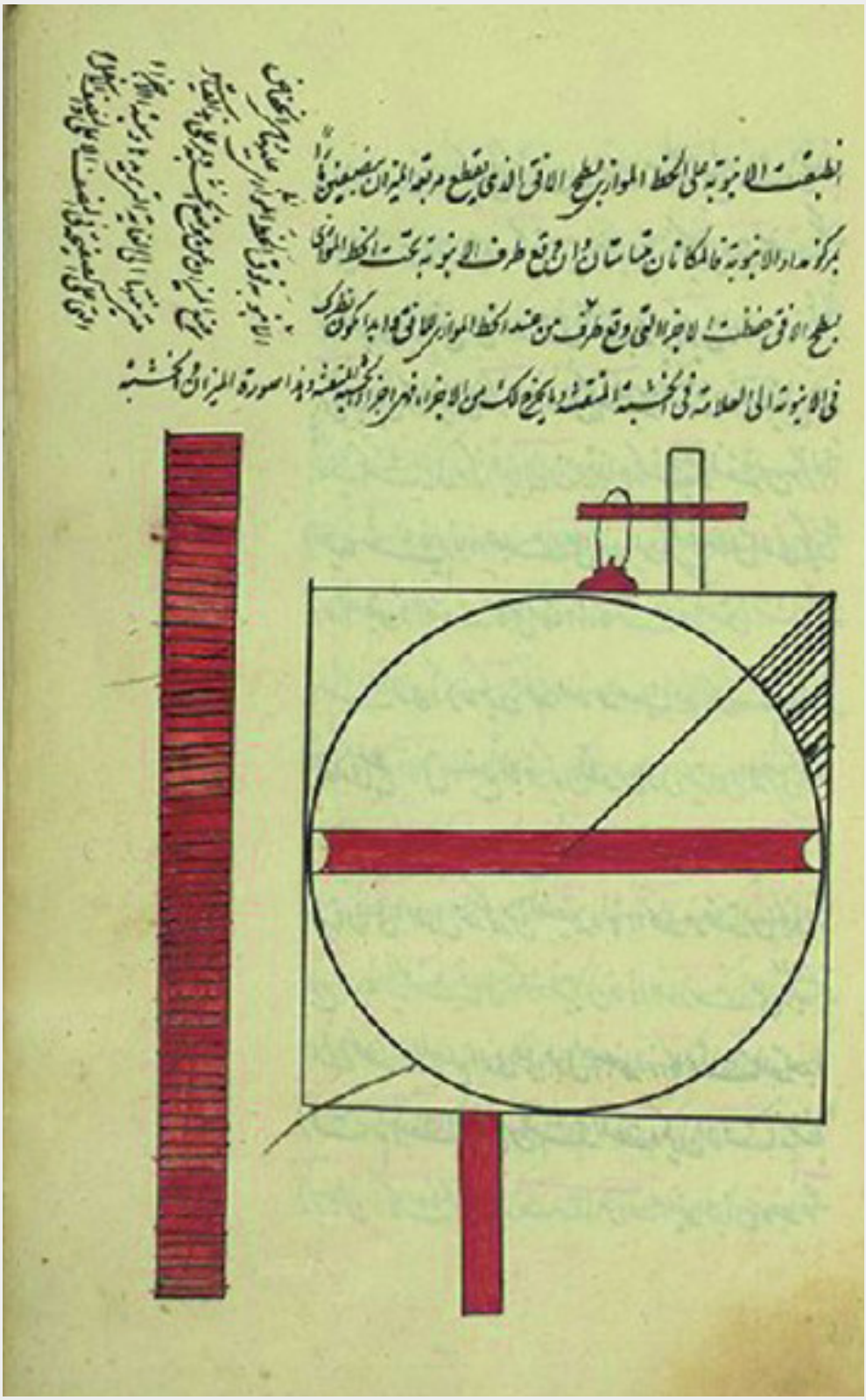

التي في الوسط حتى اذا وقع طرف الانبوبة المحدد على الدايرة ملئ
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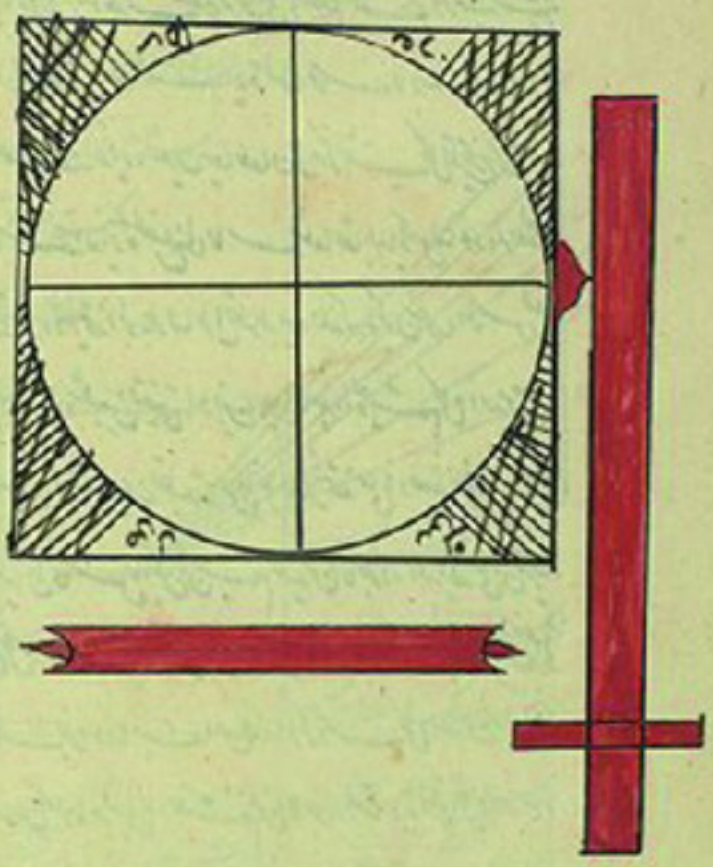

واذا اردت ان تعرف عمود جبل بعيد اكان او قريبا وعمود هو

various conditions.

Al-Karaji demonstrates that distance was conditional, depending, as ownership did, on the type of hydro-infrastructure, type of qanat, its length and depth, the geological condition of the soil, the location of the mother well and so on.

As a result, the importance of the border is more than just the protection of the right of ownership; it defines structures for protecting underground water resources.

The Qanat of Zarch

Gaining a general view from qanat hydraulic infrastructure, we can analyse more deeply the Zarch qanat that is the only surviving qanat of Yazd till today. [1]

The name of this qanat is taken from the city of Zarch near Yazd, which can be dated back to the Muzaffarid dynasty (1335-1393).

In addition, the structure and the way of construction can also provide information about its origins. For instance, in the downstream of qanat vertical shaft wells have been dug four-sided. It is believed that such construction was used by Zoroastrians long before the advent of Islam.

Digging four-sided wells helped workers in determining the right direction underground. Since in a circular well, it is very difficult to figure out which direction leads to the next well, while digging the tunnel. The dimensions of such wells are usually 80 by 120 centimetres, which can be found across Iran.

1 This part of research s is based on the book "Qanat of Zarch" by Ali Asghar Semsar Yazdi, 2014.

Figure 61: *A tool for measurement of topographical distances and it is part of a chapter which describes the ways and tools for defining the height of a mountain, the distance between a mountain and where an observer stands and as well the distance between the summit of different mountains (Al-Karaji, 1647).*

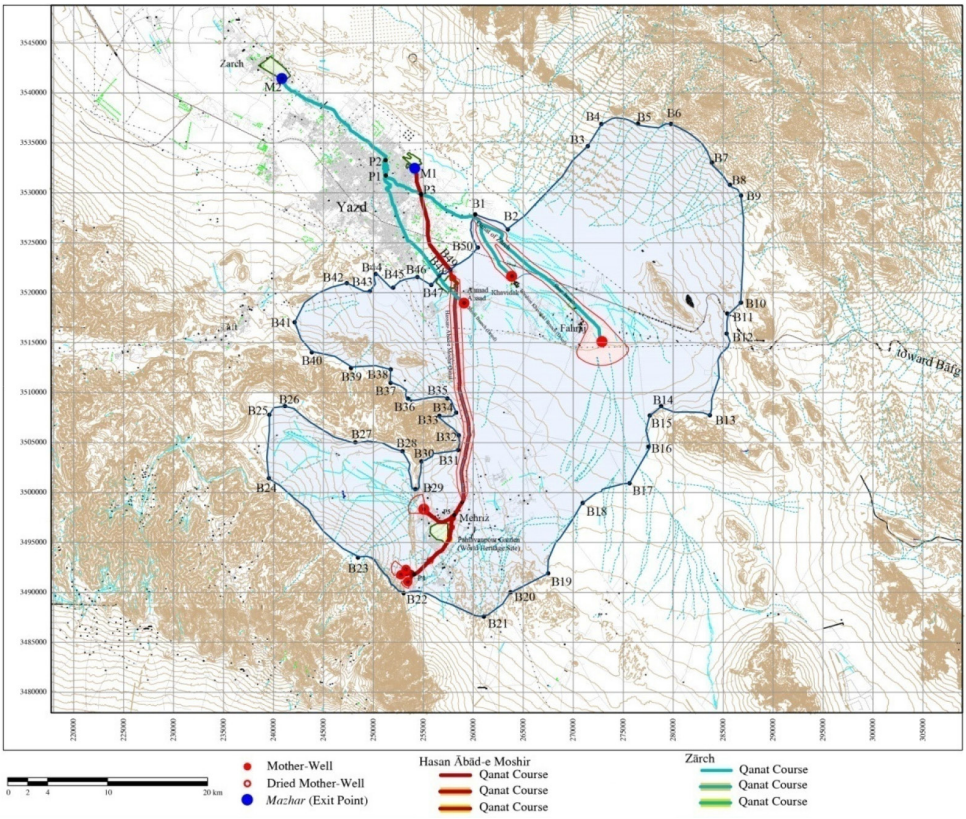

Figure 62: *Qanat of Zarch buffer Zone, (dossier of Persian Qanat, 2016)*

The water provided by this qanat was used in domestic and agricultural sectors and even in industrial sector, whereas now it is only devoted to agriculture. The cultivated lands that were once irrigated by this qanat cover an area of some 300 hectares, which demonstrates the significant discharge of it. The qanat has three branches named "Shoor" (salty), "shirin" (sweet or fresh) and "Ebrahim Khdivaki". Shoor is the only active branch and the others have long dried up in the wake of a draw-down in water table.

Shoor branch mother well is 85 meters deep and is located three kilometres away from the village of "Fahraj", southeast of Yazd. The mother well of shirin branch is around 55-60 meters deep, 50 meters away from a tube well which has been drilled as a substitute for the inactive qanat "Ahmad Abad Moshir". The mother well of "Ebrahim Khadivaki" branch is 50 meters deep, sunk near the castle of Khadivak".

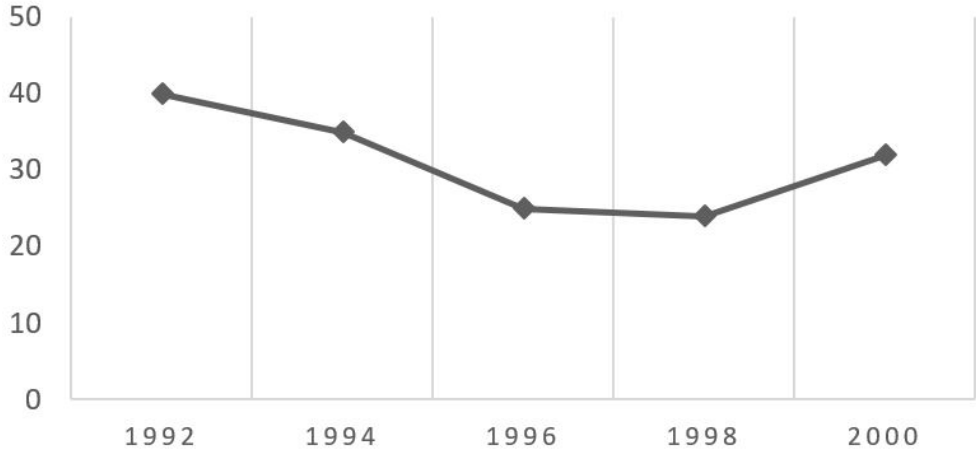

Figure 63: *Qanat of Zarch flow-rate from 1992 to 2000 (Semsar Yazdi, 2014)*

The overall length of Zarch qanat containing its side branches is more than 80 kilometres, with over 1000 shaft wells. In 2001 the qanat had a discharge of 30 litres per second that could irrigate an area of 100 hectares of cultivated lands.

The qanat's discharge is stable hence a substantial section of its gallery penetrates the aquifer, though its discharge in long term is declining due to the depletion of groundwater and shrinking of water production section. It should also be noted that around 50 years ago the qanat discharge has been reported to be as high as 150 litres per second.

"Based on a report provided in 2003 the qanat mother well was 85 meters deep, while the depth of water table was 80 meters. As a result, in 2003 the mother well went down five meters into the aquifer, and this depth decreased as the wells got shallower toward the qanat exit point.

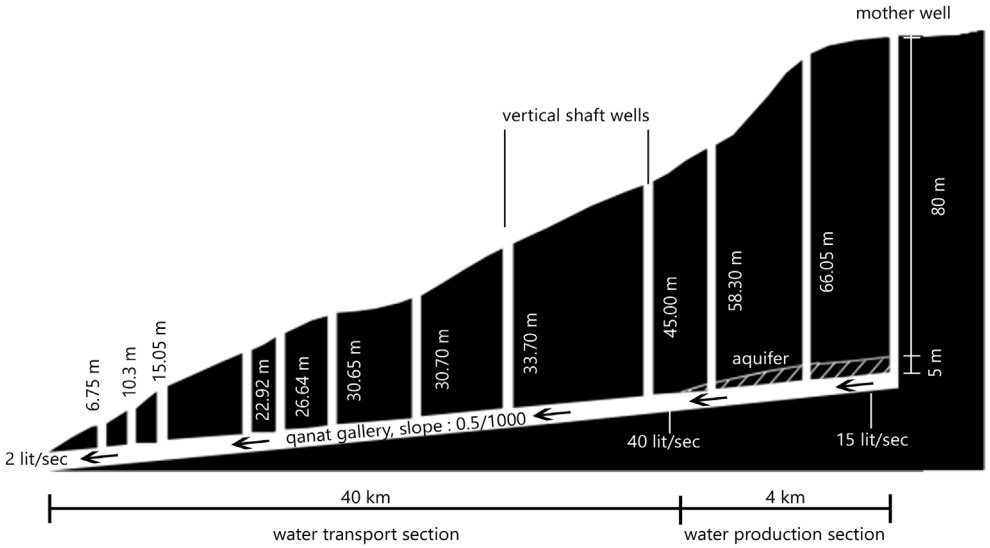

Figure 64: *Schematic longitudinal section of Qanat of Zarch, In this drawing the entire wells are not shown, and the vertical scale is 250 times higher than the horizontal scale (Semsar Yazdi, 2014) and [redrawn by the author]*

At point four kilometres down slope from the mother well, the water table and the current in the gallery both stand at the same level which is considered the border between water transportation section and water production section of the qanat.

After this point, water table gradually went beneath the qanat gallery.

In winter 2003 near the mother well, the qanat enjoyed a discharge of 15 litres per second which increased up to up 40 after being accumulated along 4 km of tunnel down to the border between water transportation section and water production section. This discharge dropped to 12 litres per second due to percolation along water transportation section to the exit point" (Semsar Yazdi, 2014).

As demonstrated in Figure 64 the qanat of Zarch presents an average gradient of 0.5/1000 meters. Its gallery has been extended 250 meters penetrating aquifer between 1983 and 2003. In this period, the shaft wells have been dug around 170 meters away from each other, while in the old part this distance is 80 meters and in the water transport section wells are only 50 meters away from each other.

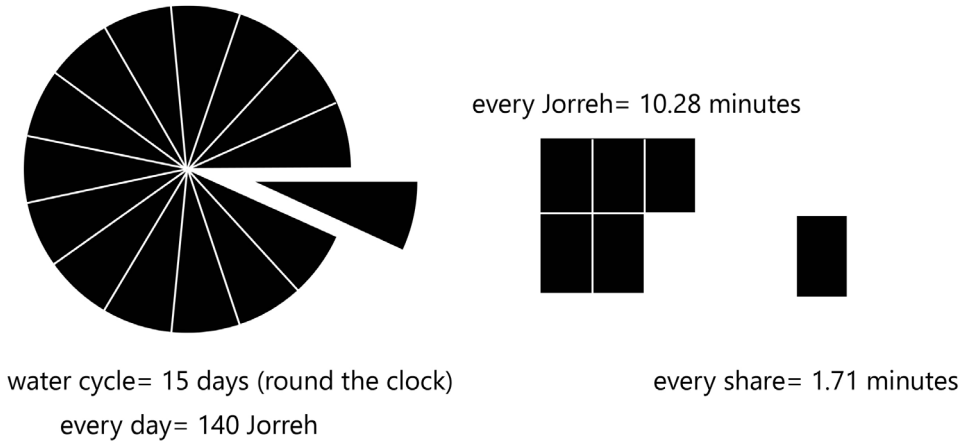

Figure 65: *Qanat of Zarch ownership system (Semsar Yazdi, 2014) [redrawn by the author]*

Overall, the qanat wells are around 75-80 centimetres in diameter. The gallery is often 1.8 meters high and about 60 centimetres wide. In this qanat some rectangular wells with the dimension of 80 by 120 centimetres also could be found that date back to before Islam.

"The qanat cuts through a combination of red clay, pebble and sand. The clay is compact and hard along the qanat gallery. Some parts of qanat are crumbling and are not in good shape where it runs beneath the area of "Seyyed Gol-Sorkh", around "Kavir tile factory" and "Salman" street.

In "Seyyed Gol-Sorkh" and "Nosrat-abad" there are still vestiges of stone lining in the qanat tunnel, which shows the workers' struggle to curb the tunnel collapse in the past. At present concrete hoops are used to shore up the crumbling parts of the qanat to prevent collapse in the gallery and shaft wells. The Qanat of Zarch does not cut through gas emitting formations, so the workers did not need to dig twin wells (Jofte Badoo[1])" (Semsar

1 Jofte Badoo is a twin well consisting of two wells dug some 1.5 or 2 meters away from each other to better ventilate the wells and gallery specially where soil emits harmful gas. Some of the geological formation gives off poisonous gases that are obviously harmful to the workers, so the workers dig two wells simultaneously and connect

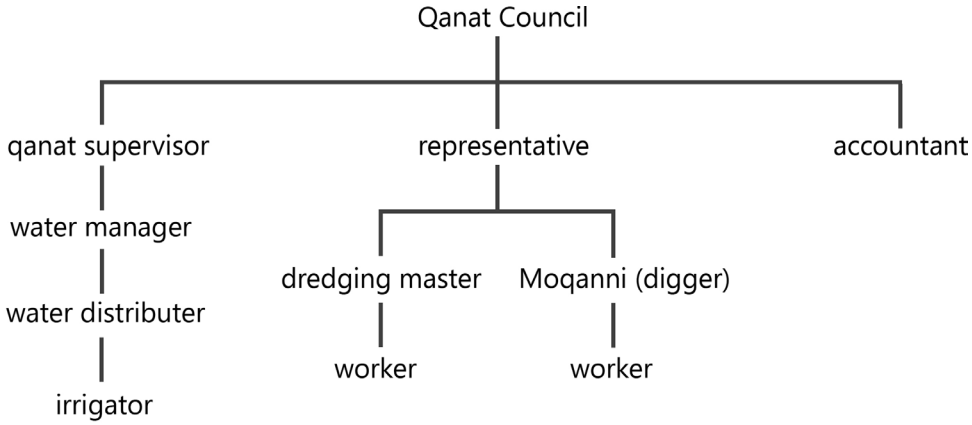

Figure 66: *Management system of Qanat of Zarch (Semsar Yazdi, 2014), [redrawn by the author]*

Figure 67: *Aerial view of qanat, photo from Deterritorialization website in January 2020*

Yazdi, 2014).

The qanat has a peculiar and accurate ownership system in which 12600 shares or 2100 "Jorreh"[1] of water are divided into a 15 days cycle (Figure 65).

This division system accuracy was depended on traditional water clocks. A water clock is the combination of two bowls made of copper in which one was small enough to float freely on the surface of water inside the larger one. The floating bowl had a tiny hole at its bottom allowing water to enter the bowl and gradually fill it up.

Qanat of Zarch is shared with various owners that often have a small share, thus the qanat council is the most important decision-making body running the qanat.

The qanat council has a representative who oversees many issues related to qanat and is in fact the executive tool of the council. In addition to the council members and representative, there are other members like "Moshref" (qanat supervisor), "Mirab" (water manager) and "Sabookesh" (water distributor) who also play important roles in qanat management.

Recently, an accountant has been also assigned and added to the council. The accountant is summoned by

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them every 10 meters by a short horizontal tunnel to ease air circulation as they go down. In this case fresh air comes down from a well and goes up through the other.

1 Each "Jorreh" is equal to 6 shares and accounts for 10.3 minutes.

Figure 68: *Aerial view of Qanat of Zarch vertical shaft, photo by Rashedi*

the qanat council to take care of the financial affairs, while the financial inspector is appointed by the qanat owners and beneficiaries to oversee the accountant and qanat budget (Figure 66).

All the mentioned aspects bring to the fore the complexity of a system that constitutes a superimposed resiliency. Zarch qanat demonstrates how geographical characteristics interwoven with social responsibilities. The resiliency of Zarch qanat or any other qanat is embedded into a comprehensive understanding of natural and social order.

Qanat is a social-ecological system that can be considered as an infrastructure or artefact in an overlapping zone between culture and nature, with interconnection in both directions.

Hessler and Kohler state that for a system to be resilient it must be dynamic and risk, uncertainty and surprises becomes norm (Hessler, &Kohler, 2014).

This in built environment could be achieved where the complexity is based on multi-dimensional order. This multi-disciplinary complexity is rooted in qanat system form its construction phase to the operation and maintenance.

Figure 69: *Aerial view of qanats, photo by Rashedi*

Figure 70: *Aerial view of qanats, photo by Ypsilantis*

Figure 71: *Qanat of Zarch vertical shafts, photos by Rashedi*

Figure 72: *Qanat of Zarch gallery, photo by Hosseni*

Figure 73: *Qanat of Zarch gallery, photo by Hosseni*

2.2 Urban Framework

Figure 74: *Left: Skyline of Yazd, photo by Saman Tahvildaran*

Figure 75: *Aerial view of Yazd in 2018 from ICHHTO*

The urban pattern of Yazd is dense and compact. The uniqueness of its urban pattern is represented by an ordered space created by volumetric uniformity between built-up blocks which corresponds to single building units.

Mehdi Kowsar, an architect who collaborated with on the study of the master plan of Yazd prepared in 1974 by Kamran Diba, states that buildings either be houses, mosques, caravanserais or etc., all follow the same footprint even if they have different functions.

At the base of this plan is the notion of balance between mass and void, in which the void is enclosed by the mass. These inward-looking units multiply and create nodes, neighbourhoods so that the entire city can be described as a harmony between mass and void.

This architecture lies over a system of regular and irregular streets with a large number of dead ends. These well-shaded urban paths are connecting the

Figure 76: *Aerial view of Yazd, photo by Rashedi*

bazaar, public bath, water reservoirs, mosques and other buildings. Once, Yazd was surrounded by walls and gates (14th century), as the walls were demolished in the 20th century, only a small section of these walls exists, and some portion of them can be still identified.

All the above mentioned urban features have brought the urban pattern of Yazd to the attention of many scholars who researched cities of the Middle East (Said, 1979, Bonine, 1979, Kamali, 1998, Rizvi,& Isendstadt, 2008). However, most of them tried to explain Yazd through the concept of "Islamic City" and religious interpretation of built environment.

Art historian Oleg Grabar, tries to define the concept of "Islamic City". He argues that *"the origins of the adjective lie clearly in the faith of Islam"* and he adds *"when applied to art, it refers to the monuments and remains of material culture made by or for people who lived under rulers who professed the faith of Islam or in social and cultural entities, which whether themselves Muslim or not, have been strongly influenced by the modes of life and through characteristics of Islam"* (Fumagalli, 2017).

Von Grunebaum describes Islamic city as *"a town was a settlement in which [a Muslim's] religious duties and his social ideals could be completely fulfilled"*

Figure 77: *Aerial view of Yazd, from UNESCO dossier of Yazd in 2016*

(Grunebaum, 1955).

In the viewpoint of Orientalists, the interpretation of Islam has been one of an all-encompassing value system embracing both the social and physical morphology of settlements in the so-called "Muslim world" including Iranian cities. In other words the city encapsulated as a by-product of Islamic faith, which could be read only by understanding Islam (Olearuis, 1647, Kaempfer, 1727, Texier, 1852). They state that everyday practice of religion is considered as an urban activity formulating the social and spatial configuration of the city.

If we consider Iranian cities, as a sub-category of "traditional middle eastern Islamic cities", then we can argue that urban environment is structured by the four elements: the mosque, the royal palace, the bazaar and other institutions or a combination of these (Von Grunebaum, 1955, Planhol, 1959, Dettman, 1969, Anschilt, 1967, Ehlers,& Floor, 1979) . According to these authors, the relation between these elements has framed the structure of the traditional city and their variation defines different types of the settlements.

This also has become the basis and reference for further research about the more recent and contemporary transformation of the Iranian context (Tabrizian, 2018). Ehlers and Floor, for example, in their study about

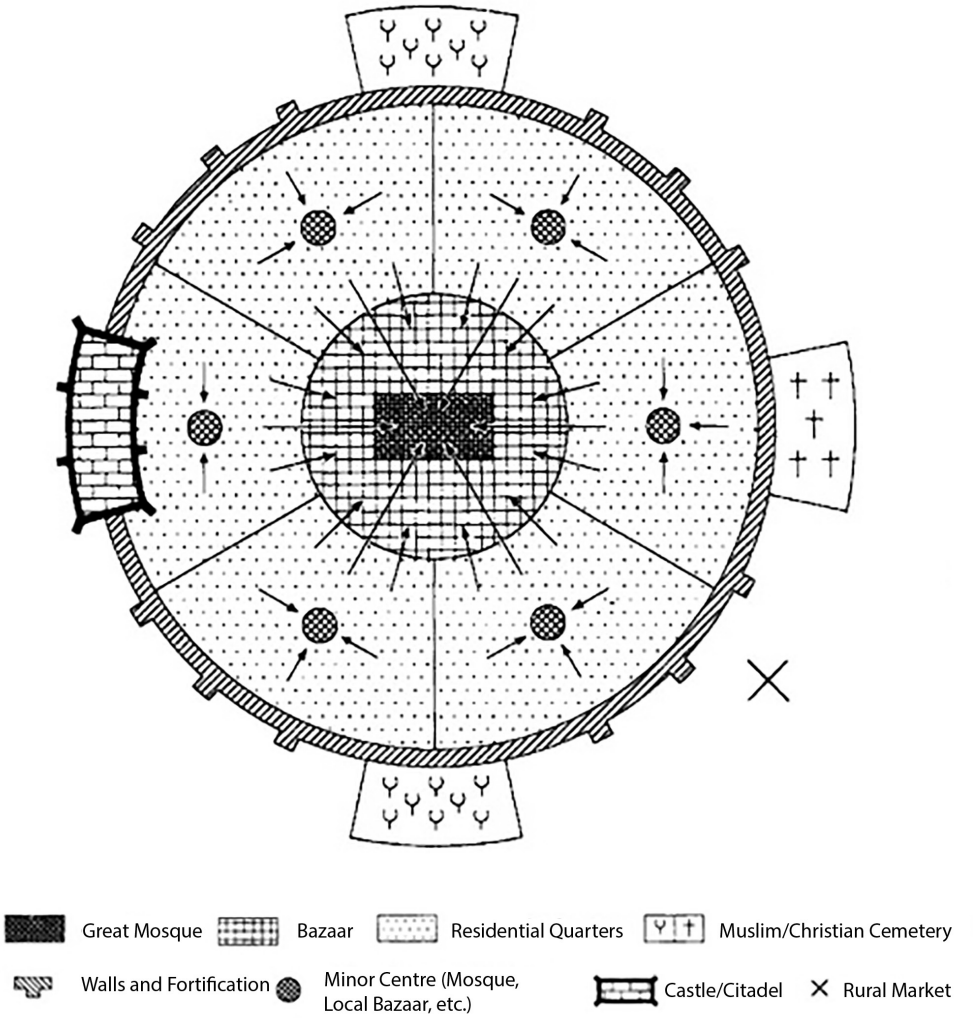


Figure 78: *Typical model of Islamic city associated to the Iranian cities (Ehlers,& Floor, 1993)*

urban change in Iran, centred their theory about pre 1920 Iranian cities in the following way:

"Characteristics [of a typical Iranian city] included the central position of the Friday mosque, The Bazaar, Public baths and other institutions, located mostly very center of the city. Surrounding these public structures were the residential areas, concentrically ethnic separation. Arranged, divided into quarters and often distinguished by ethnic separation. The winding narrow alleys often linked up with the bazaar on one hand and ended in cul-de-sac on the other" (Ehlers & Floor,1979).

The "winding alleys" feature depicted by Ehler and Floor relates to one of the most evident characteristic linked to Islamic cities (Von Grunebaum, 1955, Planhol, 1959, Scharlau, 1960). The typical Islamic (and Iranian city) is often defined as a maze of twisting and narrow pathways, a disordered array of dark streets and blind alleys or as a labyrinth of twisting alleys and cul-de-sac (Ehlers and Floor, 1979) .This has been associated with most Middle Eastern contexts and cities with a different pattern are identified as exceptions.

Although this assumption partially applies to some contexts in Iran for example the cities of Kirman,Semnan and Hamedan, it undoubtedly cannot be considered the principal driving force behind the development of Iranian environments (Tabrizian, 2018). American Geographer, Michael Bonine, in his influential article "The Morphogenesis of Iranian Cities", argues that in Iran and particularly in the central plateau this commonly accepted description of the Middle Eastern urban environment has been misinterpreted.

Michael Bonine states that Iranian cities cannot be equated to the notion of Islamic city. *"Traditional Iranian cities have an orthogonal network of streets which does not conform to the maze of irregular, twisting lanes postulated for the ideal Islamic city"* and further on he adds *"in Yazd, what at first appears to be confusion in the street plan upon closer inspection shows a clearly defined pattern. A number of rather straight streets, some of them more than a kilometre in length, intersect at right angles. There are many blind alleys, but they usually are short and they branch off the longer linear streets at right angles. The long, straight streets are almost always wider than the shorter ones. Th entire system is basically an orthogonal pattern oriented in a northwest-southeast and northeast-southwest direction crossing at right angles. The wide avenues built through the city in the 20th century follow the same orientation as the older linear streets"* (Bonine, 1979).

In fact a number of Iranian cities feature a geometric and orthogonal pattern rather than an irregular and organic pattern often such layout is integrated with the

irrigation network and related agricultural activities. This pattern could be recognized in Iranian cities such as Sabzevar, Shiraz, Kerman, and Ardekan.

Another aspect deriving from the interpretation of Iranian cities as a sub-category of the Islamic cities concerns settlement orientation. Donald Wilber postulated that two factors influenced the orientation of Iranian cities in medieval times, namely a major artery running between the palace and the Friday mosque, and the necessity of orienting the mosque so that the "qibla" wall would be in the direction of Mecca. *"Iranian mosques are rectangular with open courtyards and the qibla wall must be to the south-west, in the direction of Mecca Streets often parallel the mosque and the grid system might have developed from an extension of streets around a mosque-oriented perpendicular to and toward the southwest. Even in cities founded in pre-Islamic times, when Mosques were later established, the same principle might apply to nearby, newly established quarters"* (Wilber, 1974). Bonine's studies about the orientation of Yazd reveal that traditional linear streets of the city have inadequate correspondence with the direction to Mecca (Bonine, 1979).

Noghsan Mohammadi, a professor from the Yazd Faculty of Architecture argues in favour of Bonine's theory and states that in Yazd, there are three main moments in development of the city. The last moment is concerning the modern development and would require its own investigation, but the other two regard to the walled city that refer to early Islamic era to 14th century.

As demonstrated in Figure 79 there is a clear distinction between the direction of streets inside section A and B: while the main pathways in section A are ordered and follow the same direction, they tend to be more irregular in section B. Discussed in the first chapter, those sections were constructed in different eras and consequently the urban pattern could differ. Section A was built in Kakuyid era (10th to 12th centuries) and section B was constructed in Atabeg era (12th century). Nevertheless, the unity, integration and continuity in Yazd built environment is such that this claim could

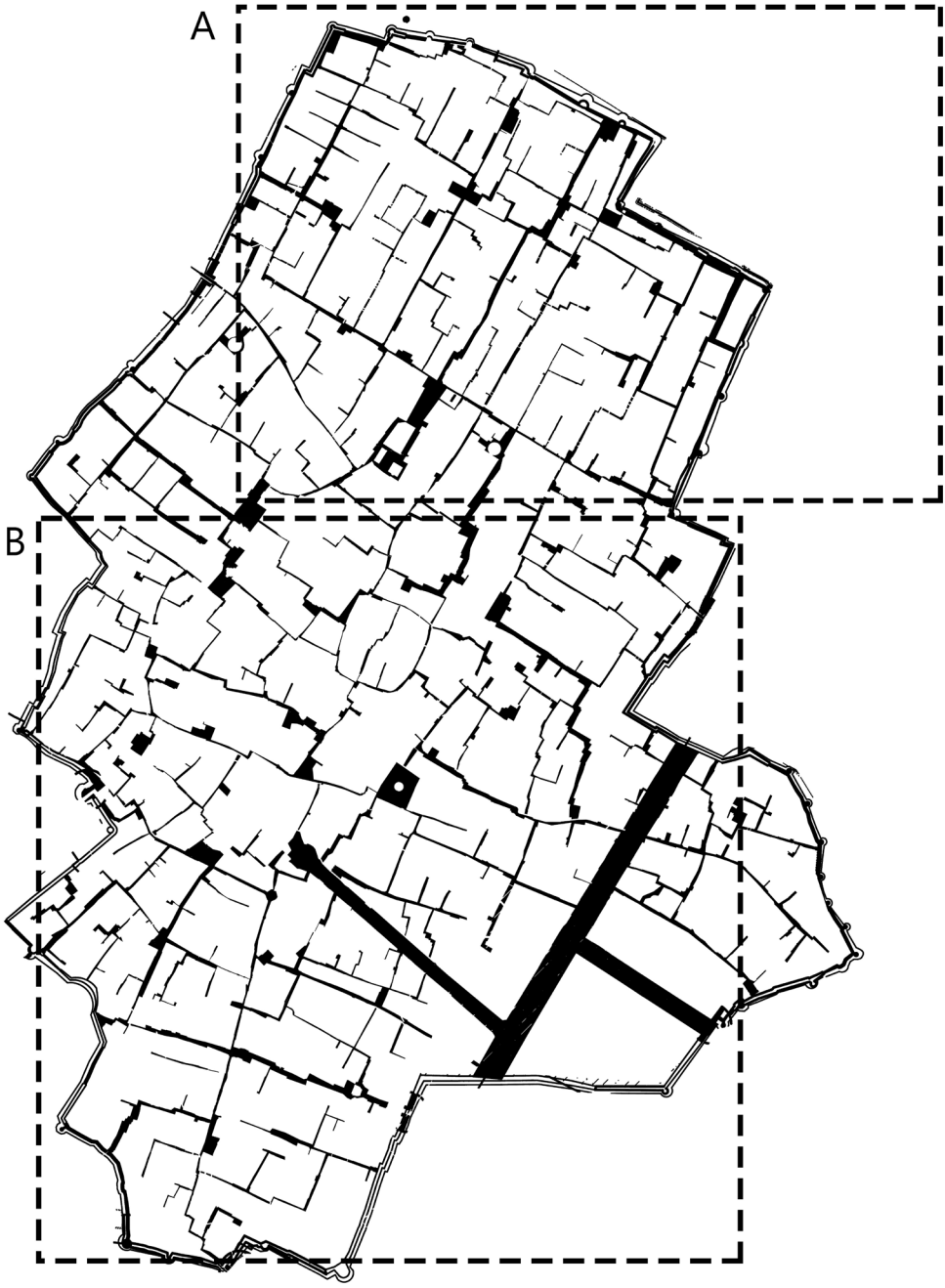


Figure 79: *The streets lay-out with the open spaces within them inside walled city of Yazd [drawn by the author]*

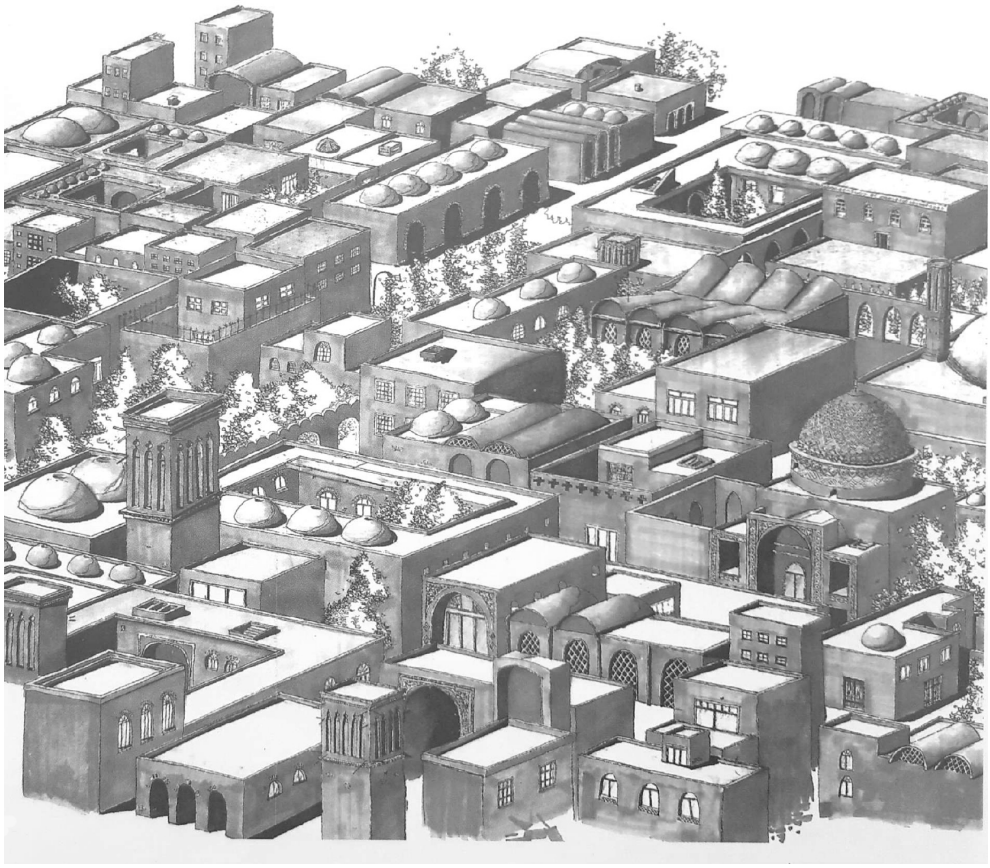
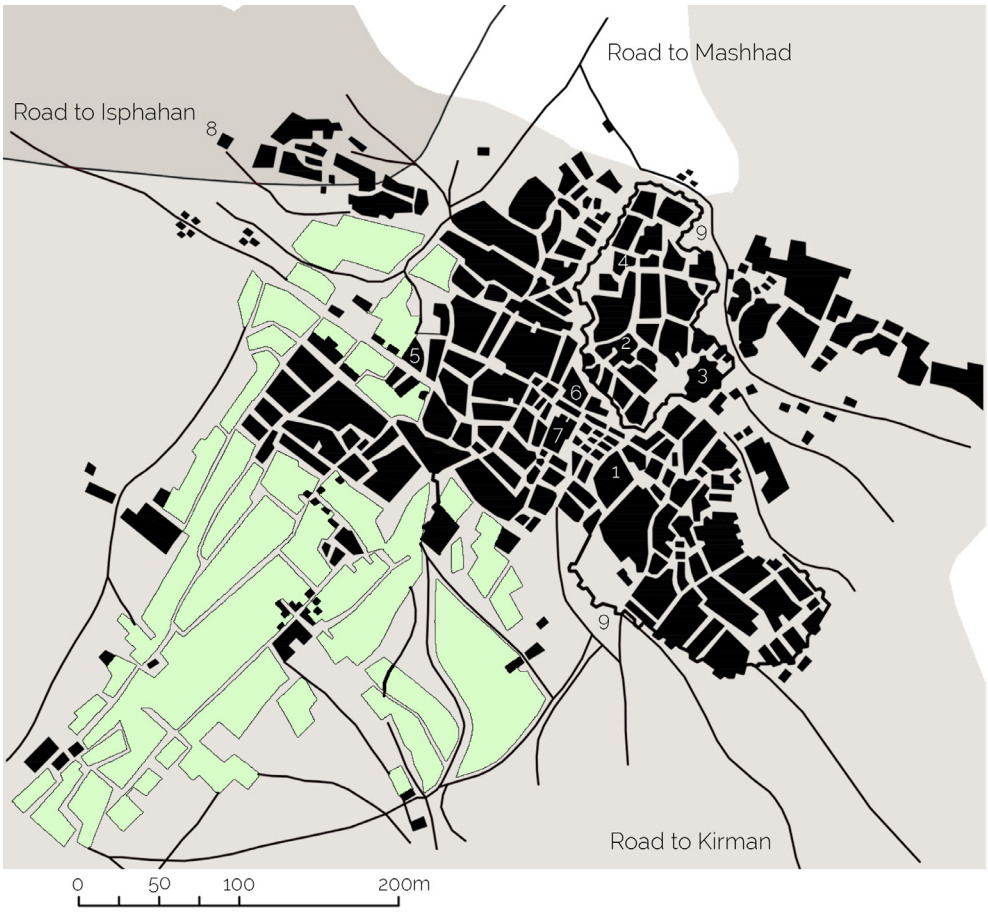


Figure 80: *Aerial sketch of Yazd, from Sedigh, & Roasaei,& Alaei, (2012)*

not account as the only reason for this distinction. When we take into consideration the presence of qanat infrastructure, this apparent discontinuity could be explained in a unified version.

Noghsan Mohammadi argues that a detailed examination is fundamental to achieve a better understanding of Yazd texture and its relation with qanat system (Noghsan Mohammadi, 2018). Thus, it is essential to understand firstly the relation of qanat and irrigation system with the urban pattern and secondly demonstrate this interrelationship with the urban pattern of Yazd.

Tabrizian claims that the irrigation system is significantly organizing the mobility and infrastructure networks the cities pattern. The extensive underground qanat infrastructure has evidently structured the street and



alley network with respect to the topography. Many of the aquifers flow to cultivated lands and orchards around the city or to villages at a greater distance and located downhill.

The direction of these qanats within the basin usually follows the same orientation as the main urban arteries of the city, both intimately related with topography and tied to the logics of landscape or in other words natural order. The street network is comprised of linear passages oriented toward or perpendicular to the main slope and perfectly aligned with the water channels (Tabrizian, 2018).

As a result, in case of Yazd the correlation between qanat system and urban pattern is fundamental to understand the street layout, urban artefacts and qanat

Figure 81: *Yazd in 1861, Map drawn by Nikolai Vladimirovich Khanykov, [redrawn by the author],*
1.Amir Chakhmaq Mosque
2.Jame Mosque and Mola Aqa Baba Synagogue
3.Citadel
4.Alexander's Prison
5.Gowdale Mosalla Caravanserai
6.Bazaar
7.Sadat Caravanserai
8.Dolat Abad Garden

Mapping the Backbone of Yazd

pathways and check whether there is a connection or not.

Unfortunately, there is no archaeological survey for all the qanats running through the city. However, the Qanat of Zarch - still active and operating- and the Qanat of Vaqf Abad have been fully documented by Semsar Yazdi and we are able to track their pathway (Semsar Yazdi, 2014,& 2017).

Mapping Qanat of Zarch and Qanat of Vaqf Abad course throughout the city and cross-checking them with on-site survey, interviews and historical records, became the initial phase of superposing and cross-scaling materials which resulted in an interpretive map. The next in this process accounts for mapping the main streets layout. Despite the fact that the major pathways often are wider in length, there is no assurance to this claim in historic cites such as Yazd.

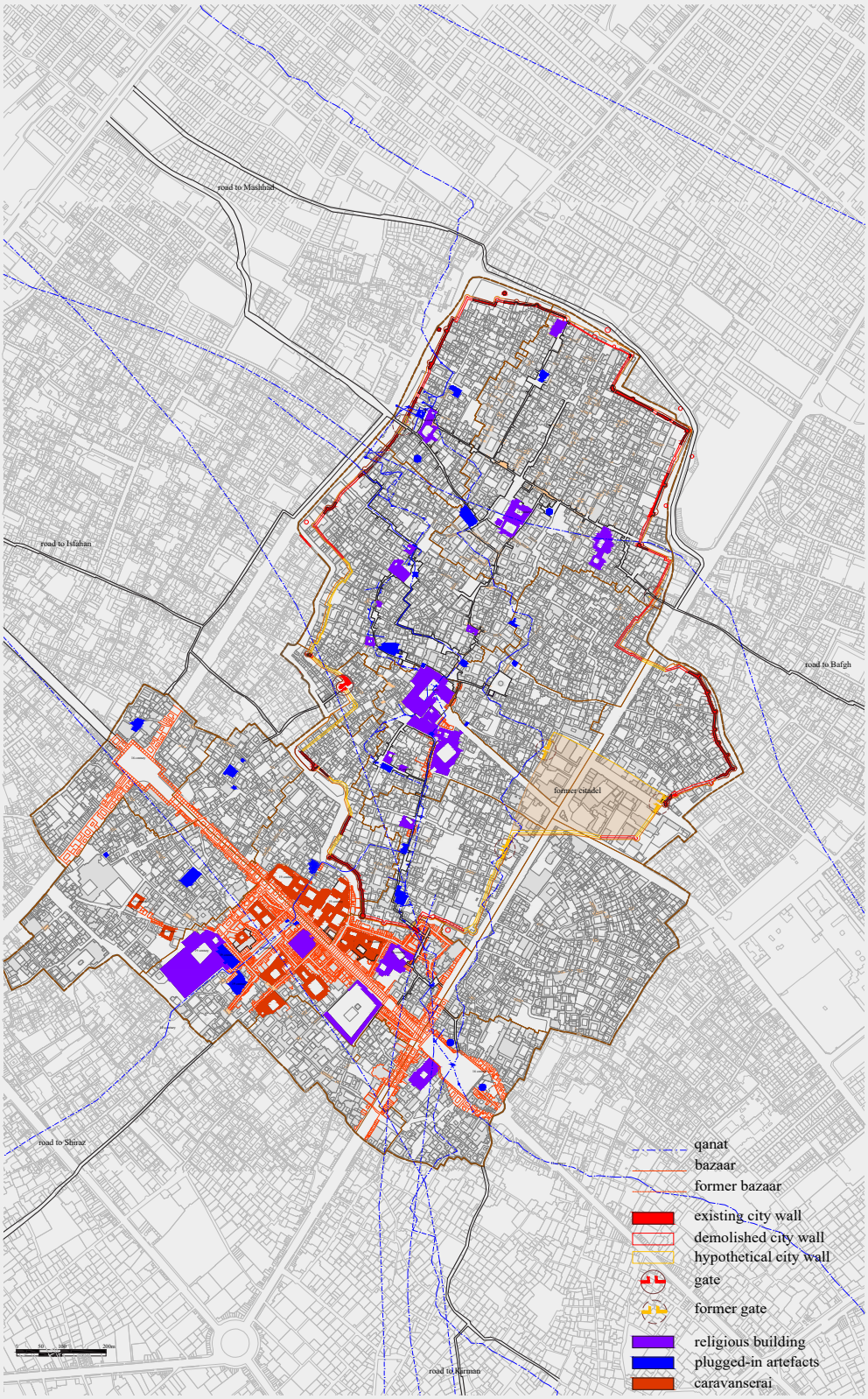
Thus, to be certain as much as possible, the streets that were linked to city gates, long distance trade routes, public buildings, bazaar and main open spaces were selected. In addition, the oldest map of Yazd which was drawn by Nikolai Vladimirovich Khanykov in 1861 was used to determine the trade routes, urban lay-out and cultivated lands.

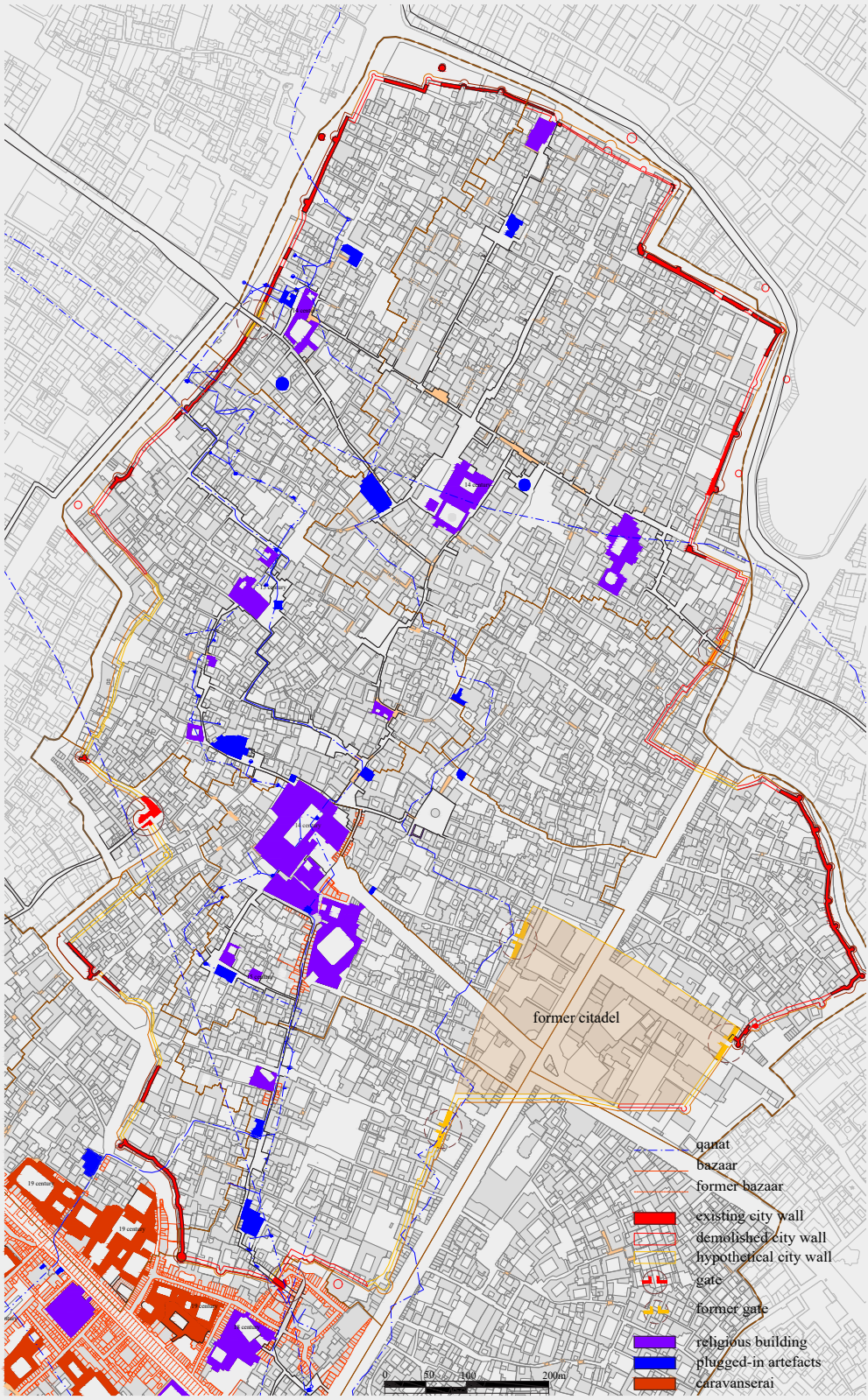
Aerial photographs collected from Municipality of Yazd and Iran National Cartographic Centre were also a fundamental tool in understanding the major changes of the city, in particular the wide avenues built through the city in the 20th century. Since they were taken constantly since 1950s.

City walls were mapped by on-site survey and documents gathered from Cultural Heritage, Handicrafts and Tourism Organization of Yazd, however, most of them were demolished mainly in the early 20th century. Among demolished city walls, some could be traced based on the existing urban pattern and the rest were assumed on the basis of interviews and map provided by Nikolai Vladimirovich Khanykov in 1861.

Religious buildings together with commercial districts were considered in the interpretive map as the main

Figure 82: *Interpretive map of Yazd, correlating qanat infrastructure, bazaar, religious buildings, plugged-in urban artefacts and long distance roads with urban pattern, [drawn by the author].*


road to Mashhad
road to Isfahan
road to Bafgh
former citadel
road to Shiraz
road to Jiarman
qanat
bazaar
former bazaar
existing city wall
demolished city wall
hypothetical city wall
gate
former gate
religious building
plugged-in artefacts
caravanserai


former citadel
qanat
bazaar
former bazaar
existing city wall
demolished city wall
hypothetical city wall
gate
former gate
religious building
plugged-in artefacts
caravanserai
0
50
100
200m

public nodes and created an important layer in mapping the backbone of Yazd. Bazaars were studied with respect to understandings of first chapter and their connection with long-distance trade routes. The position of the gates played an important role in acknowledging the main trade routes and their interaction with bazaars inside the city wall.

The main bazaar, developed mainly in Safavid era (16th century), used to connect Shah Tahmasb square with Amir Chakhmaq square. It was placed outside city walls and accompanied several caravanserais. However, with the developments in the early 20th century, a large section, including Shah Tahmasb square, replaced by an avenue. Thus, to map its origin condition, schematic map provided by Mahmud Tavassoli, was taken into consideration. To confirm and cross-check Tavassoli's interpretation, aerial photos the map showing the existing urban pattern were used.

Mapping buildings that were linked directly or indirectly to qanat system became the next step in the superposition of layers. Semsar Yazdi in mapping both Zarch and Vaqf Abad qanats uses qanat related buildings as a reference to determine the course of qanat. He makes an assumption about qanat course, by overlapping materials such as local history and vicinity and the juxtaposition of qanat related buildings (Semasar Yazdi, 2014,& 2018).

His work sheds light to numerous questions about the development of Yazd. His approach was followed in this research and site survey together with historic texts and travellers reports became great tools to illustrate the relation of qanat system to city structure. This process is essential to conceptualize whether that qanat infrastructure has been prior to urban artefacts or not.

When we correlate the course of Zarch and Vaqf Abad qanats with the urban pattern, we understand that the main passageways of the qanat are mainly under dwelling units or sometimes under the main streets or close and parallel to them. This is clearly demonstrated in southern part of city and in the area close to Jame

Figure 83: *Interpretive map of Yazd, correlating qanat infrastructure, religious buildings and plugged-in urban artefacts with urban pattern, [drawn by the author].*

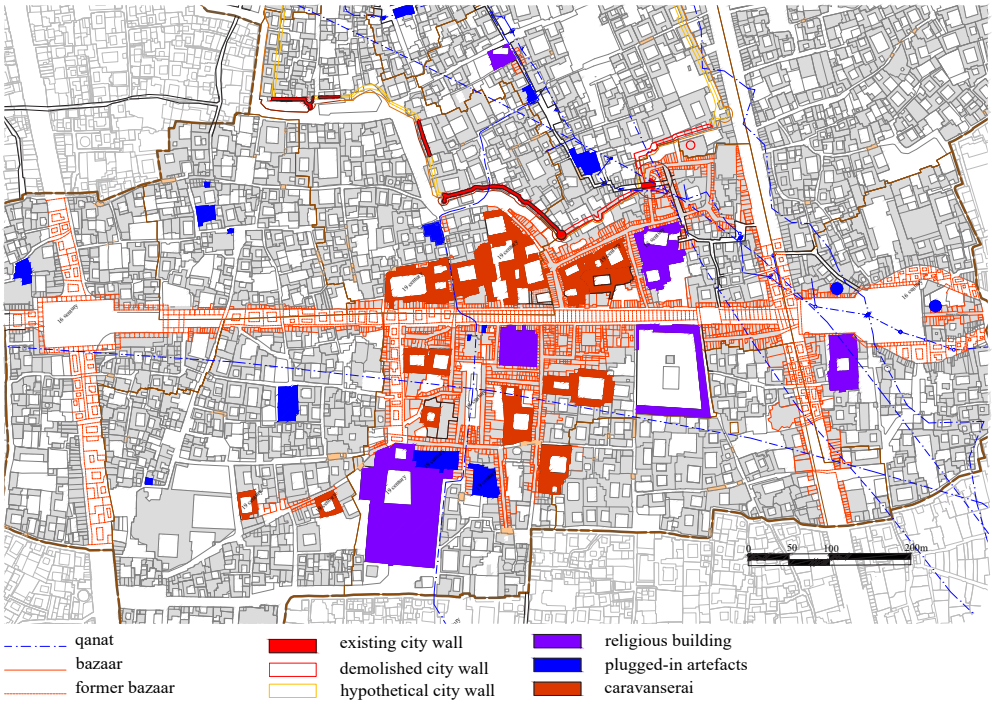


Figure 84: *Bazaar of Yazd, [drawn by author]*

Mosque, where streets seems to be more irregular.

Iraj Afashr in his book Tarikh-i- Yazd[1] states that the area around Jame mosque was built mainly around 14th-15th centuries. He mentions also that Qanat of Zarch existed at that time. Hence, this statement alongside with the fact that main public buildings were placed adjacent to the qanat and streets layout follow the course of qanat, could be seen as an evidence of the relationship between qanat infrastructure and public buildings .

However, on the northern part of the city, the pattern is different and a series of linear streets which some of are remarkably long without any twist. Bonine, Noghsan Mohammadi and Ayda Alehashemi claim that the reason for this type of pattern lies in the irrigation system (Bonine, 1979, Noghsan Mohammadi, 2018, Alehashemi, 2018).

1 One of the first reliable local historical texts about the Yazd region is Tarikh -i Yazd, (History of Yazd), written in the 15th century. The information of the book is mainly concerned with Islamic era, from eleventh century (Atabekan period) till the author's time, 15th centu-

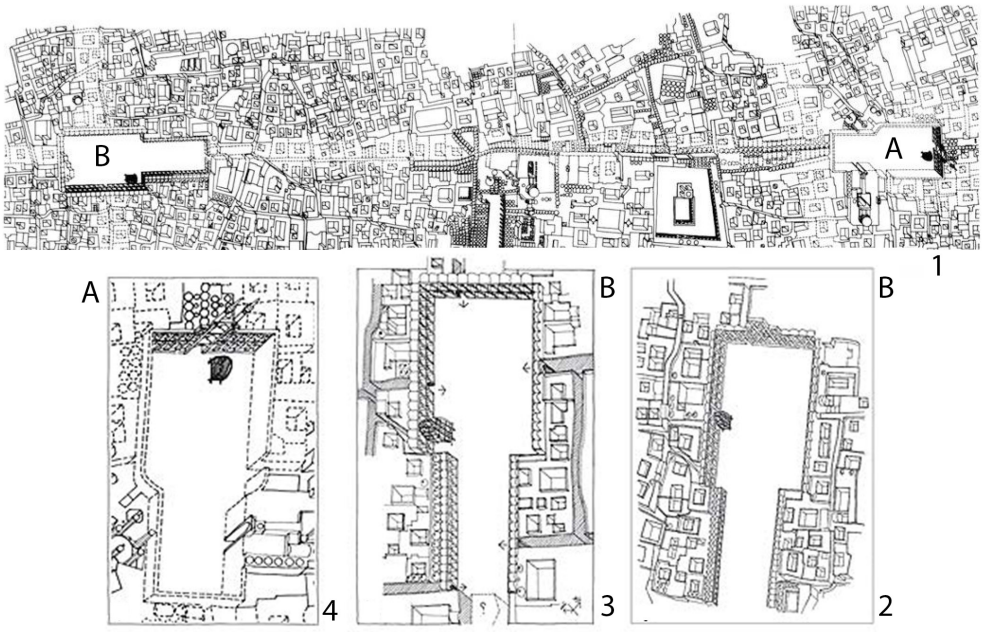
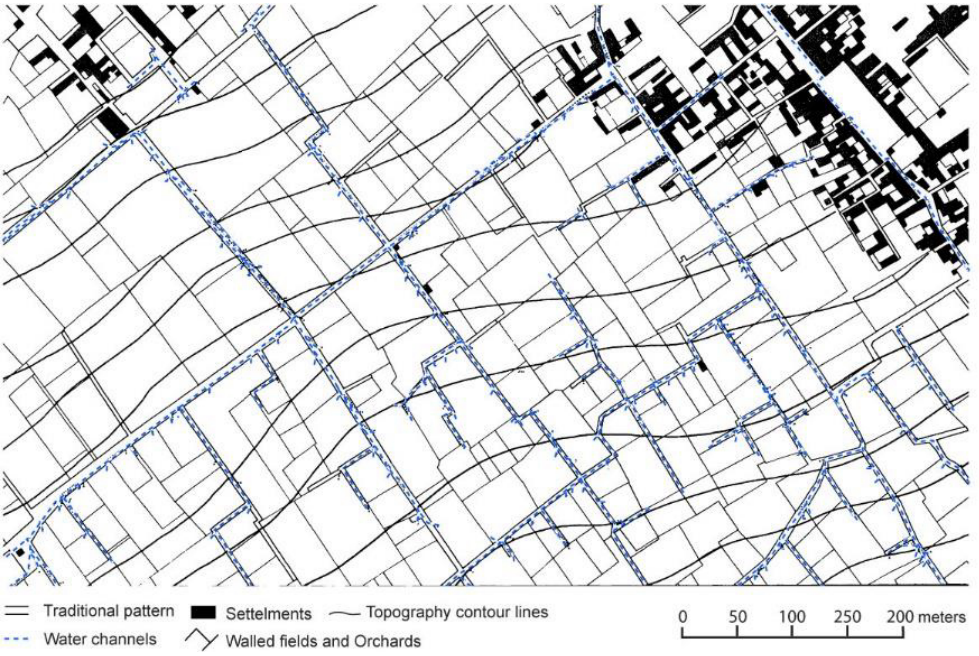


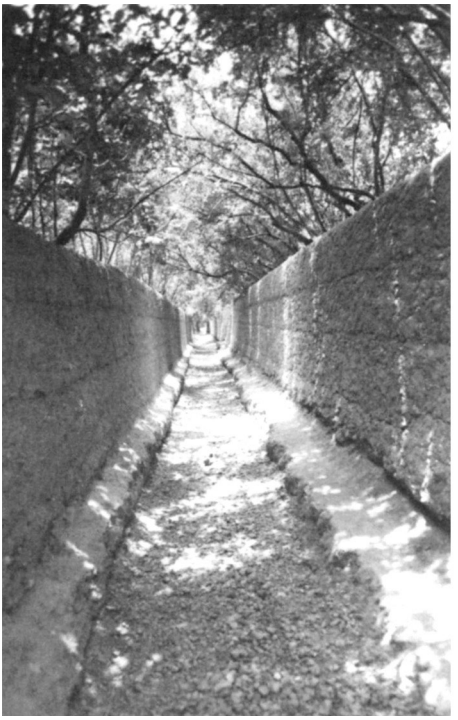
Figure 85: *1: Schematic plan of Yazd's bazaar before its demolition in 1928. 2: Schematic situation of Shah square drawn by Vahid Vahdat Zade. 3: Schematic situation of Shah square drawn by Mahmud Tavassoli. 4: Schematic-situation of Amir Chakmaq square drawn by Mahmud Tavassoli.(Tavassoli, 2018)*

They consider that this area used to be cultivated lands outside the city and became part of the city. Hence, a grid network of irrigation channels and streets existed to reach a quadrangular field system or else such plots were designed to conform to an orthogonal irrigation distribution. It appears, then, that the rectangular, irrigated walled fields organized street patterns. In spite of not being able to identify the exact rationale for the field system, the important fact is that channels and fields are orthogonal and they are oriented in the direction of greatest slope.

Yet, as Noghsan stated, further investigation and

ry. The book also covers a summary of information about pre-Islamic and early Islamic period. Historical studies in the present book are specially based on a comparative study between contents of Tarikh-i Yazd and remains of structural elements in the years 1971-1972. At this time, many spaces and places mentioned in Tarikh-i Yazd were still survived with their old names. See Ja'far b. Muhammad b. Hasan Ja'fari, Tarikh-i Yazd, (composed in 845/1441) edited by Iraj Afshar Tehran (1965). Also for historical pattern of Yazd region, see Abu Eshaq Ebrahim Estakhri, Masalek va Mamalek, edited by Iraj Afshar, Tehran (1969).


Traditional pattern
Settelments
Topography contour lines
Water channels
Walled fields and Orchards
0 50 100 250 200 meters



archaeological survey is needed to clarify this assumption. We could find some evidence by looking into smaller towns in the region of Yazd that have less changed than Yazd, could justify this relationship, since the criteria for development is similar (Tabrizian, 2010).

Mehriz, for example a small city near Yazd along Qanat of Zarch reveals a significant relationship between infrastructure, water channels, and walled fields oriented in the same direction. The streets have irrigation channels while smaller passageways provide entry to the walled plots. Wider streets are associated with the main channels and smaller lanes follow the secondary branches (Figure 86).

The hierarchy of infrastructure in terms of length and width is carefully organized with respect to the water distribution policies. The main irrigation ditches and branch channels are associated with streets or alleyways because the ditch needed to be accessible to the person in charge of diverting water to channels and fields. Particularly among walled fields and orchards the straight public water channels and passages are advantageous for keeping a watch on the channels and preventing any theft of water.

If we apply the same principles to Yazd, we notice that the qanat system constitutes the backbone of structure of the city. . In other words, the city initially has been formed by linear elements and quarters filled the spaces in-between them and finally they were all surrounded by city walls.

Thus, Contrary to the view formulated by Orientalists for the ideal Islamic city, Yazd is not a labyrinth of twisted alleys. *"There is no need to explain street patterns in terms of the tenets of Islam or the preferences of civil authority. Even though more blind alleys develop as houses fill in fields between major streets, this is not symptomatic of decadence. Rather it denotes a reasonable solution to the practical problem of providing access to a compact assemblage of houses"* (Bonine, 1979).

Mahmud Tavassoli presents four main elements in

Figure 86: *Left Top: Settlements and agricultural fields in relation to water channels and topography in Mehriz (Bonine, 1979).*

Figure 87: *Left Down: The configuration of Infrastructure in relation to and water channels in Mehriz (Tabrizan, 2018).*

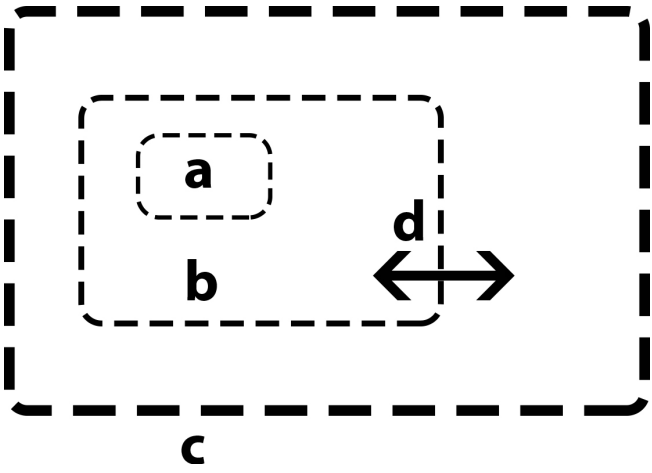


Figure 88: *Structure of Iranian cities from (Tavassoli, 2016), [redrawn by the author]*

Iranian cities' structure (Figure 79). a: Citadel, Arg/Kohandez, b: Inner area Sharestan, c: Outer area Rabaz, d: Bazaar

The bazaar was the main centre of economy and finance, including main organizational and financial systems of wholesale trade and retail business. The bazaar exhibited the concentric hierarchy of crafts and trades with its functional elements such as qaysariyah[1] , caravanserai, and timchah[2]. Each guild operated in a separate spatial area belonging to different branches of businesses such as rosary sellers, stationeries, shoemakers, jewellers, grocers, and textile sellers.

Although commercial districts or bazaars were always associated with the city, the main bazaar complex which exists today had its origins in the 14th century. On the south side of the wall built by Muzaffar a new commercial zone began to develop near the Mehrijerd (Mehriz) gate. It evolved outside the 14th century city wall, a pattern somewhat different than the inner-city commercial areas of Central Asian cities (Giese 1980)

1 A section of bazaar which is either domed or have a cross plan and is devoted to expensive goods

2 Timchah is a small caravanserai

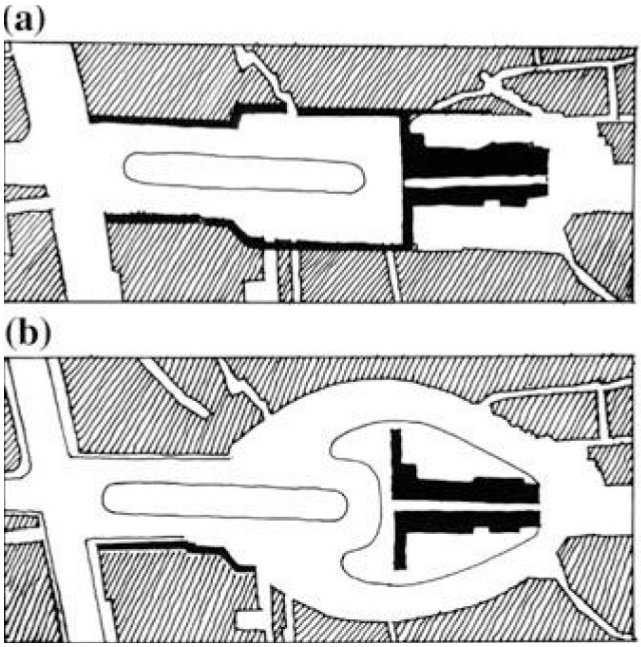


Figure 89: *Different stages of the demolition of Amir Chakhmaq square between 1928 and 1970s, a: The original shape b : Constructing car access from (Tavassoli, 2018)*

or some Iranian cities such as Tabriz (Schweizer 1972).

Qanats and Bazaar formed also the socio-spatial structure of Yazd. Textile and weaving textiles -the main export product of Yazd- were significant players in the socio-economic fabric of the Yazd. Social classes in the weaving crafts consist of rich merchants and landlords, middle-class weavers, and lower-class weavers, who, in some cases, worked in neighbourhoods outside of the walled city (villages) as small farmers.

The relation between ethnics, occupation and juxtaposition of qanats with neighbourhoods demonstrates clearly how deeply the entire city depend on the water system and bazaar. Many areas of the city despite being built on different periods were enjoying one or more qanats and the presence of qanat related urban artefacts such as water reservoir shows this dependency.

It must also be mentioned that the majority of inhabitants' occupation was also linked to these two key element (bazaar and qanat). People often worked with fabric in various ways that used to be the main export product of Yazd.

Overall these neighbourhoods create a homogeneous

pattern whose prevailing character is the relationship between mass and void. The domination of mass over void at the city level is noticeable. On a city scale, void embraces open public areas, streets and alleys, central courtyards of the houses, etc., and on a residential scale, void includes all the openings such as windows, doors, etc. onto the mass of the walls (Hamouche, 2008).

The major courtyard buildings are one or two stories; therefore, the historic centre comprises low-rise buildings forming simple vertical compositions (without vertical spatial complexity); while we see rich horizontal compositions among the different volumes. The "main" spaces are located around the regular geometrical courtyards; and the "secondary" and "services" spaces, have been oriented at the second layer or the corners of courtyard: courtyard is identified as a basis for spatial configuration. Although most of the lots have irregular undetermined shapes; yet, due to existence of the regular courtyards as well as the continuity of urban tissue, the lots irregularity could not be easily distinguished. Such lots are connected through different directions; and a physical "border" is not distinguishable between them.

In hot-arid regions in the Persian Gulf area, especially in Yazd, the material used for traditional buildings is adobe and unbaked brick, with a layer of clay and straw. The outer layer on walls and roofs reflects most solar radiation and a small amount is absorbed and then released to both exterior and interior spaces. A brilliant white would be a better colour to reflect solar heat; however, this traditionally was achieved through the use of pure lime coating but such materials were not locally available as they require pure carbonate limestone. It is also important to recognize that white surfaces will become covered with the light yellow dust of the surrounding landscape, without rain to wash them clean.

Figure 90: *Bazaar of Yazd, photo from karavansera website in January 2020*

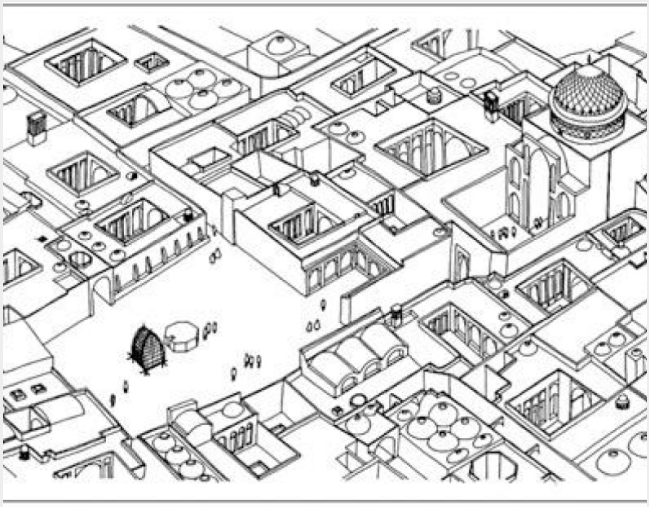
In this pattern the object is mitigated by the significance and character of the voided spaces, in which the singular urban configuration is created. Individual units being

public buildings or houses cannot be isolated since they are all one at the same time that is the patterned landscape. Amir Chakhmaq square which used to be an unexpected open resting area (void) carved out of mass, illuminates this fact by its unfortunate transformation.

In this compact city, high-density urban structures of mixed land use are thought to promote walking and cycling as the main modes of movement for short distance. While on an urban scale, the street appears as if carved out of a mass, in reality the wall defining it is a thick layer at the building scale. Concentrated urban texture diminishes penetration of dusty wind into houses and public buildings, as far as heat influence on the building surfaces. Covered passageways and narrow alleys with long walls make the shade and thermal comfort conditions in the hot summers. In addition, their direction is in a way to avoid hot summer sun rays and stormy winds.

Visually, the unity of the city fabric is reinforced by the use of clay and mud brick as a main building material, which is found locally, reduce the heat absorption and also reflect the sunlight. This city with the domes and vaults of mud and baked brick, has been formed by the different levels: street, court, balcony, roof .The roof turns into to be a surface, as active as any on the ground. The tenuous relationship of levels animates the fabric of the city just as the roof-scape animates the horizon with its domes, balustrades, wind towers, and steps.

Yazd unique imposing atmosphere imprints a singular urban configuration where the mass is diluted by the significance and character of the voided spaces, be it a narrow passageway or an unexpected open resting area conditions for a unique public square.



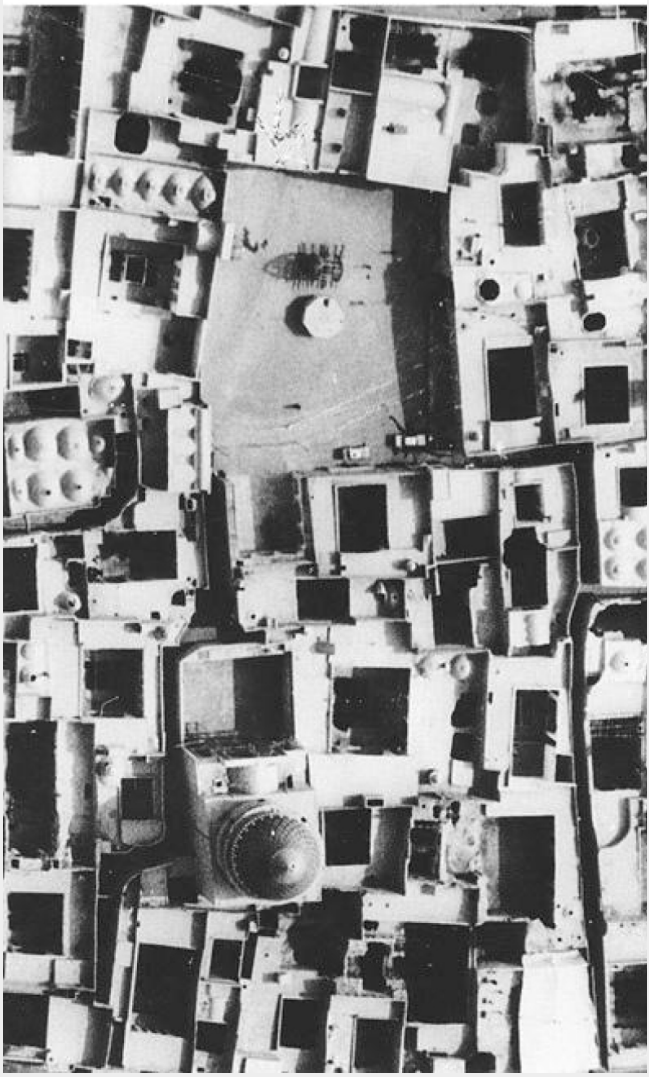


Figure 91: *A neighbourhood centre at the intersection of four narrow lanes, and Seyyed Rokn O'Din Tomb (Tavassoli, 2018).*

Figure 92: *Right: The Historic core of Yazd, a: first street in 1930s, b: remains of 14th centuries towers, c: the former citadel, d: Jame Mosque*


a
b
c
d

Figure 93: *Left: Shah Tahmasb Square before changes in 1928, from Yazdnegar*

Figure 94: *Amir Chakhmaq square in 1917, photo from Yazdnegar*

Figure 95: *Amir Chakhmaq square in 2017, photo from Cultural Institute of Iran*

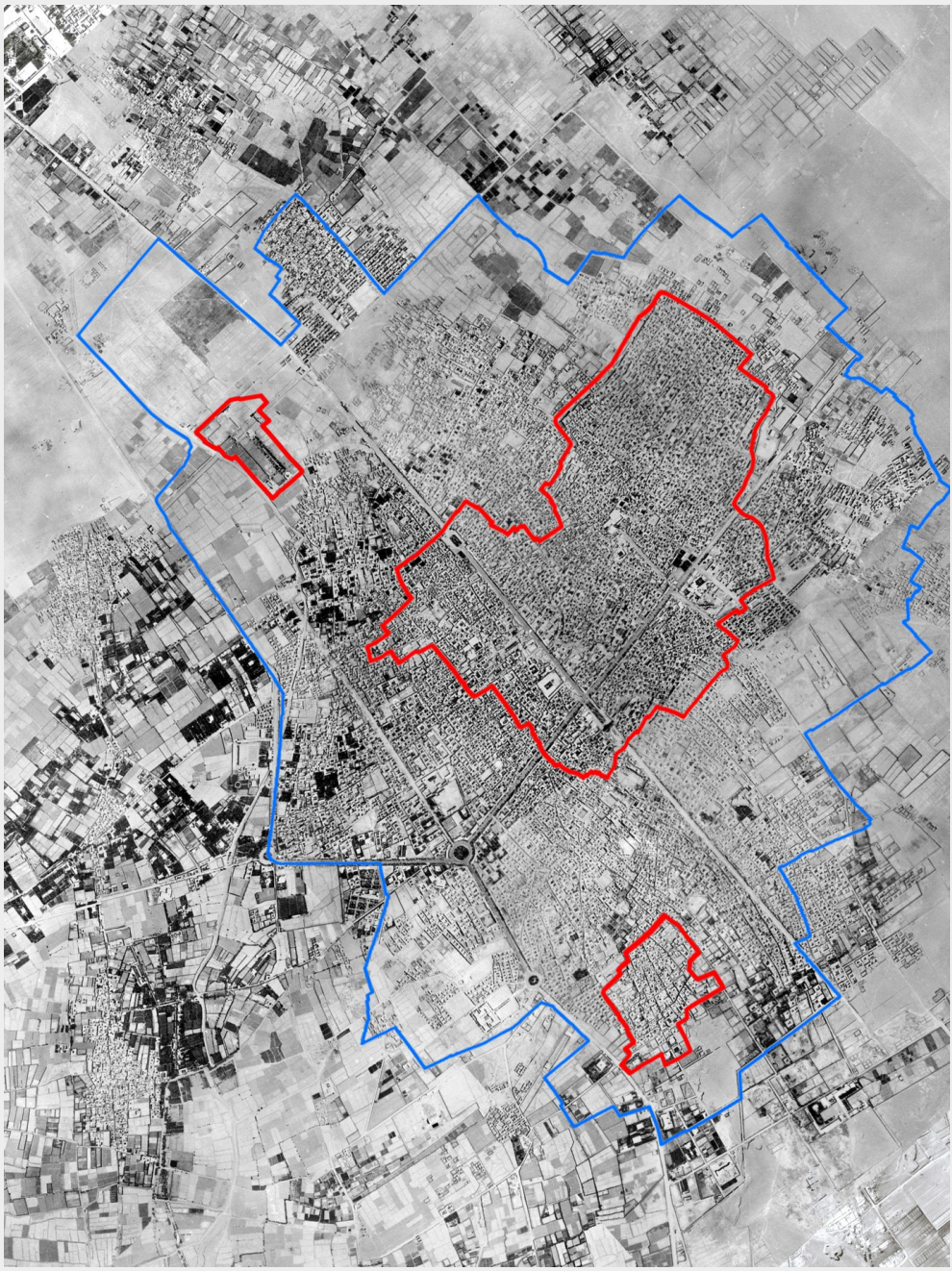


Figure 96: *Yazd aerial photo in 1956, red: UNESCO core zone, blue: UNESCO buffer zone, from dossier of UNESCO for Yazd (2017)*

Figure 97: *Yazd aerial photo in 1973, red: UNESCO core zone, blue: UNESCO buffer zone, from dossier of UNESCO for Yazd (2017)*

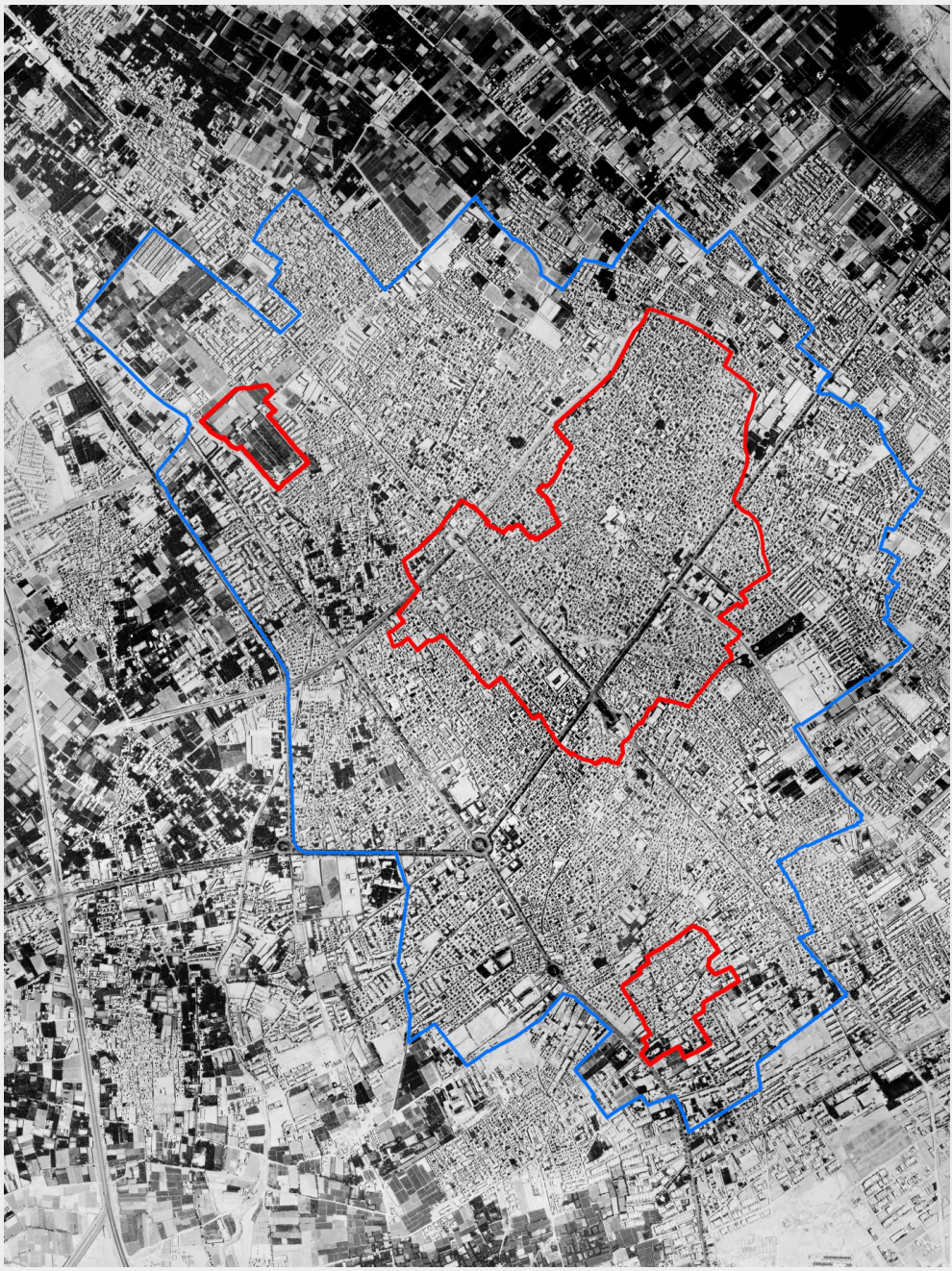


Figure 98: *Yazd aerial photo in 1980, red: UNESCO core zone, blue: UNESCO buffer zone, from dossier of UNESCO for Yazd (2017)*

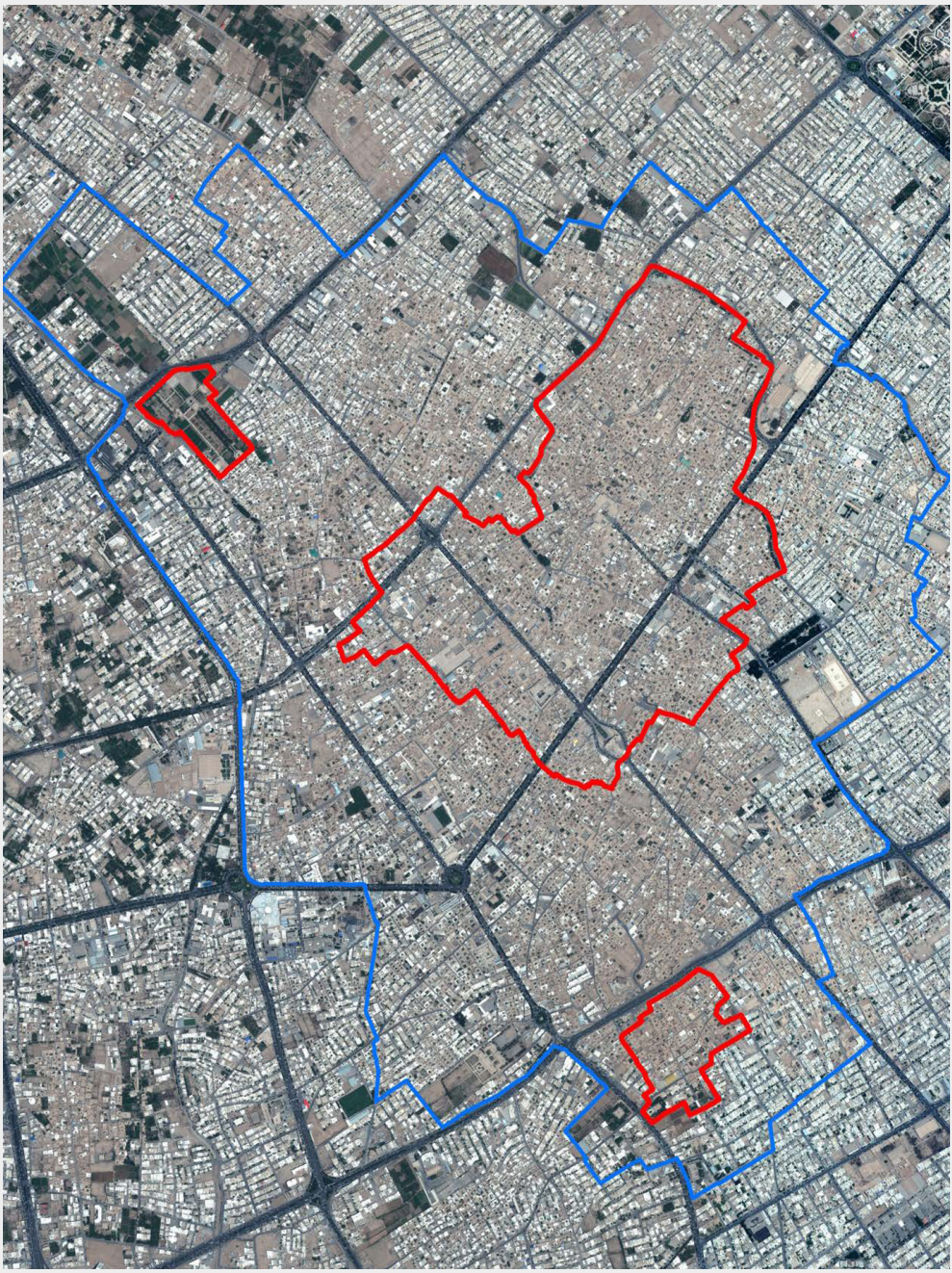
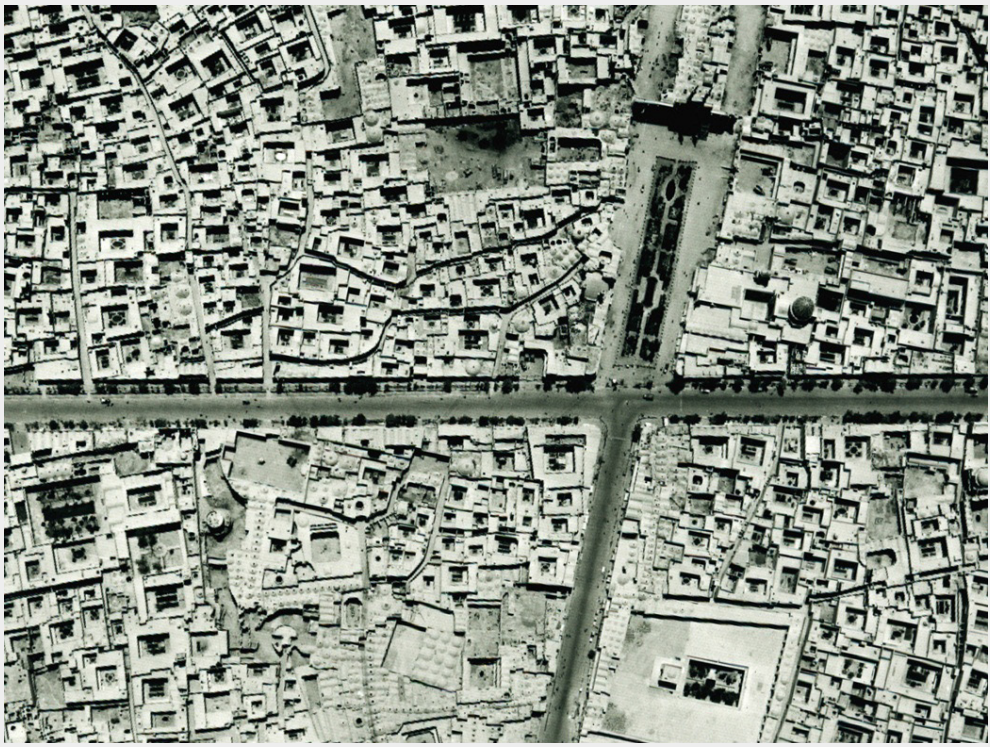


Figure 99: *Yazd aerial photo in 2011, red: UNESCO core zone, blue: UNESCO buffer zone, from dossier of UNESCO for Yazd (2017)*



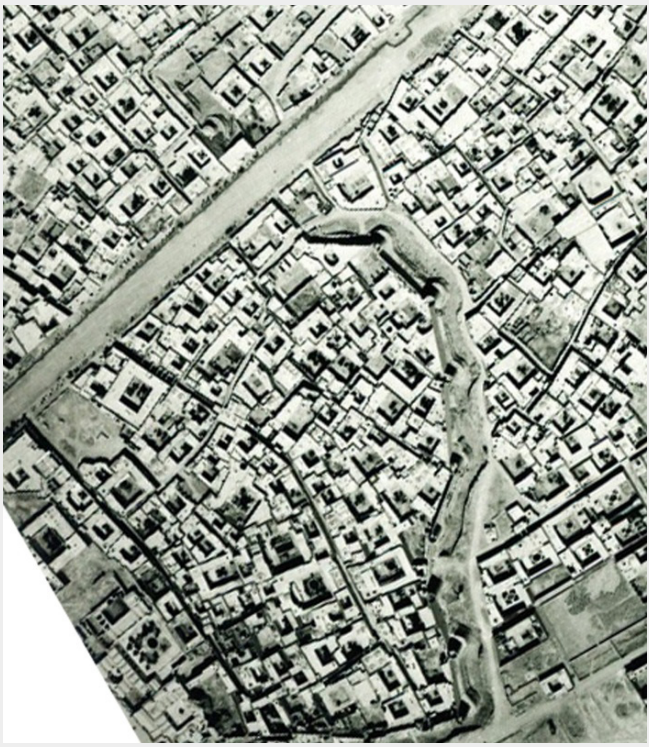
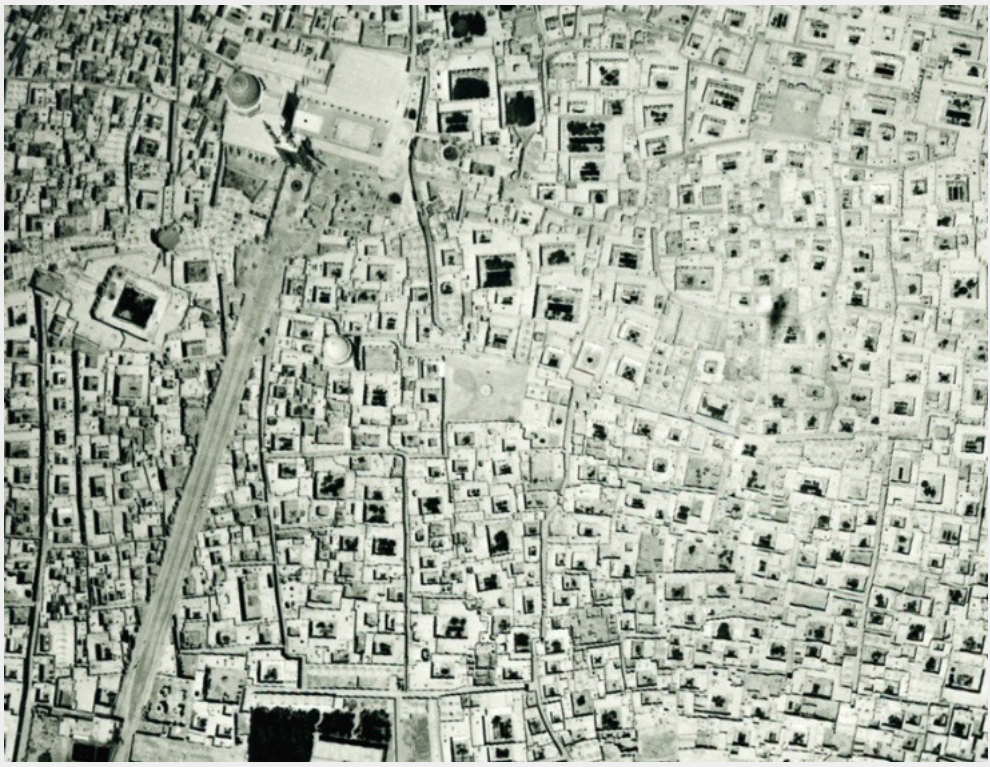


Figure 100: *Left Top: aerial photo of Amirchakhmaq Square in 1956, Left Down: Areal photo of Amir-chakhmaq square in 2015, from dossier of UNESCO for Yazd (2017)*

Figure 101: *Top:aerialphoto of Qaleh Kohneh district in 1956, Down: Areal photo of Qaleh kohneh district in 2006, from dossier of UNE-SCO for Yazd (2017)*



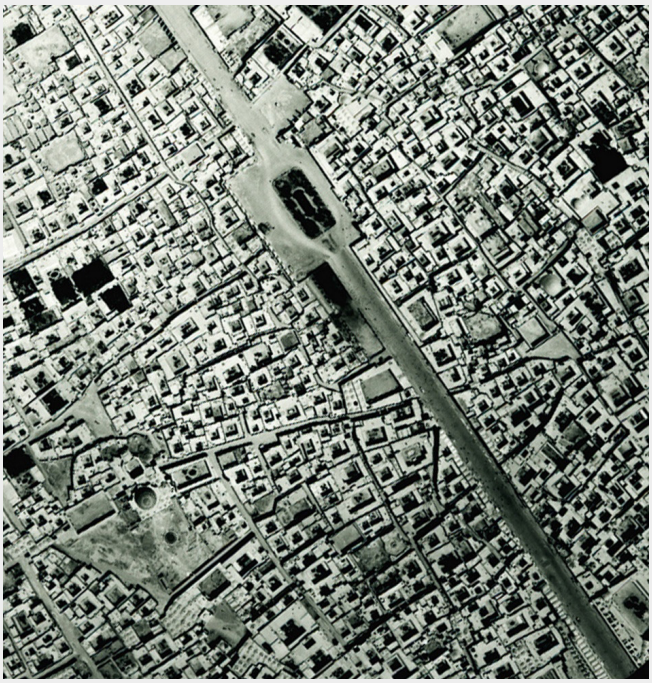


Figure 102: *Left Top: aerial photo of Vaqt-o-sa'at district in 1956, Left Down: aerial photo of Vaqt-o-sa'at district in 2015, from dossier of UNESCO for Yazd (2017)*

Figure 103: *Top:aerialphoto of Imam-Zadeh district in 1956, Down: aerial photo of Imam-Zadeh district in 2006, from dossier of UNESCO for Yazd (2017)*

Figure 104: *Top: aerial photo of Fahadan district in 1956, Down: aerial photo of Fahadan district in 2006, from dossier of UNESCO for Yazd (2017)*

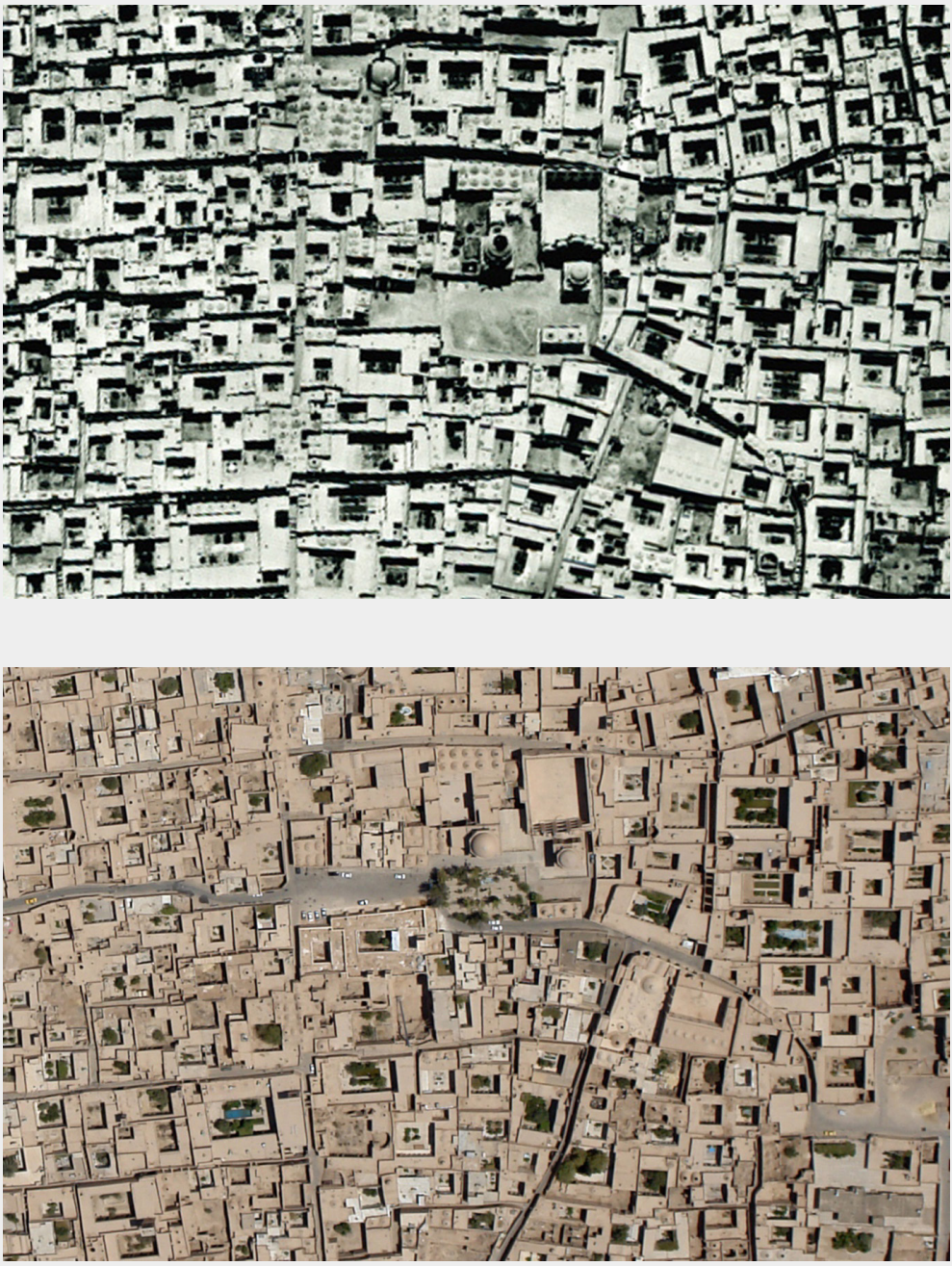


Figure 105: *Top: aerial photo of Fahadan district in 1956, Down: aerial photo of Fahadan district in 2006, from dossier of UNESCO for Yazd (2017)*

Figure 106: *Sketch of Yazd*
by Ramin Jalalpoor

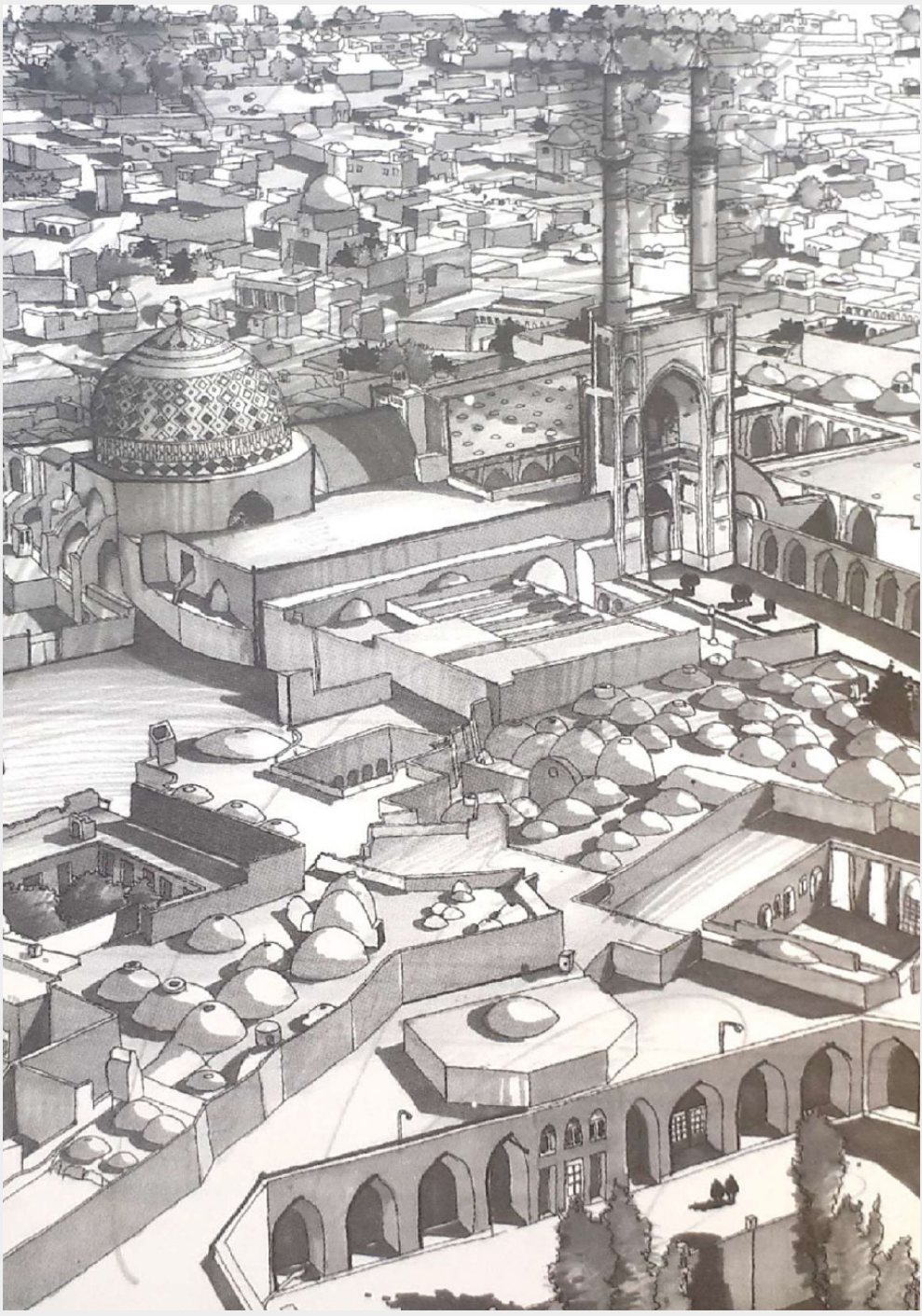
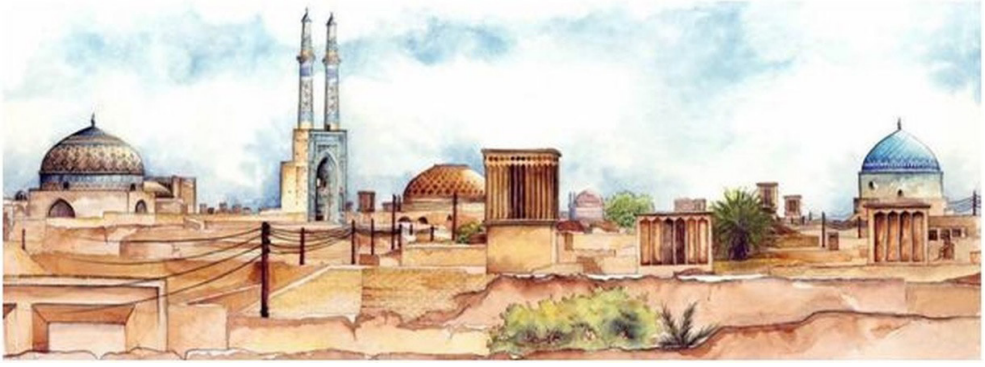
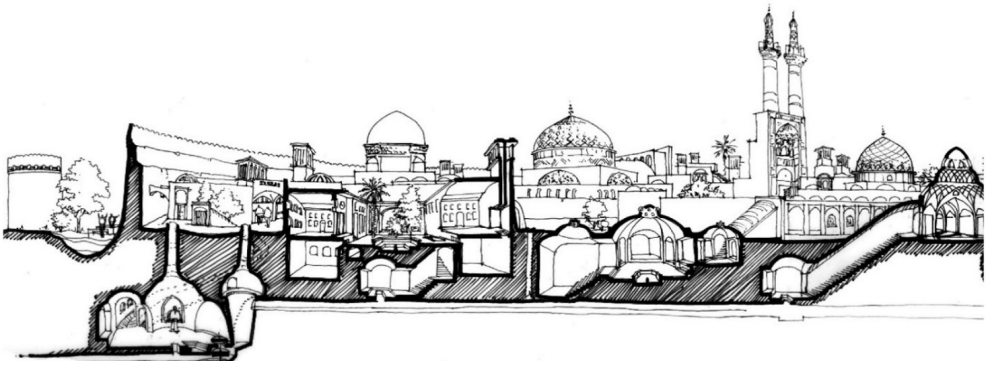


Figure 107: *sketch of Yazd, from Sedigh,& Roasaei,& Alaei, (2012)*





3. Plugged-in Artefacts

Millennia of evolution have sharpened the design of the robust traditional systems for grist milling, cooling houses, creation of settlements and providing clean water (Beazley and Harverson, 1989).

In Yazd, these systems can be seen as plugged-in artefacts (wind-catcher, payab, water reservoir, water mill, ice house and courtyard houses). These artefacts, each with a specific kind of activity, are plugged-in to a hydraulic structure (qanat) through a process of zooming in and out constantly between the buildings, the neighbourhoods, the entire city and the territory.

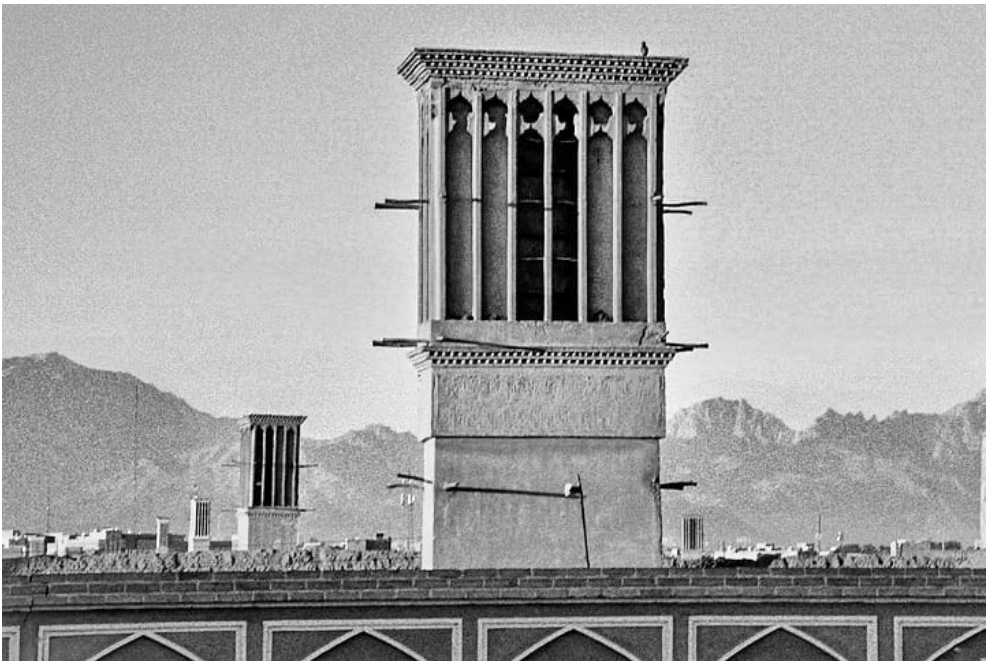
The integration of qanat system with plugged-in artefacts and urban pattern, indicates ingenious measures that have had key roles in the settlement of man in desert regions of Iran and ideally addressed the specific needs of each community over centuries (Fanood, 2014).

Those measure changed and adopted to reality of their time and resulted to a dynamic system in which artefacts not only are in tune with the urban pattern and the natural environment, but also they constitute a resilient unity.

Figure 108: *Skyline of Yazd, photo by Saman Tahvildaran*

Figure 109: *Skyline of Yazd, sketch by Najme Naderi*

Figure 110: *Cross section of historic city, sketch by Najme Naderi*



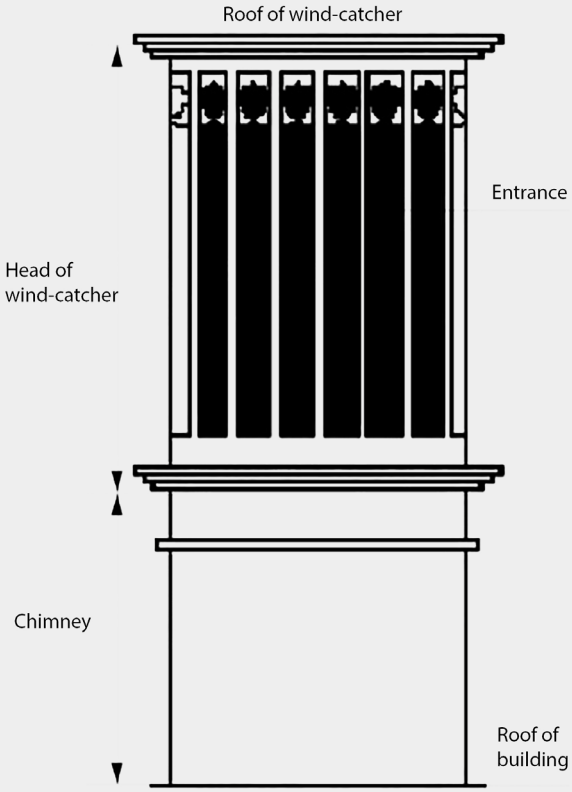
3.1 Wind-catcher

Figure 111: *Wind-catcher of a house in Yazd, photo by Ali Akbar Kermani*

Wind-catcher is a mechanism devised to "catch" the wind at higher elevations and direct it into the inner environment of a building. They have an efficient and significant role in cooling and ventilating living spaces such as caravanserais, water reservoirs, prayer halls of mosques and houses (Roaf, 2005).

Wind-catchers are often consisting of the chimney and valve directing air into the building. Simultaneously with a blowing of wind, air enters the valves above the funnel into the chimney. In the middle of this chimney, there is a thin wall causing pressure to reduce the wind out of the valves behind the wind catcher. This wall starts at the top of wind catcher and continues down the chimney (Mansour, 2012).

Jomezadeh describes the operative principles of a wind-catcher. They are mostly based on wind driven ventilation and stack (buoyancy) effect (Jomezaeh, 2016):



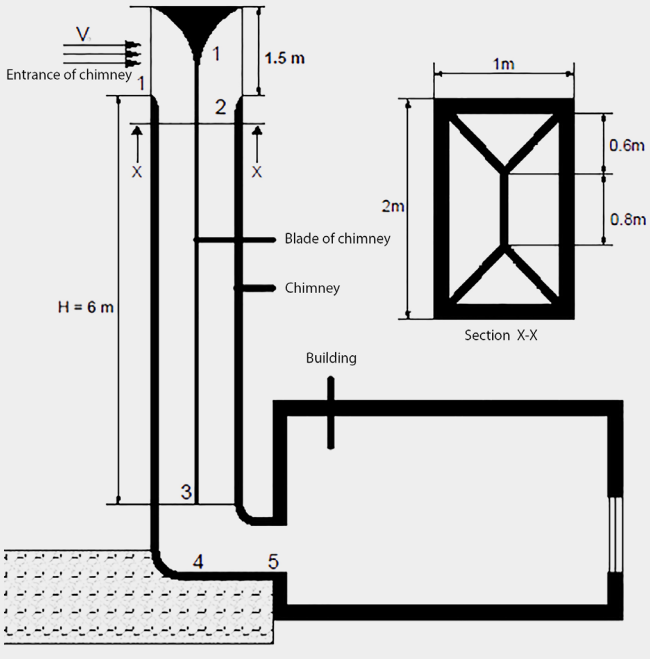
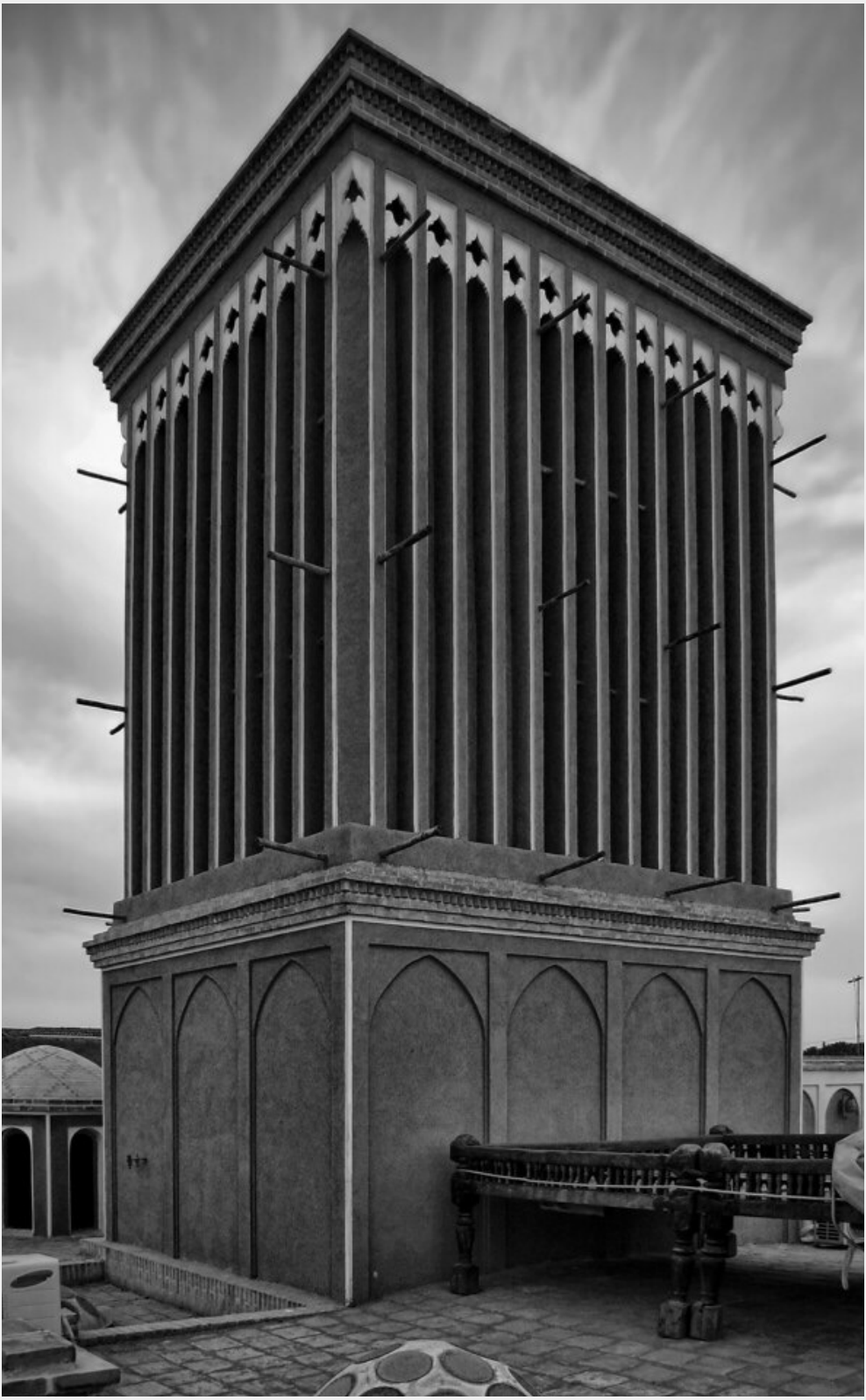


Figure 112: *Four-sided win-catcher:*
1. Valves on the wind-catcher
2. Beginning of the chimney
3. End of the chimney
4. Midpoint of the elbow deflector
5. Midpoint of the air inlet to the building (Mansour,2012).



"During the daytime, by the movement of external wind at roof level, a positive pressure on the windward side of the structure and at the same time, negative pressure on the leeward side are produced. This pressure difference is highly sufficient to deliver fresh air to indoor space and extract stale and warm air out. During night-time, in the absence of air movement or in low wind conditions, the wind-catcher device operates using the natural buoyancy of thermal forces like a chimney, which is yielded on the account of air temperature gradient between inside and outside of a building. When the ambient air temperature is considerably lower than the indoor temperature, the subsequent of pressure difference and air density gradient of the internal and external air masses leads to rising up low dense indoor air and expelling through the wind-catcher leeward side; simultaneously, descending denser cool air through the windward side of the system" (Jomezaeh, 2016).

Many wind-catchers in Yazd are integrated with qanat system to decrease the air temperature and humidify the indoor environment. It is the large enthalpy of water vaporization that makes evaporative cooling possible. During evaporation, water absorbs high amount of heat from surrounding air which results in air temperature reduction (Santamouris, 2013).

As demonstrated in Figure 114, warm dry air enters the qanat and passes a distance to reach the building. Throughout this passage, the interaction between warm air and cool water causes the evaporation of water which leads to decreasing in air temperature. On the other side, wind blowing around the windcatcher causes a negative pressure on the leeward side of the opening which exhaust the warm indoor air and replace with fresh cooled air coming from qanat (Calautit, 2016).

There are two readings that categorizes wind-catchers. The first reading is based on their orientation towards the wind and the second accounts for their plan. According to Roaf on the basis of the orientation the are four types that can be found in Yazd (Roaf, 2005).

Figure 113: *Wind-catcher of a house in Yazd, photo by Armin Hage*

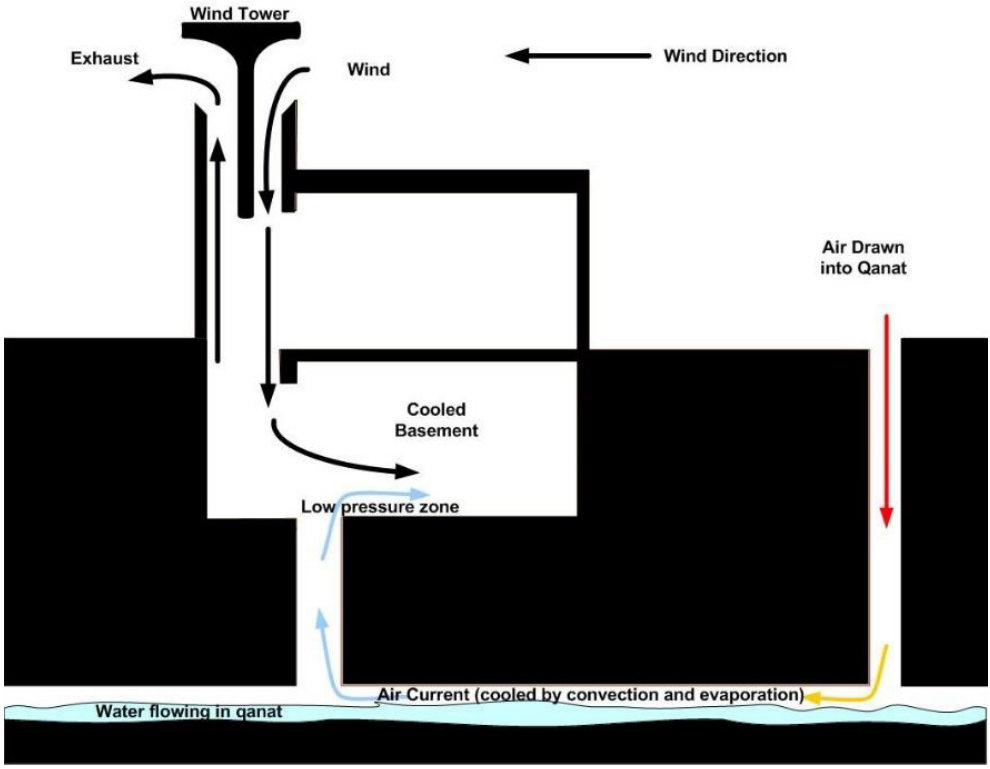


Figure 114: *Cooling performance of wind-catcher incorporated with qanat (Calautit, 2016), [redrawn by the author]*

1. One-sided: These towers have sloping roof and each has one or two vents only which are generally positioned to north-west or north. Only 3% of the wind towers in Yazd were unidirectional

2. Two-sided: This type of tower is divided into two shafts by a vertical brick partition. These two vent wind catchers are often referred to base on direction, such as north-south towers, 17% of the towers in Yazd are of this kind and they all are found on the ordinary houses.

3. Four-sided: These towers are the most popular. They have four main vertical shafts divided by partitions. Almost all wind towers in hot humid region are the four sided type whereas more than half of wind towers in hot and hot-dry climate are of this kind.

4. Multi-directional: In a survey by Roaf, only 2% of the wind catchers of Yazd are of this kind. This type of wind catcher is commonly equipped with a water cistern.

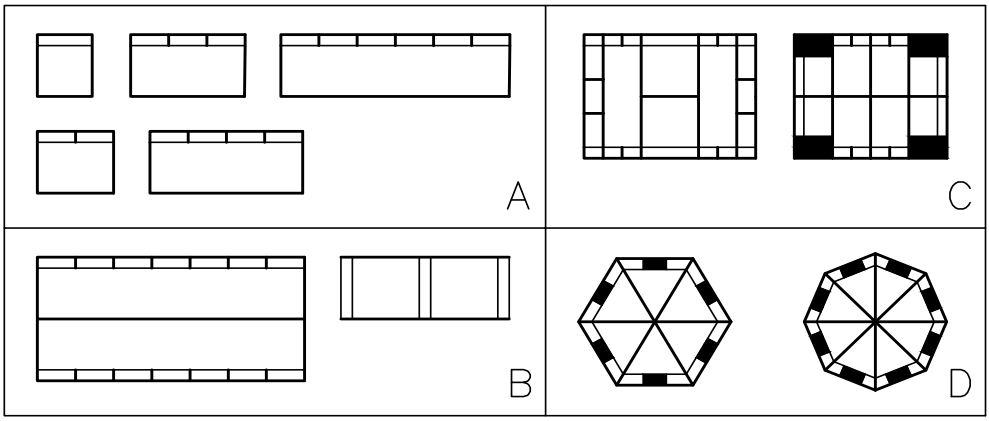


Figure 115: *Wind-catcher categorization based on their orientation: A. One sided, B. Two sided, C. Four sided, D. Multi-directional (Ghadiri ,2012), [redrawn by the author]*

Based on their plan they come in variety of types in Iran such as circle, octagon, polygon, square and rectangle. However, no triangular wind catcher can be found in the Middle East. Wind-catchers with a circular plan are very rare and are not used in common houses. One, two and four directional wind towers usually have rectangular plans whereas the square form is used in the four directional wind towers. Eight directional wind towers are those with an octagonal plan.

In a vast country such as Iran, with different climatic zones, traditional builders have presented a series of logical solutions for human comfort. Due to lack of access to modem heating and cooling equipment in ancient times the architects were obliged to rely on natural energies to render the inside condition of the buildings pleasant (Roaf,1982).

3.2 Payab

Figure 116: *A payab in Yazd, Photo by Almani*

A payab is an access point to the qanat's water. In fact qanat water either passes across districts as an open stream or is consumed via payabs which were usually built in urban squares or in the courtyards of mosques, so that people could have access to qanats traversing beneath residential districts, small towns or large villages.

Payab can be reached by access buildings provided with stairs descending underground. The main space of payab is consisted of a square or a hexagon room

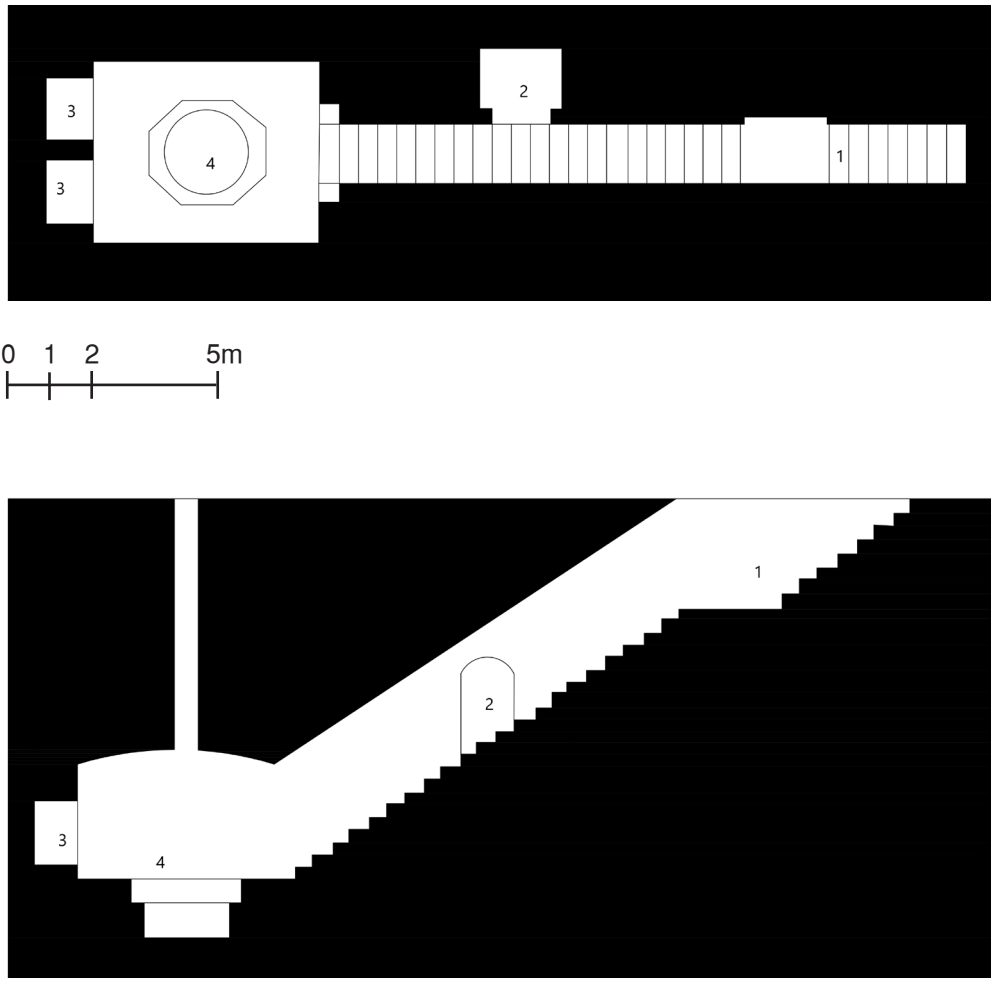


Figure 117: *Lariha Payab: 1.staiways, 2. Platform, 3. Shelves, 4.Pool, Mapping by ICCHS, [redrawing by the author]*

with a round or polygonal water basin on its floor. The qanat water enters the basin from one side and goes of it from its other side. Occasionally, two qanats reach these basins by two different trails. Moreover an orifice is inserted usually into yards which is located above them in order to allow ventilation and natural light.

The deeper the qanat the longer the payab. The slope of the payab is calculated so that the end of gallery meets the bottom of one of the shaft wells of qanat. The size of a payab stairway is such that at least two persons can go up and down side by side easily and their heads will not touch its ceiling. The payab is built perpendicular to the direction of the qanat gallery in order to prevent the collapse of the gallery.

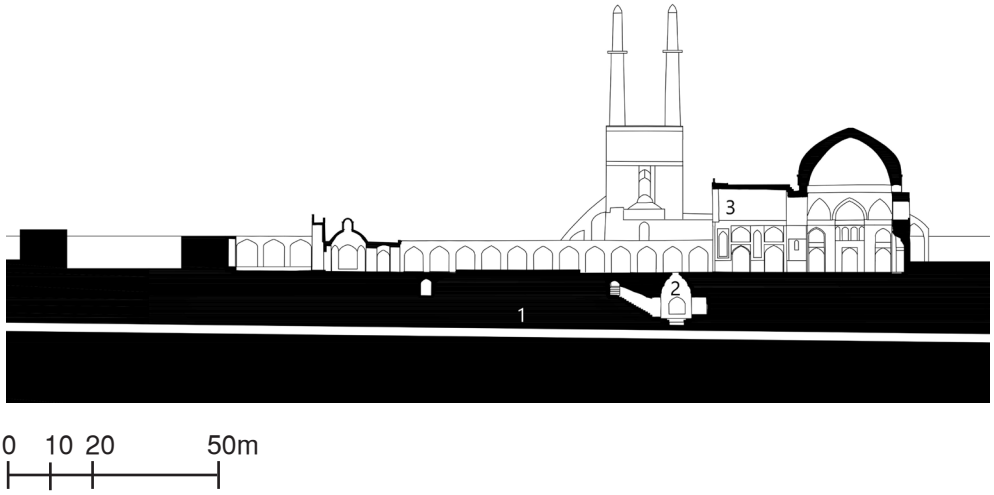


Figure 118: *Section of Jame Mosque and its relation with Zarch qanat, 1. Qanat, 2. Payab, 3. Ivan, mapping by ICCHS, [redrawing by the author]*

Inside the payab the temperature is about 15-25 C cooler than outside in summer.

The payab is a domed structure, resistant to collapse, encompassing a single space which can be rectangular, square or octagonal, with a pool at its centre.

The distinguishing features of a payab include the access stairway tunnel, often lined with platforms forming niches, for people to sit and rest. Public payabs are usually located near a mosque along the road inside the bazaar or in a caravanserai. Yet, in Yazd, many houses do include a private payab.

Robert Grant Watson who visited Yazd in 1850s states that most houses have private payabs located 20-25 meters below the ground level in order to get access to qanat (Watson, 1866). Private payabs, have some shelves to put food stuff on. Also, there is a rope hanging from the ceiling above the pool, tied to a basket at the end to place food, such as meat and fruit, to be kept fresh.

Somehow, being directly connected to the qanat or to some of its branches entering the city, which also dictating a kind of social hierarchy. The payab may well exemplify the combination of natural and social order which finds a tangible expression in the built environment of Yazd.

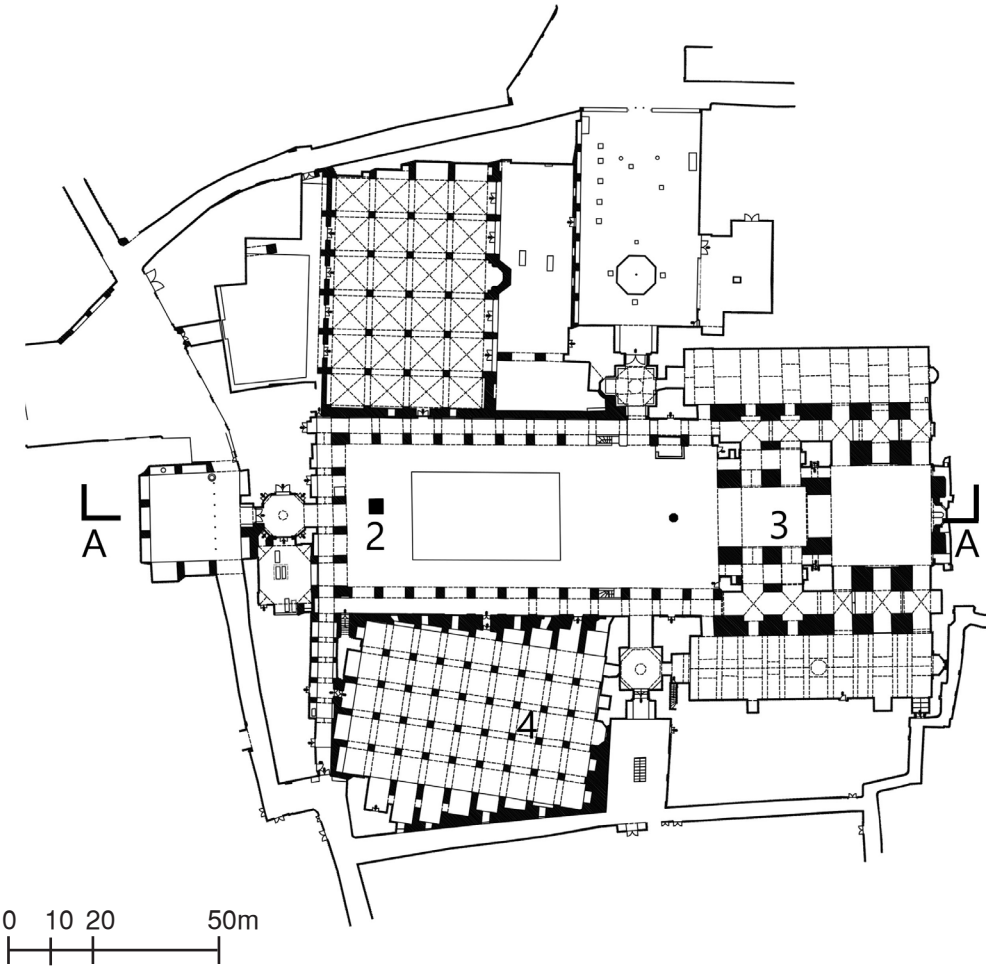


Figure 119: *Plan of Jame Mosque and its relation with Zarch qanat, 1. Qanat, 2. Payab, 3. Ivan, 4. Shabestan, mapping by ICCHS, [redrawing by author]*

3.3 Water Reservoir

Figure 120: *Water reservoir and tower of silence (Zoroastrian cemetery) in Yazd, photo by Mansour Alam*

The water reservoir is a part of a water management system in regions dependent on permanent or on seasonal water (Holad, 2012). A settlement's capability for storing water ensured its survival over the hot, dry season when even the permanent water supply would fade.

The primary purpose of a water reservoir is to provide a completely waterproof container for a large volume of water (its capacity generally varies from 300 to 3000 cubic metre, depending on its depth and diameter) while permitting appropriate ventilation and access.

The typical reservoir mostly consists of three key elements (Fanood, 2014): the water tank, built underground permits proper cooling, resists water pressure and earthquakes; an access platform to a faucet (pashir); wind-catchers provide ventilation.

The qanat system fills water reservoirs during the winter months before the floods, (additional flood water is

often stored in open tanks, as well as in the large, public, covered reservoirs) (Wulff, 1977). Water reaches to the reservoirs through branches of the main qanat or holding tanks and is controlled by sluice gates.

To prevent sedimentation, water reservoirs include a setting basin (a pool) receiving water directly from the qanat. Then after the sediment settles, the clean water is directed to the storage tank. In addition, salt stones are used to disinfect water, by putting them in water while recharging the reservoir. Salt stones are gradually dissolved in water, producing the gas of chlorine which to kill the pathogens (Semsar Yazdi, 2018).

Understanding the thermal performance of water reservoir is a matter of out-most importance. Studio Integrate[1] carried out an extensive study on Fahadan water reservoir, with the purpose to evaluate the thermal performance of the reservoir as well as the internal air pressure. The use of a computational fluid dynamics (CFD) model permitted to simulate the effects of wind-catchers and the significance of the building shape on the reservoir performance.

The building's layout is formed around a central water tank with a single access. The reservoir can be accessed from the adjacent bazaar by a staircase comprising 51 steps, with two skylights providing natural light and ventilation. This staircase tunnel connects to the bazaar at ground level to the foot of the faucet, placed almost a meter above the base level of the chamber for the water to be extracted using the pressure created by its own weight while preventing the residue at the base level to enter into the faucet.

The water tank of the reservoir is covered by a dome, acting in union with four wind-catchers to regulate the temperature of the tank. Two of these symmetrically arranged wind-catchers are four- sided and built from brick while the other two are single-sided built from clay.

"The careful positioning of these two different types of

1 Studio Integrate is an Architecture, Design and Research Studio based in London and Sydney. It was founded by Mehran Gharleghi 2011.

wind towers facilitates the utilization of local wind patterns. The towers are designed to prevent dust and airborne pollutions from entering into the water reservoir, whilst enabling a constant flow of fresh air to circulate the space. Fresh air enters into the cistern through the four sided wind towers and exits through the single-sided ones" (Studio Integrate, 2011) The water tank is buried in the ground for structural reasons as well as to make use of the thermal mass capacity of the ground to maintain a stable water temperature cool.

Modelling Fahadan Reservoir with the surrounding buildings and ground fabric through computational fluid dynamics (CFD) permitted a precise environmental assessment. The result of the thermal analysis from tests carried out on indicates that while the outside ambient temperature reaches 42 degree Celsius in summer, cool drinking water with the temperature ranging from 12 to 13 degree Celsius is obtainable from the faucet. In their parametric studies over water reservoirs, Ali Dehghan and Alireza Dehghani state that decreasing induced wind velocity over the water surface or increasing the ambient temperature leads to an increase in the top water layer temperature, while the bottom water layers are not significantly affected (Dehghan,& Dehghani, 2011). This understanding is important, since it confirms the water reservoirs are efficient in protecting the bottom cold-water layers from harsh outdoor environment. *"Applying the experimental results, an energy and energy analysis shows that around 80% of the cooling capacity stored in the winter can be retrieved during the summer time at a desired temperature. Comparing the energy content of the stratified reservoir with that of the fully mixed tank shows that the formation of stable thermal stratification is responsible for preserving the quality of the extracted cold energy"* (Dehghan,& Dehghani, 2011).

Arthur Pope, in his book "Survey of Persian Art: Pottery and Faience" states that *"while private houses may have had their own reservoirs, filled in turn from the qanats or streams, in desert towns such as Yazd the more notable structures were built for public use within the city as well as on caravan roads"* (Pope, 1973).

Figure 121: *Fahadan water reservoir, photo by Diego Delso*

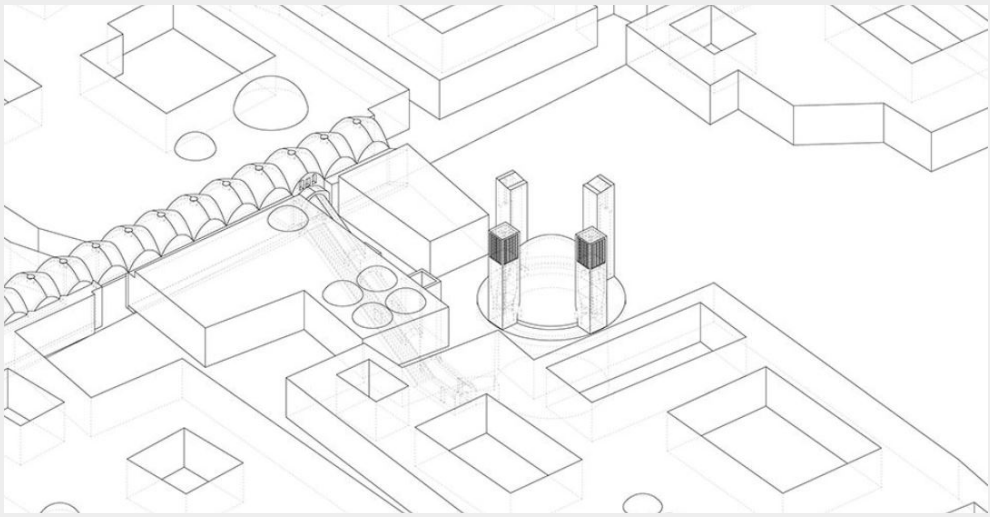
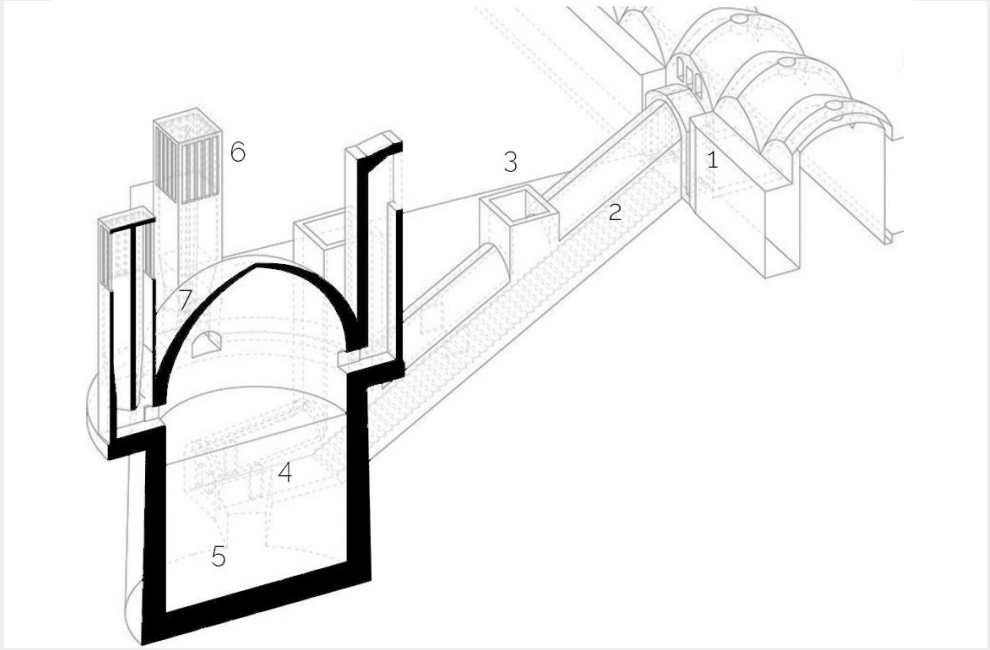


Figure 122: *Fahadan water reservoir, 1.Entrance, 2. Stairway, 3. Skylight, 4.Pashir, 5.Storage tank, 6. Wind-catcher, 7. Dome (Studio Integrate, 2011), with [modification by the author]*



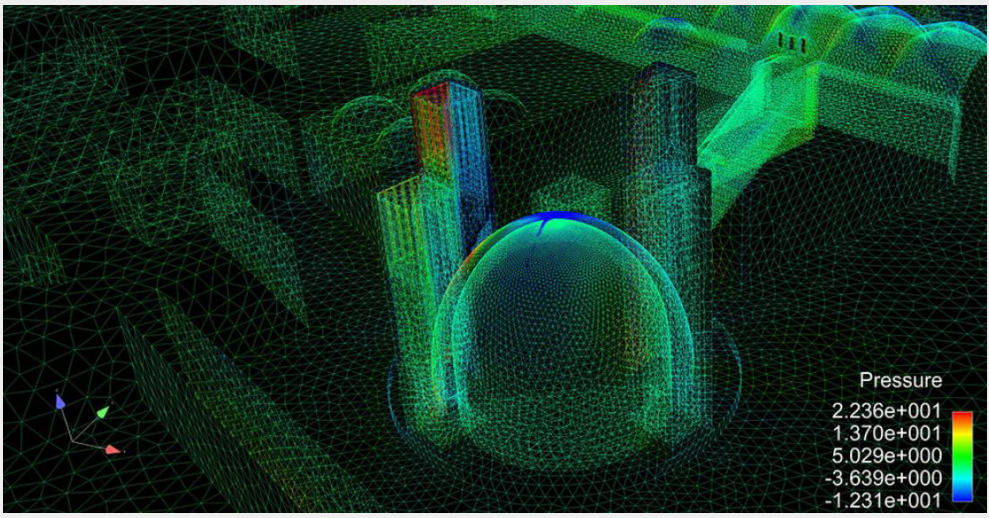
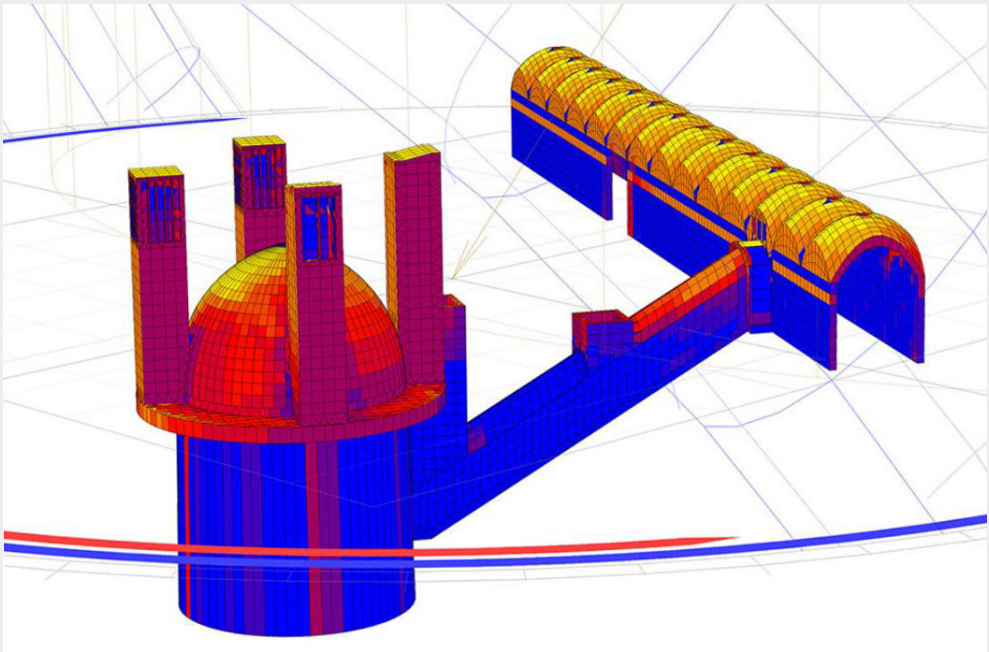


Figure 123: *CFD model of Fahadan reservoir in Yazd showing the wind pressure*

Figure 124: *CFD model of Fahadan reservoir in Yazd showing the temperature of each element*



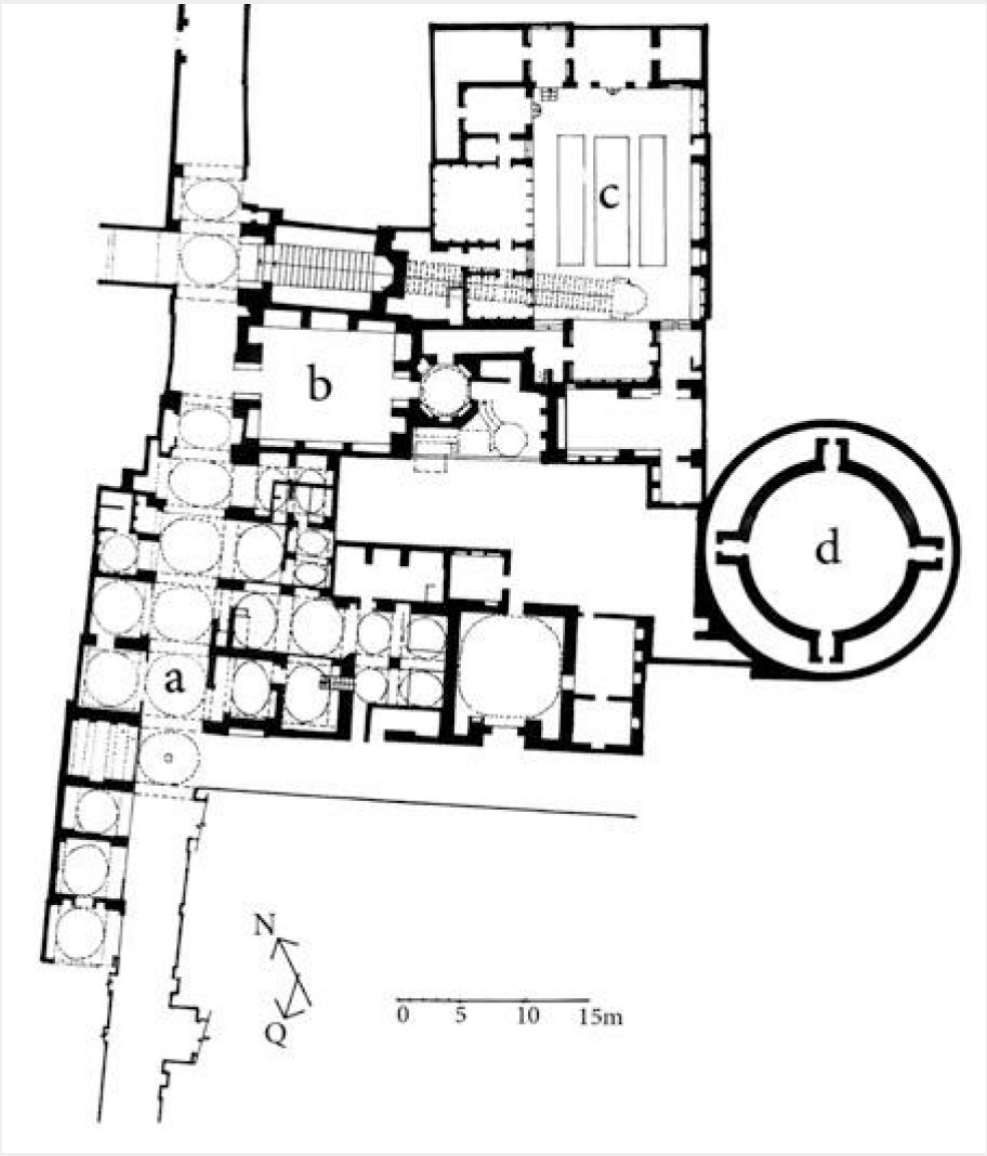


Figure 125: *An urban node in Yazd, a. Bazaar, b. Hosseinieh (religious building), c. House, d. Fahadan water reservoir (Tavassoli,2018)*

Despite the fact that their main objective has always been providing water for citizens, reservoirs play a crucial role in determining skyline of Yazd and its urban layout. The entrance of the reservoir is often decorated with sophisticated ornaments and larger reservoirs often accommodate bazaar, mosque/hosseinieh and public facilities, signifying an urban institutional status (Figure 125).

As a public place, the water reservoir acts as an "urban mediator", identifying the centre of neighbourhood, attracting other public facilities. Bonine claims that the hierarchy of urban spaces where reservoir are placed are defined by the size and the scale of reservoir (Bonine, 1975).

This could be defined by the number of wind-catchers since they are directly linked to the size of reservoir. Thus, minor neighbourhood reservoirs are usually bequeathed with fewer wind-catchers while larger city centre reservoirs are often equipped with six or more wind catchers.

Water reservoir highlights the efficiency of this architectural solution in extremely harsh climate conditions such as Yazd. Fahadan reservoir expresses this solution with a very strong integration with its surroundings and its context. As the context changes, the problems at hand also change and new answers are needed. In Yazd, while the climatic conditions might remain the same, the other factors differ. Thus, this has resulted in different types of water reservoirs.

For instance, Nosrat Abad reservoir, Hojat Abad reservoir and Gorde Faramarz reservoir are built on carvan routes. Thus, in addition to the reservoir, they also house another architectural type that is caravanserai. The resiliency here is embedded in the integration of two types (reservoir and caravanserai). It is through architectural solution that two different programmes become one entity.

With the change of programme and settings, the answer changes. For example, in Akhond reservoir and Khaje reservoir, we find an entrance pavilion featuring

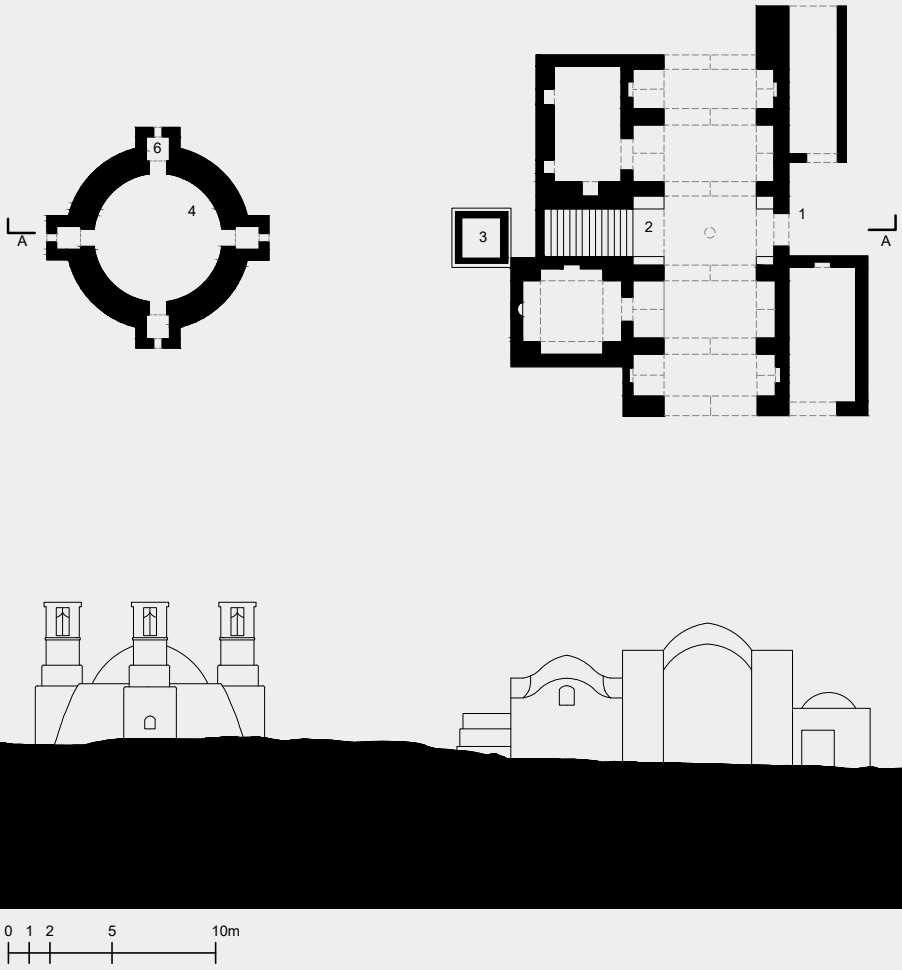
a cross-in-square plan and cosequently, form barrel vaults (chartaghi).

Gonbade Sabz reservoir is a combination of two similar types. In this reservoir, one storage tank could not provide the needed amount of water, as a result, two storage tanks are placed in close juxtaposition with one another.

Seyed Fathodin reservoir also articulates two similar architectural elements within reservoir. Since, this reservoir is constructed inside the compact urban pattern of Yazd, the convenient access to water is a priority. Thus, the builders provided two different access points from opposite directions.

The examples show the level of integration between water reservoir and urban fabric, as well as the adaptability of qanat-related structure to become part of architectural complex such as in case of Khormiz reservoir. It houses three different programmes (mosque, tower and reservoir) that are in total unity. Each architectural type is a response to specific problem, but it is through their integration that a unified architectural solution is created. Water reservoir is an efficient response to the harsh climate conditions of Yazd, but it is its role as an urban artefact that permits it to be interwoven with social demands.

Figure 126: *Nosrat Abad water reservoir, plan, elevation and section: 1.Entrance 2. Stairway 3. Skylight, 4.Pashir, 5.Storage tank, 6. Wind-catcher, [mapping and drawing by the author]*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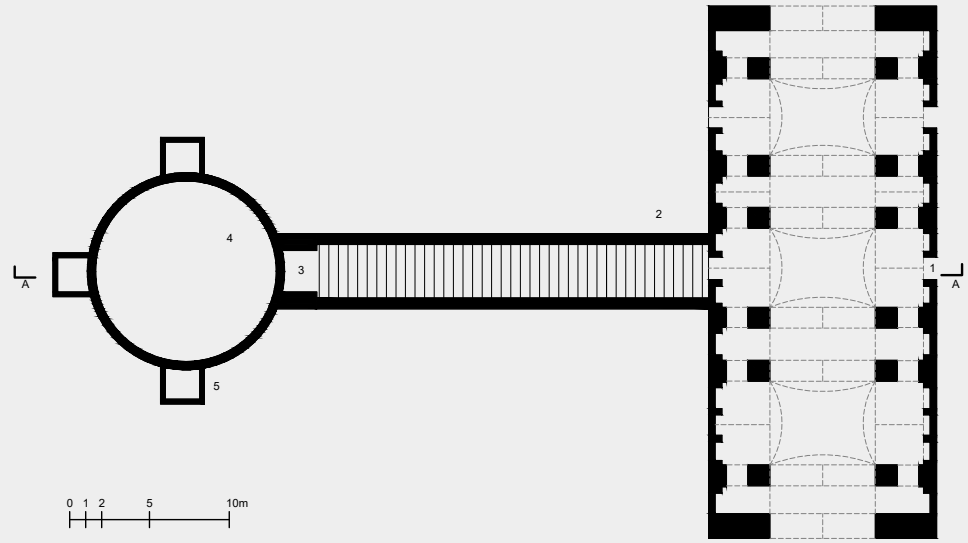
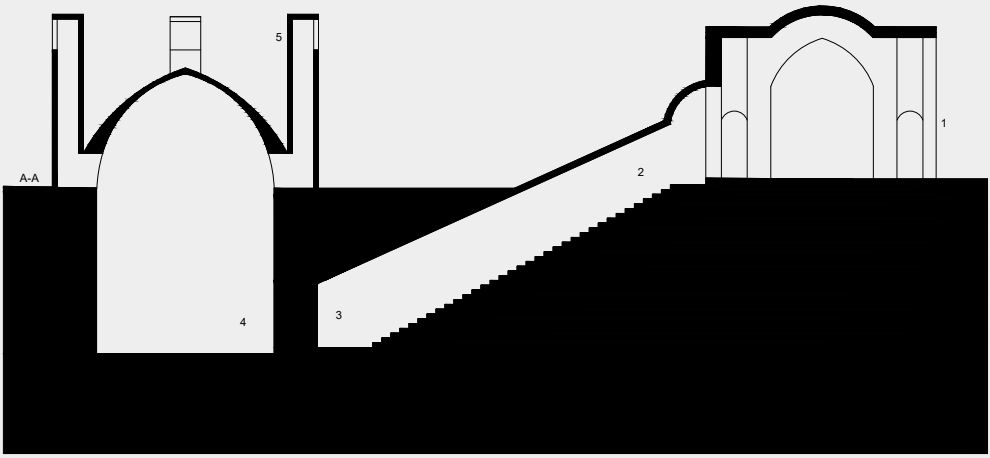


Figure 127: *Hojat Abad water reservoir, plan and section: 1.Entrance 2. Stairway 3. Pashir, 4.Storage tank, 5. Wind-catcher, mapping by Yusef Zamani ,[redrawn by the author]*



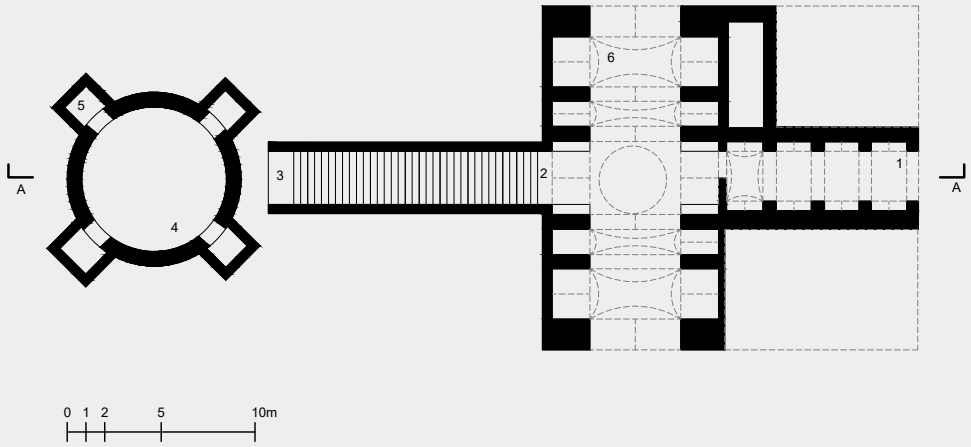
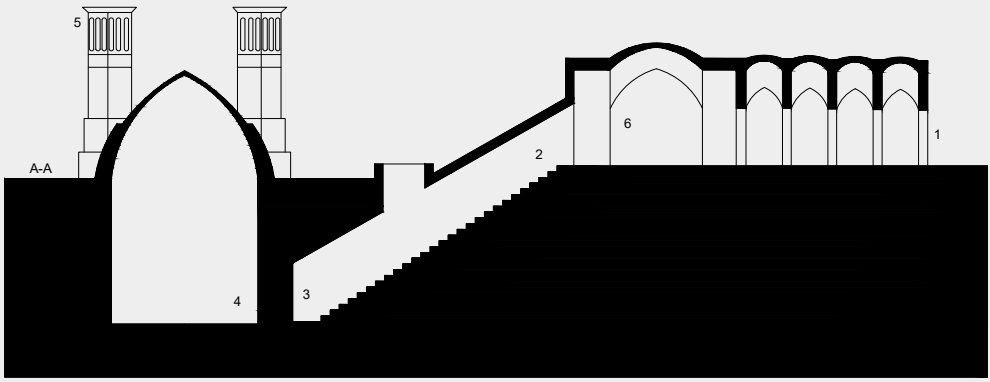


Figure 128: *Gorde Faramarz water reservoir, plan and section: 1.Entrance 2. Stairway 3. Pashir 4.Storage tank, 5. Wind-catchers, 6. Caravanserai, mapping by Yusef Zamani, [redrawn by the author]*



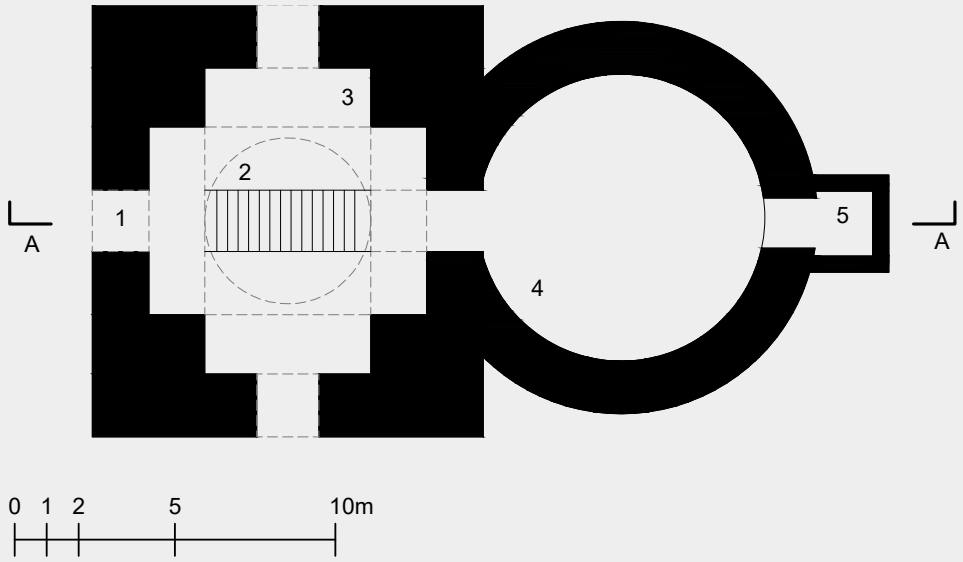
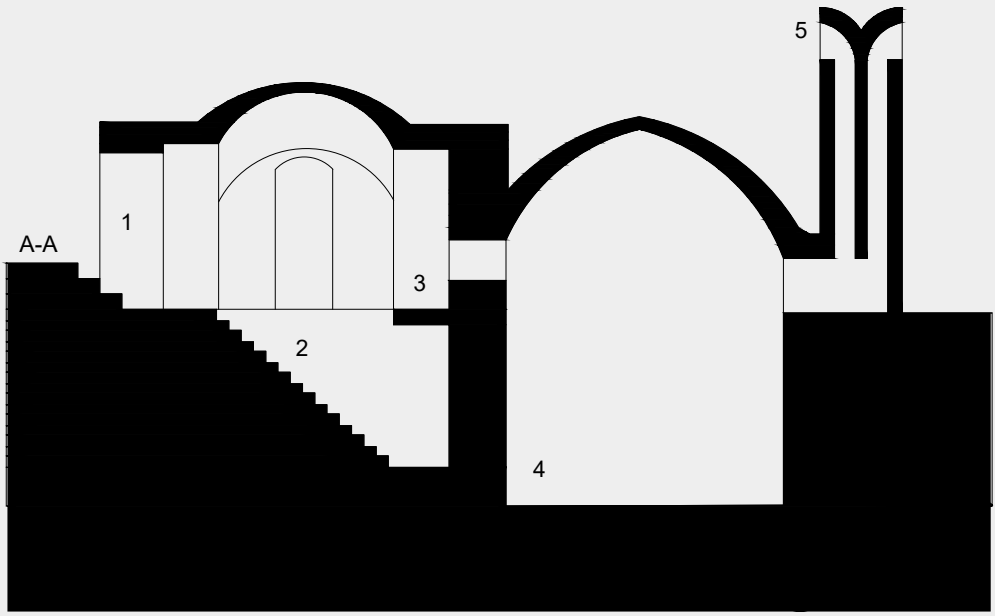


Figure 129: *Akhond water reservoir, plan and section: 1.Entrance 2. Stairway 3. Chartaghi: 4.Storage tank, 5. Wind-catchers, mapping by Yusef Zamani, [redrawn by the author]*



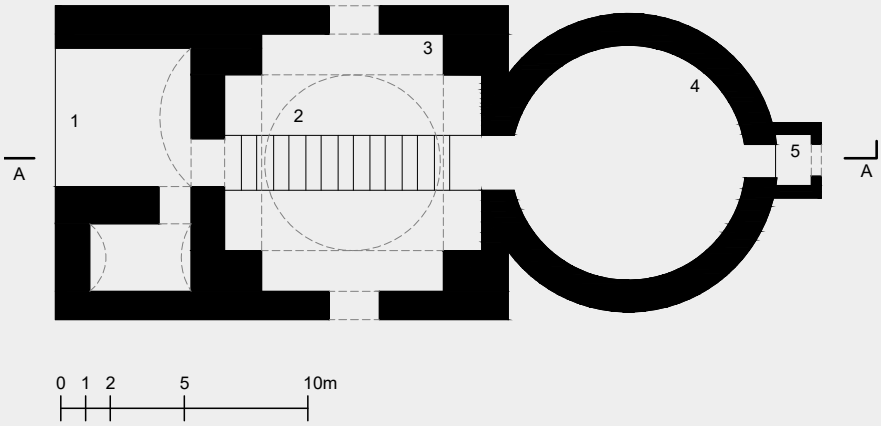
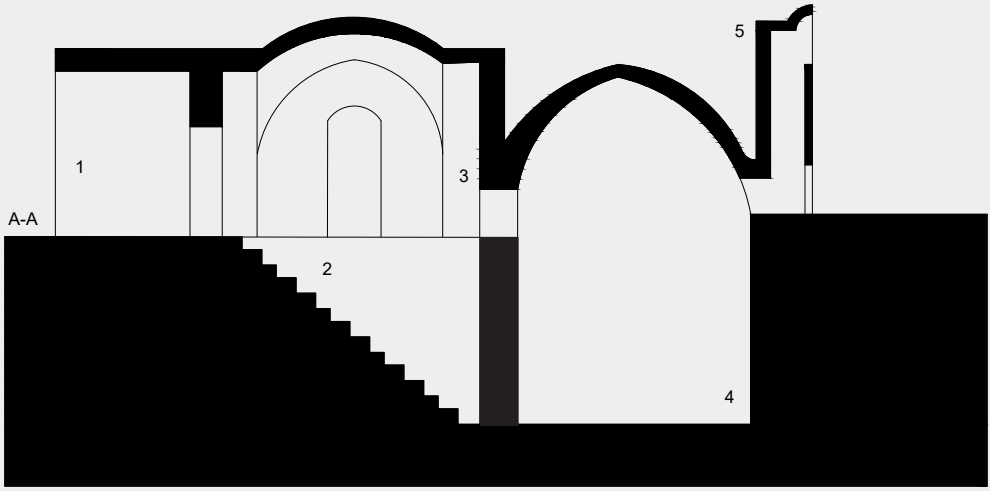


Figure 130: *Khaje water reservoir, plan and section: 1.Entrance 2. Stairway 3. Chartaghi: 4.Storage tank, 5. Wind-catchers, mapping by Yusef Zamani, [redrawn by the author]*



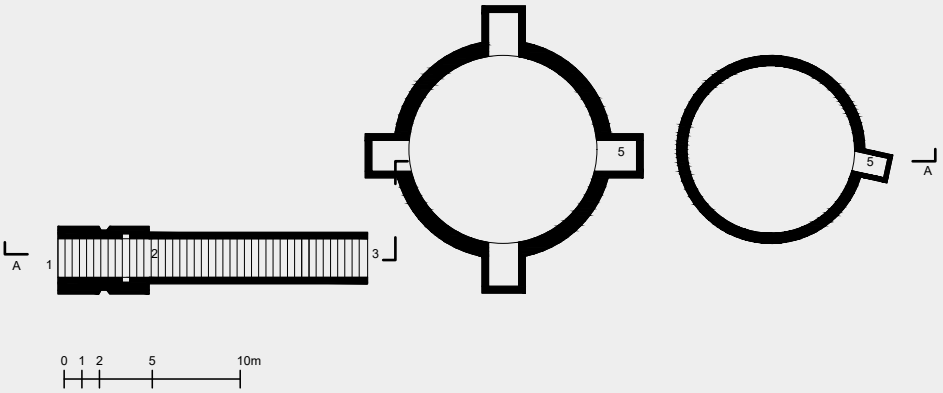
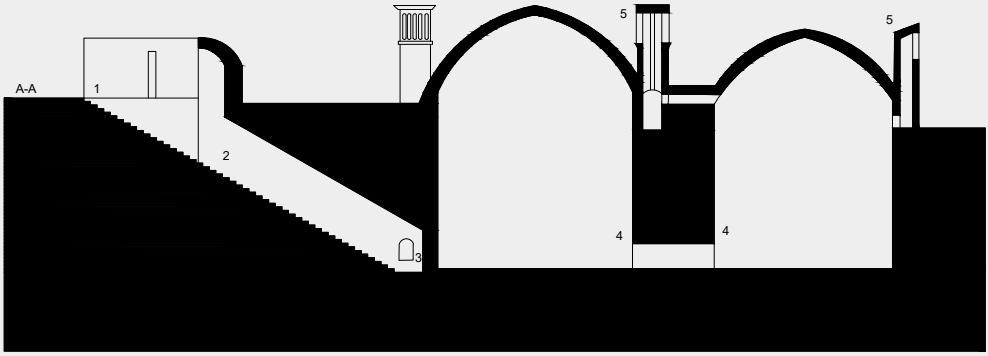


Figure 131: *Gonbade Sabz water reservoir with two Storage tank, plan and section: 1.Entrance 2. Stairway, 3. Pashir 4.Storage tank 5. Wind-catchers, mapping by Yusef Zamani, [redrawn by the author]*



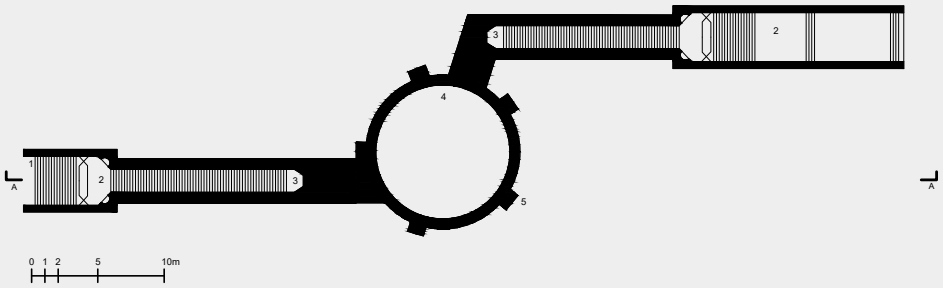
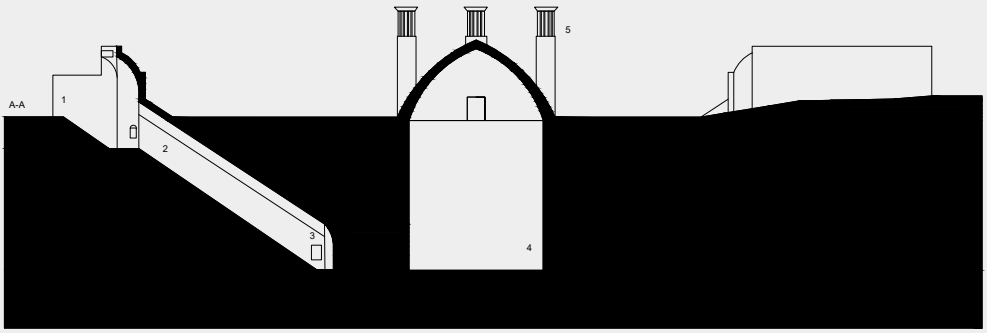


Figure 132: *Seyed Fathodin water reservoir, plan and section: 1.Entrance 2. Stairway 3. Pashir 4.Storage Tank 5. Wind-catchers, mapping by Kourosh Bozorgmanesh, [redrawn by the author]*



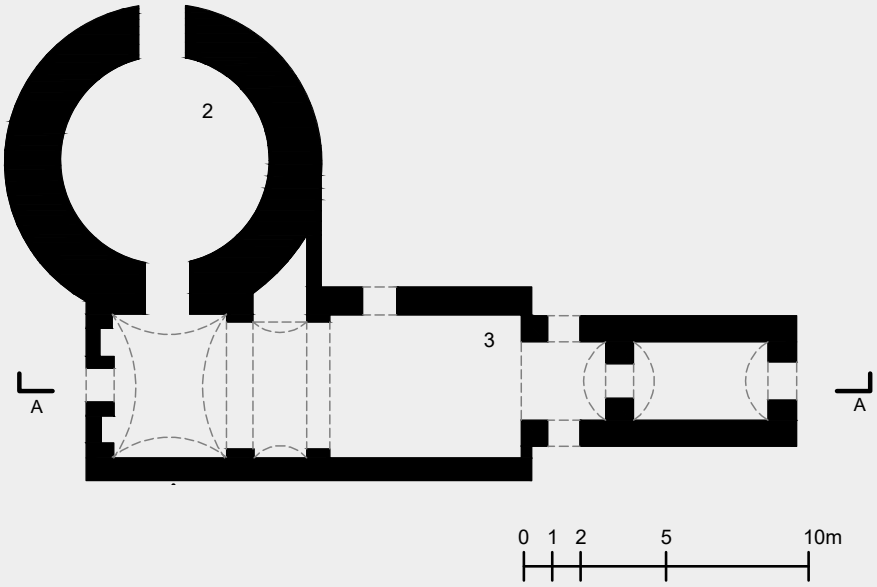
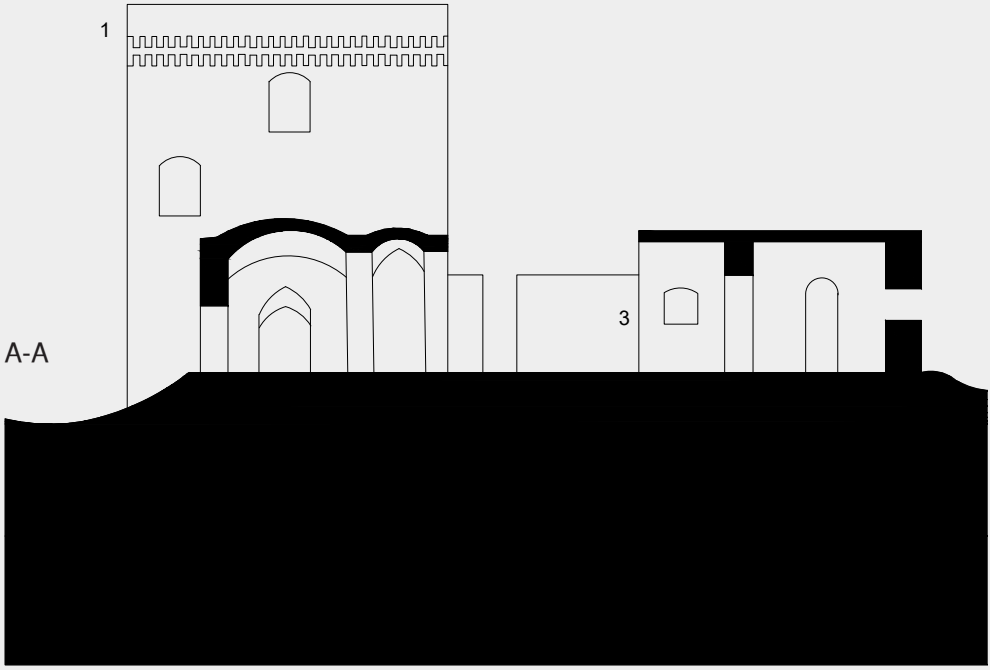


Figure 133: *Khormiz water reservoir, plan and section: 1.Tower 2. Reservoir 3. Mosque, mapping by Yusef Zamani , [redrawn by the author]*



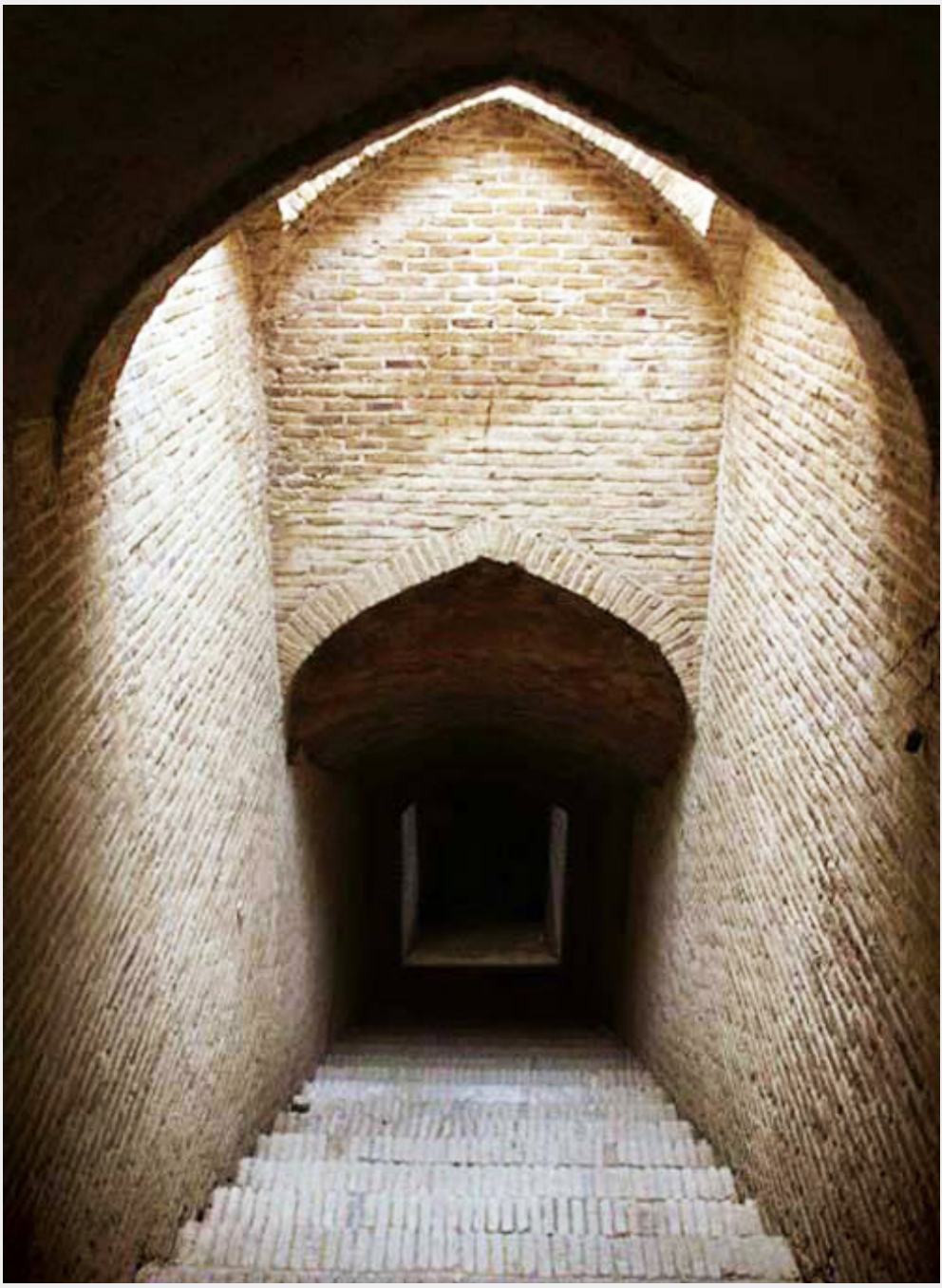
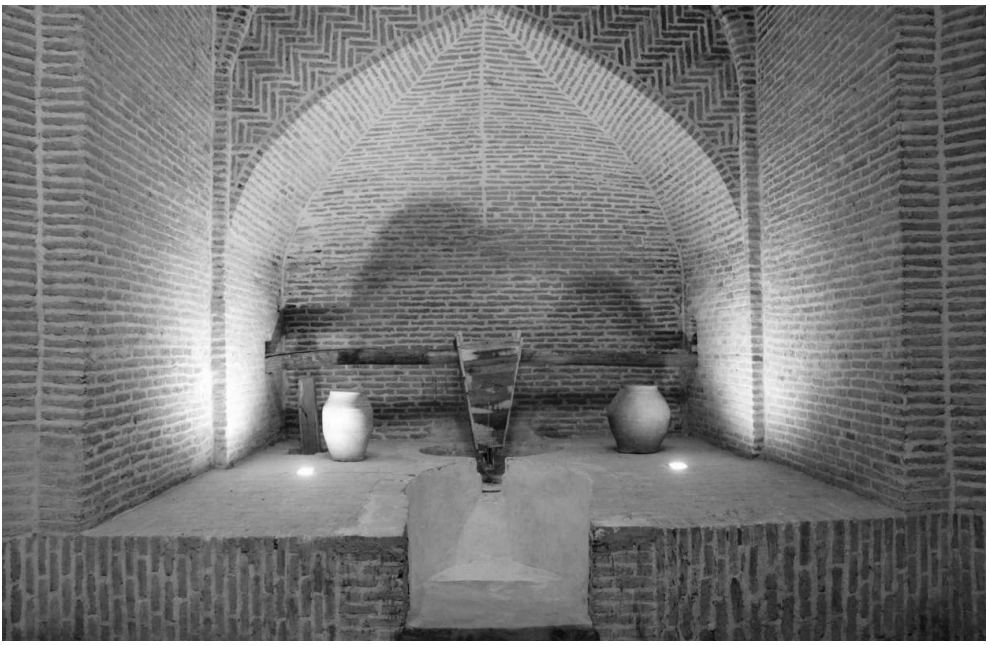


Figure 134: *Giv Water Reservoir, stairway and access to Pashir, photo by Faride Hassani*

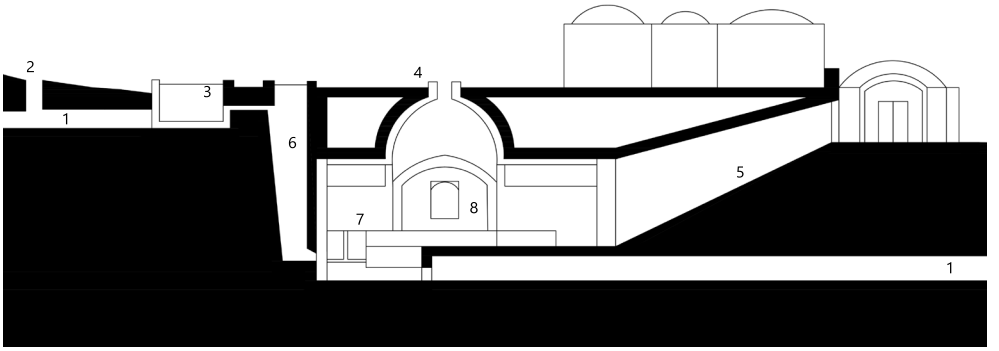


3.4 Watermill

Figure 135: *Watermill in Askhkezar, Yazd, photo by Irna*

The watermill is an underground structure devised to turn wheat to flour without using any non-renewable energy. Its main parts are a water house, two millstones, rotor blades and an axis which connects the rotor blades and upper milestone vertically (Tavassoli, 2018). Potential energy of water in relation with the height difference of the water house makes the watermill operational, the deeper the water house, the more energy is produced.

In fact the water house is a cylindrical reservoir dug in the ground that receives and accumulates water. Sometimes the water house is located 10m below the qanat, in order to increase the water pressure. When the qanat water reaches the water house, it fills it up and then gushes out from a tiny nozzle at the bottom, hitting the rotor blades, making the blades rotate, and imparting energy to the rotor which then turns the upper milestone. The lower milestone is motionless. The friction between the upper and lower milestones grinds



the wheat into flour. In some places, several watermills operated by the water of only one qanat.

Watermill has an important role in defining the settlement location as well as rural and urban fabric (Abbasi, M. 2018). In qanat- based civilizations, the location of settlements are deeply connected with qanat outlet. The qanat has a standard slope that conferring to the situation to be from 0.5/1000 up to 2/1000. Thus, water appears on the ground in a fixed location where it may not be desirable. In addition, in extremely harsh climate conditions like Yazd, evaporation rate is very high. Consequently, it is not feasible to transfer water on the surface. In such cases qanat water emerges before the settlement, and needs to be directed underground again. In such cases, the watermill is a practicable solution to redirect qanat water far from initial qanat outlet (Figure 136). The watermill may be regarded as an attainable case that indicates the intricate relationship between the qanat, people and qanat related infrastructure.

Figure 136: *A water Mill, section: 1.Qanat 2. Qanat shaft 3. Pool 4.Vent 5. Ramp 6. Zorna 7. Stone, 8.Hall, Drawing by Abbasi Harafte, [redrawn by the author]*

3.5 Ice House

Figure 137: *Abarkooh ice house, photo by Beazley in 1970*

The ice house (Yakhchal) is devised to produce ice in winter and store it throughout the summer in a hot desert climate (Mahdavinejad, 2012). The building complex encompasses a domed structure with a pit to store ice, a shallow ice making pond that is filled each night from the qanat water and a shading wall that protects the pond from the heat of low-angle winter sun. The wall also shields the pond and channels from the wind to facilitate the process of freezing.

The dome can reach a height of 15m and the pit about 5m deep. The dome walls approximately can be around 2m thick at the base and 0.5m thick at the top where there is a vent hole.

Ice is harvested from the pond and transferred into the Yakhchal ice store. These types of Yakhchals are reported to have been constructed from locally-sourced adobe, containing mud and binding materials such as animal hair and egg white (Poche, 2017).

Poche and Gunstone state that the rate of ice production in a shallow pond depends on several various

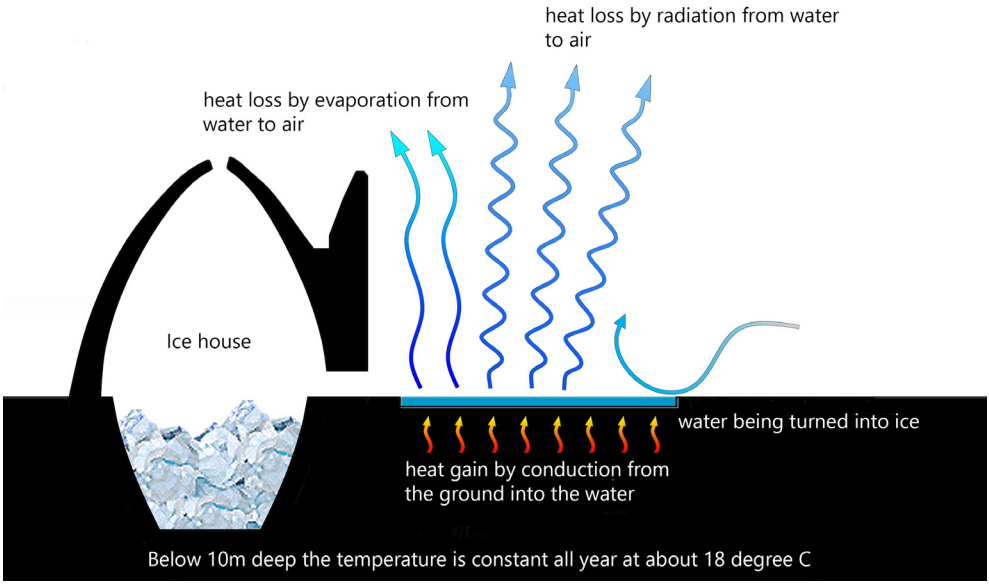


Figure 138: *Ice production in ice house (Pooche,2017) [with modification of author]*

factors including the climate variables, the ground temperature, the water starting temperature, and how the process was managed. Mahadavinejad and Javanroodi, in their extensive study on the "Meybod" ice house, provide some equation on how the ice in ice house is provided (Mahdavinejad & Javanroodi, 2014).

"If we have a piece of ice in shallow ponds with a determined height, and some water with a diameter equal to "s", the following relationships can be expressed to determine the size of the ice made, where Eq 1 describes the cooling of water up to freezing point and Eq 2 describes the freezing of water in a layer of water at zero degrees" (Figure 138), (Mahdavinejad ,&Javanroodi, 2014).

Eq1:$(Qr1+Qe1+Qc1-Qs1)\Delta t1=pw*As*Cw*twi$
Eq2:$(Qr2+Qe2+Qc2-Qs2)\Delta t2=pw*As*hif$
Where:
Qr1:transitive heat of radiation
Qe1: transitive heat of evaporation
Qc1: transitive heat of convection
Qs1: transitive heat of water above ice surface
$\Delta t1$: Time to cool the water to zero degrees C
$\Delta t2$: Time to freeze the water
pw: Density of water
As: Area of ice surface in cavity
hif: Freezing enthalpy

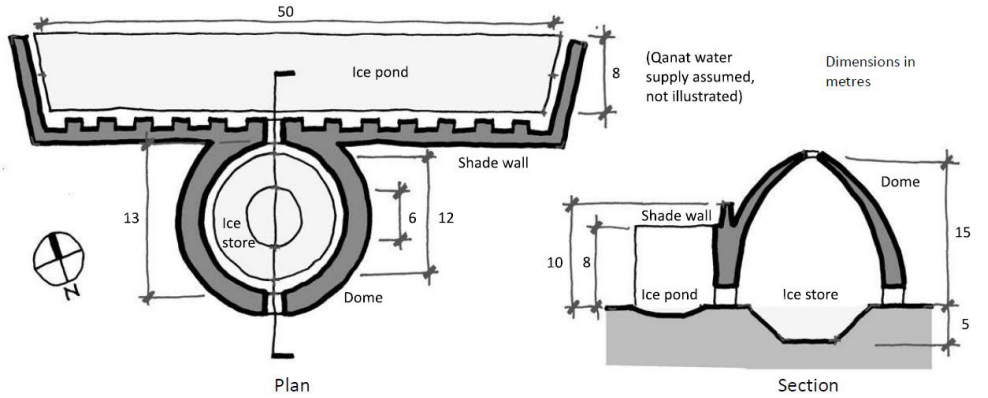


Figure 139: *Meybod ice house (Gobadian, 2011)*

Figure 140: *Right Top: Model predicted temperatures inside the dome for 3 days in June. Comparison between a Yakhchal made from traditional materials and another made from modern materials with superficially equivalent thermal properties (Poche & Gunstone, 2017).*

Figure 141: *Right Down: Ice storage model setup. The model runs an hourly simulation for a whole year to calculate the amount of ice melt from the store (Poche & Gunstone, 2017).*

twi: Primal temperature of the water
Cw: Specific Heat of waterTherefore, the size of the ice the can be made can be calculated from Eq 3.
$S'=pw * s/pi* \Delta t$
Where $\Delta t=\Delta t1+\Delta t2$

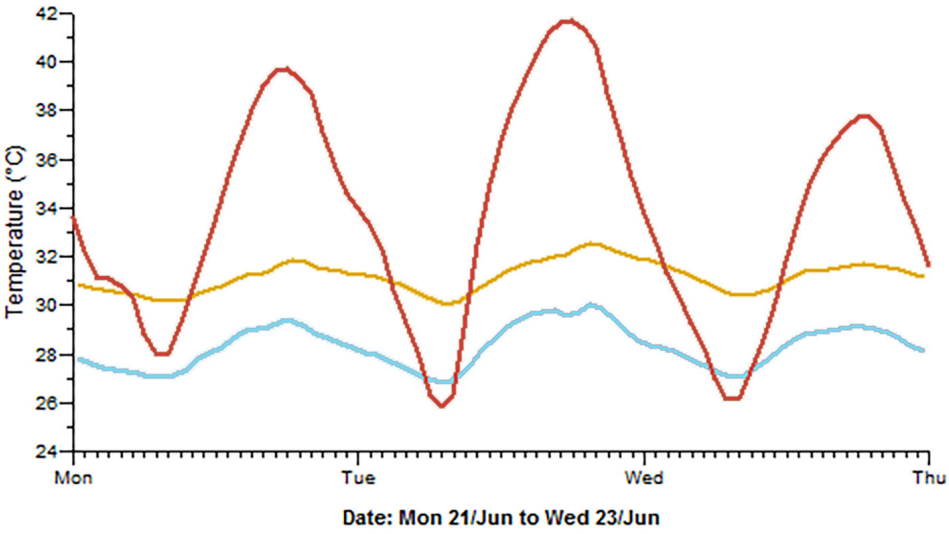
It is reported that Yakhchal ice production facilities were run both as community operations and as businesses selling ice (Namazian, 2012).

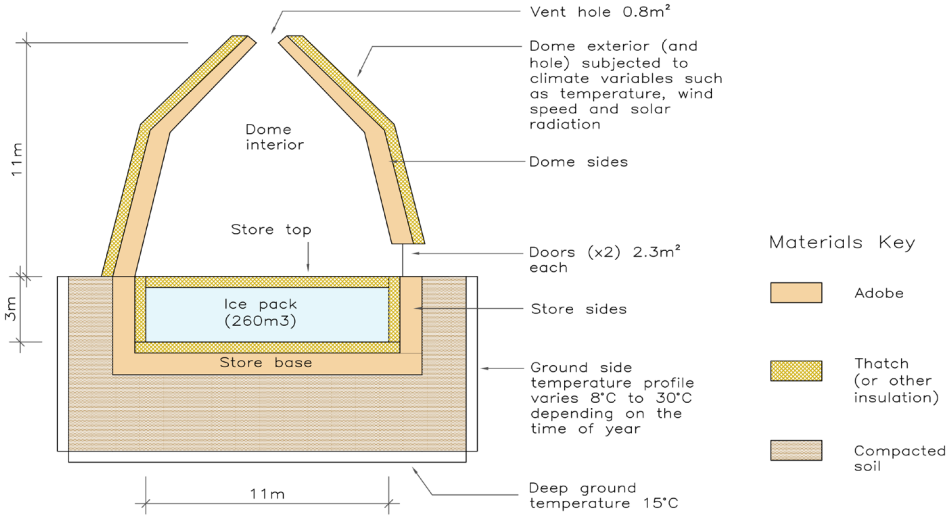
In either case the Yakhchal manager would be very keen to retain as much ice as possible, that is stop it from melting. The rate of ice melt within the ice store is determined by several factors including; the climate variables (temperature and sunlight intensity); the thermal properties of the Yakhchal structure and how the building was managed.

The ice house itself is designed to keep the ice frozen as long as possible by several means including thermal mass, insulation and evaporative cooling (Misfits' architecture, 2019).

Poche and Gunstone try to create a model for predicting the temperature inside the dome and compare it with modern materials. Their results demonstrate that the internal temperature was stable while the external temperature varied a lot (Poche& Gunstone, 2017).

Thick wall construction techniques such as rammed earth, stone or structural brick will superficially appear to have limited cooling properties, and may therefore


Temperature (°C)
42
40
38
36
34
32
30
28
26
24
Mon
Tue
Wed
Thu
Date: Mon 21/Jun to Wed 23/Jun
Internal temperature: Tradiational materials: 1m adobe + 1m thatch
Internal temperature: Modern materials: 0.1m concrete + 0.4m polystyrene
External temperature


Vent hole 0.8m²
Dome exterior (and hole) subjected to climate variables such as temperature, wind speed and solar radiation
Dome interior
Dome sides
Store top
Doors (x2) 2.3m² each
Ice pack (260m3)
Store sides
Store base
Ground side temperature profile varies 8°C to 30°C depending on the time of year
11m
3m
11m
Deep ground temperature 15°C
Materials Key
Adobe
Thatch (or other insulation)
Compacted soil

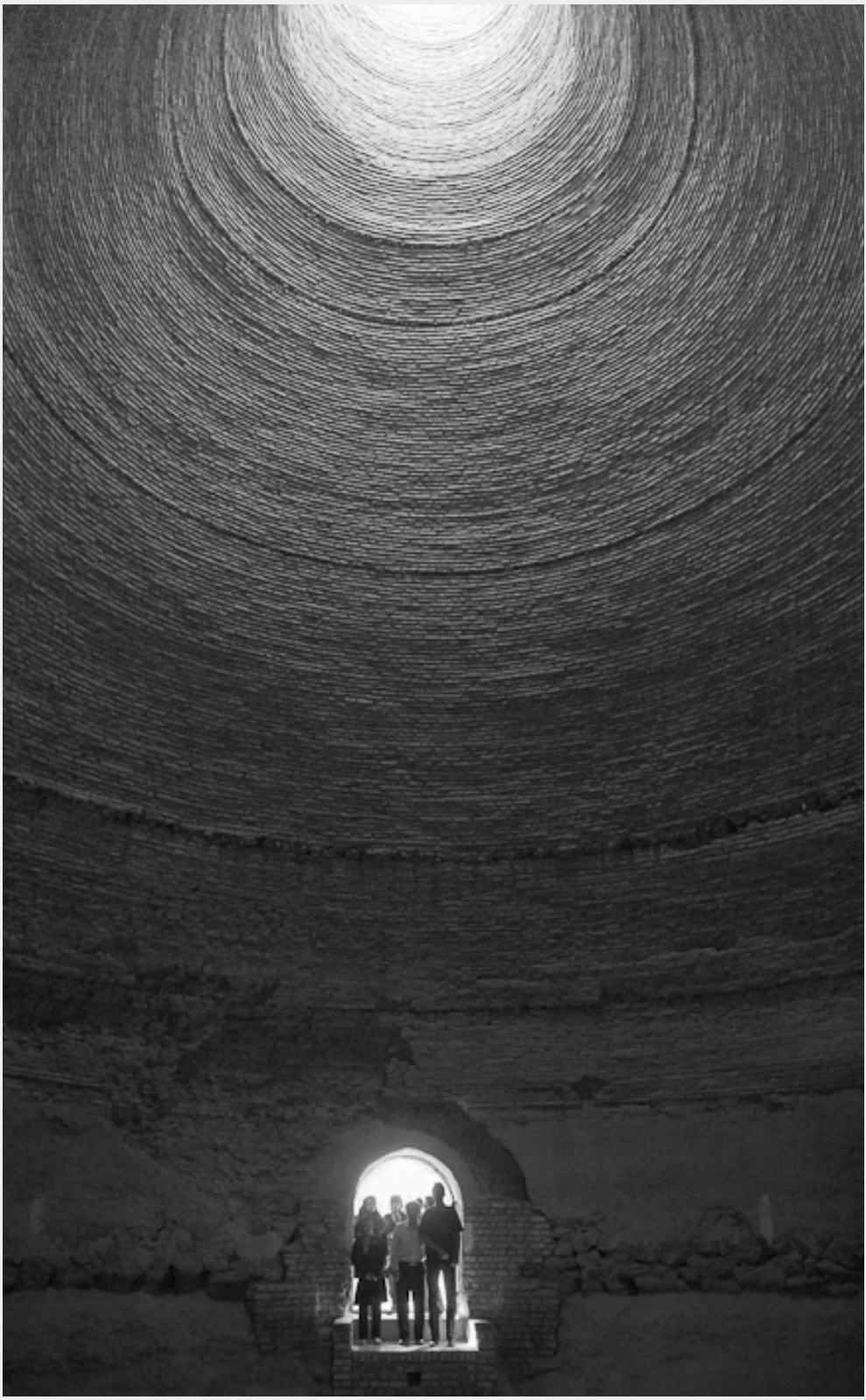
be hastily discarded as a design option. However, dynamic thermal simulation will reveal them to have higher cooling capacities than initially expected, due to their ability to store cold from winter to summer.

This accounts for another demonstration that this fusion of complex solutions with various entities such as qanat system, building materials and techniques has been efficient and resilient over the long period of time. Ernest Holster, who visited Iran in Qajar dynasty, describes ice house of Iran and their performances in the following:

"There were plenty of yakhchals in Iran; some of them were for private use. Nevertheless, the poor could also use the yakhchal to cool water. Sherbets and fruit were preserved with ice in all shops. Huge chunks of ice were carried by donkeys and sold all over the province. In Isfahan, people could buy ice either in the bazaar or straight from the yakhchal building" (Holster, 1897).

In such ice houses have spread across Iran in areas where the climate allows the freezing of ice on-site in winter, or where ice and snow could be brought from nearby mountainous areas (Poche, 2017).

Figure 142: *Abarghu ice house near Yazd, photo by Qunitin Lake*



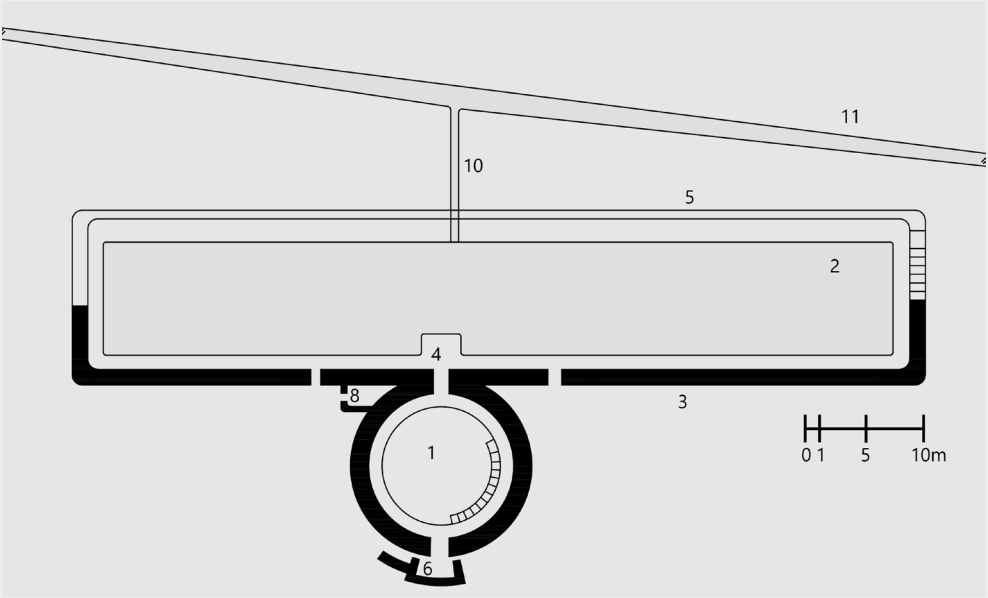
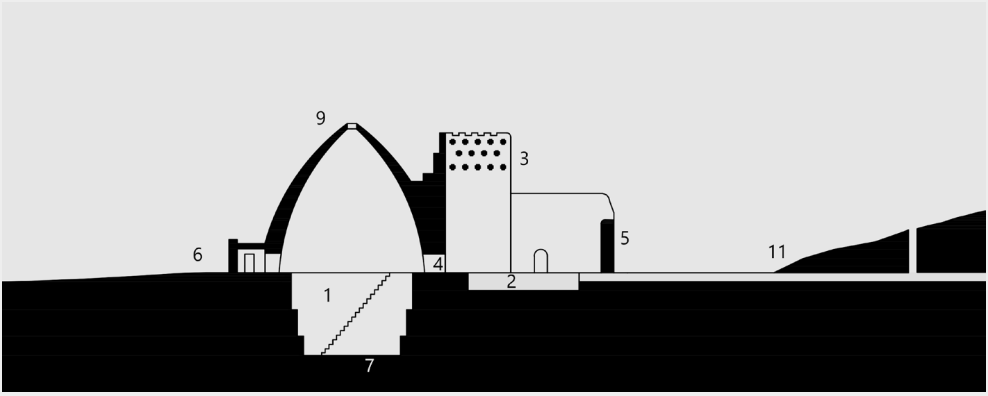


Figure 143: *An Ice House, plan and section, 1.Ice pit 2.Pool 3.Shading wall 4.Ramp for ice 5.Garden wall 6.Porch 7.Soak away 8.Shelter 9. Vent 10.Water channel 11.Qanat, drawing by M. Mahdavinejad, [redrawn by the author]*



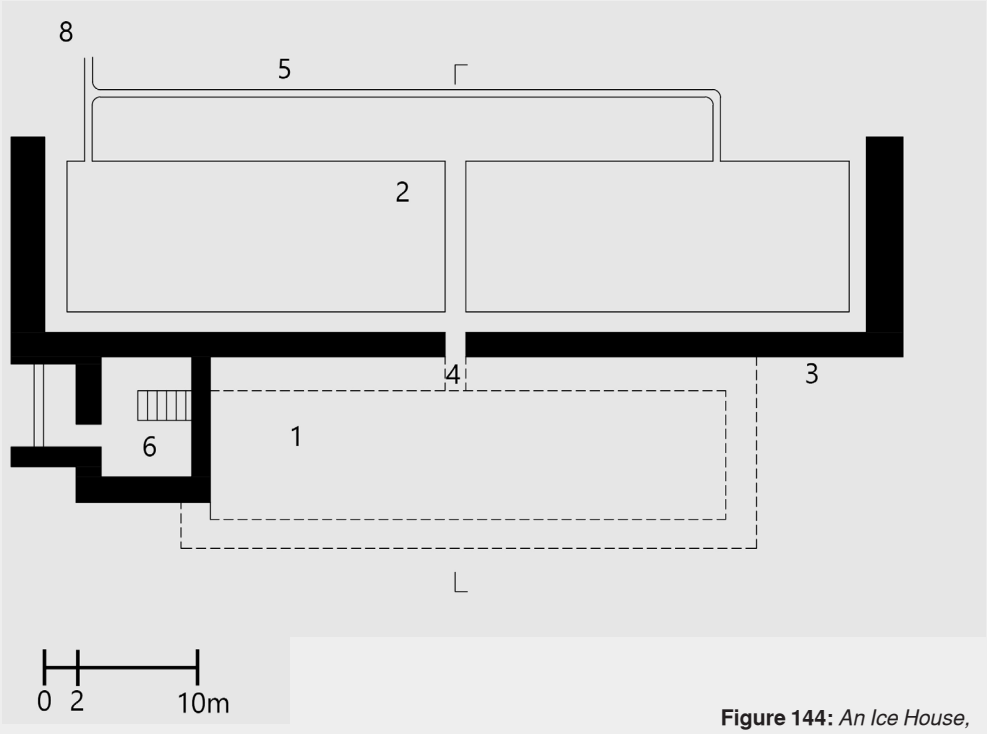


Figure 144: *An Ice House, plan and section, 1.Ice pit 2.Pool 3.Shade wall 4.Ramp for ice 5 Garden wall 6.Porch 7.Soak away 8.Water channel, drawing by M. Mahdavinejad, [redrawn by the author]*

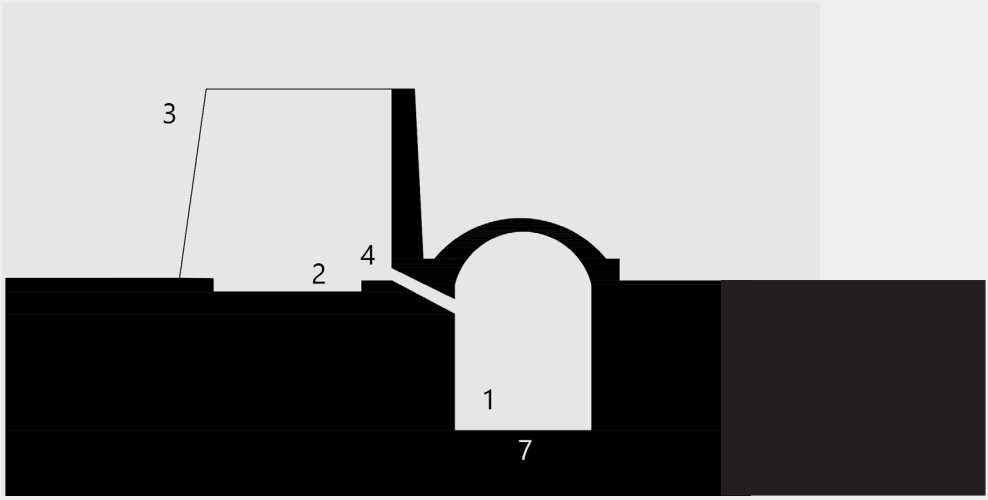


Figure 145: *Meybod ice house, photo by Mansur Alami*

Figure 146: *Meybod ice house, photo by Mansur Alami*

3.6 Courtyard House

Figure 147: *Lariha House in Yazd, photo by the author*

In hot-arid regions, houses with courtyards are a time-tested and valuable design pattern. This solution has been used from pre-historic times in central Iran, and back in antiquity other dry regions of the Middle East. Houses surrounding central yards are the most beneficial form for decreasing the exposure to harsh weather conditions. In desert regions, rooms facing out to the yard are usually protected against the extreme heat of the summer, the cold of the winter, and from wind, storms, and sand (Keshtkatan, 2011).

In this type of houses, nature is blended into people's lives. Families migrate to different parts of the house in different seasons. Thus, houses are divided into two parts, a summer section and a winter section.

In most houses in Yazd, the main living units face north-east. In the summer, this part of the house is shaded for most of the time. The winter section is placed across the yard opposite to the summer section. It offers the warmth of the sunlight during the winter (Keshtkaran, 2011). Houses with courtyards in the middle and two other sections that connect the summer area with the

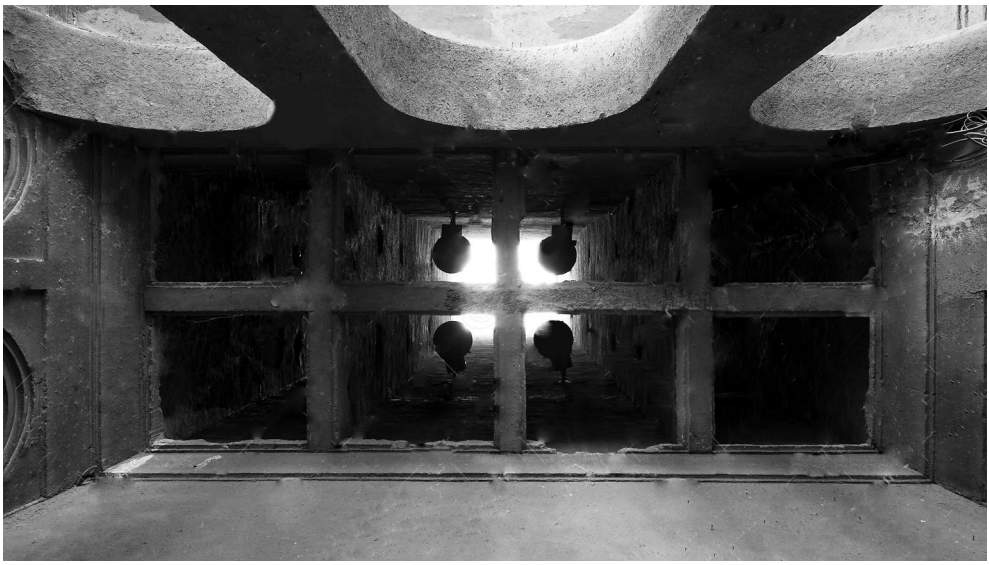


Figure 148: *Under the wind-catcher of Lariha House in Yazd, photo by Vahid Afsahinia*

winter area, are called four-season houses (Memarian, 1999). However, it is the summer section with Ivan that illustrates how of architecture protects people from harsh climatic conditions. The Ivan is a space used on summer evenings when the sun has passed below the front wall. It is usually three or more steps higher than the courtyard, often including a wind-catcher. This slight elevation also permits the basement to be ventilated through the vent placed under the steps.

"All parts of these houses including foundations, walls and roofs are of mud plastered adobe. Traditionally the adobe was made from the clay produced by excavation of the land on which the house was to be built in. The adobe walls are very thick, usually 70 cm but sometimes reaching 100 cm, and are covered with mud plaster. Roofs have two layers with a curved form inside which changes to a flattened form outside. The only opening of the house to the public area is the entrance door and all windows open to the central court" (Bonine, 1980).

Houses could have one, two or even multiple courtyards. The courtyard is usually a rectangle with its long axis rotated 30 degrees clockwise from the North. Houses are often built with one level above the ground and one underground although the latter is usually only

on the southern side of the court (Bonine, 1980).

Rooms have a variety of uses on different sides of the courtyard. In the larger houses, the northern side often has one big room, called "panjdari" (five doors) or "haftdari" (seven doors) (Memarian, 1998). This is the most decorated room, mostly used for guests. The western is the longest side, has several small sized rooms usually called "sedari" (Memarian, 1998). These rooms were used during the winter. In most houses, the eastern side has no rooms, in some cases it is lined with porches, which are good for summer morning use (Foruzanmehr, 2014).

The southern side holds a very big, high space called the "Talar" or "Shahneshin" which is used in summer (Kheirabadi, 1991). This side of the house often accommodate a wind-catcher in the back and a "Kolahfarangi" in the corner (a heightened space with a domed roof with several openings), which are both used for ventilation and cooling.

The underground level holds several rooms used mostly at noon in summer (Khajezadeh, 2016). Thus, in addition to the horizontal migration during seasons, the vertical movement is a solution to get a comfort habitat at different hours of the day. These movements show how deeply social behaviours are connected to natural order. The horizontal movement is due to seasonal change, but moving to the basement is the result of integration between house, wind-catcher and qanat infrastructure.

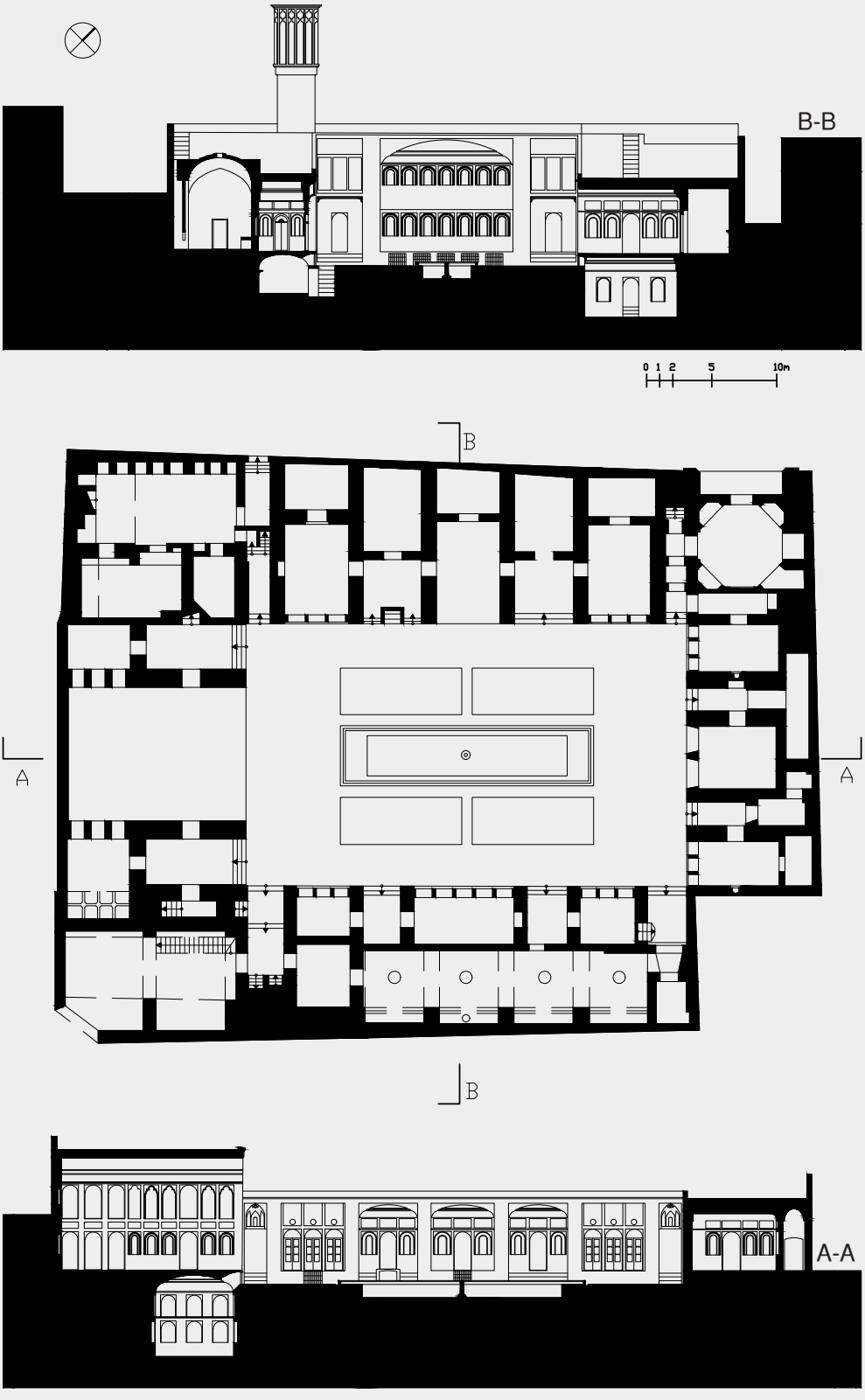
Figure 149: *Lariha House in Yazd, photo by the author*

Figure 150: *Lariha House in Yazd with one courtyard, plan and sections, mapping by hosseini, [redrawn by the author]*

Figure 151: *Malekzade House in Yazd with two courtyards, plan and sections, mapping by hosseini, [redrawn by the author]*

Depending on the direction of airflow at that specific location, wind-catchers convey fresh air to the interior of buildings to provide comfortable living conditions. In summer, Yazd receives a dominant north-west wind.

"Readings taken of the wind flow in over 19 hours suggest that the geographical location of the city on the fringe of the central desert strongly influences the diurnal pattern of flow with strong winds from the north west in the mid-afternoon, from 5.5m/sec - 9m/sec, veering round to the north in the evening and gradually tailing off by the early morning when the wind is negligible.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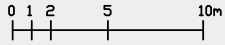
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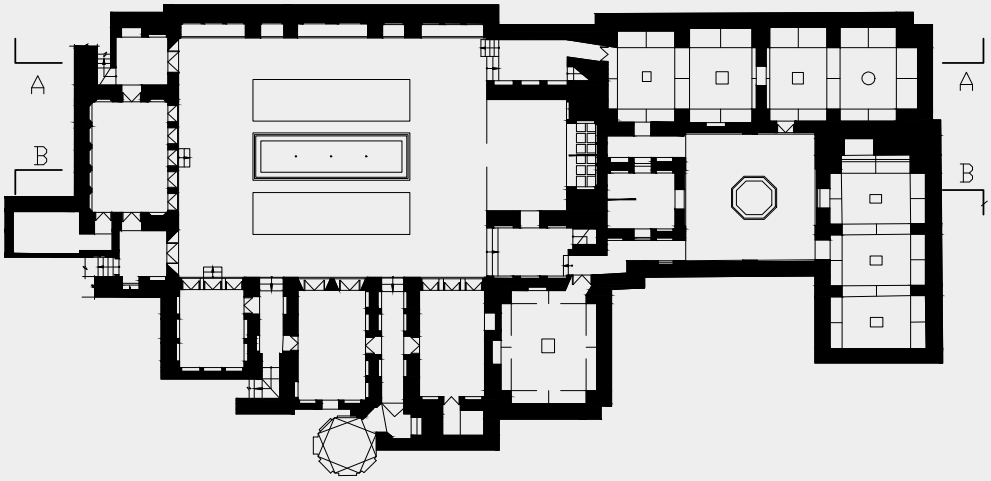
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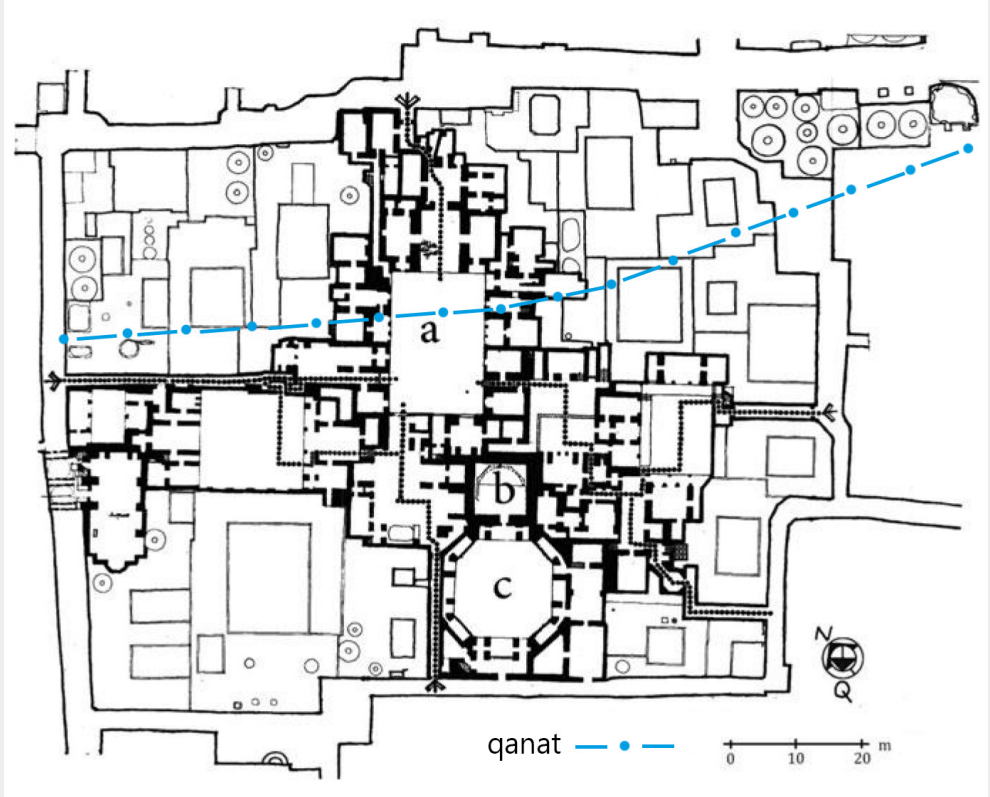
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As soon as the land mass begins to heat up, the wind increases in velocity and veers again to the north-west by mid-afternoon" (Roaf, 2015).

The evaporation caused by qanat water and the air circulation provided by wind-catcher causes a more comfortable climate inside the building and the courtyard (Karizi, 2011).

However, the relation of the courtyard house with its qanat, cannot be explained merely by use of climatic factors. In addition to the comfort provided by the payab and the wind-catchers, there is also a level of social interaction and status between qanat and house location.

Iranian scholar Mohammad Noghsan states that the closer the land to the qanat course the more it costed, since, this proximity would be accompanied by the priority of access to qanat's water and as a result water would have a better quality and sanitary. In addition to it, this juxtaposition would result usually in higher share of water due to the slope of the ground and water waste through its pathway. Both Michael Bonine and Mohammad Noghsan claim that during the urban growth, the residential areas have been built upon or near the cultivated lands (Bonine, 1979). In other words, the evolution of city was based on qanat infrastructure that cultivated land was replaced by residential units.

Cultivated lands are relatively more adjacent to the qanat and consequently, the ground is softer. Construction on soft ground is a great challenge; many problems and in various forms such as slope instability, bearing capacity failure or excessive settlement could occur either during or after the construction phase due to low shear strength and high compressibility of this soil. Thus, in order to overcome this problem, local builders need to dig deep to reach compressed soil that is capable of bearing the loads.

Deepening the ground imposes a great cost to the construction process. Furthermore, they substitute brick with mud in order the stabilize the ground. However, due to the scarcity of timber as fuel for brick kiln, brick

Figure 152: *Aerial photo of Yazd in 2010, from municipality of Yazd.*

Figure 153: *Detail of a urban block, built in 14th century, showing the role of qanat infrastructure in the placement of house: a. House, b. School, c. Religious building, (Tavassoli, 2018), [with modification by the author]*

becomes an expensive material in Yazd.

Overall, although the juxtaposition of houses to qanat results in a various advantages, those benefits come with a great cost. Thus, despite the fact that the compactness of urban pattern with its abstractness dilute the idea of social hierarchy, it is the vicinity to qanat infrastructure that indicates social status. The relation of qanat infrastructure with the placement of houses, demonstrate how deeply natural order and social order are interwoven.

Courtyard houses with their relation with qanat system has become a general typology in Yazd, however, sociocultural patterns that are embedded in them cannot only be explained by this relationship.

"In territories where religious practices and traditional beliefs are strong and deeply rooted, sociocultural variables such as religion, culture and customs might be strong parameters to determine the spatial arrangement" (Edwards, 2006).

Courtyard houses in Iran often are based on special principles. In fact, the physical features of traditional Iranian houses reflect natural, cultural needs and the occupants' requirements (Nabavi, Ahmad, Goh 2012). Culture and religious beliefs have been greatly concerned about the Iranian users to have a suitable dwelling to fulfil their requirements. This effect of culture on architecture has caused to organize plan distribution of the house in order to create privacy (Shabani et al, 2010). In fact, privacy is one of he most important concerns in an Iranian courtyard house. This notion has a particular expression in Yazd (Figure 154).

"Visual privacy has an important position in the Iranian courtyard houses and similar to the Arab-Islamic courtyard houses great care is taken to protect female members from the eyes of male strangers. The courtyard house is divided into two different parts, the birooni and the andarooni. Birooni, which means the outside area in Persian, is that quarter situated close to the main entrance. Birooni is traditionally a male area, where visitors (outsiders) or men guests would be entertained

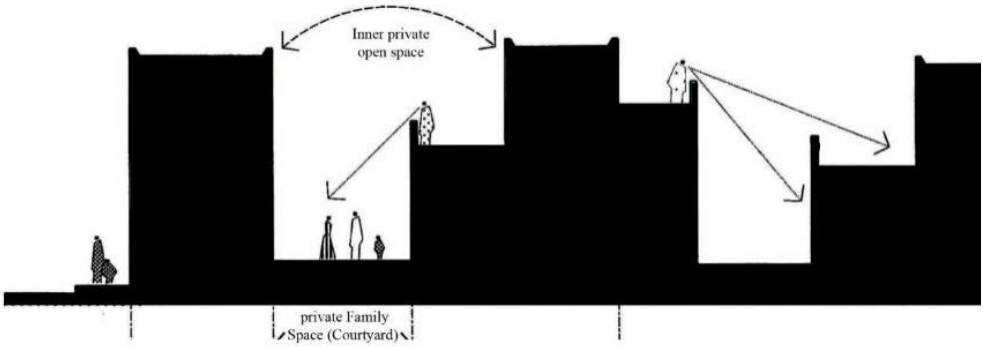


Figure 154: *A section through adjoining houses showing how setbacks are used to maintain privacy between neighbours (Edwards,2006), [with modification by the author]*

by the lord of the household. Andarooni, which means 'inside' in Persian, allocated for family members especially female ones. Of course in some events female guests are entertained in the reception rooms within the birooni. In large houses, there were separate servants for the two areas; female servants for the andarooni and males for the birooni" (Hosseini, 2014).

In fact, this characteristic is recognized in the first element as one encounters this type of houses. The entrance door has separate knocks for male and females. Women use the door knocker with a thin voice and men use the hammer knocker which has the stronger voice which leads to the gender limits (Figure 108)(Nosratpour, 2012).

This feature moves along and magnifies till the moment that the spatial arrangement of the house is formed. Hosseni states that through history, each society and ethnic has created and architecture that meets its own specific requirements (Hosseni, 2014). In Yazd there have always been different ethnics and with different religions that lived together and they create an architectural language of their own. These languages comply fully with the environment while trying also to answer the particular needs.

This is clearly demonstrated by the differences between a Zoroastrian and a Muslim house. While different sections in Zoroastrian houses have open spatial relationship, in Muslim houses the spatial relation is limited (Figure 156 and Figure 157). This is deeply rooted in

the differences between two religions. Despite the fact that privacy is a fundamental notion in both, Muslims tend to have higher level of isolation than Zoroastrians. As a result, this notion is rendered highly in Muslim houses.

In the study on climate and privacy in Iranian houses, Gholamhossein Memarian and Arezou Sadoughi provide a detailed analysis of the spacial relationship inside Rasoolian House in Yazd. Their analysis reveals that although harsh climatic conditions of the city have had a high influence on the orientation and spatial organization of the house, the spatial relation is deeply connected with social demands.

Four cycles can be drawn in the Rasoolian house reflecting the summer movements within the dwelling: 1. In the morning, activities take place in the eastern ivans or small verandas; 2. In the late morning movement is toward the basement where the inhabitants stay untill afternoon; 3. In the late afternoon and evening activities are concentrated in the talars and the courtyard, 4. The roofs are used as a cool place to sleep for the night (Beazly,& Harverson, 1982).

"Another relevant characteristic of this house is the separation of private and reception areas. The larger zone is the private area, while the smaller is the reception area. Seasonal movements occur in the reception area as well. Both areas have the same entrance and the two domains are linked by a vestibule with stairs leading to the roof" (Memarian & Sadoughi, 2011).

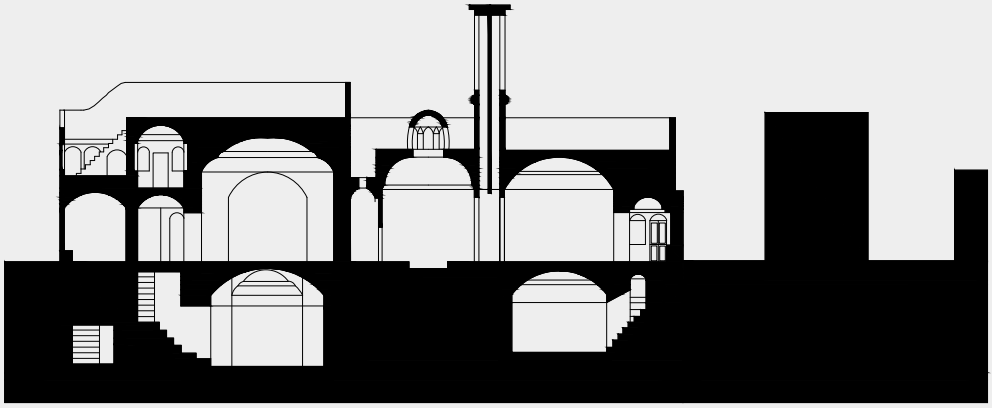
The access pattern to this house in different circumstances can be shown by graphs. The first one demonstrates a general graph without considering seasonal movements (Figure 158).

This graph consists of 64 vertices. The courtyards and vestibules connect a number of spaces, which may be considered the most active circulatory elements in all seasons.

Figure 155: *A south facing room in Yazd, photo by Luciano Napolitano*

The second graph shows the spatial relation without taking into consideration the reception area. *"In practice, this area is not used all of the time, but occupied*

Figure 156: *A Muslim house in Yazd with limited connections between family quarters. a. Family's private (Andaruni), b. Guests and men (Biruni). c. Small garden and men reception, d. Stable, (tavassoli, 2016), [redrawn by the author]*



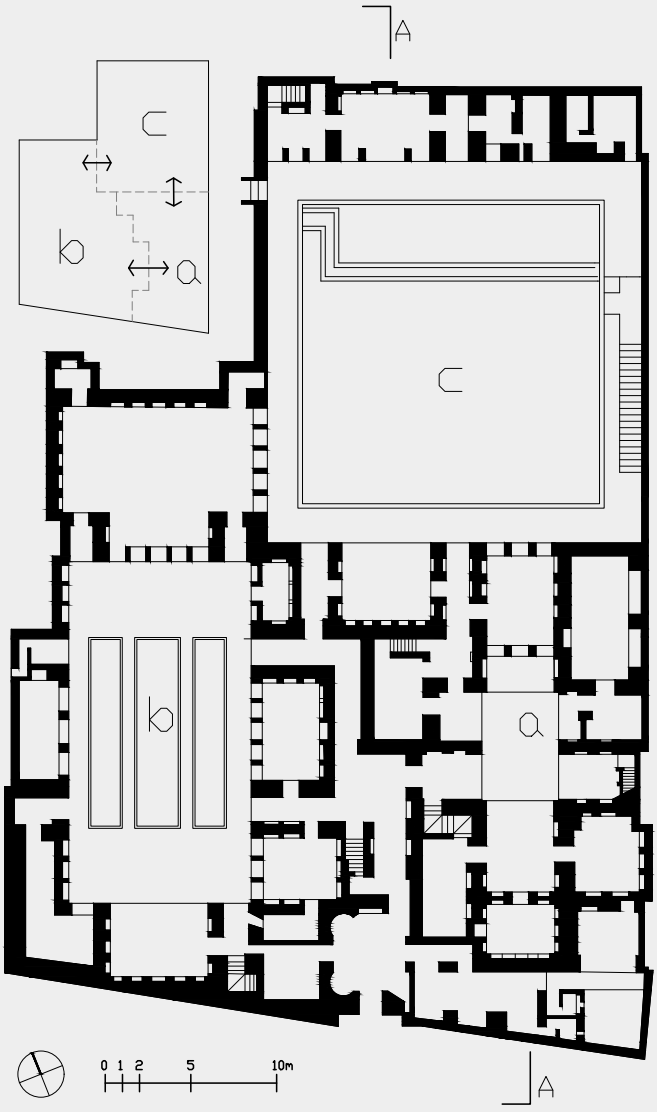
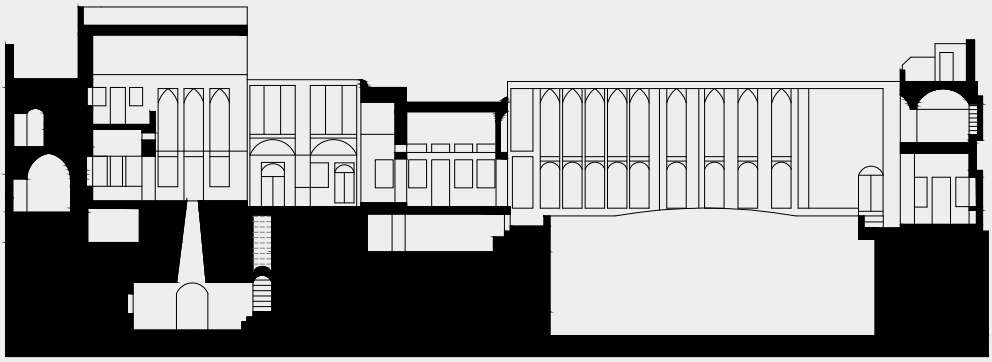


Figure 157: *A Zoroastrian house in Yazd with open spacial relation between different sections. a. Four Ivan court, b. Four season, c. Workshop garden, (tavassoli, 2016), [redrawn by the author]*



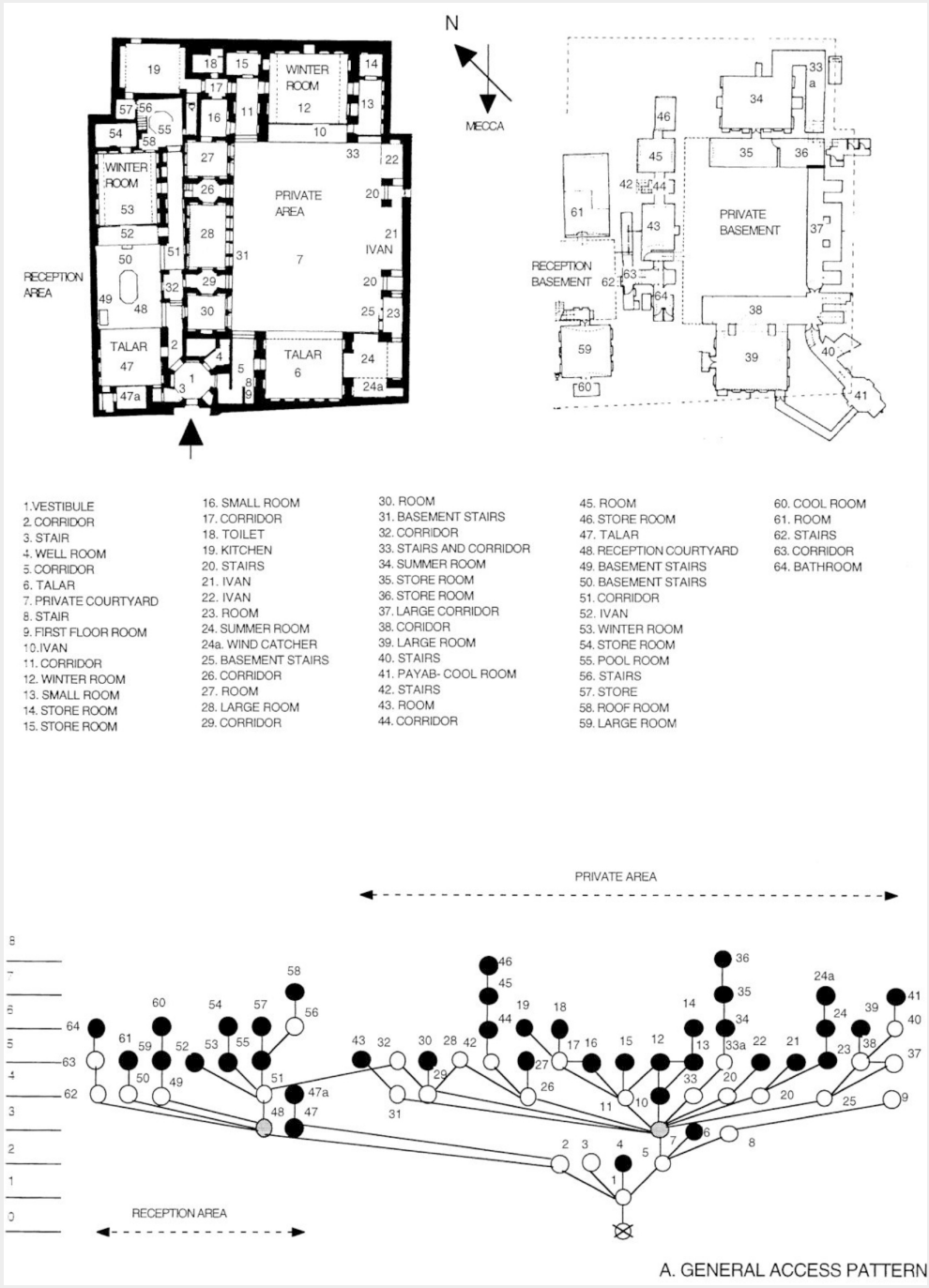


Figure 158: *Yazd, Rasoolian House, access patterns (Memarian & Sadughi, 2011)*

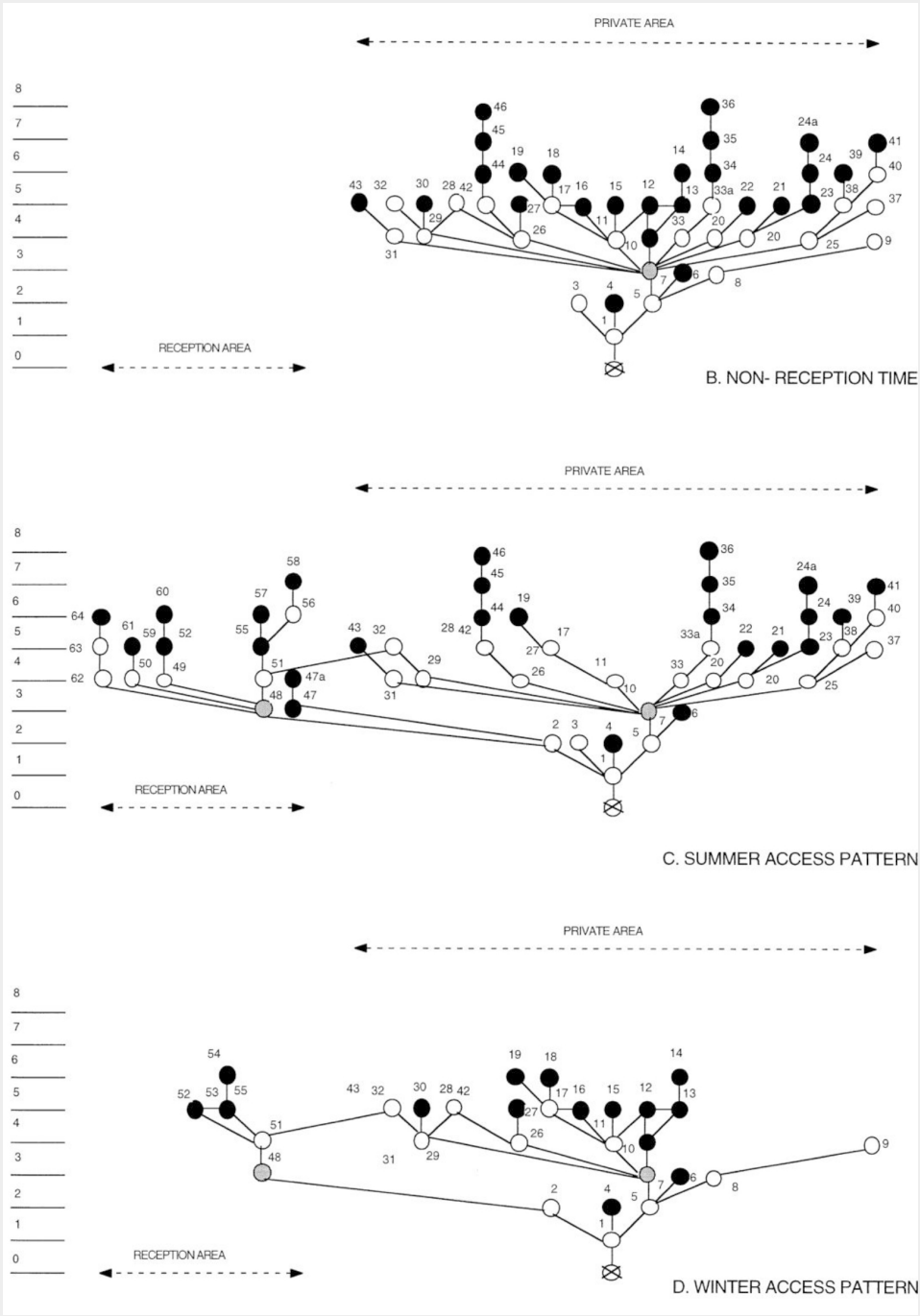
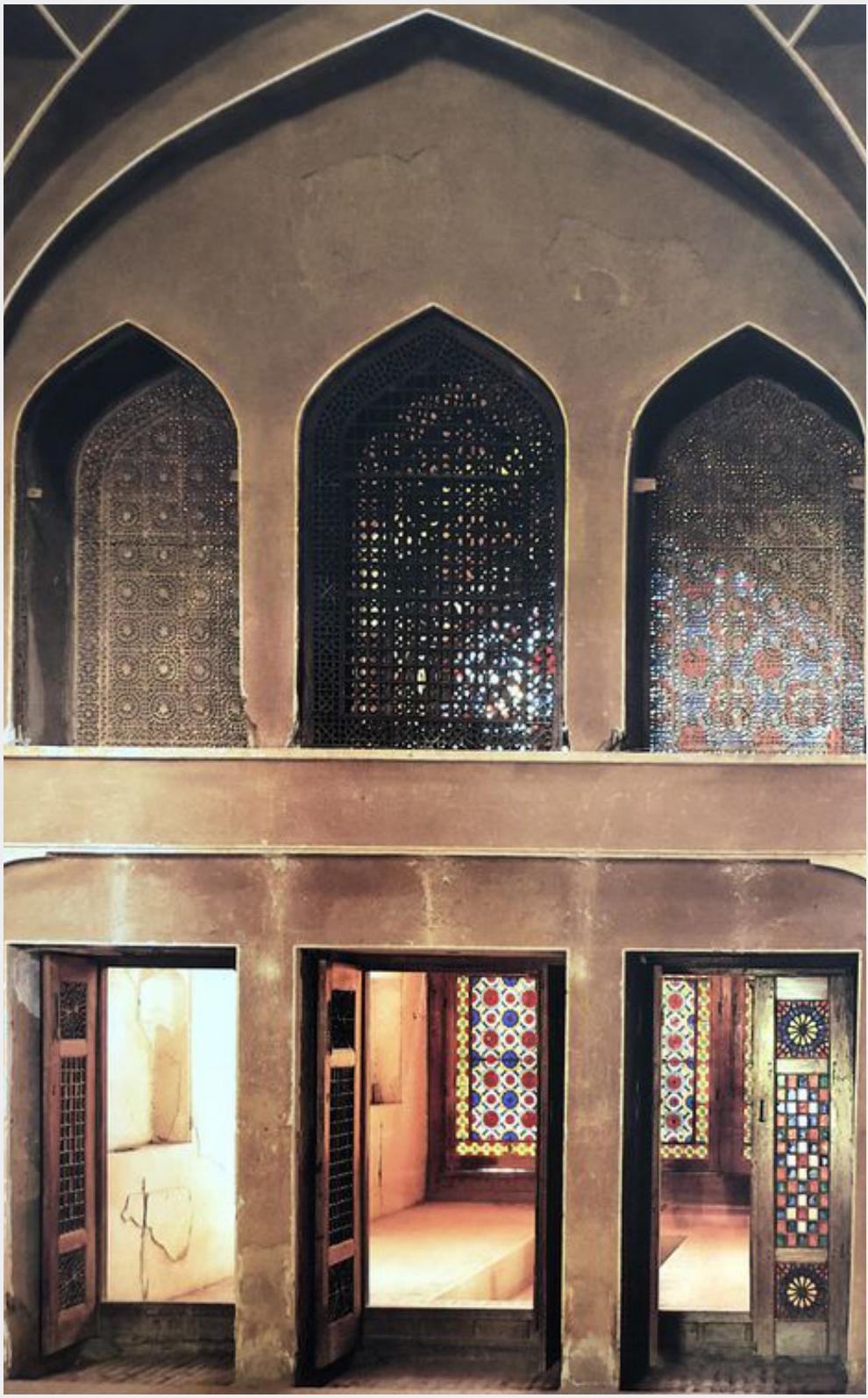


Figure 159: *Yazd, Rasoolian House, access patterns (Memarian & Sadughi, 2011)*



for limited periods only; usually on Iranian weekends, Thursday or Friday afternoons. Again, it demonstrates how time is an important factor which can influence the degree of segregation and integration" (Memarian & Sadoughi, 2011).

The seasonal graph shows some notable insights. The winter graph includes those spatial relations that take place between autumn and early spring; the summer graph represents the spatial pattern from the end of April until early autumn (Memarian & Sadoughi, 2011). *"The summer graph has 8 levels in the reception area and 9 in the private area. The deepest element in the reception area is the staircase that leads to the roof from the pool house. The deepest space in the private area is a room in the basement. The two deepest points in the private and reception areas are therefore related to the climatic conditions of the house. One reflects access to the roof for night use, and the other to a cool space in the basement for summer use. In the case of the winter graph, all those summer spaces on the south side and in the basement are ignored. Neither the large talars nor the Ivans are in use in this season. The winter graph has 7 levels in the private area and 7 in the reception area. In the deepest spaces are storerooms adjacent to the pool room. It is used as a cool room in the summer, probably for male visitors, which are not considered, here, as the most private spaces. As noted, in each season a number of spaces are completely segregated and others have varying degrees of integration"* (Memarian,& Sadoughi, 2011).

A spatial pattern of this complexity can only be properly interpreted by a very precise knowledge of the spatial organization for each season and time. In the courtyard houses of Yazd, the main objective is to create a comfortable and qualified spaces. Spaces that are not mere answer to functional or climatic demands. They are the product of constant adaptation,evolution and response to natural environment and social order.

Figure 160: *Rasoolian house, photo by Lani*

In-Between Territory and Artefact

Over the last decades, water as fundamental resource for life has gained momentum for scholars from many disciplines. To realise this, it may suffice to consider that "Water innovation" is one of the main focus areas of the "Climate action, environment, resource efficiency and raw materials Challenge" in Horizon 2020. In parallel, the built environment and the world population are currently called upon to face climate change, which, obviously, will have a great impact on the availability of water in many regions of the world.

Figure 161: *Covered street in Yazd, photo by Vahid Afsahinia*

As science and technology have progressed, many cities have taken distance from close intimacy with natural resources, namely water, and in many cities have even turned their back on water systems as a whole (Hubert, 2018). Town planners intend to restore the relation between hydraulic system and planning.

Christian Piel, urban planner and hydrologist who represents this viewpoint, intervenes in the areas associated with water and the city, by approaching water like a tool for structuring the urban environment, and the nature like a tool for preventing the risks of fluvial or rain flooding in urban areas. In the project "Deh-Sabz", Piel and his team try to optimize the presence of water in the city, both in terms of risk and resources, by fusing the resources and storage methods and usage (Piel, 2018). Ali Chavoshian, Iranian urban planner has

similar points: in his article "toward blue-green plan in Teleghan city", he proposes a blue-green method by taking into account not only the city, but also water and inhabitants. (Chavoshin, 2018).

Water for engineers, is still an opportunity or a constrain in between different factors involved in the final design or construction: In recent years, Jose-Frederic Deroubaix, French engineer from Ecole des Ponts ParisTech, has focused more particularly on the dissemination processes of wastewater and storm water management models and their appropriation by users, flood management and urban planning in the city: The question of the user's place in policies of preservation of the water resource.

On the other hand, the viewpoint is different for architects; Gazal Banan, architect from BOM design agency, Paris, interprets water as our "common good" or "collective memory". She states that Yazd testifies how civilizations deal with limited resources and overcome constrains. These restrictions created artefacts based on water which exceeded their mere function and became gathering spaces, deeply rooted in the city's inhabitants' memory (Banan, 2018). This research argues in favour of this view point. However, it is essential to understand that these artefacts are part of a larger system and are interwoven with the urban pattern and the qanat infrastructure. It is through a deep interrelationship between them that results in forming this "collective memory".

The relationship is not a mere answer to physical demands. The social order is an inseparable part of Yazd built environment. Ayda Alehashemi, an Iranian landscape architect, who has studied qanat system in various Iranian cities, in her article "rethinking the multidimensional integration between water networks and urban structures in Iran" states that the key solution to gain the multidimensional integration between water networks and urban structures is to consider both physical and non-physical facets. Which means consider this integration not only in the master planning but simultaneously in the social, cultural, educational

and economic sectors in the city (Alehashemi, 2018). Thus, it is the multi-scale integration of natural and social order that results in a complex system. A system that while each part has its own identity and character, it has a essential role in the whole. Therefore, as each element respond to the social and physical demands, the whole system becomes fully integrated with them.

With the current trend of technological sophistication, it may be envisioned that by the end of the 21st century even the poorest human beings would enjoy the basic needs of life, nonetheless, reaching this status may involve unthinkable human suffering. Furthermore, according to climate scientists, more floods and droughts would be very likely in the 21st century (Emami, 2015).

Yazd has been suffering from the drought in the past years and qanat system is greatly vulnerable to this natural phenomenon. Although, drought and other natural hazards were always present, the system has continued to benefit societies. However, introducing the modern technologies has amplified the effect of natural conflicts.

In 1940, 100 % of water usage of Yazd was provided by qanat system and fountain while this number drops down dramatically to 19 % in 2015. Consequently, deep wells with 54 percent and semi-deep wells with 27 percent of share replaced the qanats (Semsar Yazdi, 2018).

The drop of the underground water table could be interpreted as the main item that puts the system at risk, but it is not always by means of drought or deep wells. One of the disadvantages that is attributed to the qanat system is the low income obtained through it. the lands irrigated by qanats are usually cultivated in a traditional manner with a low efficiency and in addition, the cost of this production is remarkable and a relatively high share of this cost is allocated to the maintenance of qanat (Semsar Yazdi,& Labbaf Khaniki, 2013).

Governmental policies have played a key role in qanat life span, since government were deeply dependent on qanats water supplies (Bartold, 1970), (Khosravi,

1969). For example the "white revolution" that was a far-reaching series of reforms in Iran, launched in 1963 by Shah Mohammad Reza Pahlavi that lasted until 1979 resulted in significant Land reforms and social changes (Abrahamian, 2008).

These reforms had a great influence on land ownership and water management systems and as a result, the "bone" system that in brief is an agricultural unit on which have some right to work cooperatively, lost its function (Semsar Yazdi,& Labbaf Khaniki, 2013). As such, it is important to bring to the light that qanats not only in Iran and particularly in Yazd are in danger. This is a common issue between societies that has benefited from the system. As Pietro Todaro mentions that today, interest in ingruttati (qanats) of Palermo is only cultural and touristic because they have lost the hydraulic function for which they were built.

Qanats demonstrate the long relation between culture, nature, artificial landscape and built environment and they can be regarded as a collective response of human communities to the environmental conditions. Nonetheless, in the case of Yazd, there is only one active qanat that passes through the city (Kazemnejad, 2018). In the new urban development some ignore the fact that annihilation of qanats could result in an end for a long history of traditional knowledge. The knowledge that still can be used as a tool to encounter the existing challenges more effectively (Semsar Yazdi, A. 2018).

In the past 40 years, with the phenomenal urban growth and annihilation of qanat system, new urban areas in Yazd have dramatically increased, while the integration between artificial, natural and inhabitants no longer exists.

The expansion of urban land between 2000 and 2009 almost equals all urban land developed during Yazd 2000 years history. This form of development shows a disordered pattern that, among other impacts, reduced spatial unity (Keshtkaran, 2011). Since 1975, and in addition to rapid expansion, urban growth has remained disproportional, scattered and leapfrogged. Also, such rapid and unplanned growth has created

important problems such as lack of enough services and facilities for the residents, insecurity, increase of commuting length and local climate change, among other matters (Halbwachs, 1992).

Although there is a need for in-depth reading of new urban areas in Yazd, the lessons learned from (re)reading of historic city could be a fundamental apparatus in understanding urban sprawl strengths and weaknesses. The cross-disciplinary / multidisciplinary approach applied in this research could be embraced as an undeniable factor for future design in all its scales and social meaning and significance. Since the approach taken in this research, focuses on the integration of people, nature and objects and the appreciation of how social relations are mediated through artificial and natural, it could be applied in calibrating the architects intake on contemporary planning and city management.

In 2005 and upon the decision of UNESCO member states, ICQHS (International Centre on Qanats and Historic Hydraulic Structures) was established under the auspices of UNESCO in Yazd (Ghafori, H. 2015). ICQHS also held a workshop in Yazd in 2015, trying to build upon the last one in order to investigate more into the questions around historical, social and technical evolution of qanat, and to exchange ideas on how to help qanats survive the ongoing global changes. In addition to ICQHS, IPOGEA Traditional Knowledge Center is encouraging the further study, conservation and rehabilitation of qanats and, more broadly, facilitating the search for ways to incorporate modern advancements with traditional knowledge about water resources management.

In 2013 international Water Association (IWA) held its first workshop on "Traditional Qanats Technologies" which took place in Morocco. The aim of the workshop was mainly to explore the technical values of qanats and its engineering heritage left for our generation to build a more sustainable future.

The latest international workshop "water and city; hydraulic systems and urban structures" that was hold in Yazd in 2018, perused identifying today's issues,

solutions and achievements in the relationship between water and city.

These recent workshops and other studies, such as enhancing economic efficiency of qanats, done by Semsar Yazdi and Labbaf Maleki, try to make room for qanat in the realm of modernity.

However, at the same, architecture and design are splitting up into a wide range of fragmentary competences, from sustainability to energy efficiency, adaptive reuse and etc.

Against this background, the notion of resilience, that is the intrinsic ability of a system to overcome critical situations, has pushed many scholars into the concept of built-in resilience. Lee Bosher defines built-in resilience as a quality of a built environment's capability (in physical, institutional, economic and social terms) to keep adapting to existing and emergent threats. This definition is based on the assumption that the built environment is currently facing new emerging catastrophes and requires relatively new solutions. Recent natural and human-induced events have highlighted the fragility and vulnerability of the built environment (Hamelin & Hauke 2005).

In addition to those lines of research, there have been many studies and practices to build a system that is resilient through various notions. In many cases such as Peter Cook's proposal in Archigram, the artificial tried to substitute the natural.

"Plug-in City" was proposed in 1964 by Peter Cook. It presented an enthralling new approach to urbanism, rethinking of traditional perceptions of infrastructure role in the city (Merlin, 2013). This confrontational project proposes a visionary movable city, consisting of modular units operating as residential units or services in which they are plugged into a central mega infrastructure. The Plug-in City is in fact an evolving machine that its constituting elements are all movable by giant cranes and the "craneway" facilitates continual rebuilding. Peter Cook proposes that to do the revision on our traditional cities, we must put our emphasis on

the infrastructure. He tries to bring to the fore the notions of gradual infill, replacement and regeneration of parts plugged-into the mega-structure with a specific kind of activity. His proposal offers a seductive vision of a glamorous future machine age; however, social and environmental issues are left unaddressed.

Despite the fact that Cook's proposal is futuristic and looks for new notions in the urban planning, his ideas may be considered that are rooted in the past. The plug-in city is important, since it brings up fundamental notions that are also present in forming the backbone of Yazd. He emphasises on the infrastructure as the initial phase of his project-based city and afterwards, units, each with a specific function, are plugged-in to the infrastructure. Finally, the urban layout is formed by gradual infill of residential units in-between the infrastructure and plugged-in units. This clearly happens in the case of Yazd, with the importance difference that in Yazd, firstly, artificial do not replace the nature, and secondly, social order is an inseparable part of it.

Cook's plug-in concept looked into architecture as an event that could only be realized by the active involvement of inhabitants and he insisted on the idea of architectureness and neatness in his proposal. However, on the contrary, his idea to build a resilient city was challenged because of lack of integration between nature, people and different disciplines, namely architecture.

Kohler and Hasller consider the built environment as an artefact in an overlapping zone between culture and nature (Kohler,& Hasller, 2014). Artefacts that have existed over long period of time can be considered as intrinsically resilient. In other words, the built environment is a long-term document of adaptation, response and evolution in history. Thus, assessing resilience in built environment demands an in-depth understanding of the expertise and knowledge that is embedded essentially in existing cities.

The adaptation, evolution and response is well presented in the case of Faculty of Architecture in Yazd. It started as a clustering process in which adjacent houses accumulated new set of programmes. Despite the fact

that the programmes are new, diverse and essentially different from the original ones, the pre-existing spaces are tailored to meet the requirements. This pragmatic example shows how while each one of these houses is a complex system of its own, it is a part of bigger one. The systems that at their core are intrinsically resilient artefacts. They embody an active relationship between form and function which results in creation of meaningful architectural spaces. These artefacts maintain their form and adapt their function to current needs over time, remaining a vital element in Historic city of Yazd.

The key notion in understanding historic resilient cities is to unveil relations that are articulated through narratives which connect disparate pieces and integrate them into a unified and apparently coherent whole. These relations could be interpreted as structural themes and design topics in order to set design concerns and guidelines/priorities for contemporary planning. This approach may search for new meanings in existing typologies and find how to adapt them to contemporary scale and requirements without loosing existing qualities.

Annexes

Mapping Urban Change

The following table[1] shows the urban change of Yazd from the Muzaffarid era (14th century) to the Qajar era (20th century). The review of the urban change of the city indicates that development and evolution have been important characteristics of Yazd in different periods.

Today, the existing city may be regarded as the result of long process of urban growth. The development outside the city walls permitted the city to expand and accommodate new set of programmes such as bazaar in Muzaffarid era, public squares in Safavid era (16th to 18th century) and creating new neighbourhoods in Qajar era. On the other hand, the development inside the city walls was more focused on consolidation process like completion and expansion of Jame Mosque, or building housing units in empty plots (often former cultivated lands). This can be seen as a continuous process in all the eras, which resulted in the physical development of the city.

Figure 162: *Jame Mosque of Yazd, photo by Mariette Quentin*

1 This table is based on the research "Yazd physical development from 11th to 19th century" done by Mohesn Abbasi Harafte in MEMARI - VA- SHAHRSAZI (2015), [translated by the author from Persian to English].

Muzaffarid era
(14th century)

Development Type	Actions Taken	Actions Type	Actions Results
outer development	formulation of new communities	new construction	expansion
	attachment of some outer communities to city		expansion
	construction of public buildings	new construction	expansion
	construction and completion of fort	new construction	completion
	construction of three gates	new construction	completion
	construction of Bazaar	new construction	completion
	development of north-south axis	new construction	completion
	axial development		evolution
	development with extending and demolishing gardens	reconstruction	expansion
inner development	construction of public buildings	new construction	completion
	construction of Bazaar adjacent to Jame Mosque	new construction	completion
	construction around Jame Mosque and making it the city centre	new construction	completion
	restoration of fort	restoration	consolidation
	completion and development of Jame Mosque and other public buildings	renovation	completion
	restoration and renovation in deteriorated parts	restoration renovation	completion consolidation
	construction of housing units	new construction	completion consolidation

Development Type	Actions Taken	Actions Type	Actions Results
outer development	formulation of new communities	new construction	expansion
	formulation of a new city centre (Amrichaqmaq)	new construction	evolution
	construction of public and governmental buildings	new construction	evolution
	connection of suburbs to city	new construction	evolution
	construction of Bazaar	new construction	completion
	deepening the ditch	new construction	completion
	axial development towards south and south-west		completion
	formulation of new trade axis (east-west)	new construction	evolution
inner development	construction of Bazaar and revival of north-south axis	new construction	completion
	restoration of houses and public buildings	restoration	consolidation completion
	completion and development of Jame Mosque and other public buildings	renovation	completion
	restoration and renovation in deteriorated parts	restoration renovation	consolidation completion
	construction of various buildings	new construction	completion
	new construction by demolishing deteriorated parts	new construction	completion consolidation

Safavid era (16th to 18th century)

Development Type	Actions Taken	Actions Type	Actions Results
outer development	formulation of new communities	new construction	expansion
	formulation of a new city centre (Shah Tahmasb square)	new construction	evolution
	connection between new centre (Shah Tahmasb square) and old centre (Amrichaqmaq) and revival of east-west axis	new construction	completion
	axial development towards west, south and south-west	new construction	evolution
	development with extending and demolishing gardens	reconstruction	expansion
inner development	construction of gates	new construction	completion
	construction of public buildings	new construction	expansion completion
	formulation of religious buildings	new construction	evolution
	completion and development of Jame Mosque and other public buildings	renovation	completion
	restoration and renovation in deteriorated parts	renovation	completion consolidation
	demolition of citadel and construction of a community	reconstruction	evolution
	construction of housing units	new construction	completion consolidation

Development Type	Actions Taken	Actions Type	Actions Results
outer development	formulation of new communities	new construction	expansion
	formulation of a new city centre (khan complex)	new construction	evolution
	construction of public buildings	new construction	expansion
	construction and completion of fort	new construction	completion
	development towards north-south trade axis	new construction	expansion
	development with extending and demolishing gardens	reconstruction	expansion
inner development	construction of public buildings	new construction	expansion
	completion and development of Jame Mosque and other public buildings	renovation	completion
	restoration of fort	restoration	consolidation
	restoration and renovation in deteriorated parts	restoration renovation	consolidation completion
	construction of religious and commercial buildings in-between existing fabric	new construction	completion consolidation
	regulation and organization of previous city centres	renovation	completion
	construction of buildings with new progammes such as post office and telegraph	new construction	evolution

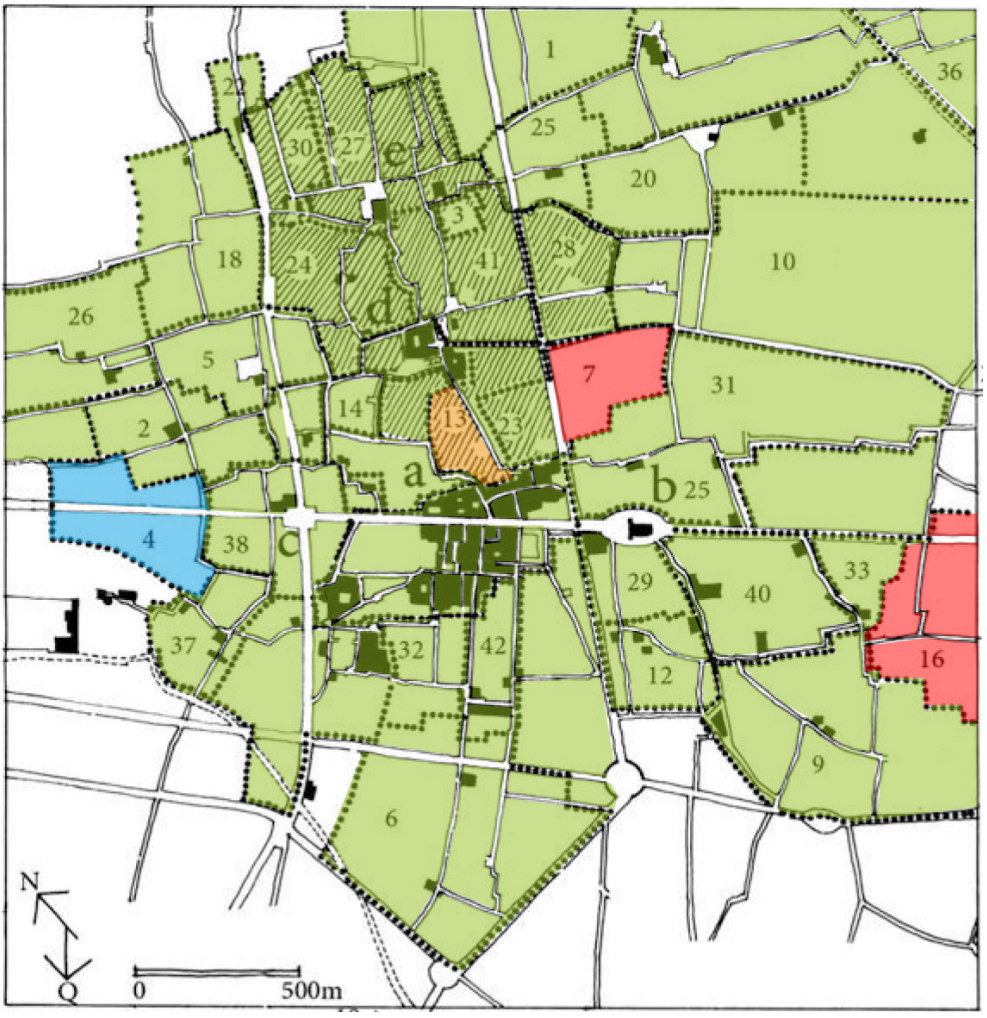


Figure 163: *Division of city into neighbourhoods each is shown by dotted lines: green represents Muslim neighbourhoods, red accounts for Zoroastrians, Oranage for Jews and Blue goes for Turkmans, h, a: bazaar, b: Amir Chakhmaq, c: Shah Tahmasb square d: Jame Mosque e: Alexander Prison, (Tavassoli, 2018) [Modified by the author]*

1.Abe Shur 2.Abolmaali 3.Bazaar-e-No 4.Bagh-e-Sandal 5.Bagh-e-Gandom 6.Posht-e-Bagh 7.Pir-e-Borj 8.Takht-e-Ostad 9.Tal 10. Ju Hor Hor 11.Char Minar 12.Khaj-e-Khidar 13.Dar Al-Shafa 14. Darvaz-e-Shahi 15.Do Minar 16.Zardoshtiha 17. Sar-e-Polk 18.Sar Cham 19.Sar-e-Dorah 20.Sar Sang 21.Sarsabil 22.Gol-e-Sorkh 23.Fazel 24.Shah Abul Qasim 25. Shahed Baz 26.Shaykh Dad 27.Fahadan 28.Qaleh-e-Kohne 29.Bagh-e-Gandom 30. Kooshk-e-No 31.Gazorgah 32.Musallah 33.Lard-e-Asiab 34.Lard-e-Kaywan 35.Malamir 36.Maryam Abad 37.Moltakiyah 38.Meydan-e-Shah 39.Amir Chakhmaq 40.Nazar Kardeh 41.Vaqt Va Saat 42.Hashim Khan 43.Yaqubi

Mapping Yazd's Neighbourhoods

Neighbourhoods in Yazd are urban expanses whose residents have gathered around each other based on ethnical, lingual, religious and professional commonalities and have made a homologous and coherent community. Such an issue is exemplified in the history of districts. For example inhabitants of Posht-e Bagh district were mostly coppersmiths but in Tal and Khorram shah districts they were mostly builders, Sahl ibn-e Ali and Golchinan districts are inhabited by merchants and weavers used to live in Fahadan and Shah Ab-ol-qasem districts. Also religious minorities like the Jewish society were mostly concentrated in a specific area (located south of the Jame mosque) with its own synagogue as well as its exclusive elements. On the contrary, Zoroastrians used to dwell and still reside in various districts such as: Khalaf Khanali, Khorramshah, Naeim Abad, Aharestan, Koocheh Boyuk, Nersi Abad (Nasr Abad), Tal district, Eysh Abad, Kheir Abad and Kasnavieh.

Each neighbourhood takes its shape based on the juxtaposition of residential houses around its focal point. Narrow alleys and paths provide linkage between houses and centres of districts. Neighborhood relations strengthen such commonalities and increase the sense of belonging to the neighbourhood.

Although the centre of each neighbourhood is easily distinguishable, no definitive borderline can be specified for each district. In fact, their margins overlap each other with only the centre or the focal point of them being vividly discernible. Thanks to the sense of belonging which people show, vitality is seen within neighbourhood despite urban development.

Amongst all the neighbourhoods of Yazd, 19 of them are placed inside the core zone of the city.

Neighbourhood Name	Construction Period	Ethnics (Religion)	Occupation	Related Qanat	Main structures
Abshahi	15th century	Zoroastrian Muslim	Agriculture	Nasim-Abad	Jame Mosque Water reservoir Public bath
Abeshur	14th century	Muslim	Agriculture Fabric weaving	solghor-Abad	Mausoleum Mosque
Abolmaali	15th century	Muslim	Fabric weaving	Zarch	Mosque Tomb Public bath Water reservoir School
Akbar Abad	20th century	Muslim	Agriculture Animal husbandry	Nasim-Abad	Mosque Public bath Water reservoir
Imam Zadeh Jafar	12th century	Muslim		Narsu-Abad	Mosque Caravanserai Water reservoir Shrine
Amir Chakhmaq	16th century	Muslim		Zarch Medi-Abad Dehuk	Bazaar Mosque Caravanserai Water reservoir Mausoleum
Aharestan	16th century	Muslim	Agriculture Animal husbandry	Taft Nasiri Vaqf-Abad	Mosque Water reservoir
Bazaar-e-No	16th century	Muslim	Fabric making Dyeing Carpentry	Mollabashi	Mosque Public bath
Bagh-e-Sandal	14th century	Muslim Turkman	Fabric weaving	Narsu-Abad	Mosque Bazaar
Bagh-e-Gandom	14th century	Muslim	Agriculture Fabric weaving	Zarch Mollabashi	Mosque Water reservoir Mausoleum
Bagh-e-Masjed		Muslim	Agriculture	Vaghf-Abad	Mosque Watermill
Posht-e-Bagh	13th century	Muslim	Fabric weaving Textile manufacture	Ez-Abad	Mosque Water reservoir Mausoleum Public bath Caravanserai

Neighbourhood Name	Construction Period	Ethnics (Religion)	Occupation	Related Qanat	Main structures
Panbeh Karan		Muslim	Cotton threading	Dehuk Vaqf- Abad	Mosque Water reservoir
Pir-e-Borj	15th century	Zoroastrian Muslim	Fabric weaving	Firooz-Abad Mollabashi	Bazaar Mosque
Takht-e-Ostad	15th century	Muslim	Fabric weaving	Narsu-Abad	Mosque Bazaar Water reservoir
Tall		Muslim	Agriculture Construction	Dehuk	Mosque Gate Bazaar Public bath Garden Water reservoir
Janat-Abad	19th century	Muslim	Agriculture Fabric weaving Carpet weaving	Fahraj	Caravanserai Water reservoir
Ju Hor Hor	19th century	Jewish Muslim			Cemetery Mosque Water reservoir
Char-Souq	15th century	Jewish Muslim			Jame Mosque Bazaar Library
Char-Kouche		Zoroastrian Muslim	Agriculture	Zarch	Mosque Bazaar Water reservoir
Char-Monar	15th century	Muslim	Fabric weaving	Gord-Faramarz	Mosque Public bath Caravanserai Water reservoir Mausoleum
Hasan Abad Moshir	19th century	Muslim	Agriculture	Hasan-Abad Mari-Abad	Mosque Water reservoir Public bath
Khoram-Shah		Zoroastrian Muslim	Agriculture Animal husbandry Production of herbal drinks	Nasiri Taft	Hall Fire temple Sacred place Mosque Water reservoir

Neighbourhood Name	Construction Period	Ethnics (Religion)	Occupation	Related Qanat	Main structures
Khalf-e-Khanali		Zoroastrian Muslim	Fabric weaving	Zarch Mollabashi	Library Water reservoir Public bath
Khajeh-Khezr	15th century	Muslim	Dyeing Fabric weaving	solghor-Abad	Water reservoir Traditional gym Mausoleum
Kheir-Abad	15th century	Zoroastrian Muslim	Agriculture Animal husbandry	Dehuk	Mosque Castle Water reservoir
Dar O'Shafa	15th century	Jewish Muslim		Zarch	Ice storage Mosque Public bath Synagogue Gate of Mehriz
Darvaze Shahi	12th century	Muslim	Fabric weaving	zarch	Mosque Bazaar Water reservoir
Dolat-Abad	19th century	Muslim		Dolat-Abad	Garden Water reservoir
Rahim-Abad	19th century	Muslim	Agriculture Animal husbandry	Rahim-Abad	Garden Water reservoir
Zartoshtiha		Zoroastrian Muslim	Agriculture	Rahim-Abad	Fire temple Water reservoir Hospital School
Zangian	14th century	Muslim			Water reservoir Shrine
Sar-e-Polok	15th century	Muslim	Fabric weaving	Zarch	Mosque Water reservoir Bazaar
Sar-e-Cham	14th century	Muslim	Fabric weaving	Nasiri Taft	Mosque Bazaar Mausoleum
Sar-e-Dorah	16th century	Muslim	Agriculture Masonry		Mosque Water reservoir Public bath
Sar-e-Sang	14th century	Muslim		Chahuk	Mosque Water reservoir
Salsabil	19th century	Muslim	Agriculture Fabric weaving	Mollabashi	Mosque

Neighbourhood Name	Construction Period	Ethnics (Religion)	Occupation	Related Qanat	Main structures
Sahl ebn Ali	15th century	Muslim		Narsu-Abad	Mosque Water reservoir Public bath Timche Caravanserai Mausoleum
Seyyed-e-Sahra	16th century	Muslim			Water reservoir Shrine Cemetery
Seyyed-Fathodin		Muslim		Yaqubi	Mosque Mausoleum Water reservoir
Seyyed-e-Golsorkh	16th century	Muslim			Mausoleum Mosque Water reservoir Bazaar
Shah-Abloghasem	15th century	Muslim		Taft Mollabashi	Mosque Bazaar Water reservoir Mausoleum
Shahed-Baz	19th century	Muslim		Zarch	Water reservoir Mosque
Shesh-Badgir		Muslim	Masonry Oil extraction Carpet weaving		Mosque Water reservoir
Sheikhdad	15th century	Muslim	Fabric weaving	Zarch Mollabashi	Mosque Water reservoir Public bath School
Sadr-Abad	19th century	Muslim	Agriculture	Sadr-Abad Jafar-Abad	Mosque
Araq-Pazha	20th century	Muslim	Production of herbal drinks		School Bazaar Caravanserai
Eish-Abad	20th century	Muslim	Agriculture Masonry Animal husbandry	Vaqf-Abad	Mosque Water reservoir
Ghassabha	17th century	Muslim	Butchery Trade	Zarch Dehuk	Bazaar Caravanserai Mausoleum

Neighbourhood Name	Construction Period	Ethnics (Religion)	Occupation	Related Qanat	Main structures
Fahadan	12th century	Muslim	Fabric weaving	Yaqubi	Mosque Water reservoir Public bath Mausoleum Bazaar School
Ghasem-Abad	20th century	Zoroastrian Muslim	Agriculture	Ghasem-Abad	Water reservoir Mosque
Ghaleh-Kohne	15th century	Muslim	Fabric weaving	Firooz-Abad Mollabashi	Mosque Fort
Kathnavieh	11th century	Muslim	Agriculture	Narsu-Abad Kathnavieh Ashkezar Firooz-Abad Aliaqa	Mosque Public bath Pigeon tower Bazaar Tomb
Kouche-Behuk	16th century	Zoroastrian Muslim	Agriculture Animal husbandry	Taft Aharestan	Mosque Water reservoir
Kouche-Henna	20th century	Muslim	Henna production Carpet weaving Brick kilns	Ez-Abad	Caravanserai Mosque School
Kouche-Kolahdoozha	20th century	Muslim		Zarch	Lard Mazari
Koushk-e-No	9th century	Muslim	Fabric weaving	Vaqf-Abad Mahmud-Abad	Mosque Water reservoir Watermill School Bazaar
Gozargah	19th century	Muslim	Fabric dyeing	Mollabashi	Mosque Water reservoir Public bath Mausoleum Hospital
Golchinan	20th century	Muslim	Fabric dyeing Trade	Narsu-Abad	Mosque Water reservoir Bazaar Caravanserai Lard

Neighbourhood Name	Construction Period	Ethnics (Religion)	Occupation	Related Qanat	Main structures
Gonbad-e-Sabz		Muslim	Agriculture Fabric weaving	Yaqubi	Mosque Water reservoir
Guod-e-Shahriari	20th century	Zoroastrian Muslim	Agriculture Fabric weaving Trade	Ghasem-Abad	Goud (low land) Mosque
Gonbad-e-Mosalla	16th century	Muslim	Fabric weaving	Kathnavieh	Mosque Caravanserai Mausoleum Bazaar
Lab-e-Khandaq	15th century	Muslim	Fabric weaving	Zarch	Caravanserai Mausoleum Bazaar
Lard-e-Asiab		Muslim	Fabric weaving	Zarch	Mosque Caravanserai Lard
Lard-e-Keiwan		Muslim	Fabric weaving	Mollabashi Zarch	Lard Caravanserai Mosque Bazaar
Malamir	14th century	Muslim	Fabric weaving		Mosque Gate
Mahmud-Abad	12th century	Muslim	Agriculture Animal husbandry Threading	Mahmud-Abad	Mosque Water reservoir Garden
Maryam-Abad	14th century	Muslim	Agriculture	Maryam-Abad	Mosque Water reservoir Mausoleum
Molla-Farajillah		Muslim	Agriculture	Ez-Abad	Mosque Water reservoir School Markar square
Mehdi-Abad	19th century	Muslim	Agriculture	Sadeq-Abad	Citadel Mosque Park Water reservoir
Shah Tahmasb Square	16th century	Muslim	Fabric weaving	Narsu-Abad	Mosque Public bath Shah Tahmasb square Traditional gym

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Figure 164: *Jame Mosque of Yazd, photo by Vahid Afsahinia*

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Figure 165: *Covered street in Yazd, photo by Vahid Afsahinia*