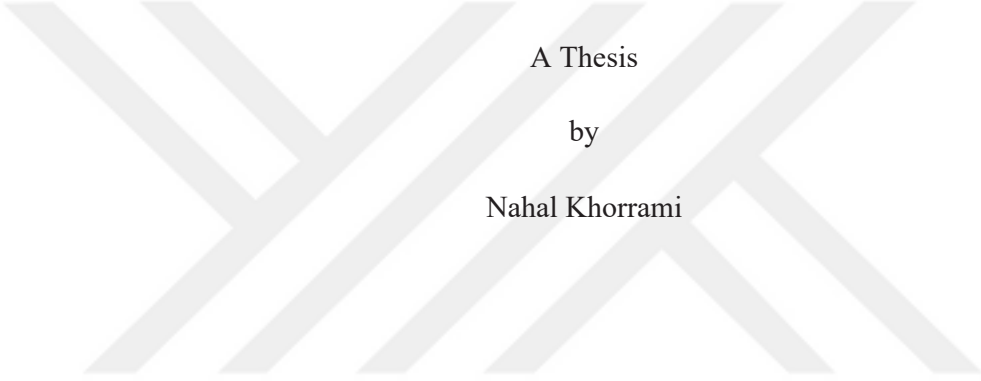


Water and Urban Tissues: The Qanat System and the Formation Process of Yazd, Iran



A Thesis

by

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Water and Urban Tissues: The Qanat System and the Formation Process of Yazd, Iran

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*To my mom Leila
and my dad Amir Masoud*

ABSTRACT

This research has analysed the *Qanat* system to discern its influence on the formation process of Yazd, Iran. In arid areas where agriculture depends on irrigation, water shortage was one of the main motivations for many innovations, such as the underground watercourse, referred to as the *Qanat* system. This system played an important role in maintaining and developing civilization on the Iranian plateau [1]. In Yazd, there exist a total of twenty-two *Qanats*, with only two among them presently retaining water, the *Zarch Qanat* and the *Firozabad Qanat*. Regrettably, the remaining twenty *Qanats* have succumbed to drying up over time [2]. The research has been structured into two primary phases. In the first phase, the study focused on identifying and characterizing the *Qanat* system. Subsequently, in the second phase, the research has directed a morphological analysis of Yazd. The study has determined the correlations between Yazd's urban configuration and the *Qanat* system across four distinct scales, the territorial scale, urban scale, urban fabric scale, and building scale. Furthermore, the study has investigated the architectural structures associated with underground watercourses such as cisterns, watermills, and *Payabs*. The main aim of the research is to recognize the impacts of the *Qanat* system on the formation process, urban tissue, and architectural characteristics of Yazd. This research has exposed the significant attributes of the *Qanat* system and illuminated their complex interaction with the formation process of Yazd, Iran.

Keywords. Urban Morphology, Urban Planning, Urban Formation Process, *Qanat* System, Building Typology, Architectural History.

ÖZET

Bu araştırma, İran'ın Yazd'in oluşum süreci üzerindeki etkisini ayırt etmek için *Qanat* sistemini analiz etti. Tarımın sulamaya bağlı olduğu kurak alanlarda, *Qanat* sistemi olarak anılan yeraltı su yolu gibi birçok yenilik için su sıkıntısı ana motivasyonlardan biriydi. Bu sistem, İran platosunda medeniyetin sürdürülmesinde ve geliştirilmesinde önemli bir rol oynamıştır [1]. Yazd'de toplam yirmi iki *Qanat* var, bunlardan sadece ikisi şu anda su tutuyor, *Zarch Qanat* ve *Firozabad Qanat*. Ne yazık ki, kalan yirmi *Qanat* zamanla kurumaya yenik düştü [2]. Araştırma iki ana aşamada yapılandırılmıştır. İlk aşamada, çalışma *Qanat* sistemini tanımlamaya ve karakterize etmeye odaklandı. Daha sonra, ikinci aşamada, araştırma Yazd'in morfolojik bir analizini yönetti. Çalışma, Yazd'in kentsel konfigürasyonu ile *Qanat* sistemi arasındaki korelasyonları, bölgesel ölçek, kentsel ölçek, kentsel kumaş ölçeği ve yapı ölçeği olmak üzere dört farklı ölçekte belirlemiştir. Ayrıca, çalışma sarnıçlar, su değirmenleri ve *Payabs* gibi yeraltı su yolları ile ilişkili mimari yapıları araştırmıştır. Araştırmanın temel amacı, *Qanat* sisteminin Yazd'in oluşum süreci, kentsel doku ve mimari özellikleri üzerindeki etkilerini tanımaktır. Bu araştırma, *Qanat* sisteminin önemli özelliklerini ortaya çıkarmış ve İran'ın Yazd'in oluşum süreciyle karmaşık etkileşimlerini aydınlatmıştır.

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CHAPTER I

INTRODUCTION

1.1 Research Problem and Background

The concept of Iranian urban planning and architecture has been an issue of constant debate, comprising discussions among Iranian designers, as well as between the government and the design community within the country. This continuing controversy has resulted in a lack of an appropriate and coherent urban planning approach, which should be based on the existing built environments and remarkably, their formation process [3]. The urban form analysis in Iran has not become an organised research stream [4]. Presently, urban planners employ a subjective approach in the absence of well-defined guidance, relying on sensory perception and their personal experiences and stylistic preferences. Hence, there is an evident requirement for morphological studies and urban analysis due to urban development in Iranian cities. These studies are essential for founding a framework to guide urban planning, both in newly grown areas and historic urban spaces [3], [5].

1.2 Research Aims and Questions and Outcomes

This research constitutes an urban morphological study with the aim of comprehending the urban formation process of Yazd, Iran, within the context of the *Qanat* system's influence across four various morphological scales. The study necessitated an immense literature review, which leads to the assortment of three primary objectives:

- Identifying the *Qanat* system and its characteristics as the morphological element.
- Considering the interaction of these underground watercourses with the urban configuration of the city by reconstructing the formation process over time.
- Examining the architectural structures associated with the *Qanat* systems such as cisterns, watermills, and *Payabs*.

The urban context of a city undergoes a repeated process of construction and reconstruction. Consequently, this research attends as a morphological analysis into the formation process of the urban tissue of Yazd over an extended historical period, encompassing the entire history of the city. The research has investigated the hypothesis that the *Qanat* system has influenced the formation process of the city of Yazd. Several important questions that can be highlighted include:

- How were the urban formation process of Yazd, influenced by the *Qanat* systems?
- What correlation exist between the urban configuration of Yazd and the *Qanat* systems?
- What are the architectural structures associated with these underground watercourses in Yazd, and what are their distinctive characteristics?

The predictable outcome of this research is to expose the significant attributes of the *Qanat* system and clarify their elaborate connection with the urban tissue and architectural features of Yazd.

1.3 Research Scope

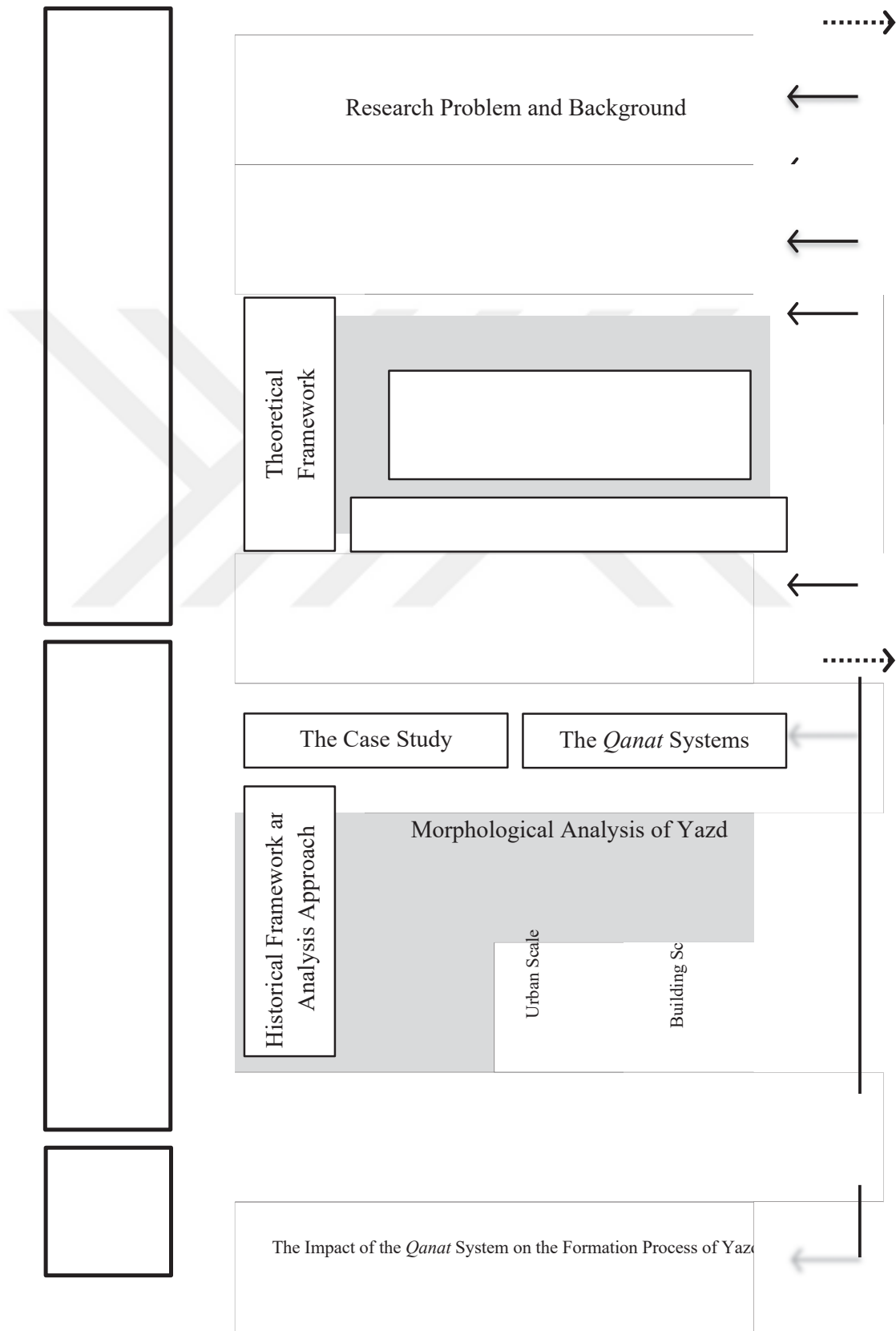
The research scope includes the consideration of the gradual formation and transformation processes that have shaped the urban fabric of Yazd, Iran. Moreover, it sought to analyse the urban configuration of the city influenced by the *Qanat* system. The main purpose is interpreting the correlation between underground watercourse and formation process of Yazd. However, it is crucial to emphasize the importance of exploring the correlation between the physical characteristics of the built environment and socio-cultural variations.

1.4 Research Methodology

This research is an urban morphology study. The theoretical approach of this study, similar to Caniggia's methodology, aimed to achieve a comprehensive understanding of the relationships between the urban components of the city of Yazd by reconstructing the city's formation process throughout its history [6]. The past is the key to understanding the present. Hence, this research has reconstructed the phases of emergence and formation of the built environment of Yazd from beginning to the 19th century AD [7]. Through the examination of historical maps, remaining structures, documents, and written sources, this research has retraced the various phases that the city of Yazd went through during its formation process. This analysis aims to interpret the placement of urban components next to each other. The concept of form in space and time is the fundamental tool which is essential for the reconstruction of the city's formation process [6]. The study has considered forms and studied their spatial arrangement throughout the development stages of the city. Furthermore, it has analysed the correlation between the *Qanat* systems and forms within their typological process.

The investigations of this research about the spatial relationship of built forms, similar to Caniggia's consideration, are based on a series of subdivisions that form a hierarchy of spatial arrangement. These subdivisions include elements, a structure of element, a system of structures, and an organism of systems [6]. The elements represent buildings, the smallest unit of the studied arrangement. through the aggregation of several elements, structures are formed, that represent the urban tissue. These structures may be different, but they all consist of grouping of elements. Similarly, through the combination of structures, the system of structures is formed, that represent the region or district. Eventually, the organism of systems, that represent the territory, is formed from the amalgamation of system of structures [6]. The research has applied this conceptual framework to investigate the formation process of the city of Yazd and to explore the influences of the *Qanat* systems on this process. Therefore, it has analysed the emergence and formation of Yazd within four scales, territorial scale, urban scale, urban tissue scale, and building scale. Moreover, through studying the *Qanats* technology and examining its relationships with each scale, the research has explored the impacts of *Qanat* systems on the formation process of Yazd.

1.5 Research Design



1.6 Literature Review

The literature review has observed ten articles that specifically focus on the urban morphology of Yazd, Iran, and the *Qanat* system and their classifiable characteristics. These articles collectively contribute comprehensions into the historical evolution and transformation of the urban context of Yazd and its surrounding regions over time, shedding light on the various influencing factors, including the role of the *Qanat* system. Additionally, these articles provide information regarding the correlations between underground watercourses and architectural structures.

In [8], the author outlines the formation process of Yazd's urban tissue, as a claim, by classifying it into three distinct classes, each related with a specific historical period: the historical zone (inner area), the old zone (middle area), and the new developed zone (outskirts area). To broadly investigate the influence of *Qanat* system on the urban formation process of Yazd, it becomes necessary to identify and analyse the transformation that have occurred within the urban fabric over time. Likewise, [9] contributes valuable insights into the morphogenesis of traditional Iranian cities, including Yazd and Kerman, as a claim.

In [10], the author presents extensive evidence regarding *Qanat* systems in the central Iranian plateau, as a claim. To comprehensively study the role and effects of *Qanat* systems, it is imperative to gain a thorough understanding of these systems, for instance, their various components and the processes involved in their construction. Similarly, both [11] and [12] describe valued information concerning water-supply systems, including *Qanat* systems and their distinctive features, not only in central Iran, such as *Dasht-e-Kawir*, but also in various other countries, as a claim.

In [13], the authors provide a remarkable contribution by presenting both two-dimensional and three-dimensional hypothetical images of Yazd and the *Vaqfabad Qanat* route, as a claim. This visual representation is indeed interesting and adds depth to the research. In addition to examining the impact of the *Vaqfabad Qanat* on the transformation of the urban context, this research also explores the changes that have occurred within the *Qanat* system itself over time. Lastly, the study investigates the influence of the *Vaqfabad Qanat* on the buildings constructed along its route. [14] provides a comprehensive report on the *Dolatabad Qanat* in Yazd, Iran, covering aspects such as its history, builder, transformation process, path, and length, as a claim. This research constitutes an appreciated contribution to the understanding of this specific *Qanat*.

In [15], the author offers an insightful examination of the effects of *Qanat* systems on the physical structure of *Mohammadiyeh* village, as a claim. This research investigates various components including location, urban tissue, the formation of communication arteries and network of passages, as well as the development of public spaces and residential units. In a sense, this study acts as the glue that binds together the various pieces presented in the other articles, creating a more comprehensive understanding of the subject matter. Likewise, [16] puts forth an argument observing the influence of *Qanats* on the urban morphology of Yazd, Iran, as a claim. This research adds another layer to the understanding of how *Qanat* systems have shaped the urban tissue of the city.

Eventually, in [17], the authors present valuable perceptions into a morphological approach to cities and regions, along with methodologies for directing research in this field, as a claim. This effort come up with the theoretical and methodological foundations of urban morphology, improving the overall understanding of the issue.

However, there is an agreement amongst these authors regarding the urban tissues growth under the impact of numerous factors, such as *Qanat* systems, it is necessary to admit that there are also noteworthy differences. These distinctions mainly rise from variations in case studies and the precise concentration of each research endeavour. Indeed, all ten articles under consideration have concentrated on case studies at the urban scale, except for [17], which differs from this repetition. Remarkably, [13], [14], and [15] explored the building scale in addition to the urban scale.

It is apparent that the scope and focus of the case studies differ in these articles. While [8], [13], [14], and [16] mainly concentrate on the city of Yazd, [15] considers *Mohammadiyeh* village. In contrast, [10] and [11] lengthen their research to contain Yazd and its surroundings, referring to central Iran. On the other hand, [12] and [9] implement a wider perspective, considering not only Iran but also other countries. This variety in case studies develops the collective understanding of urban morphology and its association with the *Qanat* systems.

The consideration of the time aspect in studying their case studies is a significant distinction amongst these articles. Specifically, [8], [13], [14], [15], and [16] comprised the temporal dimension, concentrating on specific historical periods, varying from the eighth to the fourteenth century AH. In contrast, [10], [11], [12], and [9] did not explicitly issue in time considerations within their analysis. This deviation in chronological scope likely reflects variable research objectives and methodologies amongst these articles.

The ten articles under consideration display a various range of approaches to the study of urban tissues, mostly in the context of the *Qanat* systems. While [8] and [9] concentrate on urban development processes across diverse cities, regardless of the existence of the *Qanat* systems, the other eight articles involve with the *Qanats* in altered ways. [10],

[11], and [12] sought to identify the *Qanat* systems and analyse their characteristics. On the other hand, [15] and [16] sought to recognize and study the impact of the *Qanat* systems, especially at the urban and building scales. [13] and [14] sought to recognize and study specific *Qanats*, *Vaqfabad Qanat* and *Dolatabad Qanat*, and their impact on both urban and building scales. This deviation in research approaches underlines the complicated and multi-layered nature of the relationship among the *Qanat* systems and the urban environments.

The common theme amongst all these articles lies in their discussion of urban morphology, urban formation process, urban planning, and urban structure. However, apart from [8], [9], and [17], the remaining articles also explore additional dimensions such as *Qanat* systems, hydraulic systems, irrigation systems. This wider scope develops their analyses by considering the interaction between these aspects and urban growth.

The articles share a major use of descriptive-analytical methodology, except for [10], [11], and [13], which employ field methodology in their research approaches. This deviation in methodology underlines the variable research methods applied to examine their individual topics.

All ten articles rely on written and historical sources as their main means of gaining data. However, [10], [11], [13], and [15] go further by integrating interviews and field studies into their research methodologies. This wide-ranging approach allows them to cross-reference and validate the evidence obtained from numerous sources.

In [10] study regarding the *Qanat* systems within the central Iranian plateau, certain blind spots become apparent. The author's dependence on photographic materials to discuss the *Qanats*, including their construction processes, is accompanied by an absence of city maps, a crucial component for comprehensive *Qanat* discourse.

Moreover, there are recognised limitations in data gathering methodologies, mostly in the circumstance of field research, like explanations made in articles such as [13] and [15]. These limits can affect the depth and accuracy of the research's outcomes, underlining the importance of wide-ranging approach to such a critical topic. Conversely, [11] and [12] present widespread claims regarding the *Qanat* systems in the central Iranian plateau and other countries. Their research seems to be empty of any blind spots, suggesting a detailed and comprehensive consideration of the subject. These articles can be considered as providing a sufficient and complete understanding of the *Qanat* systems across diverse regions.

In the consideration of urban transformation processes in Yazd, as presented by [8], a structured classification into different historical classes is evident. However, it becomes apparent that there are blind spots in addressing effective factors like the *Qanat* systems, which can considerably impact the urban growth. This gap may be viewed as an inadequacy in the analysis. In contrast, the methods employed for obtaining data, definitions, and theoretical approaches, appear to be strong and empty of any blind spots, proposing a comprehensive foundation for the study. On the other hand, [16] examination of the urban transformation process in Yazd under the impact of the *Qanat* systems is considered by its comprehensiveness. The research seems to be empty of any blind spots, suggesting a comprehensive and detailed consideration of the subject. It can be considered as providing an adequate and balanced analysis of the urban transformation process influenced by the *Qanat* systems.

In [13] study, which contains the establishment of two-dimensional and three-dimensional hypothetical image of Yazd and the *Vaqfabad Qanat* route, the research appears to be wide-ranging and empty of any blind spots. The providing of these maps as evidence adds to the adequacy of the research. However, the data collection methodology,

which relies on field work including interviews with people from several neighbourhoods, presents blind spots. The reliance on fieldwork through interviews, while appreciated, can present potential boundaries and blind spots in the data gathering process. These gaps may affect the consistency of the evidence obtained in the research. It is essential to admit these limits and consider tactics to alleviate them when relying on such methodologies.

In [14] study on *Dolatabad Qanat* and its characteristics in the city of Yazd, the analysis appears to be comprehensive and empty of any blind spots. This suggests that the study can be considered as an adequate and comprehensive examination on *Dolatabad Qanat* and its characters within the context of Yazd.

In [15] study, which observes the impacts of the *Qanat* systems on the physical structure of *Mohammadiye* village, the analysis appears to be comprehensive and empty of any blind spots. The author's providing of data regarding the influence of the *Qanats* on the urban tissue adds to the adequacy of the research. However, similar to [13] study, there appear to be blind spots in the data gathering methodology, which relies on fieldwork. These limits should be considered within the wider context of the research.

The preliminary step in understanding the influence of the *Qanat* systems on the urban tissue of Yazd is to separately identify both the *Qanats* and the city's urban structure. Consequently, through a wide-ranging review of literature, the research has extracted valued comprehensions into the diverse characteristics of the *Qanat* systems and has investigated the processes of formation and transformation on Yazd's urban tissue. Subsequently, the research embarks on a thorough examination of how these *Qanats* effect the city's morphology across four distinct scales, the territorial scale, urban scale, urban fabric scale, and building scale. This methodical approach forms the

foundation for disentangle the multifaceted interaction between the *Qanat* systems and their urban context of Yazd.



CHAPTER II

RESEARCH ANALYSIS AND FINDINGS

2.1 The Case Study

In the developing stages of this research, it became apparent that a considerable depth of study would be essential. Given the margins of a master's thesis, the research is specifically concentrated on one settlement. Consequently, when contemplating historic cities in Iran as potential candidates, the study chose the city of Yazd as the central point. This selection aligns with the research's scope and boundaries while consenting for a comprehensive investigation of the chosen theme.

The choice of Yazd as the research case study is underlined by various reasons. The city of Yazd outstanding for its characteristic spatial pattern and historic built environment. Numerous aspects contributed to the selection of Yazd as the central point of this study:

- In comparing to the other cities in Iran, Yazd's historic zone is well-documented and preserves a great level of functional activity. This historical continuousness delivers a substantial source of data and comprehensions for the research. While only 3% of urban form studies within historical contexts are about historical context of Yazd [4]. The historical context of Yazd needs to be studied, to preserve the reminiscence of its historical values and for its future permanence in the territory [18].

- Yazd provides an opportunity to study a structural pattern crossing diverse historical eras. This contains the association of ancient and historical urban tissue with contemporary urban developments, delivering a multi-layered landscape for investigation. In contrast, the historical context of some Iranian cities such as Tehran have changed due to urban developments, referring to as typomorphological conglomerates [19].

These aspects cooperatively make Yazd an archetype candidate for the research, proposing a rich built environment for studying the influence of *Qanat* systems on urban tissue and architecture.

2.1.1 Yazd, Iran

The Yazd province is in the central part of the Iranian plateau, covering an area of 76469 square kilometres. The neighbouring provinces are Isfahan, Fars, Khorasan, Semnan, and Kerman (Figure 1). In terms of geographical configuration, Yazd province include a varied landscape. Approximately 14.3% of the land is classified as desert, 6.3% as lowland and saline land, 3% as sand dunes and sand fields, while the remaining part comprises of mountains, hills, plateaus, and pastures. This diverse geography makes Yazd province a significant case study for the research into the impact of *Qanat* systems in urban tissue and architecture. Yazd province has ten cities, the city of Yazd is the provincial capital. The smaller city in this province encompasses *Abarkooh*, *Ardakan*, *Meybod*, *Mehriz*, *Taft*, *Bafgh*, *Khatam*, *Sadough* and *Tabas* [20] (Figure 2). Marco Polo visited Yazd during his travels and documented his observations about this city in his travelogue [21]. (See Appendix A)

In Yazd, a widespread network of *Qanat* channels exists under the city, usually at various depths. These *Qanats* flow towards the agricultural lands surrounding the city or

to villages situated downslope [9] (Figure 3). In contemporary Yazd, the plan of the street network may initially appear to be confusion, but closer examination presents a defined pattern. This system is an orthogonal pattern oriented in a northwest-southeast and northeast-southwest direction crossing at right angel [9]. In Pahlavi era (1925-1979 AD), five lengthy and perpendicular streets were constructed in Yazd, passing through the historical context [3]. Similar modern street constructions in some Iranian cities, such as Tehran, have altered the historical road network over time. However, the historical context and road network of Yazd have experienced minimal changes [22] (Figure 4).

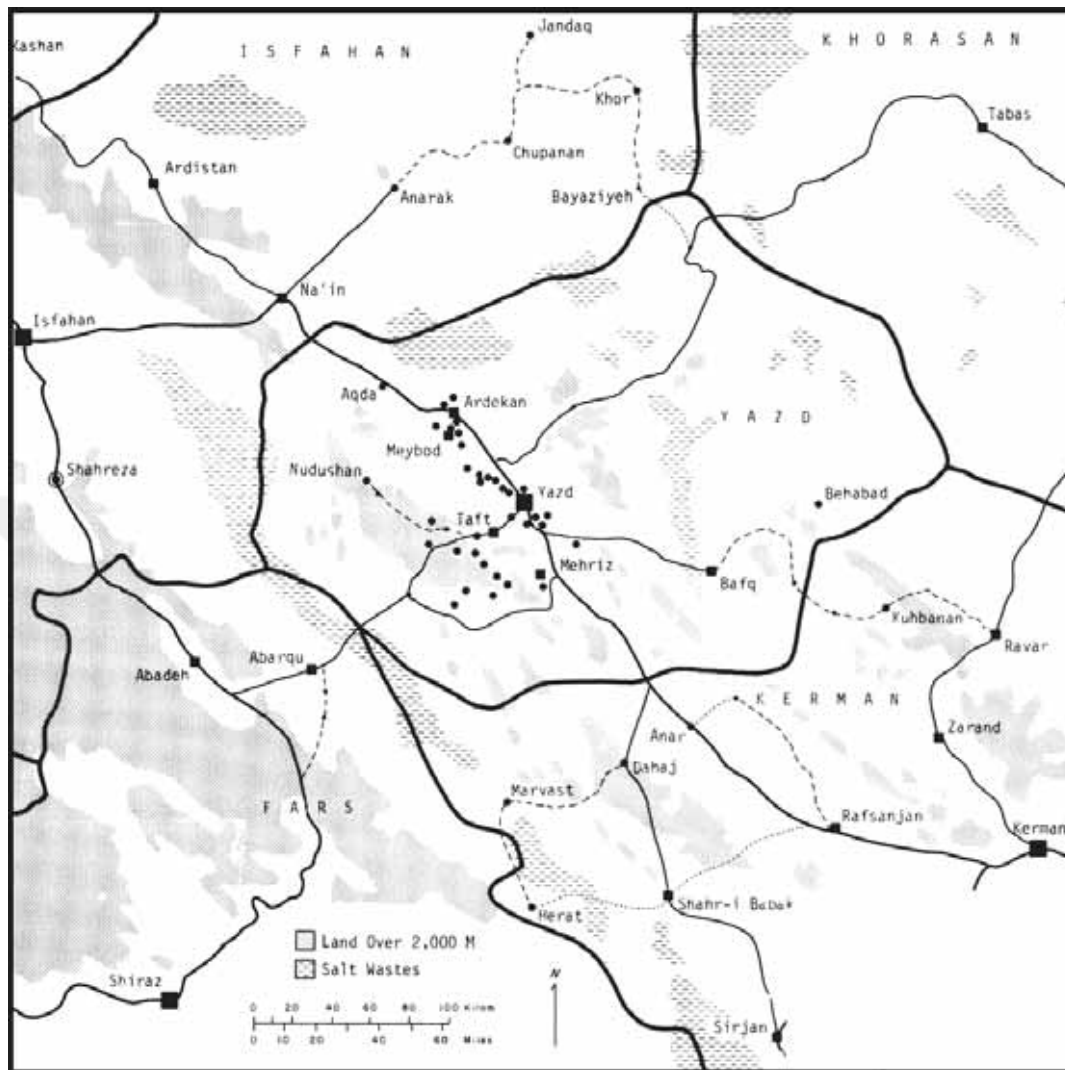
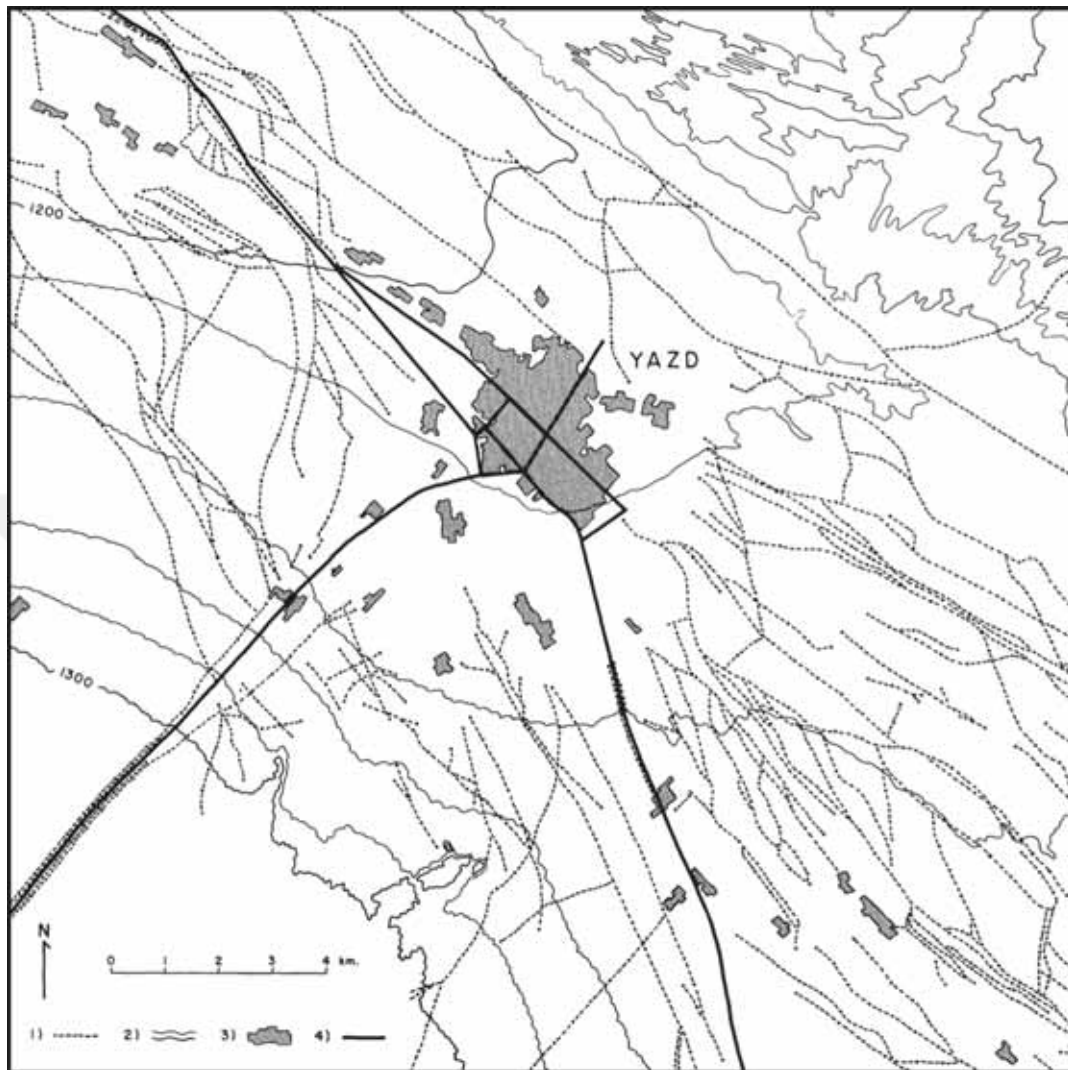


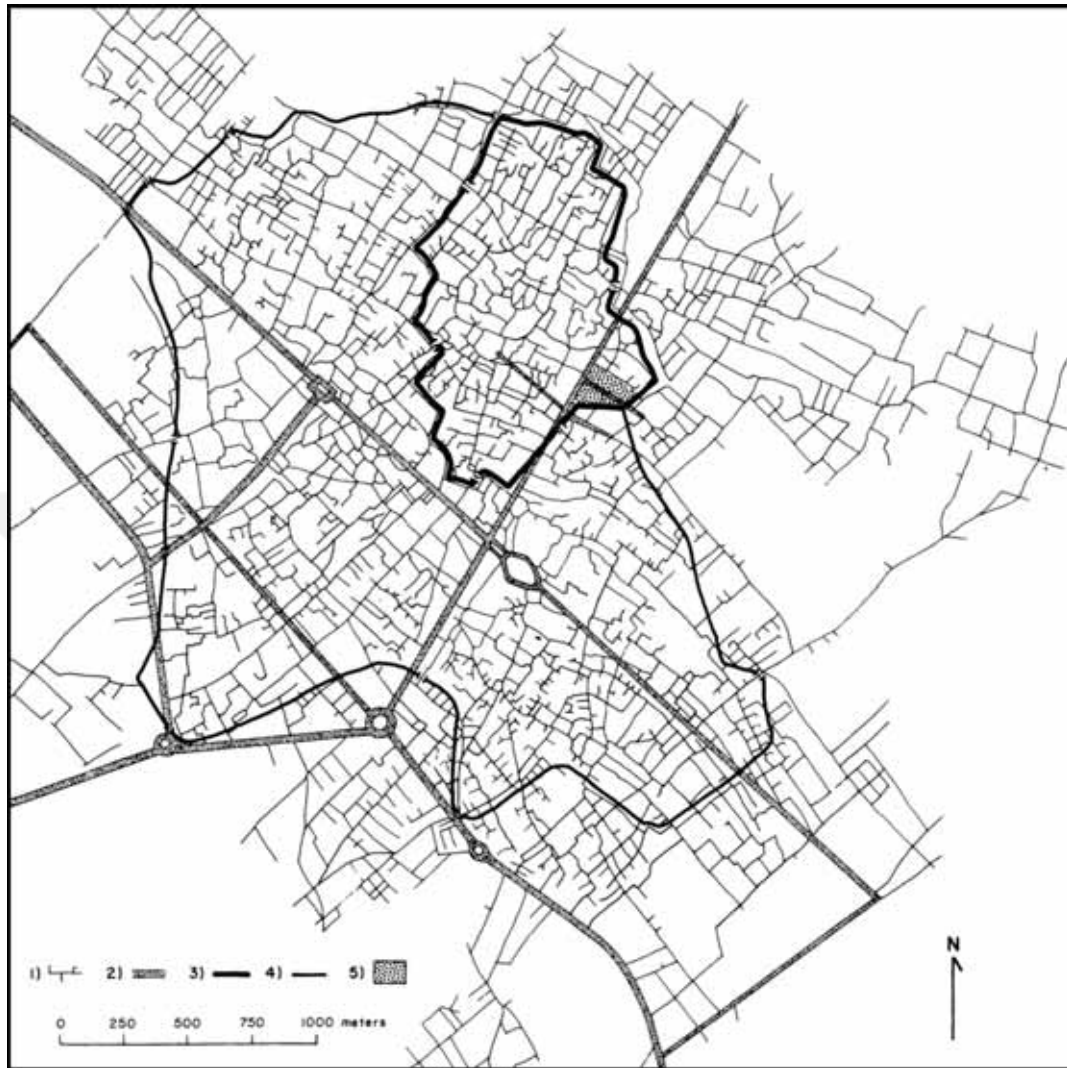
Figure 1. Central Iran [10].



1. *Qanat* systems, underground water channels
2. Contour lines, twenty-meter intervals
3. Settlements
4. Main roads and paths

Source: U.S. Army Corps of Engineers, Army Map Service, "Iran" (Scale 1:50,000), Series K753, Edition 1-AMS, Sheet 6853 I, "Yazd," 1966.

Figure 3. Yazd and its hinterland [9].



1. Historical streets and paths, widths are not scale
2. Modern roads, constructed in the twentieth century
3. Inner or old city wall, constructed in the fourteenth century (Still mostly standing)
4. Outer or new city wall, constructed before the nineteenth century (Mainly destroyed)
5. Former citadel area (Now destroyed)

Source: Iranian National Cartographic Centre, "Yazd" (Scale 1:2,500), 24 sheets, 1967/68.

Figure 4. Yazd and its street plan [9].

2.1.2 History of Yazd, Iran

Pliny the Elder (23-79 AD) is a Roman savant and author of the treasured “Natural History”, an encyclopaedic work of imprecise issues that was an authority on science up to the Middle Ages. The Natural History contains thirty-seven books which are divided into ten sections. This collection was completed, except for last touches, in 77 AD. According to the preface, it is dedicated to Titus, who came to power shortly before Pliny’s death. Books III through VI are about physical and historical geography of the ancient world. In these books, Pliny pays attention to major cities, some of which do not exist today. In book VI, he mentions, the realm of the Persians, which we currently refer to as Parthia, is situated between the Persian and Caspian seas, on the elevated territory of the Caucasus Mountain range. The Parthia is composed of eighteen kingdoms, with these divisions demonstrating its provinces. These provinces spread from the southern Red Sea to the northern *Hyrceanian* region. Out of this count, eleven are known as the “higher provinces”. They initiate at the border of Armenia and the Caspian region and spread all the way to the *Scythian* territories, where the manner of life is quite alike in all facets. The remaining seven regions within Parthia are known as the “lower provinces”. Regarding the *Parthi* themselves, Parthia has constantly been situated at the base of the *Caucasus* Mountains, which hang all these neighbouring nations. To the north of Parthia are the *Hyrcani*, to the south *Carmania* and the *Ariani*, to the east the *Arii*, and to the west the *Pratitae*, a Median people. Parthia is bounded by deserts on all sides. The Parthians inhabiting in the distant eastern regions are stated to as Nomades or Wandering Parthians, while to the west, there are deserts. In the northeast of Parthia is *Europus* or *Pyropum*, in the southeast is *Maria*, and to the west are the cities of *Issatis* and *Calliope*. In the heart of this land, there are *Hecatompylos*, the capital of Parthia, alongside with *Arsace* and

Nisiaea, a grand district within *Parthiene*, which is home to *Alexandropolis*, named after its founder [23], [24]. (See Appendix B)

Issatis is the name used in ancient sources to refer to the city of Yazd [25]. Furthermore, the geographical position as described by Pliny for the city of *Issatis*, and its corresponding demonstration in ancient atlases, aligns with the present position of the city of Yazd (Figure 5).



Figure 5. The map of the Medo-Persian Empire, 529-331 B.C. [26].

Jafar ibn Mohammad ibn Hassan Jafari is an Iranian savant from the 9th century AH (corresponds to the 15th century AD, 1398-1495) who held a position in the administrative apparatus of rulers in Yazd. *Jafar ibn Mohammad ibn Hassan*, known as *Jafari*, is the author of the treasured “Yazd History [*Tarikh-e Yazd*]”, the oldest historical work dedicated to the city of Yazd. It operates as a foundation source, with many ensuing books on the history of Yazd drawing comprehensively from its content and insights. The

“Yazd History” describes a brief historical explanation that extends from the foundation of the city of Yazd during the era of Alexander the Great, continuing until the year 845 AH (1441 AD). This historical narrative has a solid emphasis on the cultural, religious, and civilizational aspects and circumstances. In addition to reporting historical events, the author’s primary focus lies in the structures of Yazd and the persons responsible for their construction. Meanwhile, *Jafari* has dedicated the least attention to the political matters, but he has carefully mentioned the economic, civic, cultural, and religious structures and their founders. The “Yazd History” contains a preface and ten parts. This book was completed in 1441 AD. According to the preface, it is dedicated to *Zia ol-Din Masoud*, who was one of the ministers of Yazd [27]. The initial two parts of the book comprehensively cover the ancient history of Yazd, while the tenth part is specifically dedicated to the description about springs, *Qanats*, and water wells in the region.

In the first part, the author refers to the narrative of Alexander the Great, including his conflicts with *Darab*, the conquest of Iraq and Fars, his arrival in Yazd from Isfahan, and the construction of *Kasah*, which stands as the city’s initial mansion. The author provides a comprehensive explanation of this historical event. *Jafari* mentions, Alexander the Great, accompanied by some of the colonels from *Darab* whom he did not trust and could not leave alone for fear of revolt, led a march from Iraq to Khorasan. When they reached the Khorasan’s desert, which corresponds to the city of Yazd, he directed his army to construct a fortress and initiated the flow of a canal. He settled a person of his army along with the group of *Darab*’s untrusted colonels. This place became known as *Kasah*, marking the first mansion of Yazd, and it was referred to as “The Prison of the one with Two Horns [*zندان-e Zu al qarnayn*]” or Alexander’s prison. Following Alexander’s period, *Kasah* was recognized as a settlement, where a group gathered and initiated the construction of buildings and farms. In previous books Yazd is not stated,

but *Kasah* is mentioned in *Sarih al-Buldan*, the precise description of the lands, and *Masalek wa Mamalek*, Roads and realms, which provide details about the dimensions of numerous lands [28].

In the second part, the author refers to the *Sassanid* (224-651 AD) kings. *Jafari* mentions, after *Bahram* the realm came to *Yazdgerd ibn Bahram* who reigned for eighteen years (438-457 AD). He was a powerful king who had authority over both Persians and Arabs. While he was travelling within his dominions, he reached *Kasah*, where he found the climate to his liking. *Yazdgerd* said: I vowed to construct a city in this location, which he named *Yazdan*. He congregated the builders of the empire and the astrologers made Yazd under the sign of Virgo. They constructed fortresses, walls, the bazaar, baths [*Hammam*], and the great fire house [*Atash Khane*]. They also constructed the king's house and made three streams of water flow, *Yazdabad*, *Dehabad*, and *Madin* [28].

Ahmad ibn Hossein ibn Ali Kateb is an Iranian historian from the 9th century AH (corresponds to the 15th century AD, 1398-1495). *Ahmad ibn Hossein ibn Ali*, known as *Kateb*, is the author of the “New History of Yazd [*Tarikh-e Jadid-e Yazd*]”. This book describes historical events until the year 862 AH (1458 AD). It is inspired by the book “History of Yazd” written by *Jafar*, in terms of content and chapter organization. This book is nothing more than a description and extension of the contents of the *Jafari*'s book, along with the addition of some further points. It is greatly probable that *Kateb* named his work “New History of Yazd” to avoid confusion with *Jafari*'s work [27], [29].

Mohammad ibn Najm-ol Din Mahmud ibn Habib-ol Lah-e Yazdi, known as *Mohammad Mufid Mustufi Bafqi*, is an Iranian historian from the 11th century AH (corresponds to the 16th century AD, 1592-1688) who held a position in the administrative apparatus of *Suleiman Safavi* era. He is the author of the “*Jame-e Mufidi Mustufi*”, the

most comprehensive work about the history and geography of Yazd. This book was completed, in 1090 AH (1686 AD). In the sources consulted, the author refers to two books: “History of Yazd”, authored by *Jafari*, and “New History of Yazd”, authored by *Kateb* [27], [30].

Jafari attributes the founding of the city of Yazd to *Yazdgerd*. He mentions that the imperial order, which had been disrupted by Alexander the Great, was restored by *Yazdgerd*. Furthermore, *Kateb* and *Mufid* also state the growth and expansion of the city of Yazd by the *Sassanids*. However, according to their narrative, which is stronger and more systematic than *Jafari*'s, the construction and growth by the *Sassanids* in the history of Yazd was continuation of the work that Alexander had initiated. In other words, *Jafari* believes that the founder of the city of Yazd is *Yazdgerd*, but *Kateb* and *Mofid*, while acknowledging *Yazdgerd*'s significant role in the expansion of Yazd, emphasis more on the accomplishment of Alexander in the construction of Yazd. In fact, in the works of both authors, the establishment of the city of Yazd is attributed more to Alexander the Great [31] (Figure 6) (Figure 7).

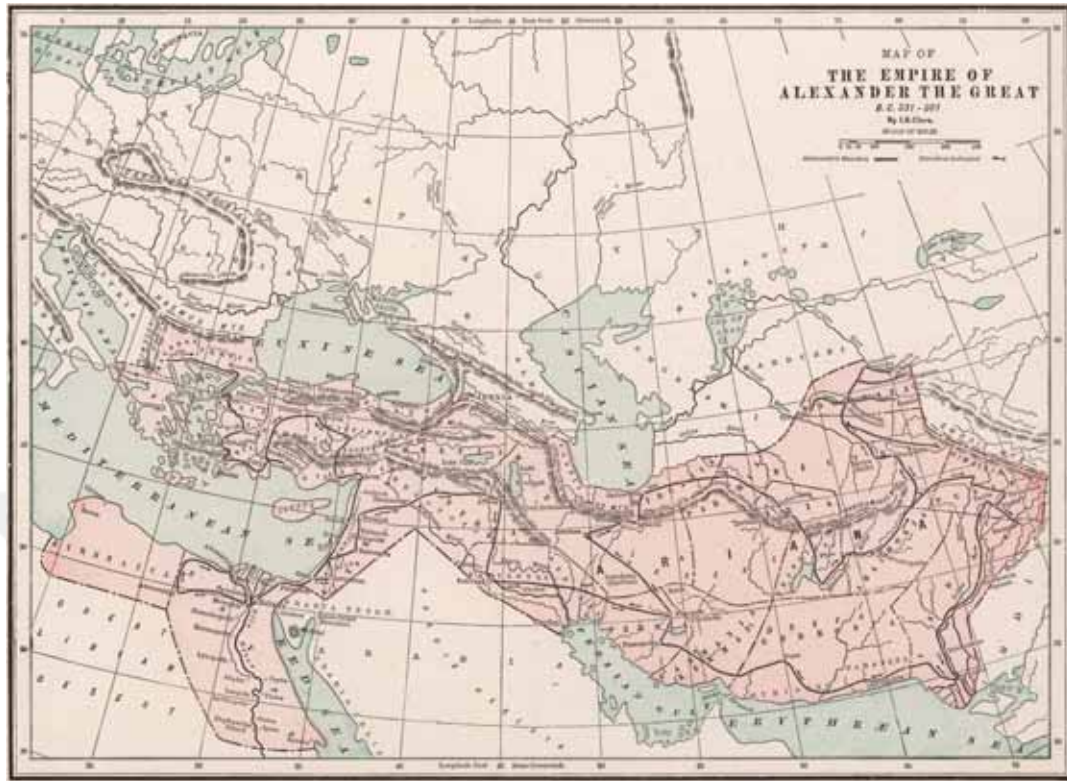


Figure 6. The map of the Alexander the Great Empire, 331-301 B.C. [26].



Figure 7. The map of the Macedonian Empire, 336-323 B.C. [32].

2.2 The *Qanat* Systems (*Karez*)

Part of the rainwater infiltrates the earth's crust, permeating through the permeable layers until it reaches an impermeable layer. At this point, it accumulates to form an underground water table [33]. Due to the considerable depth of the underground water table, specifically in the central plateau of Iran, it becomes challenging to access an appropriate water supply for irrigation without the use of modern pumps. Consequently, the *Qanat* system proves fundamental for cultivation in the absence of such contemporary pumping technology. The *Qanat* system is comprised of a nearly horizontal subterranean conduit that commences from the underground water table situated at an upper elevation. Gravity facilitates the flow of water through this conduit, eventually emerging at the surface within the village or settlement. Given that the underground water table needs to be accessed from a higher elevation, the *Qanat* systems are characteristically initiated within or near hills, mountains, or wherever there is a gentle slope over a certain distance. This landscape facilitates the functioning of the *Qanat* systems [10]. The length of a *Qanat* system or its conduit varies, depending on the slope of the terrain along its course [33]. The length of a *Qanat* system in flat and featureless terrains, where water flows in the depth of a surface without encountering any significant reliefs, characteristically ranges from 10-40 kilometres [10]. *Iraji*, in his book "The monuments of Yazd", notes that in large basin settlements like Yazd, the length of a *Qanat* system can occasionally exceed 80 kilometres [34]. This longer length is often essential to efficiently moving water from the underground water table to the settlement, considering the landscape [33]. In contrast, in mountainous areas where the landscape is characterized by steep terrain, the length of a *Qanat* system is much shorter. These mountainous *Qanats* may only extend for a few kilometres, that does not exceed 1 or 2 kilometres [10]. Yazd possesses an extensive network of *Qanats*, which are spread near each other, yet demonstrating a

noteworthy alteration in their depths. The commencement depth of a long *Qanat* can extend to a range of 80-90 meters, while shorter *Qanats* initiate at a shallower depth of 10-20 meter. This variety in *Qanat*'s depth is attributed to numerous factors, including the geographical features of the region, and the proximity to water source [10]. The majority of the *Qanat* systems in the region are characterized as *Havabin*, indicating that their water flow experiences seasonal variations from year to year influenced by factors such as rainfall patterns. The seasonal fluctuations are caused due to the passage of the *Qanats* through alluvial fans, where the terrain is characterized by a coarse rough and permeable substance that directly impacts water flow. Moreover, the alluvial fan is the water source for *Qanat* systems, confirming the pureness and quality of the water. Consequently, *Qanat*'s water is often referred to as "sweet water". In contrast, a minority of the *Qanat* systems are classified as non-*Havabin* because they initiate from stable and deeper underground water table, signifying that their water flow remains constant through the year, and does not alter even throughout a wet or dry year. The seasonal dynamics of water flow within these *Qanat* systems are categorized by highest flows occurring during late winter and spring, while water availability tends to be at its lowest during summer [10]. The entirety of the *Qanat* system, from its starting point to its end, where water flows deep underground, is the domain of the *Qanat*, with ownership vested in its owners [33]. The *Qanat* systems, mainly the larger ones, may possess several branches. These branches can extend for many kilometres, each fortified with its own set of vertical wells and a primary well [10].

2.2.1 “Qanat” and “Karez” Etymology

Table 1. “Qanat” Etymology

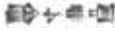
Akkadian: qanûm /qa'nu:m/: Pipe, Read and measuring reed, Cane 	
→	Arabic: قناة (qanāh) /qa.na:h/: Channel, Canal
→	Persian: قنات (qanāt) /qa.na:t/: Pipe, Conduit, Irrigation-trench, Canal Plural: قنوات (qanawāt) [35].
→	Ancient Greek: κάννα (kánne) /kán.na:/ → /'kan.na/ → /'ka.na/: Giant reed
→	Latin: canna /'kan.na/: Reed, Cane
→	Latin: cannālis /ka'na:.lis/: Channel, Canal, Conduit

Table 2. Egyptian Hieroglyphic [36]

q [k]	n [n]	t [t]
Hand	Water	Loaf
		

Table 3. “Karez” Etymology

<i>Matigan-i Hazar Datistan</i> [Book of a thousand judgements]: kahas : <i>Qanat</i> [37].
Middle Persian (Parthian): qhryz : Canal, Drain [38].
└→ New Persian: کاهریز (kāhriz), کهریز (kahriz): Underground irrigation channels [38].
└→ New Persian: کاریز (kāriz): Underground irrigation channels
Plural: کاریزها (kāriz-hā) [38].
Middle Persian (Parthian): khs : Channel, Sewer [38].
└→ Pahlavi: kahos: Channel, Sewer [39].

The *Matigan-i Hazar Datistan* [Book of a thousand judgements] was written at late *Sassanid* period, i.e., the first half of the 7th century AD. This book includes civil law of the Persians in the *Sassanid* period based on the Zoroastrian religion, i.e., before Islam. In the twenty-second paragraph of this book, *Qanat* systems and their ownership are discussed [40]. In this paragraph, *Qanat* systems are referred to as “*Kahas*” [37].

2.2.2 The Technology of Construction and Measurements

The *Qanat* systems are excavated by *Muqannis*. *Muqannis* are skilled diggers, and they possess a great level of proficiency in this complicated and dangerous endeavour. The city of Yazd is well-known for its *Muqannis*, who travel throughout various regions of Iran to maintain, repair, and clean these *Qanat* systems. The construction of a *Qanat* system commences with the master *Muqanni* estimating the starting point of the *Qanat* and determining the precise slope and path of the conduit to ultimately emerge at an existent or proposed village. In ancient times, master *Muqannis* utilized a divining rod made from a hazelnut tree to identify the location of a water sources. At the anticipated site for the water source, one or more test wells are excavated to precisely determine the

extent and depth of the underground water table. This information guides the construction of the conduit, stating its slope and depth. The procedure of excavating the nearly horizontal conduit starts at the *Qanat* system's outlet. While the *Qanat* channel is being excavated uphill towards the testing well, vertical wells (*Shafts*) are also dug out to facilitate ventilation and lifting out the excavated materials [10]. The primary or head well, known as mother well, can reach depths of up to 100 meters, making it the deepest well in the *Qanat* system [41]. When the *Qanat* system is constructed, these wells attend as access points for the maintenance and repair of the channel. Thus, these wells become a lasting and essential part of the landscape. The space between the wells (*Pushteh*), is determined by both their depth and the material being excavated, 20-30 meters. Deeper wells and less permeable materials, such as stone, necessitate a nearer arrangement of wells. These wells feature an upraised rim of excavated materials, and they mutually form the unique chain of wells that is noticeable in aerial photographs. The mounds of excavated materials around the well's edge serve to prevent pouring of stones and mud during storms. The *Qanat* system's conduit excavated to reach the underground water table, and further beyond it, to ensure an adequate water-bearing zone for the *Qanat*. In large-flowing *Qanat* systems, this water-bearing zone can extend over several kilometres. The *Qanat* system's conduit may excavated up to the test well, or it could terminate before or extend beyond this specific point. Overtime, deposits of calcium carbonate and other mineral salt tend to accumulate on the bed and sides of the *Qanat* system's channel. If these deposits are not removed every 10-15 years, it can lead to reduced infiltration into the channel and subsequently, the water flow within the *Qanat* will decrease. Therefore,

it is essential to periodically clean and repair the *Qanats*, and this is one of the cores responsibilities of the *Muqannis* [10] (Figure 8) (Figure 9).



Figure 8. The wells and their soil heaps [10].



Figure 9. The windlass for lifting out the excavated materials and ventilation [10].

2.2.3 The Main Parts of the *Qanat* System

The *Qanat* system comprises an underground conduit, known as *Koure*, which is connected to the underground water table at one end, referred to as *Tar-e kar* (*Taroun*). This conduit lightly slopes to convey the water from the *Taroun* section towards the *Qanat's* outlet at the other end, referred to as *Mazhar*. The core component of the *Qanat* system is its underground and nearly horizontal conduit, serving as the main water-carrying channel. The conduit resembles an elongated and narrow underground corridor. To facilitate the dredging and repairing the damaged walls, the channel's dimension should allow an ordinary person to move within in a bent manner. The specific length and width of the cross-section of the conduit fluctuate according to the volume of water flow. Across all *Qanat* systems, the underground conduits share a common construction technique. However, there is a dissimilarity about wells. These wells divided into two categories, Yazd's wells, and Kerman's wells. Yazd's wells possess a circular cross-section with an 80cm diameter, and they are cylindrical in shape. In contrast, Kerman's

wells have a square cross-section measuring 60cm×120cm, and they are rectangular cub shape [33]. Normally, *Qanat* systems with different lengths consist of three main parts:

- The first part, known as *Tar-e kar (Taroun)*, is the area around the primary well. It serves as the point where water pours into the underground conduit. Water can either enter the conduit from the surrounding soil or the conduit can be directly connected to the underground water table.
- The second part, known as *Tar-o khoshk*, is the area consists of two parts, semi-wet and semi-dry. It is a shorter section compared to the other two. As a result, some experts do not differentiate between these two parts, considering one part as an extension of *Tar-e kar (Taroun)* and the other part as an extension of *Khoshk-e kar (Khoshkoon)*.
- The third part, known as *Khoshk-e kar (Khoshkoon)*, is the dry part. It is considerably longer than the preceding parts. The depth of the wells in *Khoshkoon* is shallower compared to *Taroun*, and it gradually decreases to a minimum near the *Qanat's* outlet.

[33] (Figure 10)-(Figure 14)

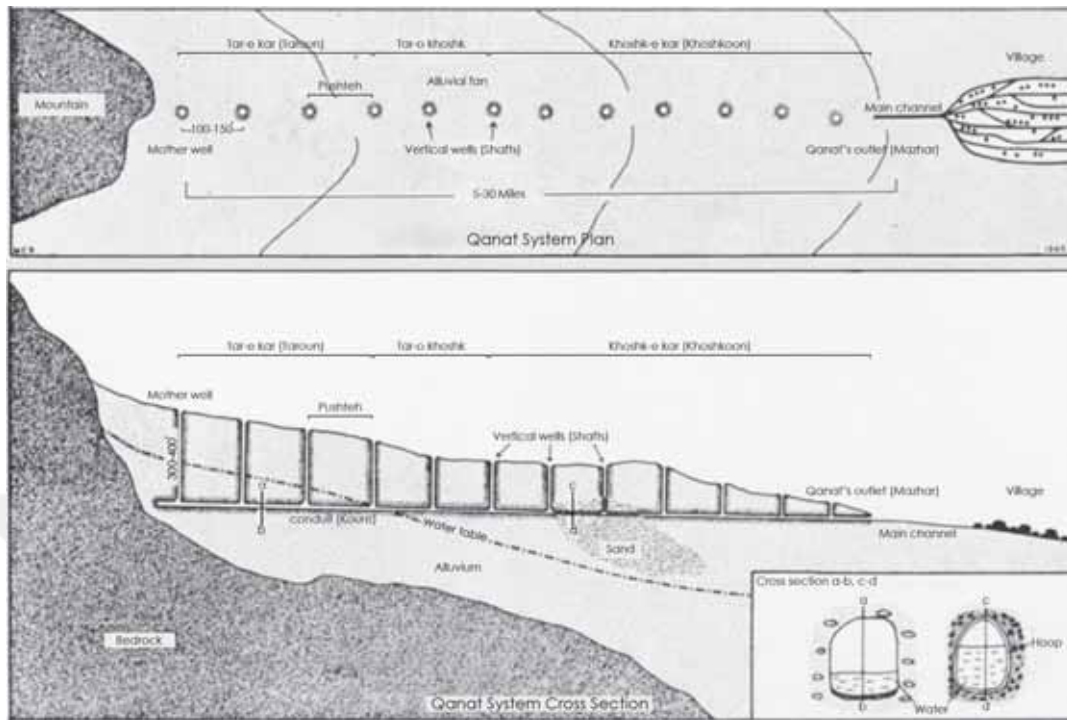


Figure 10. The *Qanat* system plan and cross section. Author's elaboration using [42].



Figure 11. The *Qanat's* outlet (*Mazhar*) in *Mehriz*. The excavation is unusual, most outlets are at the surface [10].



Figure 12. The water collection pool for distribution system at the *Qanat's* outlet in *Pishkuh-i Yazd* [10].



Figure 13. The water collection pool for distribution system at the *Qanat's* outlet [10].



Figure 14. The cleaning process of the water collection pool at the *Qanat's* outlet in *Pishkuh-i Yazd* [10].

2.2.4 The *Qanat* Systems Hierarchy

When the *Qanat's* water reaches the surface near the settlement, it flows along the main channel or branch into the village. In the case of depth *Qanat* systems like those in Yazd, the main path will be closely to the surface, gradually decreasing in depth until the water reaches the surface near the agricultural lands [33]. In settlements with several great *Qanat* systems, their branches may intersect or cross over each other rather than converging into a single main channel [10]. Through the irrigation system, the water from *Qanat* systems is distributed from the primary branches to various parts and structures within the city [43]. The agricultural lands are arranged in clusters within cultivation areas, regularly situated down-slope from the settlements. Therefore, after fulfilling the

village's water requirements, the *Qanat's* water is directed to these cultivated areas for irrigation [10] (Figure 15)-(Figure 18).



Figure 15. The aerial imagery of Yazd, including vertical wells and their soil heaps, 1960 [44].

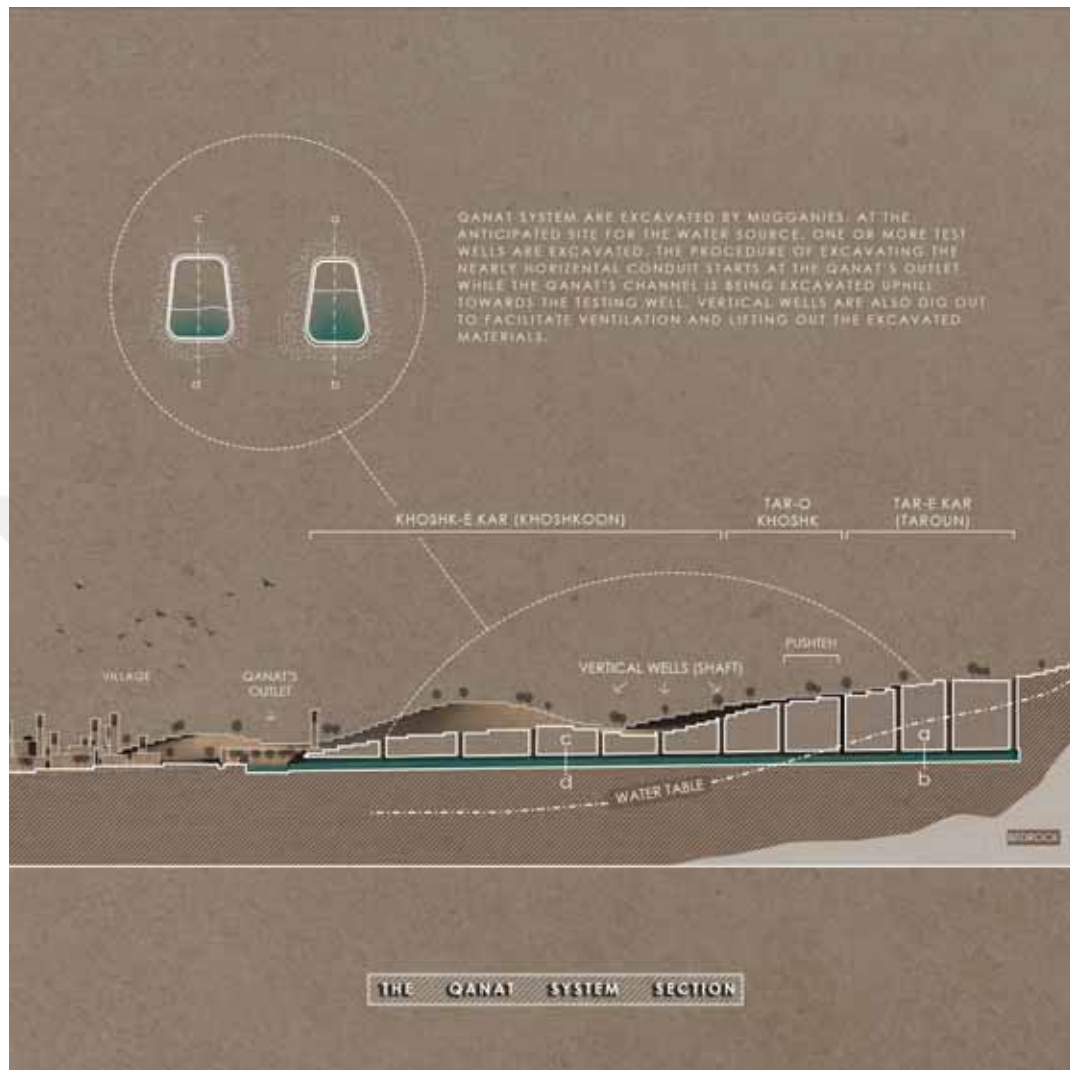


Figure 16. The irrigation system diagram. Author's elaboration using [10].

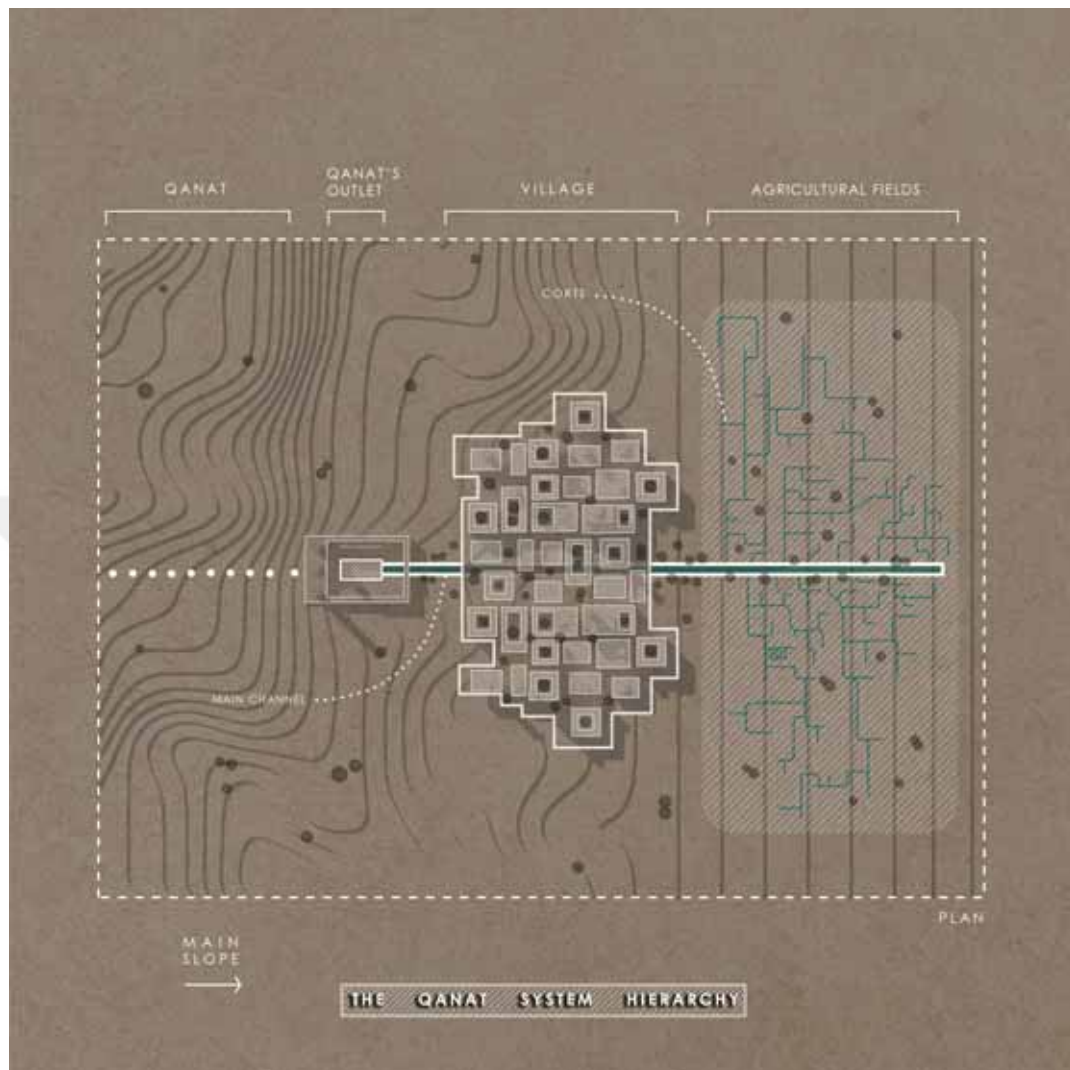


Figure 17. The irrigation system diagram. Author's elaboration using [10].

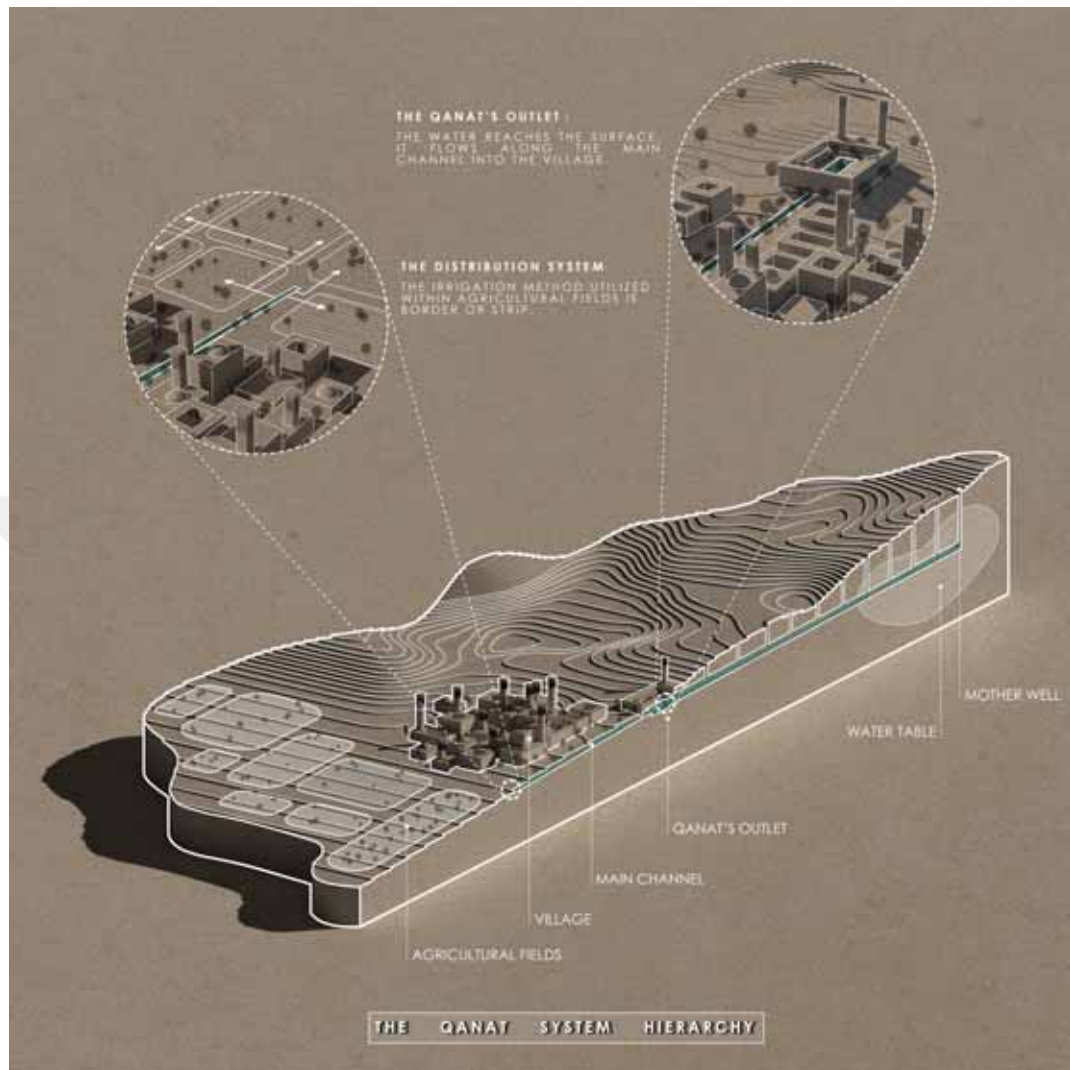


Figure 18. The irrigation system diagram. Author's elaboration using [10].

2.2.5 “Corte” Etymology

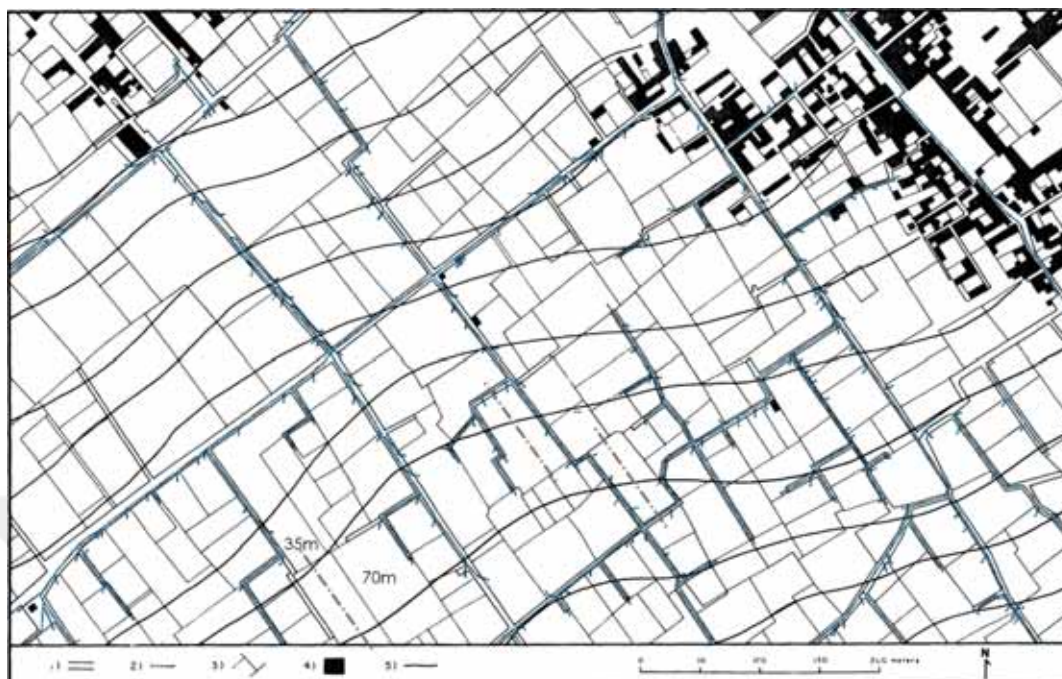
Table 4. “Corte” Etymology

Porto-Indo-European Root: g^herd^h : To enclose, To encircle [45].
→ Porto-Indo-Iranian: g^hrd^hás : Enclosure, House [46], [47].
→ Ancient Greek: χώρα (khóre) /k ^h ō.ra:/ → /'xo.ra/ → /'xo.ra/: Piece of land [48].
→ Greek: χώρα (chóra) : Main town or village [48].
→ Arabic: كورة (kūra) /ku.ra/: District or province, A type of administrative division
→ Latin: cohors /'ko.hors/: A court, A farmyard or enclosure [49].
cors /ko:rs/ (Alternative form of cohors) / Ablative: corte [49].
→ Persian: كرته (korte) : Piece of land
English: court : An enclosed space; A courtyard; An uncovered area shut in by the walls of a building, or by different buildings [50].

2.2.6 The Division and Distribution System within Agricultural Fields

In the central Iranian plateau, water is a scarce and precious commodity. The water supplied to settlements through the *Qanat* systems is utilized in a cycle, with a specified number of days and nights for usage. Land and water ownership can either be combined or separate. A farmer who possesses a share of the *Qanat's* water or has rented such a share is entitled to that water throughout the entire year, rather than just for one specific cycle. The duration of the water cycle can vary regionally due to numerous factors in the central plateau [10].

The cultivated zones are divided into a set of rectangular strips, referred to as *Corte*, using parallel and low levees or border ridges. The long axis of the *Cortes* aligns with the steepest slope in the landscape. The dimensions of these *Cortes* vary depending on factors such as the slope, water flow, and the soil texture. Therefore, these dimensions can vary significantly between different villages. In central Iran, the irrigation system utilizes the border or strip method. In this system, the *Qanat's* water is directed to the upper end of each strip and flow down slope through the fields. The border water supply system is calculated in such a way that the essential amount of water has been directed to the *Corte* until the water touches the far end of the strip. Consequently, the *Cortes* should be constructed as big as efficiently possible within the irrigation system. If they are too small, it results in a waste of time and water when moving water between *Cortes*. In contrast, if they are too large, a significant amount of water may either be absorbed or not reach the end of the strip at all. In agricultural fields, the downslope (long axis) should have a quite gentle and uniform gradient to facilitate the proper spread of water and prevent erosion. Conversely, the cross-slope (short axis) should be kept level to avoid water flowing to one side of the strip. The *Qanat's* water is expressed to the rectangular *Cortes* through an open ditch system, where channels branch off at suitable angles and parallel to the main channel, forming a grid pattern of irrigation channels [10] (Figure 19)-(Figure 34). (See Appendix C)



1. Streets and paths, including dead ends
2. Water channels and where they enter the fields
3. Walled fields and orchards
4. Public and residential buildings
5. Contour lines, one-meters intervals decreasing in elevation to the southeast

Source: Iranian National Cartographic Centre, "*Mehriz*" (Scale 1:2,500), sheet 5, 1967/68.

Figure 19. The irrigation system within agricultural fields. Author's elaboration using [9].



Figure 20. The agricultural fields pattern in the suburbs of Yazd [9].



Figure 21. The rectangular walled agricultural fields and orchards in *Taft* [9].



Figure 22. The rectangular *Cortes* in Yazd [9].



Figure 23. The rectangular *Cortes* in *Pishkuh-i Yazd* [10].



Figure 24. The main irrigation channel within agricultural fields in *Mehriz* [9].



Figure 25. Diverting water from main irrigation channel into walled agricultural fields and orchards in *Mehriz* [9].



Figure 26. The distribution system in *Mehriz* [10].



Figure 27. The distribution system in *Mehriz* [10].



Figure 28. The secondary irrigation channel within agricultural fields in *Mehriz* [9].



Figure 29. The erosion of walls by irrigation channel in *Mehriz* [9].



Figure 30. The wooden tool to measure the flow of water within water channels in *Sar-i Yazd* [10].



Figure 31. The wooden tool to measure the flow of water within agricultural fields in *Taft* [10].



Figure 32. Dragging shovels in the water channels to move water and minimize leakage [10].



Figure 33. Pulling a cloth in the water channels to move water and minimize leakage [10].



Figure 34. Dragging shovels in the water channels to move water and minimize leakage [10].

2.3 The Formation Process of Yazd

2.3.1 The Territorial Scale

The territorial type is the consciousness of the region where man dwells. This spontaneous awareness is related to a certain era and area, which comprises man's assumptions about selecting a place to settle and to establish productive activities, a means to cross the territory, and setting up a place to commerce and meet with other inhabitants [6].

The notion of territorial organism is the broadest and comprises the most components. The territory not only consists of architectural structures, built environment that man applies to live in and to creates his behaviours, settlements, and urban configurations, but also includes associated systems, for instance, routes and all major production structures. The world not only comprises buildings, villages, and cities but also in expanded scale, comprises routes and production zones [6]. This research has investigated the way the existence of the settlements and urban cores initiated from routes and productive structures in central Iranian plateau.

The city of Yazd is situated between two parallel series of top ridge routes. Since Yazd is in this geographical location, it is an example of a valley settlement. This geographical pattern is also observed in neighbouring cities such as *Taft* and *Zarch*. In other words, in this region of the central Iranian plateau, humans have settled between top ridge routes and in valleys, commonly referred to as valley settlements. There are two reasons for this geographical pattern:

- The first reason is that the mountainous areas in this region have a steep slope. Therefore, they do not provide sufficient area to form a settlement. Moreover, there are few low promontory settlements that remain unpopulated.

- The second reason is that the climate of this region is hot and arid. Consequently, these settlements used the *Qanat* systems to fulfil their water requirements. The *Qanats* originate from the underground water table located on the hillside. This system uses the natural slope of the land to transport water within its conduit from upstream to downstream, finally reaching the surface. Hence, both populated and unpopulated settlements have formed in valleys to make use of the *Qanat* system.

The intermittent streams that originate from the south, southwest, and northeast ridges converge towards the valley settlements, help to supply water to underground aquifers. The valley routes connect the various valley settlements. These routes correspond to the main road and railway of Yazd province shown on the “Map of Iran”, 1973, published by the U.S. Central Intelligence Agency. Moreover, the valley route aligns with the primary main road of the city of Yazd prior to modernization. Eventually, small villages with less population are located near the communication routes, including valley routes and cross ridge routes. This placement allows these villages to connect with other settlements in the region. According to the alterations of the urban tissue for various site morphologies presented by [51], the urban tissue and urban routes are influenced by the morphology of the territory. The site acts as an attractor (Figure 35) (Figure 36).



Figure 35. The territorial organism, 1:250,000. Author's elaboration using QGIS 3.26 and OpenDEM datasets, [52], [53], and [54].

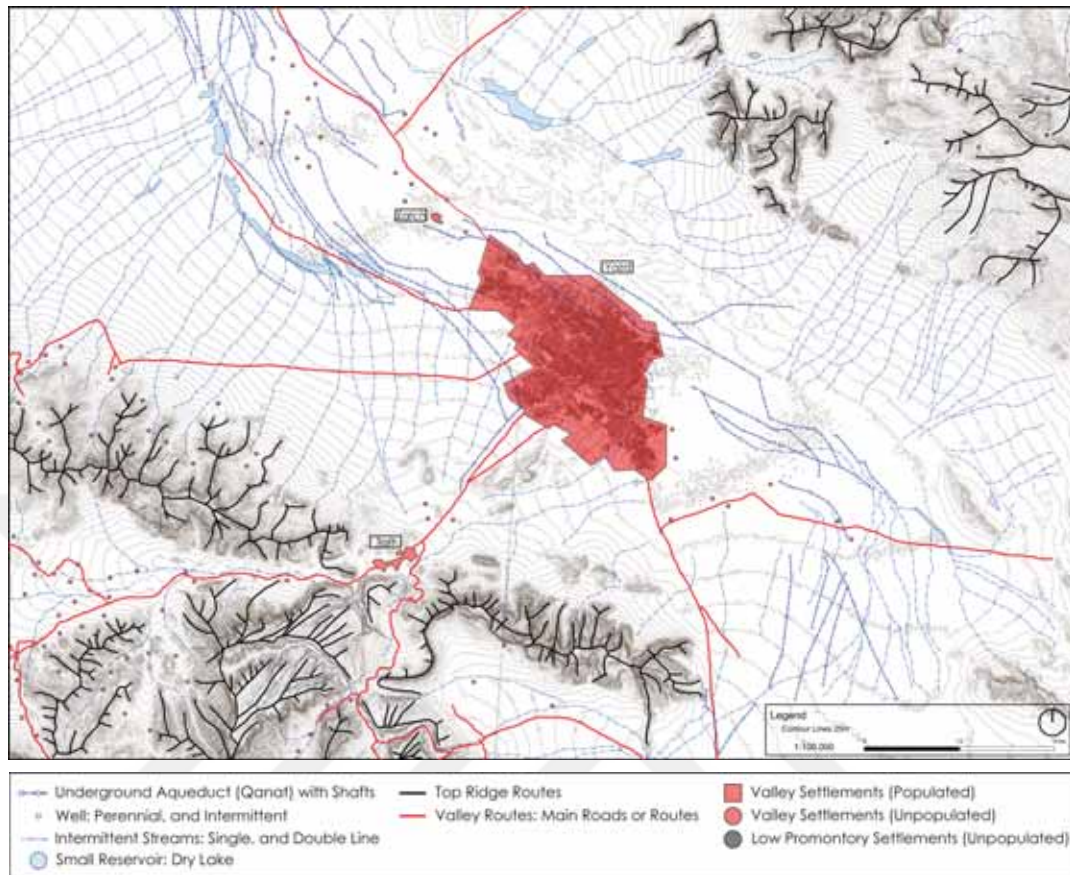


Figure 36. The territorial organism, 1:100,000. Author's elaboration using QGIS 3.26 and OpenDEM datasets, [52], [53], and [54].

2.3.2 The Urban Scale

The urban organism type is a mental project about the settlement that the constructor presents it to his contemporaries. Therefore, it is related to a certain time and is limited to a place [6].

The urban organism is produced through the integration of several basic tissues. The basic tissues consist of buildings with different facilities, street network, and open spaces. The role and characteristics of the components of this organism change with the urban development within different historical stages [6]. This research investigated the way the urban organism transformed within historical periods in the city of Yazd. Hence, the study analysed Yazd's urban organism within four stages.

- The first stage is the emergence and formation of Yazd within its city walls up to the late 14th century AD.
- The second stage is the formation and expansion of Yazd with the appearance of new neighbourhoods beyond the city walls from 15th to 16th century AD.
- The third stage is the extension of Yazd concurring with the regional constancy from 17th to 18th century AD.
- The fourth stage is the development of Yazd according to the municipal law in 19th century AD.

2.3.2.1 *The formation of Yazd up to the late 14th century AD*

In this stage the city of Yazd has five phases,

- The Alexander the Great era
- The *Sassanid* era (224-651 AD)
- The early Islamic period (662-1008 AD) and the *Kakuyid* era (1008-1141 AD)

- The *Atakaban* era (1141-1319 AD)
- The *Muzaffarid* era (1319-1393 AD) [55].

The initial structure in the city of Yazd, Alexander's prison, was constructed by Alexander the Great [28]. No remnants of this building exist today, as it has been destroyed. Archaeologists, based on historical records and local discoveries, have considered the location of this prison to be in the northern part of Yazd's historical context, situated at the intersection of two main routes, the valley route and the cross-valley route. Hence, it can be assumed that the initial pre-Islamic city centre, consisting of Alexander's prison, was located at the junction of these two main routes. Presently, the *Ziaieh* school, whose construction was completed in 1305 AD, occupies the site intended for Alexander's prison. In the *Sassanid* era, cities were enclosed by fortified wall with four gates. The evident correspondence in the urban planning of the *Sassanid* cities suggests a predetermined construction plan for these structures [55]. In the late *Sassanid* era, Yazd experienced expansion under the reign of the *Yazdgerd* [28]. At that time, the city was confined what to the *Fahadan* neighbourhood, situated in the northern part of Yazd's historical zone [55]. The *Sassanid* Empire was overthrown in 651 AD following the Arab conquest of Persia. In the 8th century AD, Muslim communities settled in the northern region of Yazd's historical context, leading to the gradual development of new neighbourhoods [29]. Upon the advent of Islam in Iran, Yazd underwent significant transformations. In the early Islamic period, the expansion of Yazd was towards the south and southwest direction, following the main slope of the territory. The unfavourable climate conditions in the north, constrained the city's growing in that direction [3]. The emergence and formation of the city of Yazd relies on the characteristics of the natural environment, including climate, land conditions for construction, and most importantly, the irrigation system. All parts of the city were planned to ensure proper access to the

Qanat systems [55]. The end of the 14th century marked a significant phase in the water infrastructure development of Yazd, with establishment of two series of *Qanats* [3]. In the *Kakuyid* era in the 11th century AD, the initial city walls with four gates were completed. A part of these walls in the northern part of the historical context still exists. In this period, the new city centre was built with elements that corresponds to Islamic culture and life, including the *Jameh* Mosque and the Bazaar [55]. In the *Atabakan* era, in addition to the natural features, the transition of the local centrality from Alexander's prison to the *Jameh* Mosque, leading to the consideration of the south direction as the main axis of the city's growth. In this period, a fifth gate was added to the fortified city walls [29]. In the *Muzaffarid* era in the 14th century, new structures such as cistern, school, and Bazaar, referred to as *Chahar Souq*, were constructed around the *Jameh* Mosque toward the south. Moreover, the number of the city wall gates increased to six during this period [29] (Figure 37)-(Figure 41).

2.3.2.2 The formation of Yazd in the 15th-16th century AD

In this stage the city of Yazd has two phases,

- The *Timurid* era (1393-1507 AD)
- The first half of the *Safavid* era (1501-1736 AD) [55].

In this period, the city of Yazd was under the rule of two empires, each had a distinctive pattern of urban expansion [55]. In the *Timurid* era, Yazd developed in the south direction. By the order of the city governor, a new district, referred to as *Amir Chakhmaq* Complex was planned and constructed. This complex with its commercial functions, including a mosque, a cistern, and a Bazaar, was arranged in the form of a square outside the city walls [29]. The expansion of the city beyond the city walls during this period considered as the initial transition period from a morphological perspective. Hence, the *Amir*

Chakhmaq Complex is the extension point for further developments in later eras [55]. In the first half of the *Safavid* era, the Bazaar underwent significant development due to the growth of trade. It becomes an important urban element integrated with the urban context. The Bazaar close to the *Jameh* Mosque initially expanded towards the south direction and later extended outside the city walls, reaching the *Amir Chakhmaq* Complex. Subsequent to this expansion, the centrality shifted from the *Jameh* Mosque to the *Amir Chakhmaq* Complex [55]. The end of the 16th century, Yazd had three series of *Qanats*, marking a further evolution in its water infrastructure [3] (Figure 42) (Figure 43) (Figure 44).

2.3.2.3 The formation of Yazd in the 17th-18th century AD

In this stage the city of Yazd has two phases,

- The second half of the *Safavid* era (1501-1736 AD)
- The *Zand* era (1750-1794 AD) [55].

In the second half of the *Safavid* era, the notion of the square became an urban planning model, integrating vital economic and administrative activities with the religious centre of the city. Hence, the prominent urban development during this period included the expansion of the city in the southwest direction and the initiation of the construction of the *Shahtahmab* Square and its mosque outside the city walls [55]. In the *Zand* era, the plan for expanding the Bazaar in a linear manner between the two squares, *Amir Chakhmaq* and *Shahtahmab*, was started. Numerous theological schools and caravanserais were constructed along the Bazaar route, forming a mixture of religious and commercial structures [55]. In this period, as the city expanded along the east-west axis perpendicular to the north-south axis, which had been the main direction of growth in previous eras, the urban tissue underwent a more balanced transformation [3]. In the 17th-18th century AD, Iran witnessed political stability, which led to the construction of

several palace-gardens beyond the city walls, representing the authority of the kings. In 1740 AD, the *Dowlat Abad* Garden, with an area of 40,000 m² and a *Qanat* for water supply, was built outside the western city walls of Yazd. This palace-garden acts as a governmental centre [55] (Figure 45).

2.3.2.4 *The formation of Yazd in the 19th century AD*

In this period, the city of Yazd was under the rule of the *Qajar* dynasty (1789-1925 AD). In this era, Yazd underwent the construction of residential, educational, medical, and governmental structures, align with the urban components of the *Timurid* and the *Safavid* era [55]. Furthermore, in the end of 19th century AD, the fourth series of *Qanats* was added to the water infrastructure of Yazd [3] (Figure 46).

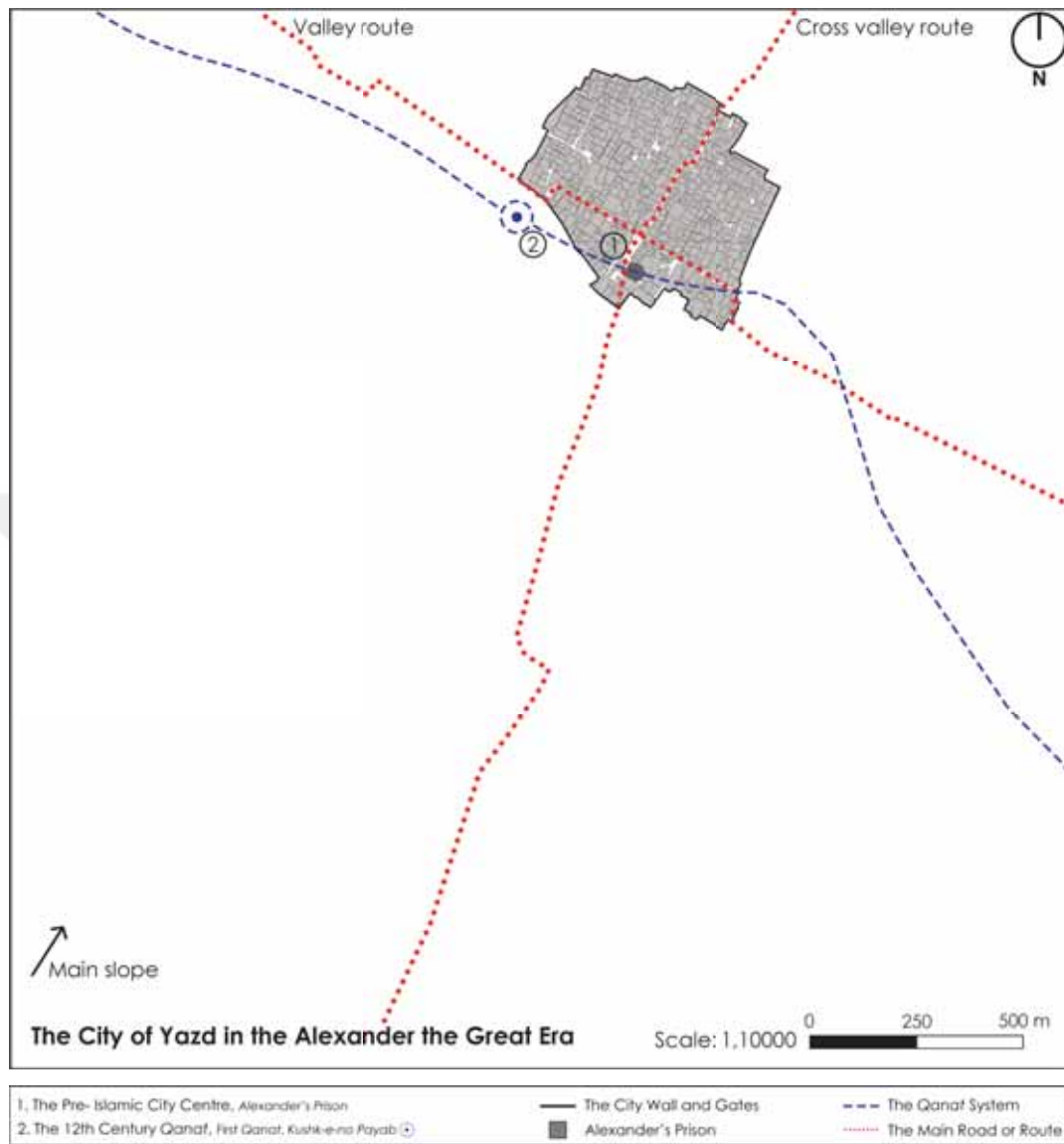


Figure 37. The city of Yazd in the Alexander the Great era. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

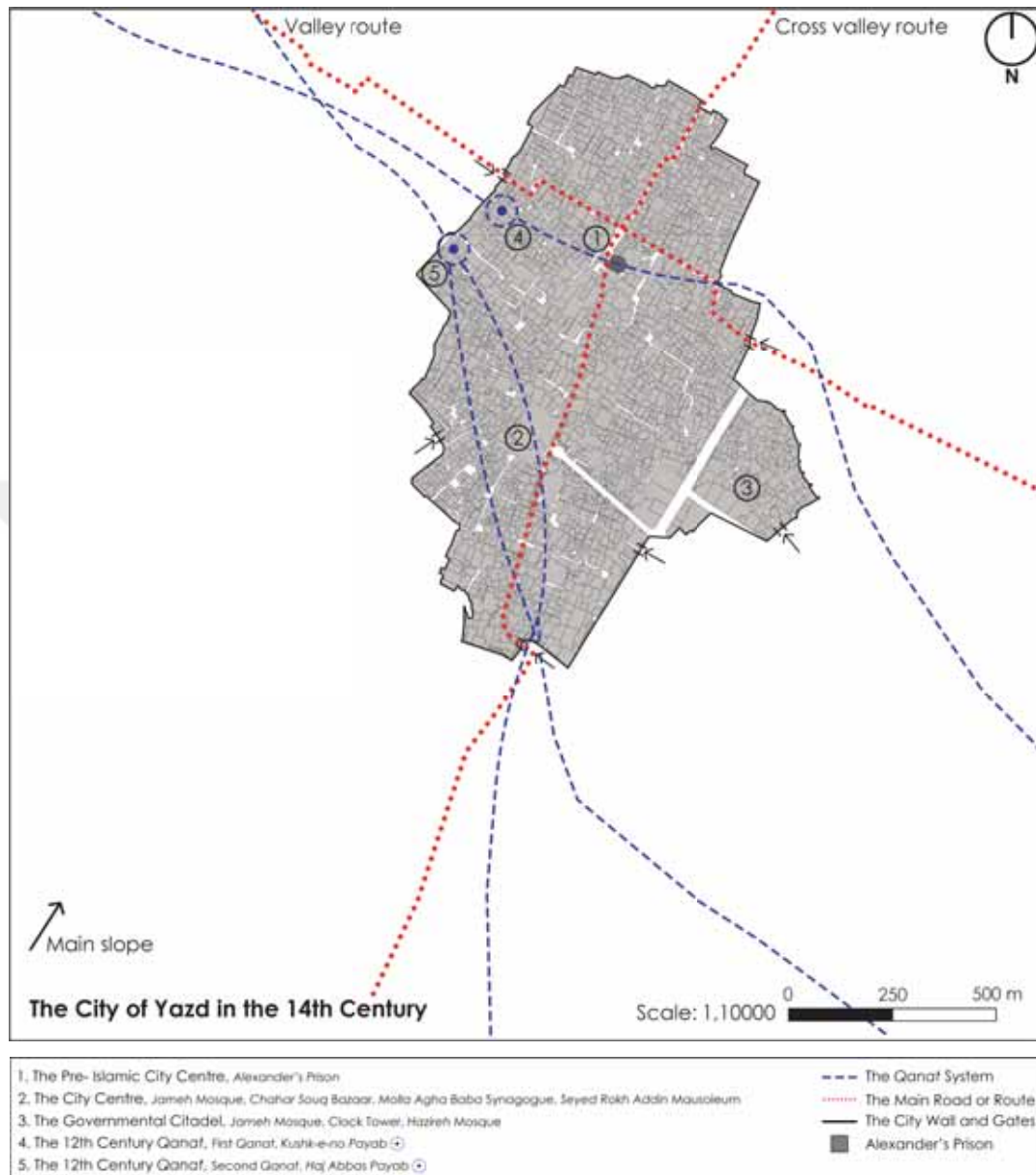


Figure 38. The city of Yazd in the 14th Century. Author's elaboration using QGIS 3.26 and NCC datasets, [3].



Figure 39. The city wall. Photo by author in November 2023.



Figure 40. The city wall. Photo by author in November 2023.



Figure 41. The aerial imagery of Yazd, including city wall, 2006 [56].

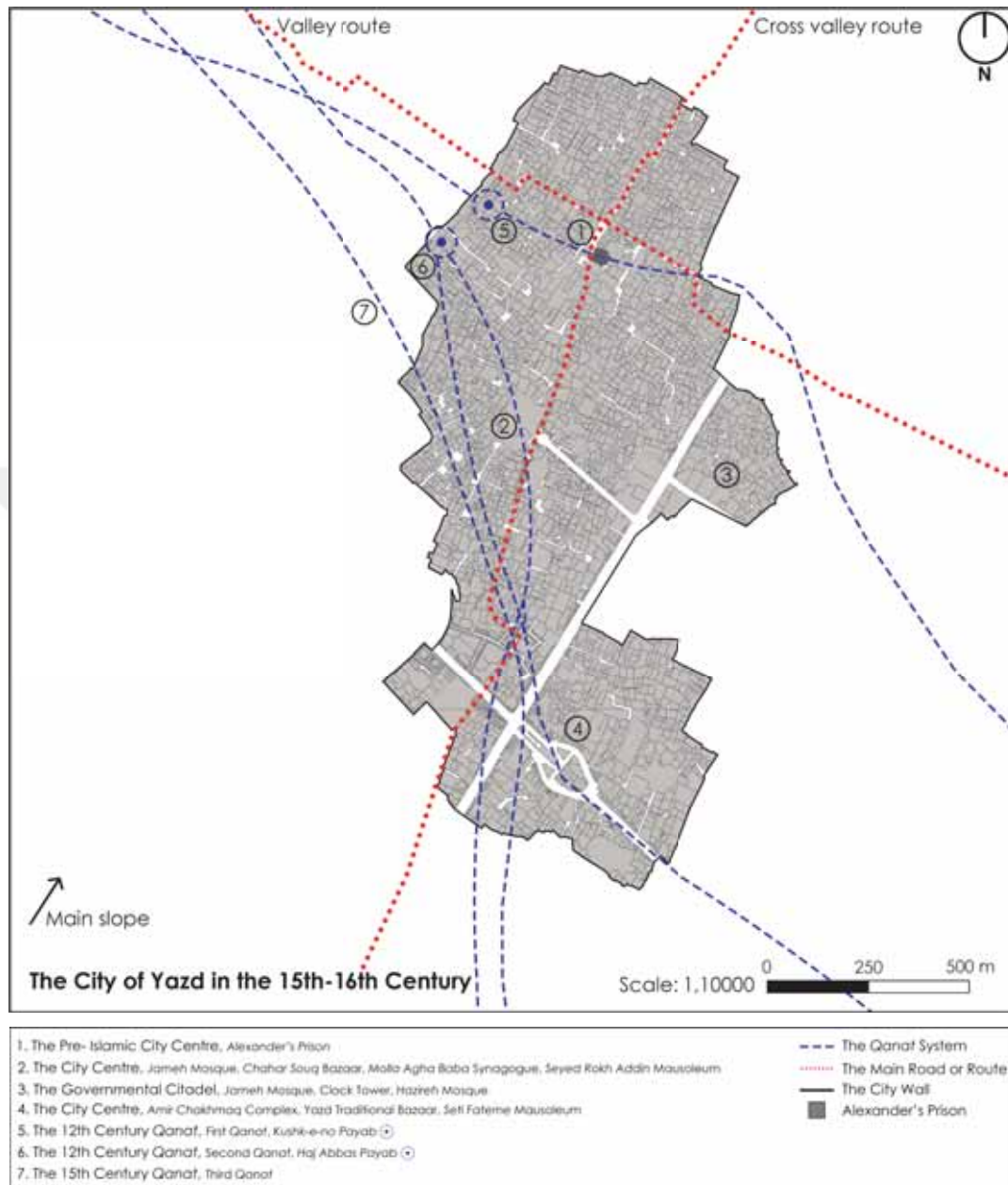


Figure 42. The city of Yazd in the 15th-16th Century. Author's elaboration using QGIS 3.26 and NCC datasets, [3].



Figure 43. The *Jameh* Mosque. Photo by author in November 2023.



Figure 44. The *Jameh* Mosque. Photo by author in November 2023.

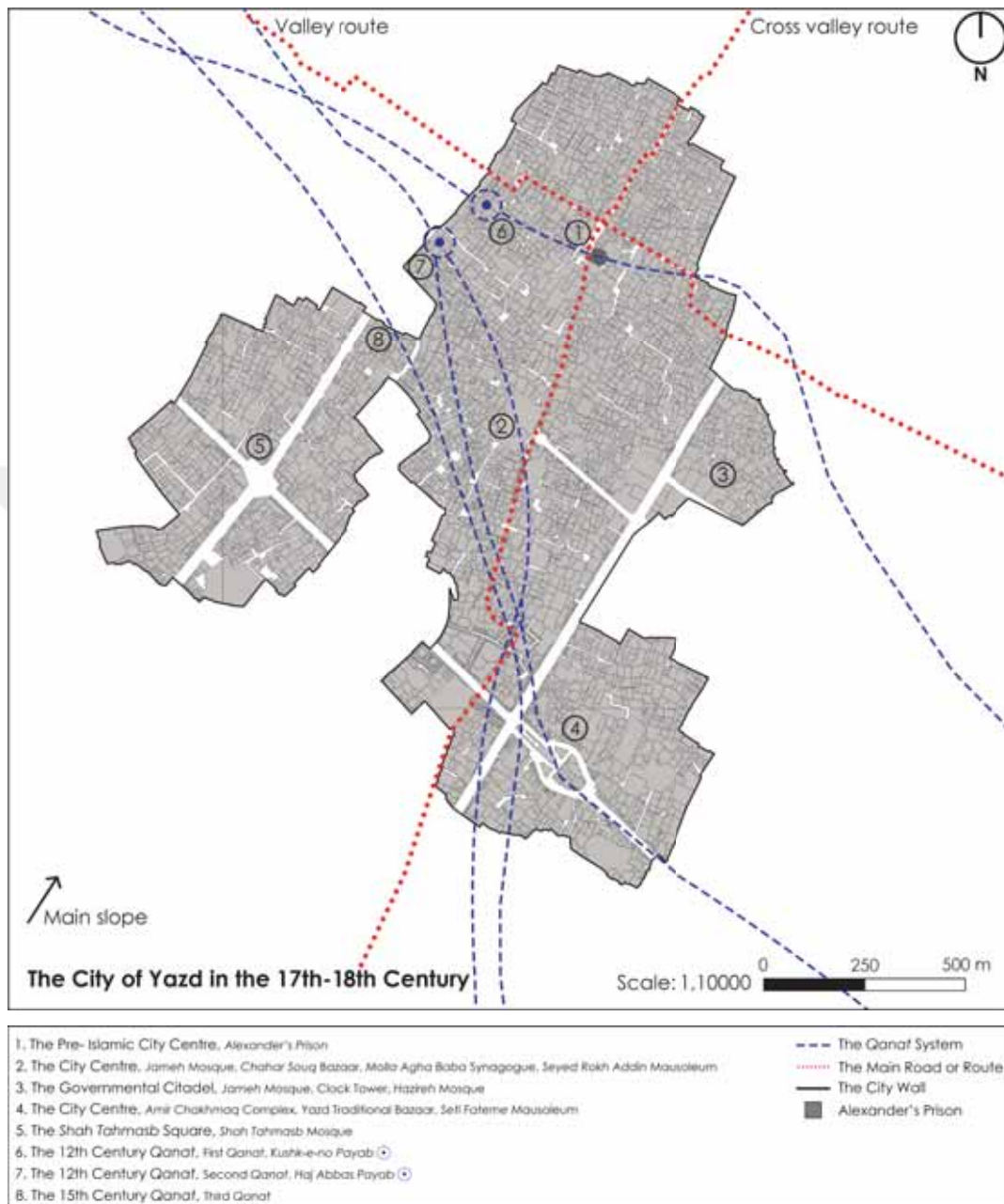


Figure 45. The city of Yazd in the 17th-18th Century. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

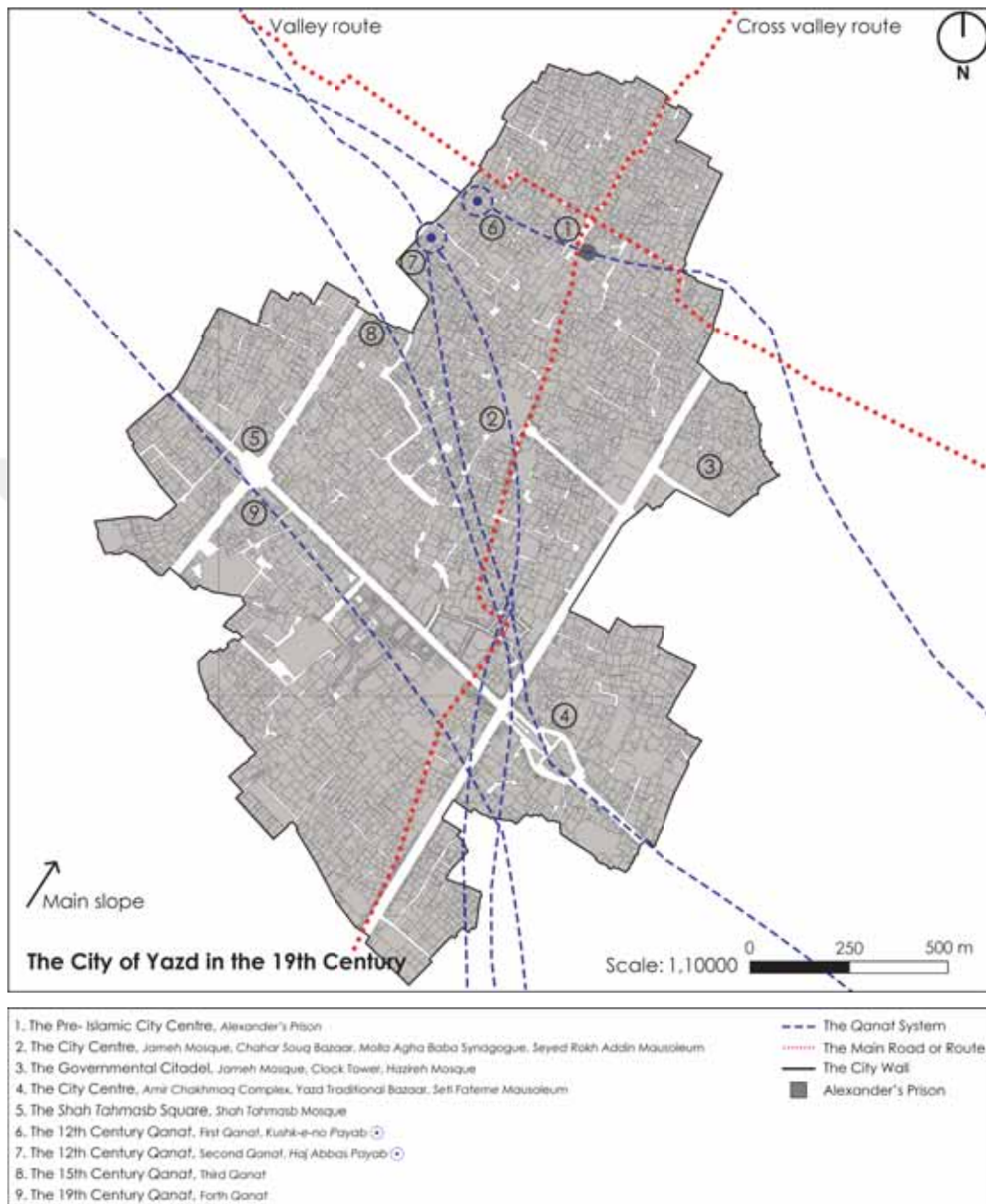


Figure 46. The city of Yazd in the 19th Century. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

Table 5. The Chronology of Urban Transformations of Yazd [55].

			Urban Planning Method	Urban Configuration
First Stage	224 AD	- Sassanid 224-651 AD	Planning base on the predetermined construction plans. In the direction of the Virgo.	The city followed a grid pattern, including city walls with four gates.
	651 AD	- Early Islamic period (Kakuyids) 662-1141 AD	Planning based on the characteristics of the natural environment, including irrigation system. In the direction of the main slope towards south and southwest.	The city followed an irregular pattern, including city walls with four gates.
	1141 AD	- Atabakan 1141-1319 AD		The number of city gates increased to five, due to the formation of new neighbourhoods inside the city walls. The shift of the city centre.
	1319 AD	- Muzaffarid 1319-1393 AD		The number of gates increased to six.
Second Stage	1393 AD	1 st Transition	Planning based on the elements that corresponds to Islamic culture and life, including the <i>Jameh</i> Mosque and the Bazaar.	The city expanded beyond the city walls and new neighbourhoods added to the city.
	1507 AD	- Timurid 1393-1507 AD	Planning bases on the growth of trade.	The Bazaar expanded inside and beyond the city walls. In the direction of the main slope towards south. The shift of the city centre.
	1736 AD	- First half of Safavid 1501-1736 AD		The city expanded beyond the city walls and new neighbourhoods added to the city.
Third Stage	1736 AD	2 nd Transition	Planning with consideration of square as an urban planning model.	The new structures constructed along the Bazaar route, including theological schools and caravanserais. Several palace-gardens constructed beyond the city walls.
	1794 AD	- Second half of Safavid 1501-1736 AD	Planning based on the Bazaar axis. Perpendicular to the main slope towards east-west axis.	The new structures constructed within the city.
	1794 AD	- Zand 1750-1794 AD		
Fourth Stage	1794 AD	3 rd Transition	Planning based on the municipal law.	
	1925 AD	- Qajar 1789-1925 AD		

2.3.3 The Urban Tissue Scale

The notion of urban tissue is a summary of formative rules and categories. The basic tissue is the concept of the coexistence of numerous buildings in the minds of the constructors before the action of constructing them. The experience of placing numerous buildings together and summarizing all aspects is a civilizational result. The basic tissue is made of aggregate. Type of aggregate is a self-regulating system that transforms over time and space. The structure of this aggregation is formed over time, deriving an arrangement of formative and progressive rules from the inherent process of formation and transformation of its structure over time [6]. The urban tissues are living organisms that alter over time [57]. This study endeavoured to reconstruct the aggregation rules to convert them into logical categories and extract factors to guide the interpretation of Yazd's urban tissue.

The route is a structure that initiates from somewhere and provides access to a place. The building needs to be connected to other buildings. Therefore, there is not a structure without a route [6]. The attractor theory is an urban study tool established on a diachronic consideration of the configuration of routes. The routes change over time, several of these deformations can be interpreted as the result of attraction or repulsion of some artifacts, referred to as attractors or repellers [58], [59]. There are different components that act as attractors in the urban environment, for instance, city walls, city gates, water infrastructures, Bazaar, and special structures [60]. Moreover, each of these anthropic attractors has a corresponding morphological attractor at the geographical scale [61]. This research investigated the historical process of Yazd's structural formation process within three phases. To reach a deep understanding of the city's form, before examining typological process of its building type.

2.3.3.1 The formation of Yazd up to the late Sassanid era (224-651 AD)

The first phase is the emergence and formation of Yazd up to the late *Sassanid* era (224-651 AD), before the early Islamic period. In this phase, the city was confined what to the *Fahadan* neighbourhood, situated in the northern part of Yazd's historical zone [55]. According to the evident correspondence in the urban planning of the *Sassanid* cities, their urban tissue was largely influenced by the natural features of the territory. These cities were enclosed by city walls including four gates corresponding to the four geographical directions. Two main routes extended from these gates. These two routes passed through different parts of the city and intersected at a right angle in its centre. Hence, they are dividing the city into four defined and limited sections. The *Sassanid* cities had a network of parallel and perpendicular roads and paths aligned with the two main routes. These roads surrounded regular and rectangular city blocks. Therefore, these cities followed a grid pattern. The city is connected to the suburbs by two main routes and through the city gates. The secondary roads within the urban tissue connected different parts of the city and do not extend beyond the city walls. These mentioned features can be seen in most cities of the *Sassanid* era [62]. The city of Yazd emerged and formed under the rule of the *Sassanid* king, *Yazgerd*, at the intersection of two main perpendicular routes, the valley route and the cross-valley route. Furthermore, the initial pre-Islamic city centre was established at this intersection. In this era, the roads and paths were parallel and perpendicular to each other, and they surrounded regular and rectangular city blocks. Therefore, city of Yazd followed a grid pattern similar to the other *Sassanid* cities. In pre-Islamic cities, the social order was structured on social class, whereas in Islamic cities, more consideration was on the religious-tribal hierarchy [55]. In the first phase, the first *Qanat* was constructed in Yazd [3]. The path of this *Qanat* aligns with one of the main routes of the city, the valley route, both are related to the slope of the terrain.

Moreover, the network of secondary roads is parallel and perpendicular to this *Qanat's* path [9]. Eventually, this *Qanat* acts as a dividing line between the first and second phases of development (Figure 47) (Figure 48).

2.3.3.2 *The formation of Yazd in the Islamic period (starting from 662 AD)*

The second and third phases are the formation of Yazd in the Islamic period (starting from 662 AD). In these phases, the city grew in the south direction of the *Fahadan* neighbourhood. The social structure's alterations of the society are the result of the *Sassanid* Empire collapse with the arrival of Islam in Iran. In this period, there was a gradual shift in the religion of the people. The structure of the urban life and the configuration of the Iranian cities transformed due to the religious, social, and political developments [62]. Stern argues that the structure of the urban life during the Islamic period is a continuation of the patterns established in the pre-Islamic eras. He believes that Islam and Muslim conquests could not destroy the existing structures of life. Moreover, the captured cities changed only in terms of configuration and appearance [63]. The Muslim conquerors in Iran faced an increasingly difficult structure of urban life. Therefore, they recognize the city as a crucial component in the administrative and governmental system. They lacked experience in executive affairs, so they used the experiences of the empires in the conquered territories. Since the control and administration of a city require a proper organization and management, Muslim Arabs initially tried to establish control over cities by keeping some individuals, positions, and urban management methods. In the early Islamic period, Iranian cities, with few exceptions, did not resist the conquerors. Hence, the previous situation was preserved to some extent. Thus, in the early stages of the Muslim conquest of Iranian cities, the urban life structure was not completely altered. Therefore, a fundamental transformation in the cities' structure and urban tissue was not expected. In the Islamic period, new spaces were

added to Iranian cities and significant alteration were made in certain urban elements compared to the *Sassanid* era. These changes are rooted in the social customs and beliefs of the Islamic society. In this period, the transformation process in the urbanization pattern of Iranian cities had central features. One significant aspect is that the pattern of alteration in cities was not similar across all regions. Hence, in each city, differences during these changes existed due to the natural, social, and economic conditions of that region. In the Islamic period, the most important urban development was the revolution of the concept of the city from a closed environment reserved for selected individuals and classes to a place for everyone to inhabit [62]. *Ibn Khaldun*, the Arab sociologist, mentioned this alteration in his book “*The Muqaddimah, an introduction to history*”. He argues that cities and capitals feature vast buildings and magnificent mansions constructed for the public rather than special individuals [64].

The characteristics of urbanization and urban planning from the *Sassanid* era were transferred to the early Islamic period. However, this process changed over time. Hence, the urban planning of the Islamic period developed its own distinct and special characteristics. The most significant urban feature of this period is the diversity and compactness of the components constituting the urban tissue of the cities. In the Islamic period, the main element of the cities’ urban tissue is the grand mosque, known as *Jameh* Mosque. The *Jameh* Mosque relates to other central components within the city’s spatial structure. The *Jameh* Mosque establishes a direct connection with both the commercial-service and the residential sectors within the city’s tissue. The concept of centrality has persisted from the *Sassanid* era, although it has progressed. The centre is not considered as a single point in space; instead, it transforms into a linear configuration over time. This pattern allows transformation and growth, confirming the city’s continuity. The linear element is represented by the Bazaar. The Bazaar originates from a central point and

expands in a natural pattern. It passes the *Jameh* Mosque and extends its way towards the city gates. In this period, the city is constructed and expanded along the Bazaar axis, and new markets are created during this process. The vital centres of the city, including schools, libraries, caravanserais, baths, cisterns, and warehouses are placed and develop within the urban fabric. Consequently, the city consists of religious, political, economic, and social functions. The residential neighbourhoods were connected to the Bazaar by a main road or its extension. The residential sector, as the main and private area of the city, had a distinct function from the Bazaar sector and it was considered as a complement to the commercial area. Thus, various urban components are interconnected, presenting a sense of unity within the city's multiplicity. In the Islamic period, one of the indicators of the spatial organization of cities are public semi-independent complexes that are not superior to each other. These complexes appear independently according to the ethnicity or occupation of the residents [62].

The city can be conceptualized as a three-dimensional mass intersected by a network of roads, facilitating movement and connectivity. Although the network of roads may appear chaotic, it is structured due to a logic. In the Islamic period, cities were formed in response to the territorial, geographical, and cultural requirements, effectively meeting the needs of their inhabitants. The main roads connected the city gates and provided the association between the city centre and its various neighbourhoods. Service and commercial functions are organized around the main roads, creating a network that facilitates access to various amenities. The dimensions of these passages are related to their significance. Wider and longer roads act as major routes within the urban tissue. The roads established a coherent network with a clear hierarchy, linking public spaces to semi-private and private areas within the city [62].

The urban configuration of Iranian cities in the Islamic period begins from the centre and directs all attention towards the central elements. Hence, the hierarchical relationships of both form and function are organized towards the centre. The formation of residential neighbourhoods in these cities followed a general process influenced by economic, population, and urban growth, eventually reaching its final shape over time. The lack of complete prediction for all urban spaces and components at the beginning of the city's formation, in some cases, caused the destruction of several houses to create a public space such as mosque. Consequently, the urban tissue of Iranian cities followed an irregular pattern. It changed over time to meet new needs, respond to the necessity of physical development, and is influenced by climate features and the main routes. Moreover, in these cities presenting a sense of unity, achieved using materials, colours, and shapes, which has developed in an irregular pattern. The analysis of these cities exposes that the appearance of the fabric has a cultural logic, not just in terms of signs and physical elements, but also in terms of the concepts of social relations. These mentioned features can be seen in most cities of the Islamic period [62]. Following the arrival of Islam in Iran and the collapse of the *Sassanid* Empire, the city of Yazd developed by a group of Muslims. In this period, the city centre shifted to the location of the *Jameh* Mosque, which was the central element of the city, and the urban tissue expanded around the axis of the Bazaar. The road network follows an irregular pattern, reflecting the coexistence of numerous buildings within the urban tissue. The absence of a predetermined plan for the roads is not the reason for their irregular pattern. Instead, there is a kind of hierarchy in the urban fabric of the city that defines the routes, directions, meeting point, and dispersion points. Analysing the cadastral map of the historical context of Yazd reveals signs indicating that the general directions of the road network lead people toward landmarks, which are the outcome of the communication network.

Therefore, city of Yazd followed an irregular pattern similar to the other Islamic cities [62]. In the second and third phase, the second *Qanat* was constructed in Yazd [3]. Similar to the first *Qanat*, the path of this *Qanat* follows the main road of the city, and the network of secondary roads is perpendicular to the path of this *Qanat* [9]. Eventually, this *Qanat* acts as a dividing line between the second and third phases of development (Figure 49) (Figure 50).

The city of Yazd experienced both regular and irregular patterns in its formation process. The outcome of these patterns is a cohesive and integrated urban fabric in Yazd, which is connected to the geographical features of the region and the principles of desert architecture [3] (Figure 51) (Figure 52) (Figure 53). (See Appendix D)

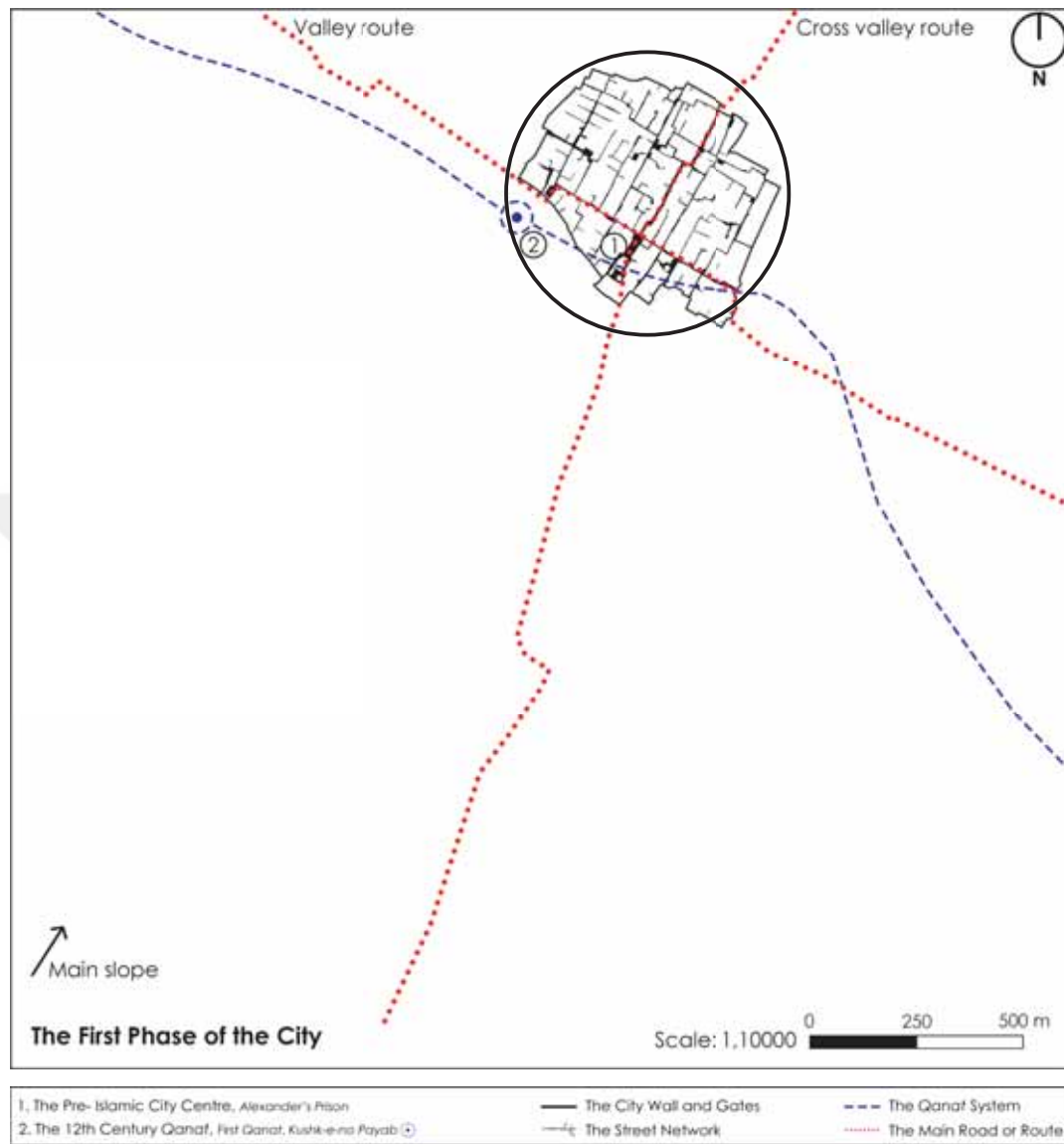


Figure 47. The city of Yazd in the first phase. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

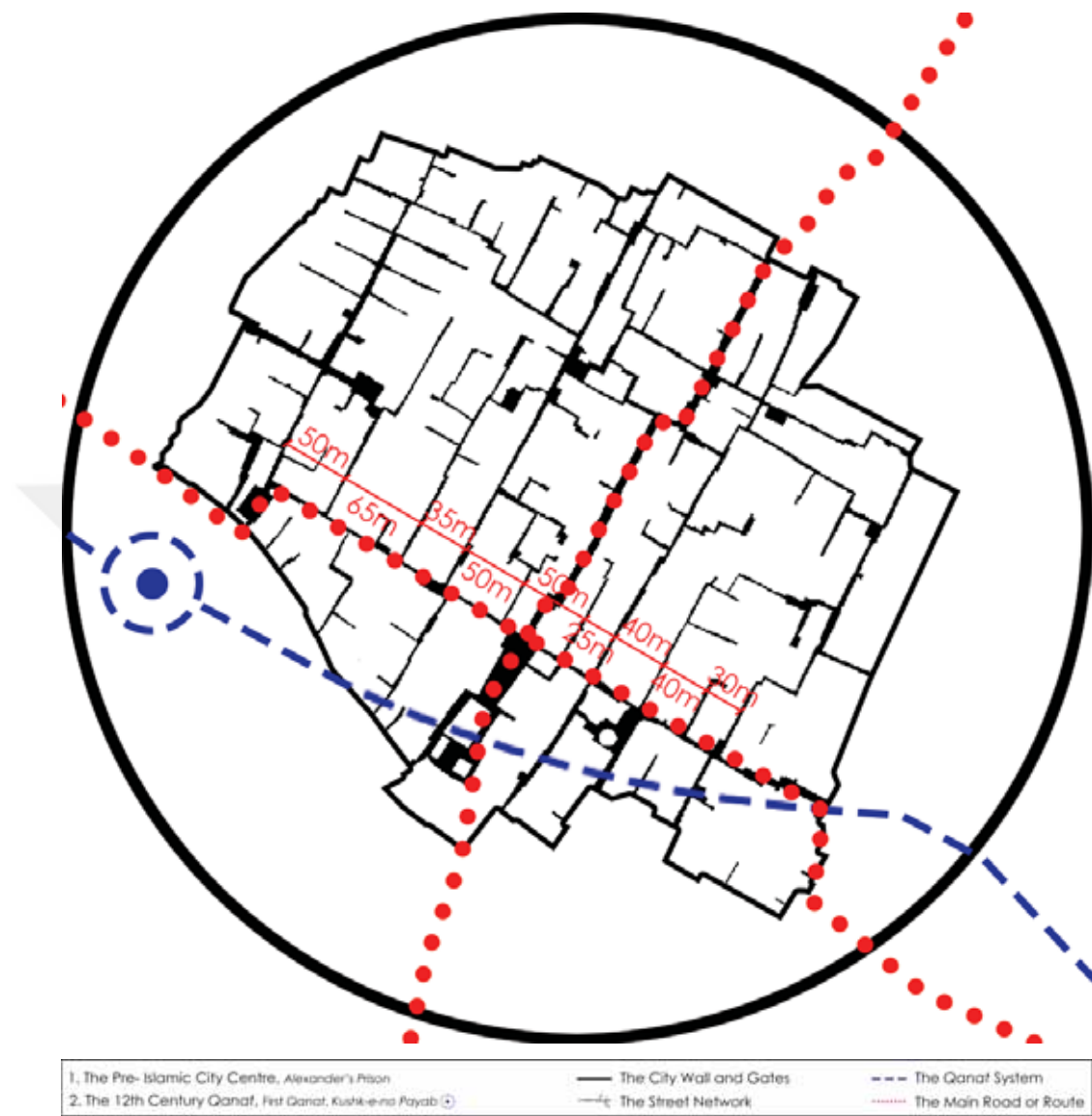


Figure 48. The layout of the city of Yazd in the first phase. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

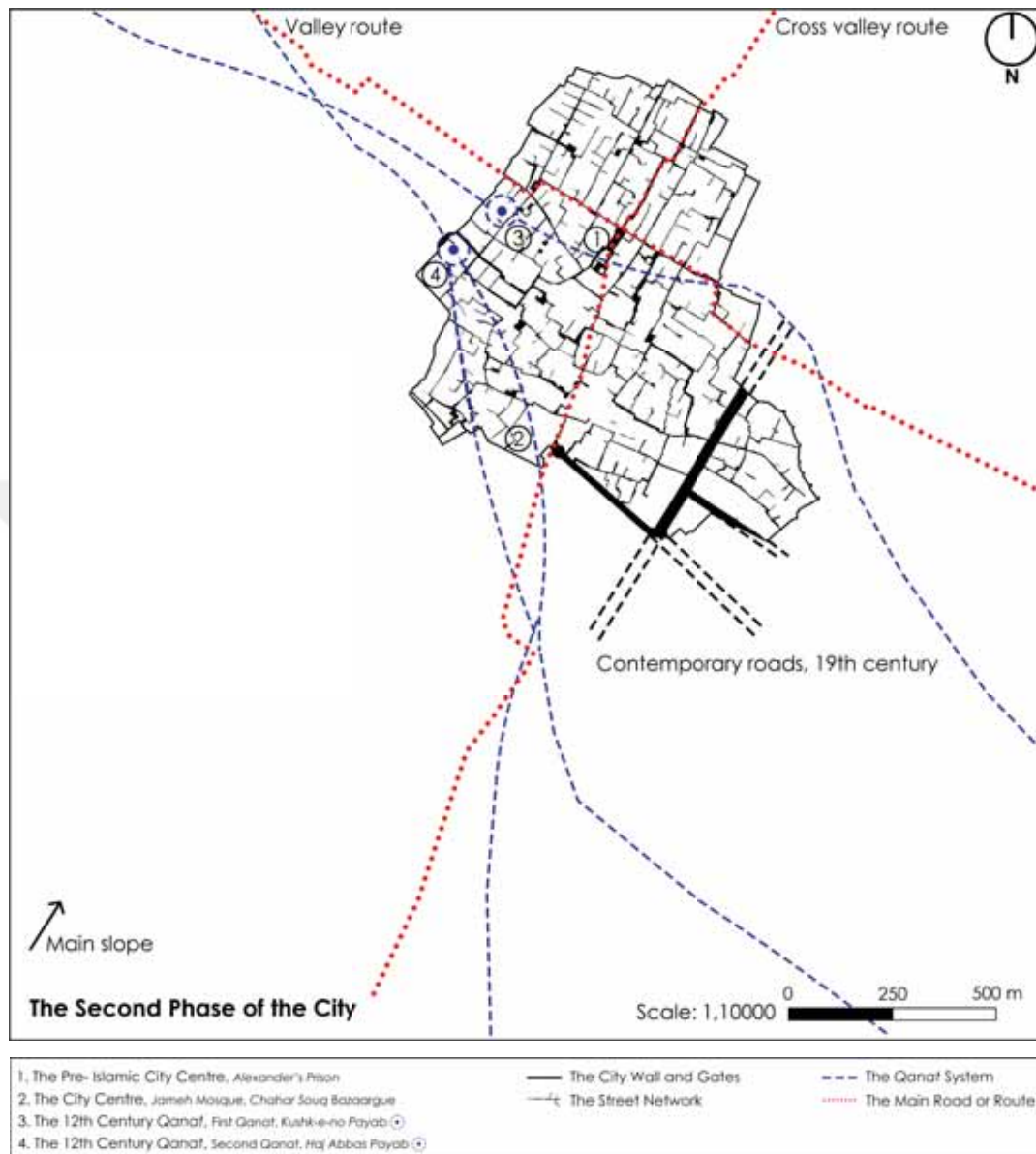


Figure 49. The city of Yazd in the second phase. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

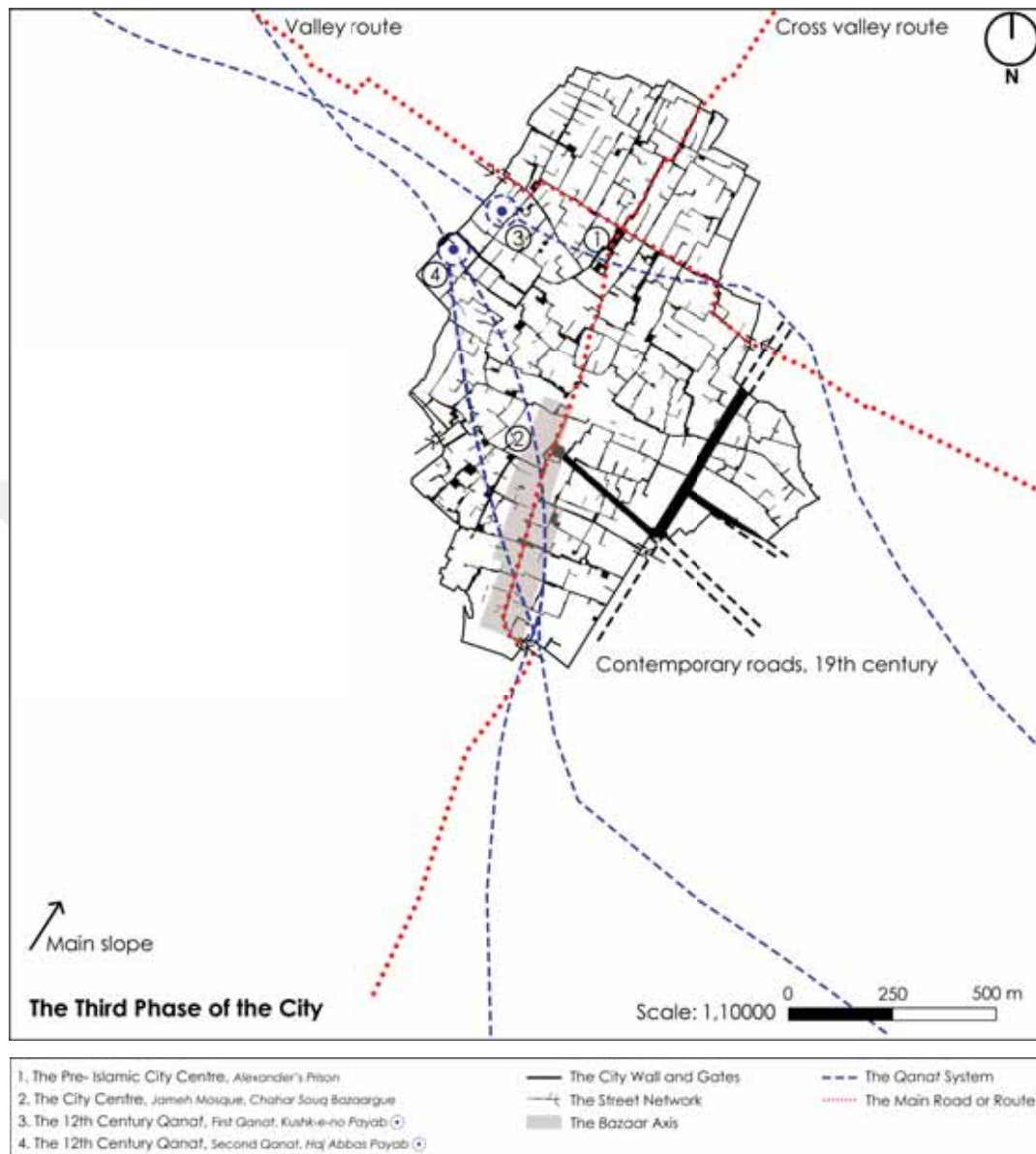


Figure 50. The city of Yazd in the third phase. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

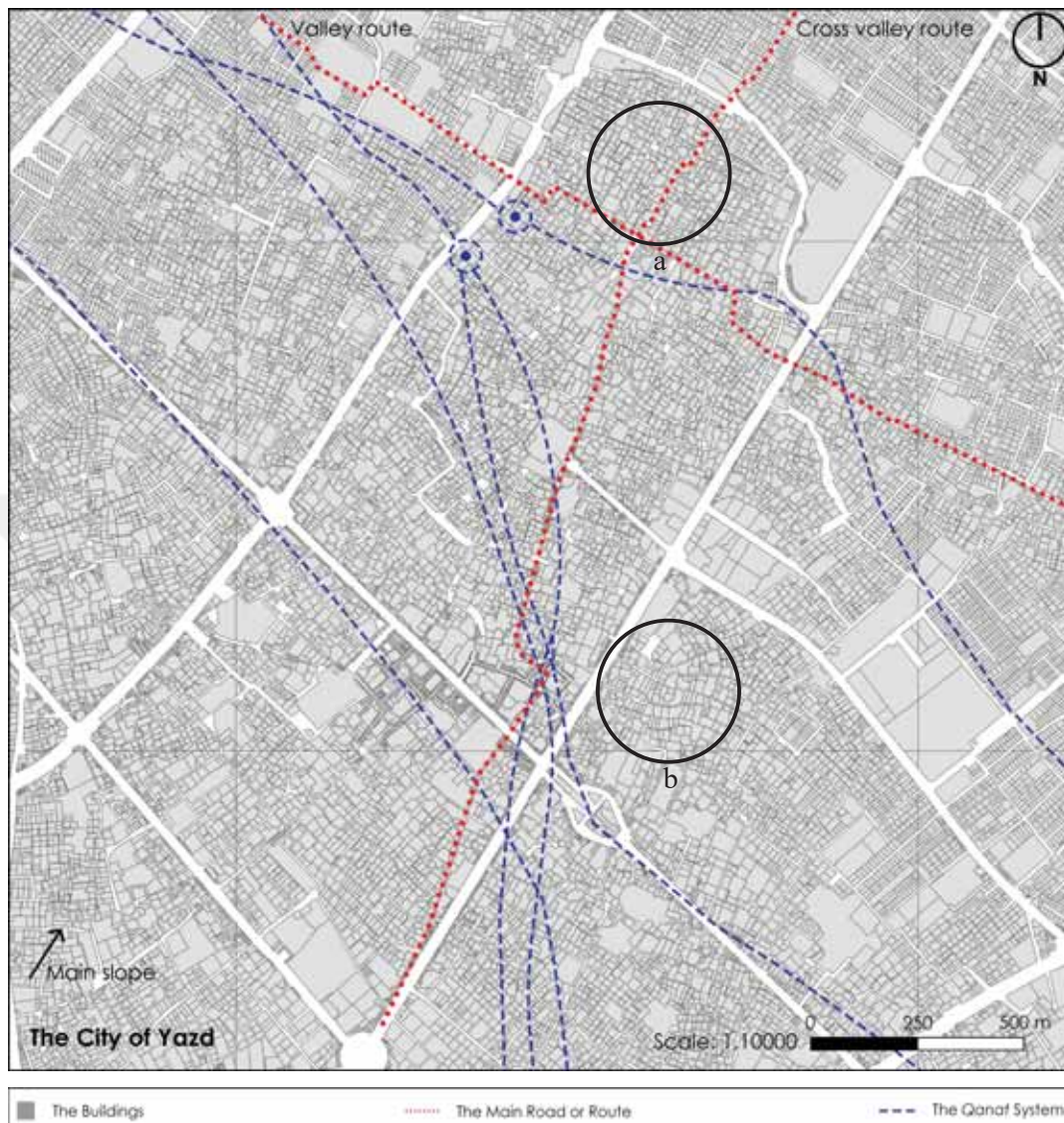


Figure 51. The city of Yazd. Author's elaboration using QGIS 3.26 and NCC datasets, [9].



Figure 52. The layout a of grid pattern in Yazd [9].



Figure 53. The layout b of irregular pattern in Yazd [9].

2.3.4 The Building Scale

I presented this part of my thesis in *6th ISUFItaly International Conference: Morphology and Urban Design, New Strategies for a Changing Society*. University of Bologna, Bologna, Italy, June 8-10, 2022.

The building type refers to a group of buildings that share common characteristics and architectural features. To explore the typological process of a building type, it is essential to conduct an examination of several historical building types within the common cultural area. The typological process expresses the progressive differentiation between them, which is more visible in the old buildings and less in recent buildings [6]. This research investigated the typological process of historical courtyard houses of Yazd within three stages.

- The pre-Islamic period (before 662 AD)
- The *Atabakan* era (1141-1319 AD)
- The *Qajar* period (1789-1925 AD) and the *Pahlavi* era (1925-1979 AD)

This study selected various historical building types, specifically courtyard houses within the cultural area of Yazd, as the case studies. Hence, twenty-four courtyard houses have been chosen from four distinct historical periods, the pre-Islamic period, *Atabakan* era, *Qajar* period, and *Pahlavi* era. The research considered both the street and building scale as the typological framework for examining the selected case of historical courtyard houses.

- The street scale comprises the building's position and its relationship with the street and other buildings, along with consideration of building form, orientation, plan, dimensions, and entrance.
- The building scale comprises both internal access and spatial patterns, along with consideration of space functions, permeability, and visibility.

Eventually, the study explored both synchronic and diachronic variants of the building types within their typological process [65].

In the historical context of Yazd, urban spaces are completely enclosed, with minimum of open spaces, as they are difficult to maintain due to unfavourable climate conditions. The road network follows an irregular pattern. The roads are designed to be narrow, allowing passage for only two individuals in some cases, and they are covered with arch. The integration of narrow roads and the high building walls is effective in generating shade to lessen the impact of intense sunlight (Figure 54)-(Figure 66). Consequently, the design endeavours to maximize the creation of shaded areas. Additionally, the irregularity and twisting configuration of the road network reduce the

intensity of desert winds. In hot and arid climates such as Yazd, buildings are designed to provide usability for settlement through all four seasons. The inhabitants of these areas considered specific aspects in the design and construction of their buildings, including residential houses, as an approach to overcoming the climate challenges in the region [66].

- Constructing introverted and enclosed buildings with courtyards

Yazd is characterized by intense summer sunlight, high temperature, significant temperature fluctuations, lower humidity levels than optimal for human comfort, and prevalent wind currents carrying desert dust. In response to these challenges, inhabitants incorporated courtyards within the buildings such as residential houses. Furthermore, the water ponds and gardens in the middle of these courtyards increased the humidity levels in the living spaces. Hence, providing more comfortable conditions for the residents of the houses. The rooms are designed to open into the courtyard to be protected against wind, storms, and desert sand. Eventually, by utilizing the courtyards, the residents can temper their enclosed spaces against the winter cold and moderate humidity during the summer [66].

- Constructing the *Ayvan* and basement

The inhabitants constructed semi-open spaces known as *Ayvan*, with an open side positioned away from the sun to prevent the penetration of heat into the building. In most courtyard houses in this region, there are large basements with cool and pleasant air [66].

- Constructing the *Badgir*

In hot and arid climates, inhabitants tried to minimize air flow between the interior and exterior of courtyard houses by limiting openings, especially during hot weather with high temperatures. Hence, architectural structures known as *Badgir* were constructed to naturally cool the enclosed spaces. *Badgirs* are positioned on the south or southeast side

of the courtyard houses, facing north or east, to transport cool air to the centre areas of the building [66].

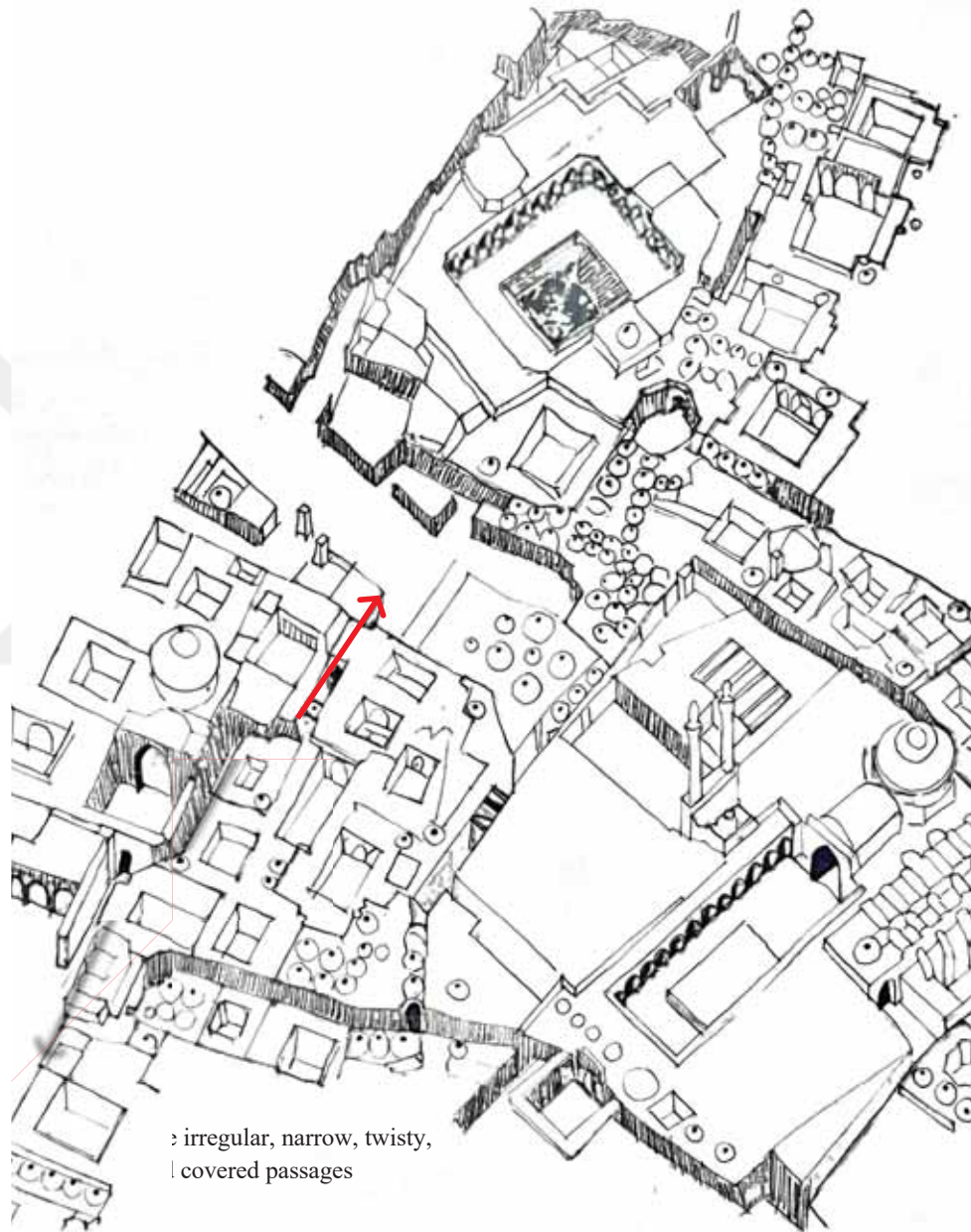




Figure 55. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 56. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 57. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 58. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 59. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 60. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 61. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 62. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 63. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 64. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 65. The paths in historical zone of Yazd. Photo by author in November 2023.



Figure 66. The paths in historical zone of Yazd. Photo by author in November 2023.

The historical courtyard houses of Yazd meet a wide range of human needs due to the central open space or courtyard that acts as the heart of these houses. The arrangement of spaces around the central open space in these houses has facilitated the integration of artificial and natural environments, and it has separated the building from the external surroundings. Hence, courtyard houses have an introverted architectural character. This introversion aligns with the climate, beliefs, religion, and lifestyle of the inhabitants. Indeed, the courtyard is the private paradise of these houses. Through continual habitation of this space, residents experience a sense of place, belonging, and attachment to their surroundings [67].

2.3.4.1 *The Pre-Islamic Period (before 662 AD)*

The residential areas from the pre-Islamic period, specifically the *Sassanid* era (224-651 AD), have been less explored. Therefore, there is a lack of a comprehensive understanding regarding the living spaces of various social classes. The living spaces of the lower classes and ordinary individuals are more ambiguous. In *Sassanid* era, a significant part of Iranian population was nomadic. Thus, the society consisted of both the settled resident population and the nomadic communities. The majority of the settled population lived in villages, with a minority lived in newly established cities. In this period, the houses belonging to ordinary individuals were constructed with less durable materials and methods compared to palaces. Hence, these houses were more susceptible to transformation and destruction due to factors such as war and natural disasters, leading to a lack of available information. However, it can be said that residential houses during this era were simplified designs inspired by palaces [68].

In *Sassanid* era, the courtyard houses consisted of one or two floors, the first floor had service functions and the second floor had a residential function. These courtyard

houses were characterized by one courtyard, including an *Ayvan* on one façade or two opposite *Ayvans*. The covered spaces were constructed symmetrically around the courtyard. The courtyard houses belonging to wealthier people had a greater number of spaces. In these houses, the *Ayvan* is positioned in the middle of one, two or three façades of the courtyard. In more comprehensive designs, there are four *Ayvans*. Moreover, not all *Ayvans* hold equal significance, the largest *Ayvan* is the most important one [68].

- *Haji-abad* House

This house is located in the south of *Darabgerd*, Fars province, Iran. *Darabgerd* region dates to the early *Achaemenid* period (559-331 BC) and there are several parts in this complex. The first part is the outer section or common court, which has a courtyard with an *Ayvan* facing it. It leads to the special court from the end of the *Ayvan*. The second part is the residential area situated in the west of the complex, and the other part is the religious area, located in the northwest of the complex [69].

- *Almaarid* House

This house is in *Ctesiphon*, which is in present-day Iraq, approximately thirty kilometres from Baghdad. *Ctesiphon* was established by the *Parthians*, and it was the political capital of the *Sassanids*. In this house, the first part is the outer section that has a T-shaped *Ayvan* with columns. The second part is the inner section that has a large courtyard with four *Ayvans*, and additional enclosed spaces surrounded the courtyard. The third part is the residential area situated in the southwest of the inner section, and the other part is the religious area, located in the south of the complex, while it has access to both the inner and outer sections [68].

2.3.4.2 *The Atabakan era (1141-1319 AD)*

- *Tagh boland-ha (Hosseinian) House*

This house is one of the oldest houses in Yazd, and it was constructed during the *Atabakan* Empire. The house consisted of four rectangular-shaped courtyards, with one of them being larger and acts as the main courtyard. The courtyards have four facades, including *Ayvans* and other spaces. The main courtyard is located along the north-south axis. The newly constructed entrance is positioned in the corner and consisted of a short, narrow, and winding corridor. The previous entrance was symmetrical, positioned in the middle of the house along the axis of the courtyard [70] (Figure 67).

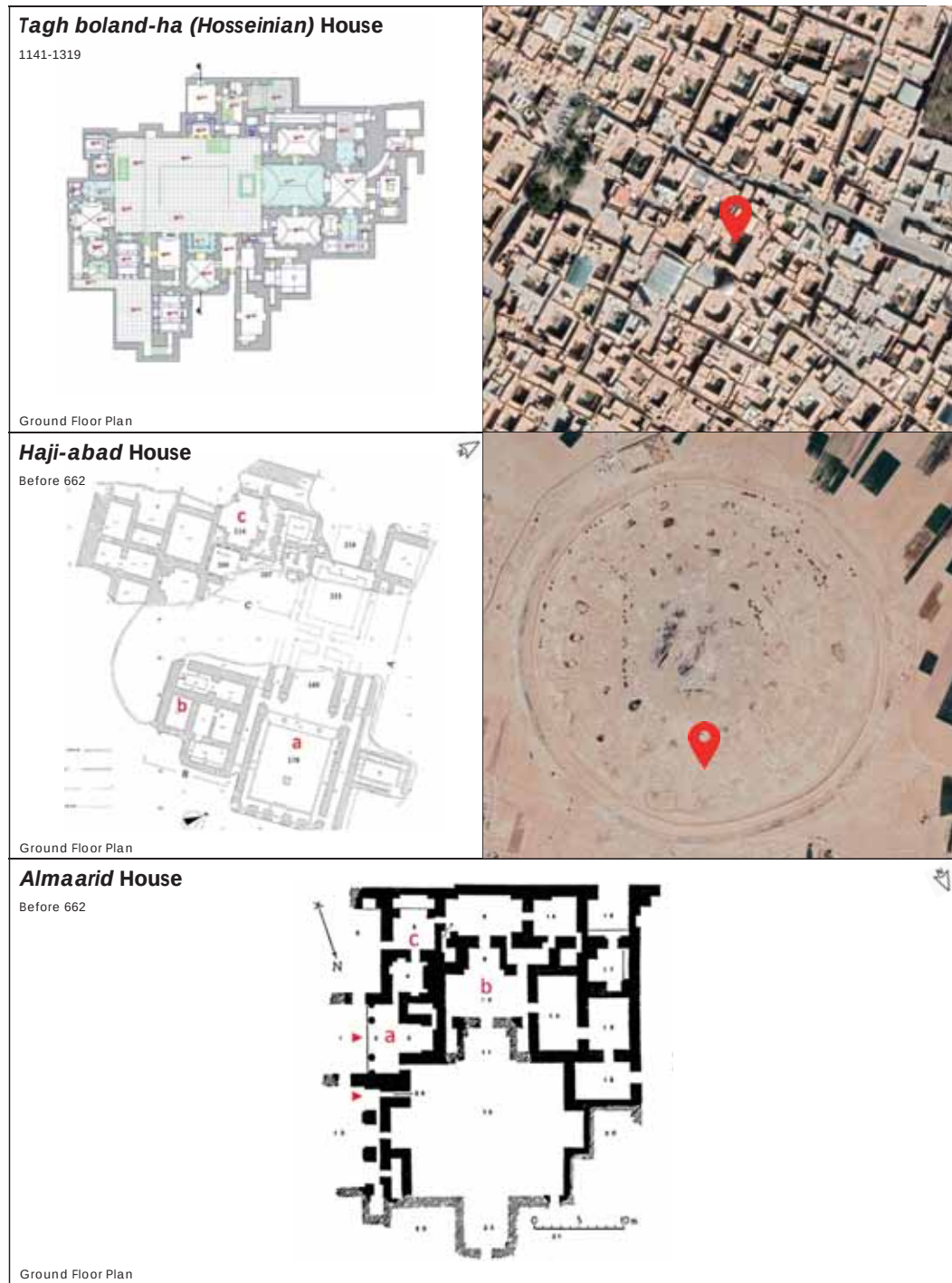


Figure 67. The drawings of *Tagh boland-ha (Hosseinian)* house, *Haji-abad* house, and *Almaarid* house. Author's elaboration using [68], [70].

2.3.4.3 The Qajar period (1789-1925 AD) and the Pahlavi era (1925-1979 AD)

These historical courtyard houses are situated in the historical context of Yazd (Figure 68).

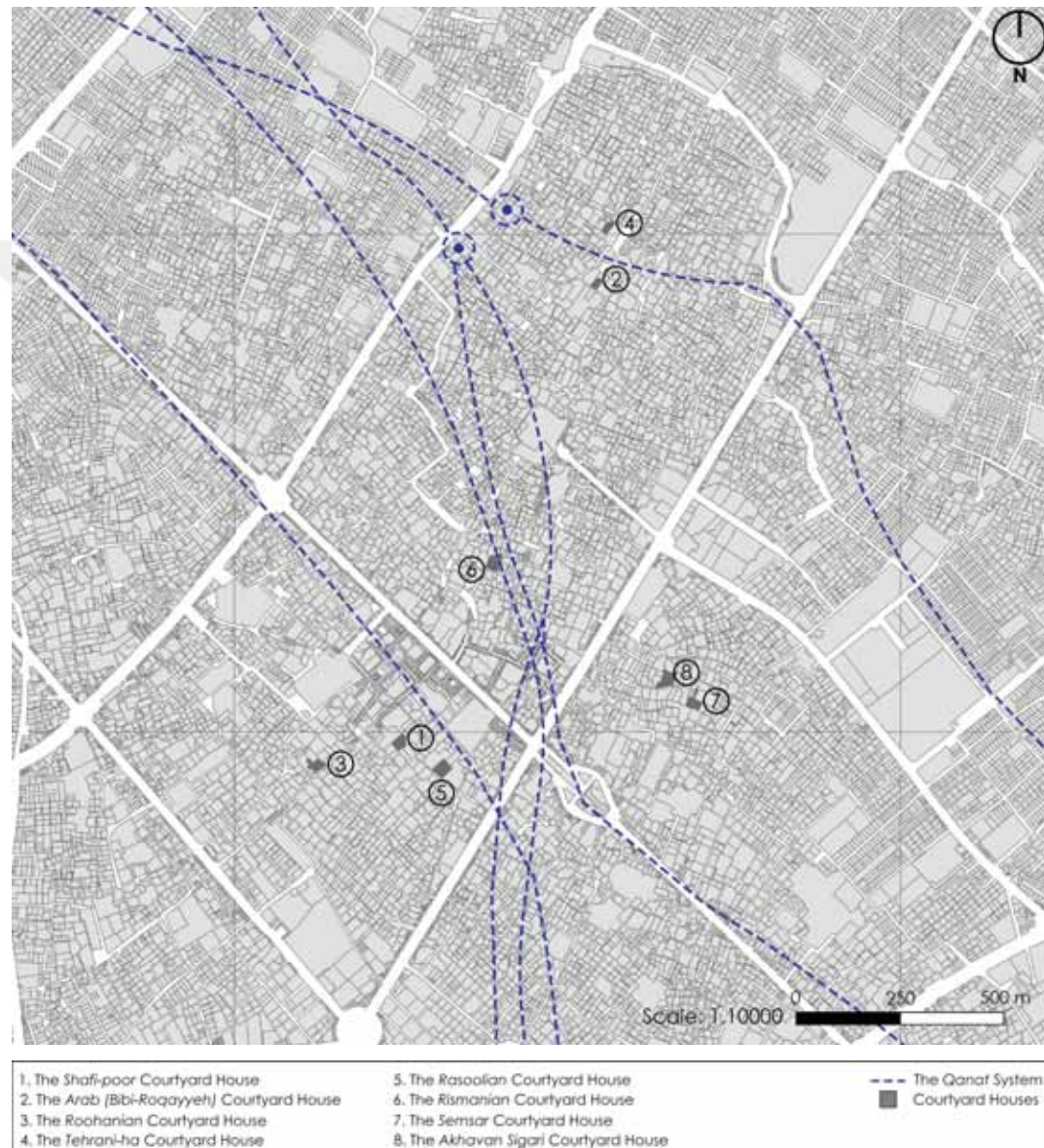


Figure 68. The location of the historical courtyard houses within the historical context of Yazd. Author's elaboration using QGIS 3.26 and NCC datasets, [71].

- Courtyard houses form, orientation, and plan

The historical courtyard houses of Yazd have a cube form, as this shape is considered the most suitable for these structures, due to the hot and arid climate of this region. The courtyard houses in this region are located between the south and 35 degrees southeast, orienting along the east-west axis, due to the angle of the sun's rays and the direction of the wind. The plan of these houses is characterized by its dense and compact design. Moreover, the external surface is less than the internal volume [66] (Figure 69)-(Figure 76).

- Courtyard houses material

The materials used in the construction of historical courtyard houses of Yazd are mainly mud, clay, and brick. Indeed, these materials have a good performance in facing the challenges of the climate. They absorb heat slowly during the day under direct and intense sunlight and release the heat gradually and slowly during the night. Hence, the temperature fluctuation is decreased during the day and night. Furthermore, these materials are native materials of Yazd, and they can be easily found in this area. In these courtyard houses, the frame of the openings is made of wood [66].

- Courtyard

In the historical courtyard houses of Yazd, the courtyards are the central elements. They are independent, introverted, and open to the sky with a geometric order. The size of the courtyard houses and the number of the courtyards depend on the financial capacity and social status of the house owner. Houses belonging to less affluent individuals consisted of several rooms and a courtyard. In contrast, houses belonging to wealthier individuals often consisted of two courtyards, an exterior courtyard, designed for men, and individuals who are not intimate enough to access women's spaces and for the house

owner's professional activities, and an interior courtyard, designed for women and men who are intimate enough to access to the women's spaces such as father, brother, uncle, and husband. Moreover, the courtyard houses of the wealthier individuals sometimes comprised of more than two courtyards, and the number could reach to six courtyards, each has a distinct function. The other four courtyards are, stables courtyard, crew courtyard, *Khaajegan* courtyard, and *Narenjestan* [67]. The main courtyards in these houses have a rectangular plan and are positioned in the centre of the houses. Consequently, other spaces are constructed around these central courtyards. The courtyards of Yazd courtyard houses are oriented along the north-south axis to be in harmony with the climate of the region. The historical courtyard houses of Yazd relate to nature, and the presence of elements presenting nature within spatial organization of these houses is mandatory. In the ancient Iranian perspective, water had a close connection with the sky and was considered one of the most vital natural elements. Water had a special role among the people in numerous ancient lands of Iran, especially in hot and arid territories where individuals faced water shortages. Hence, water was sacred among the people, leading them to construct places to its worship. In the middle of the courtyards of historical courtyard houses of Yazd, there is a rectangular-shaped pond situated along the main orientation of the courtyard. The percentage of the pond's area compared to the total courtyards area ranges from 10% to 20%. The presence of water in these houses has multiple purposes. In addition to reducing the air temperature and creating humidity to soften the air, it also induces a sense of calm through visual aesthetics and sound elements such as fountains. The inclusion of water in the courtyards of residential houses is a symbolic representation of the Iranian paradise. In these courtyards, gardens are symmetrically arranged on both sides of the pond. The presence of flowers and trees not only provides shading but also increase humidity. Thus, they are contributing to the

comfort of the space. In addition to the importance of green space and plants in regulating the environmental conditions of hot and arid climates, they make a special beauty to the courtyards [72].

- Courtyard axes

The principle of unity is one of the most important principles in the architecture of historical courtyard houses of Yazd. This principle is consisted of the axes, hierarchy, orientation, and geometry of spaces. Hence, these houses have two axes that are perpendicular to each other. These axes are crucial factors in determining the arrangement of surrounding elements, influenced by their values, dimensions, and the way life progresses within them. The first axis or the main axis is oriented in the north-south direction, perpendicular to the main façade of the courtyard, and it is longitudinal. The spaces in which family life takes place, such as *Ayvans*, are situated along the main axis. The second axis or the secondary axis is oriented in the west-east direction, parallel to the main façade of the courtyard, and it is transverse. The spaces which are less important, such as rooms, are situated along the secondary axis. The intersection of these axes is the centre of the courtyard houses, a moving and dynamic point [73].

- Courtyard facades

The courtyards of the historical courtyard houses of Yazd have four facades, that are facing and conversing with each other, two by two. The height of these facades ranges one to two floors. In the courtyards, the scale is designed so that an individual, within their field of vision, encounters a façade or set of facades that align with their height. This allows them to see the components of the facades together. Therefore, individuals can experience a sense of unity and oneness in the facades. This factor helps in understanding the place and contributes to the creation of a human environment within the courtyards.

These spaces are the central points for gathering events and concentrating forces. *Ayvans* are a semi-open space positioned inside or sitting back in the middle of the courtyard's facades. They have larger dimensions than the surrounding spaces and are situated along the main axis of the courtyards where the most important spaces are organized. This arrangement has a visual and psychological impact on the observer, attracting attention from the first encounter. They are enclosed by three load-bearing walls and a roof. The value and significance of *Ayvans* are not the same, often varying in terms of dimensions, decorations, access, integration with the surrounding spaces, and function. *Ayvans* are situated between open and closed spaces, it is connected to the building on one side and to the courtyard on the other side. This configuration creates a shared space at the intersection, enabling the utilization of both spaces. *Ayvan* is a transitional and connecting space, while it is an independent space with a distinct function [74].

- Courtyard houses entrance

In historical courtyard houses of Yazd, the organization of courtyards, open spaces, and closed areas is such that entering the houses is always associated with a sense of hierarchy. This achieved through creating a turn in the entrance path and filters such as porches and corridors. Entering these courtyard houses involves passing through three distinct parts, a porch, a narrow corridor, and the courtyard area. Each of these three spaces provides both a physical and spiritual experience during the process of entering the house. The number of entrances depends on the size of the courtyard houses. Smaller houses have one entrance, while larger houses have two entrances. In courtyard houses with two entrances, one is the main and luxurious entrance for guests and house members, while the other is a secondary entrance for employees and servants. The presence of two entrances, main and secondary, each with different uses in some courtyard houses, caused the division of the house into two parts. Each section of the courtyard houses contains

specific spaces with different uses. For instance, in one part, guest room and the owner's office are positioned, while in the other part, there are service spaces. The entrances of historical courtyard houses of Yazd are positioned in the corner of these houses and are not in the middle along the axis of the courtyard (Figure 77)-(Figure 90).



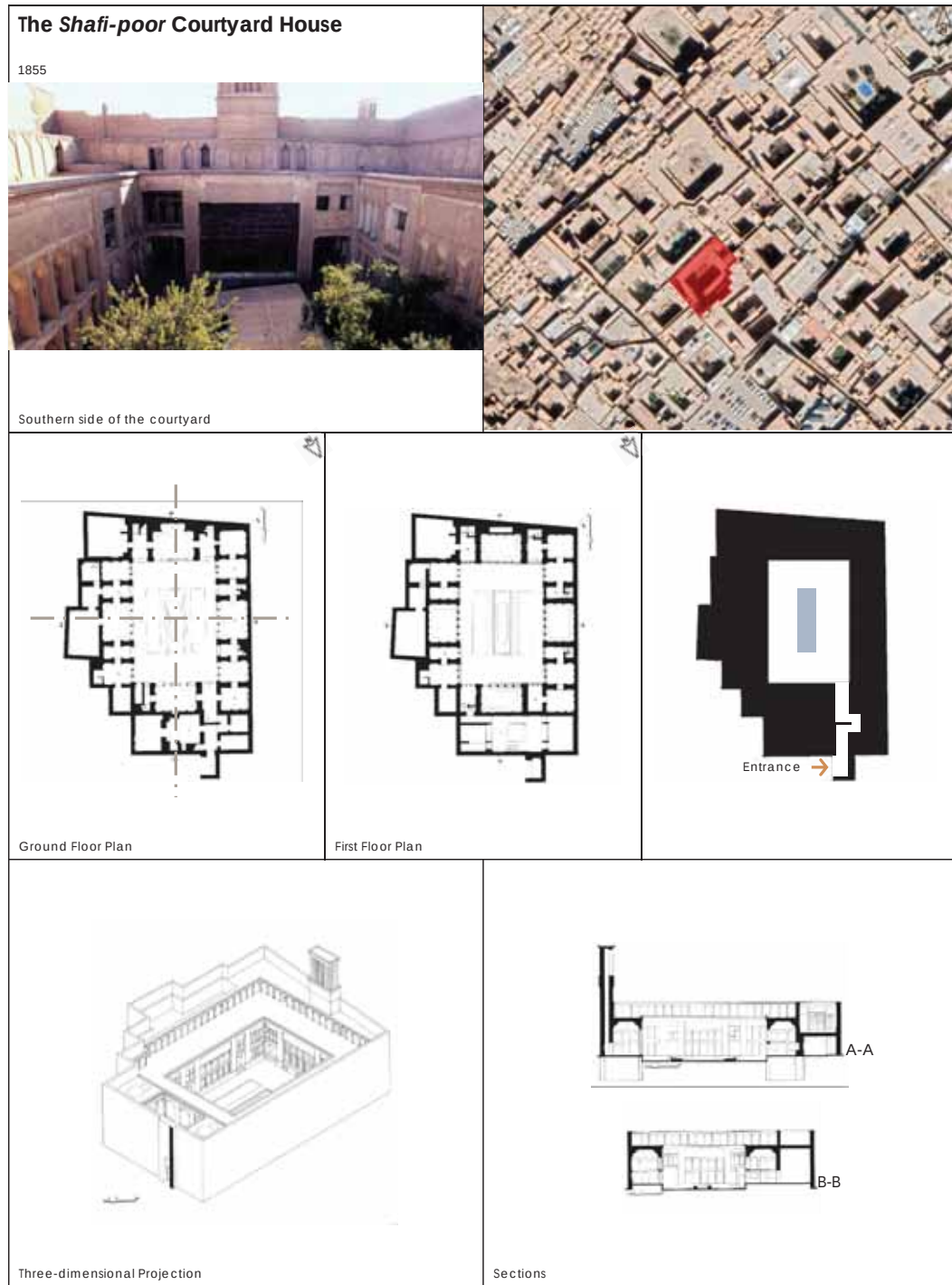


Figure 69. The drawings of the *Shafi-poor* courtyard house. Author's elaboration using [71].

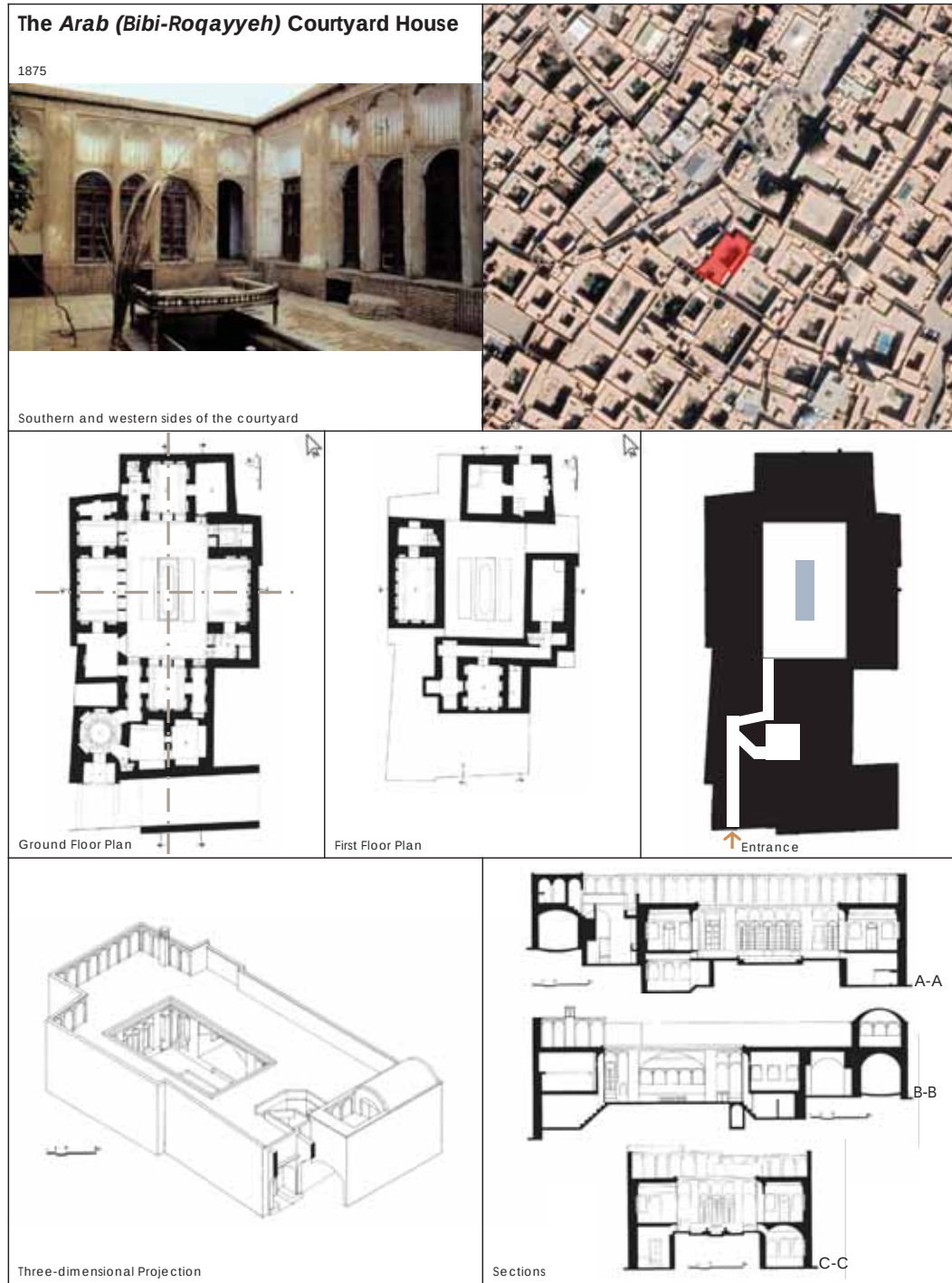


Figure 70. The drawings of the *Arab (Bibi-Roqayyeh)* courtyard house. Author's elaboration using [71].

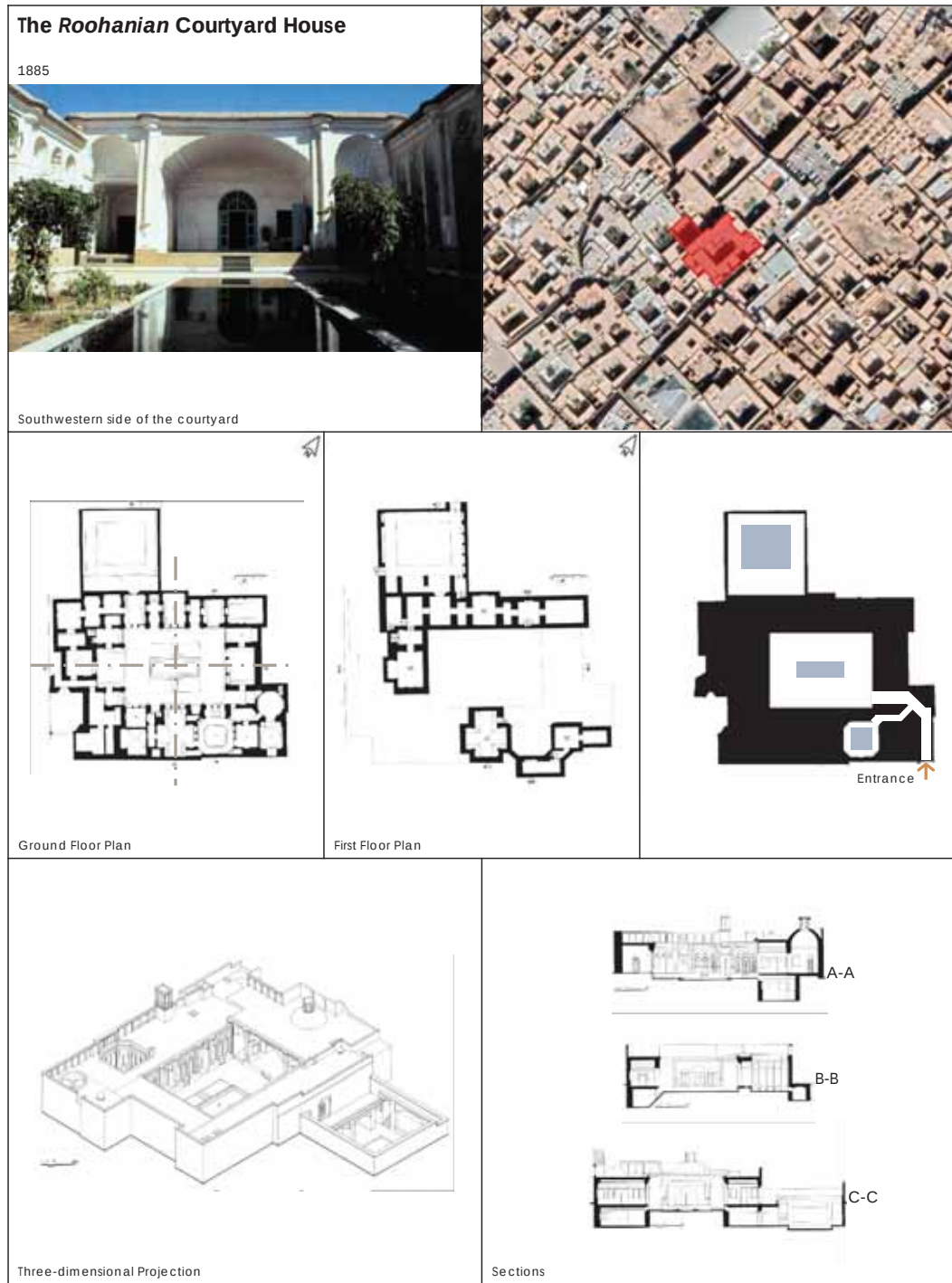


Figure 71. The drawings of the *Roohanian* courtyard house. Author's elaboration using [71].

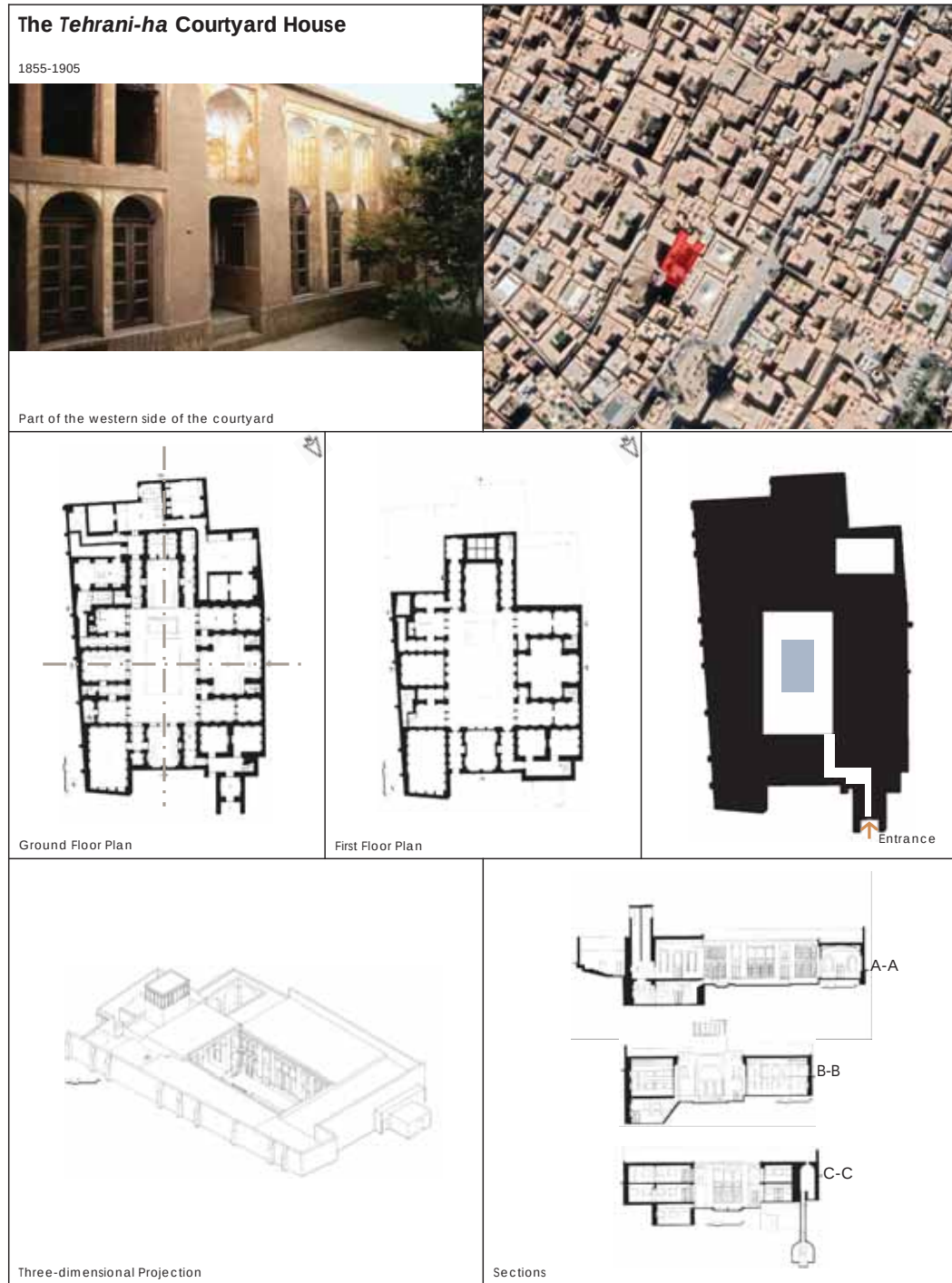


Figure 72. The drawings of the *Tehrani-ha* courtyard house. Author's elaboration using [71].

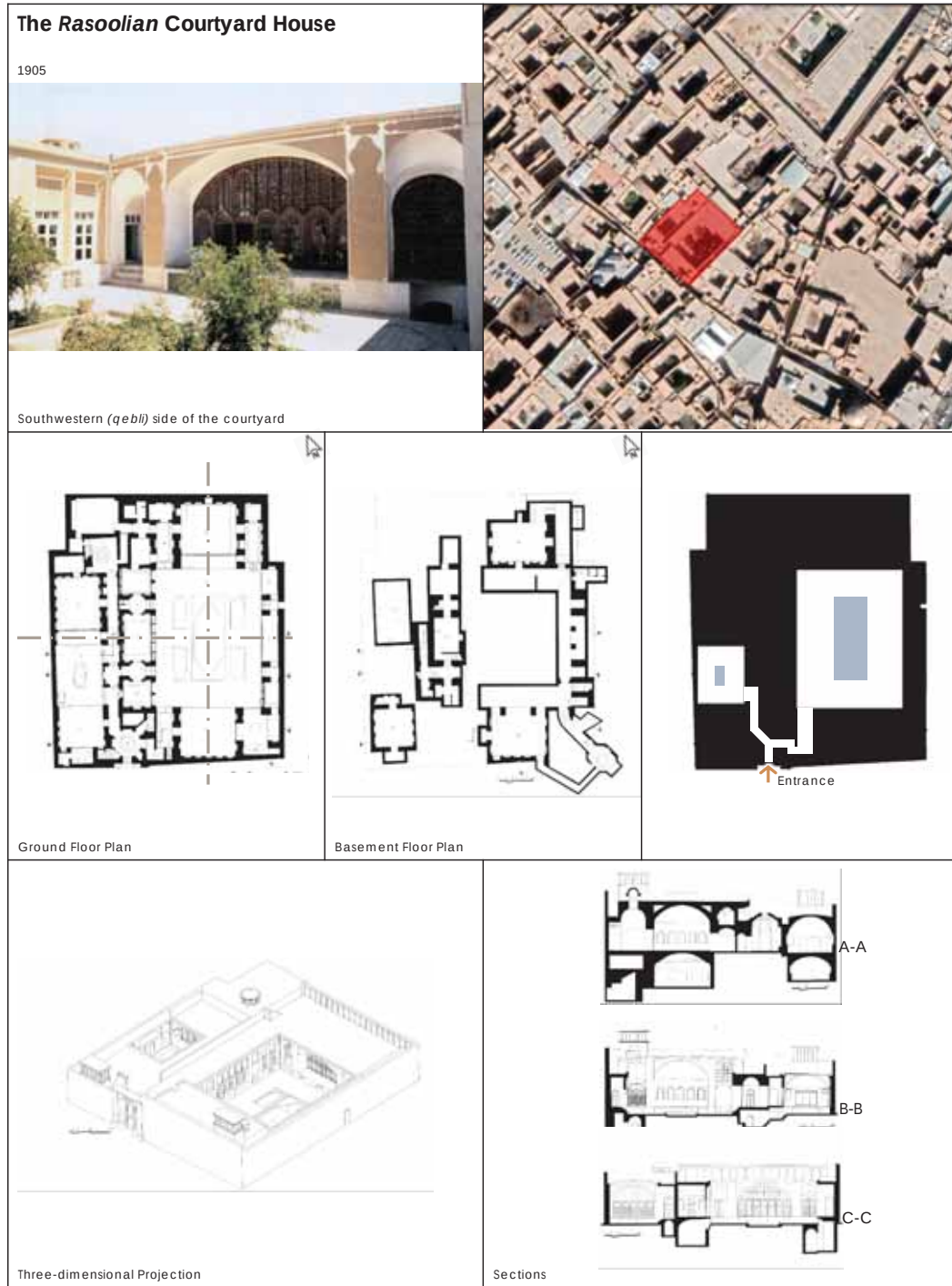


Figure 73. The drawings of the *Rasoolian* courtyard house. Author's elaboration using [71].

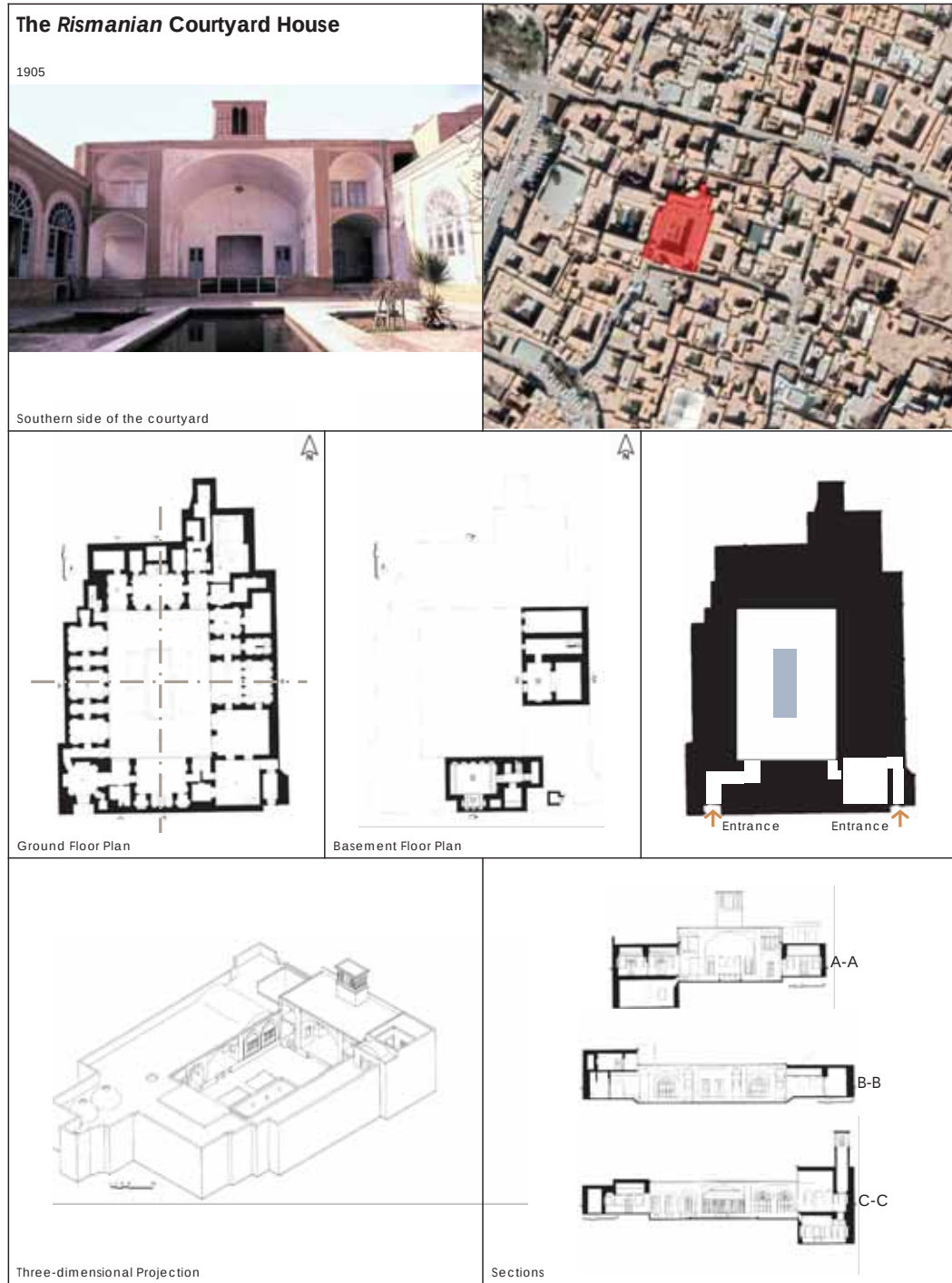


Figure 74. The drawings of the *Rismanian* courtyard house. Author's elaboration using [71].

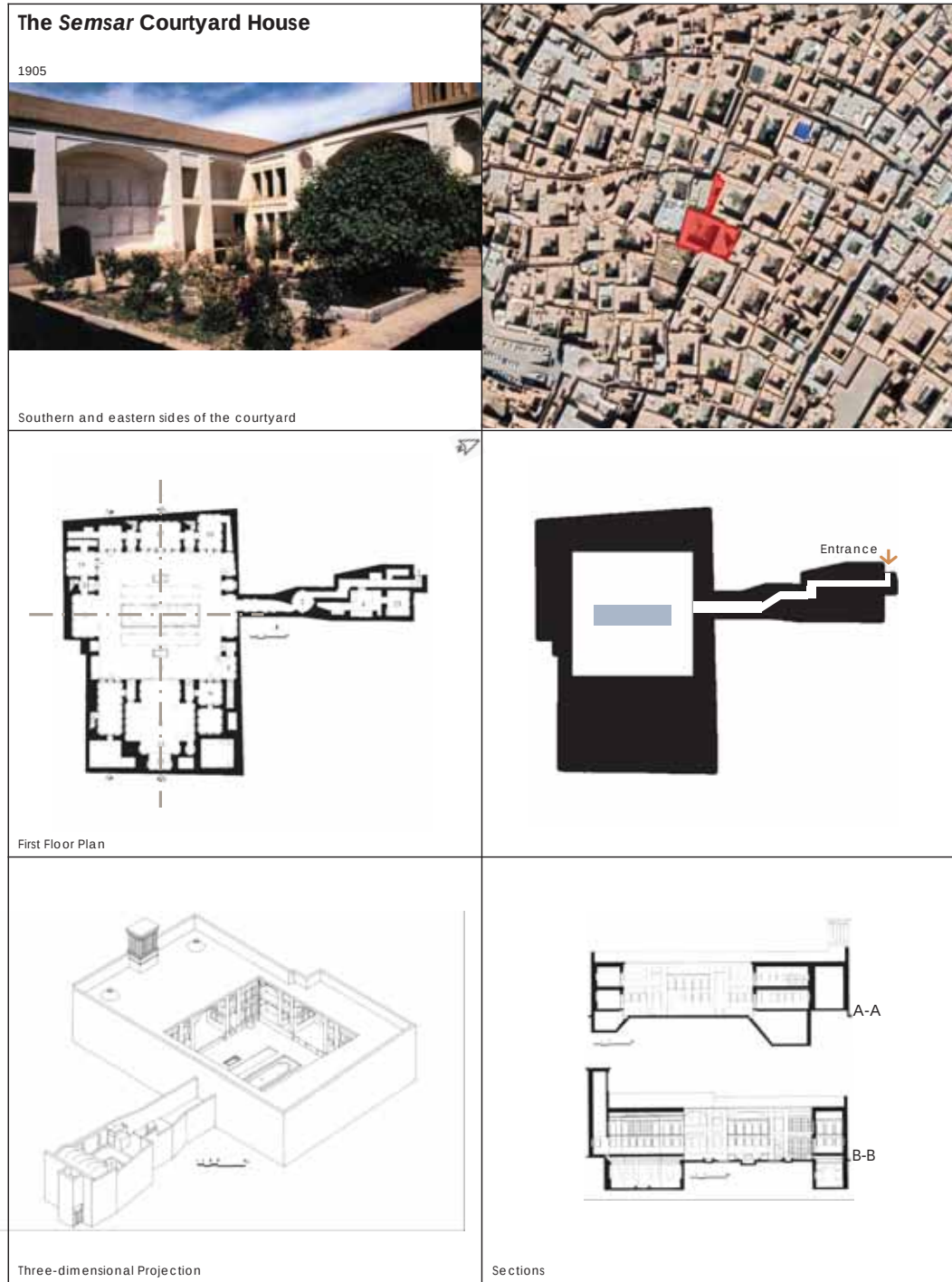


Figure 75. The drawings of the *Semsar* courtyard house. Author's elaboration using [71].

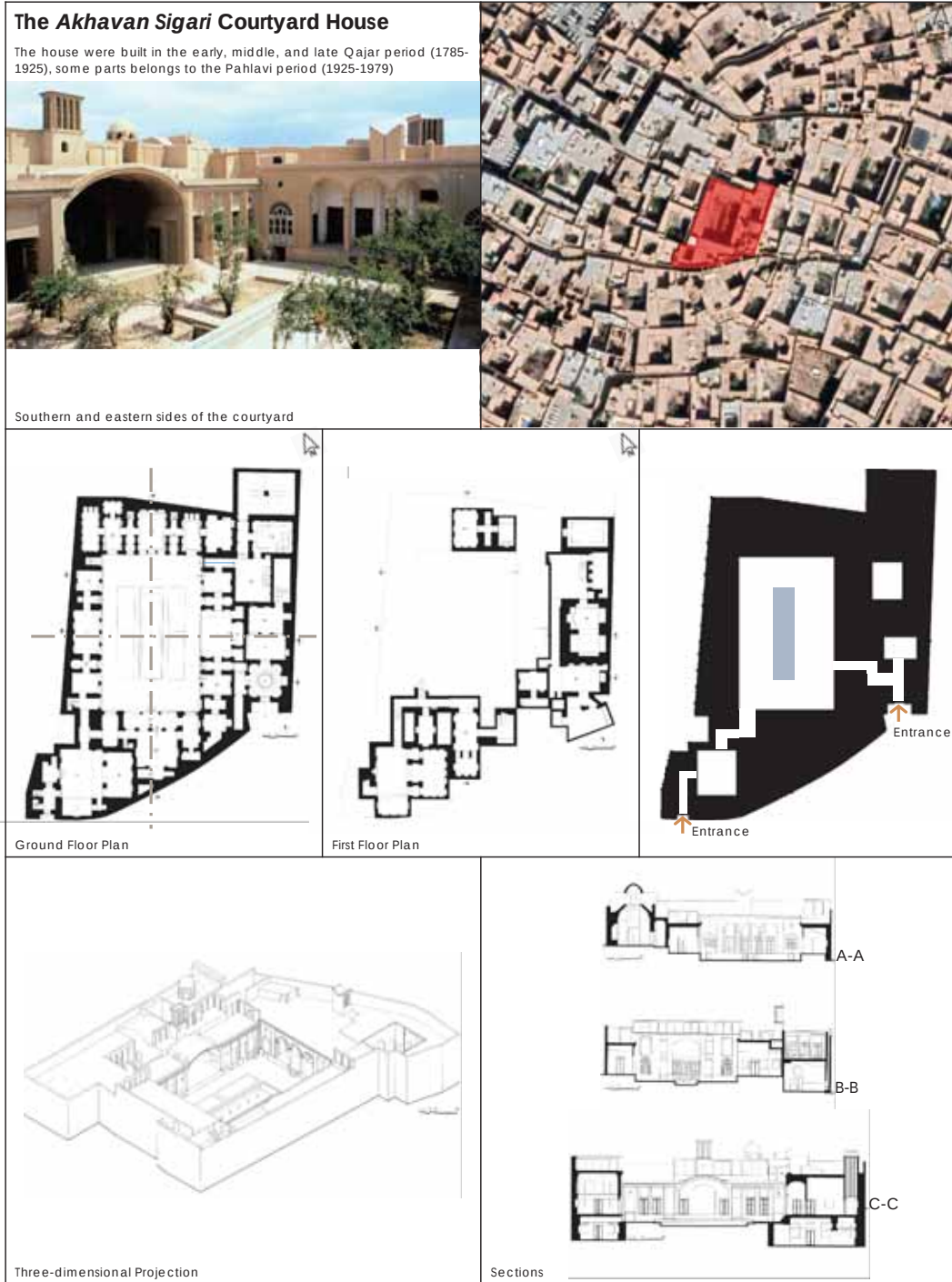


Figure 76. The drawings of the *Akhavan Sigari* courtyard house. Author's elaboration using [71].



Figure 77. The main courtyard. Photo by author in November 2023.



Figure 78. The main courtyard. Photo by author in November 2023.



Figure 79. The main courtyard. Photo by author in November 2023.



Figure 80. The main courtyard. Photo by author in November 2023.



Figure 81. The main courtyard. Photo by author in November 2023.



Figure 82. The main courtyard. Photo by author in November 2023.



Figure 83. The secondary courtyard. Photo by author in November 2023.



Figure 84. The secondary courtyard. Photo by author in November 2023.



Figure 85. The tertiary courtyard. Photo by author in November 2023.



Figure 86. The connecting stairs between the courtyards. Photo by author in November 2023.



Figure 87. The rooftop views. Photo by author in November 2023.



Figure 88. The rooftop views. Photo by author in November 2023.



Figure 89. The rooftop views. Photo by author in November 2023.



Figure 90. The rooftop views. Photo by author in November 2023.

2.3.4.4 *The typological process of the historical courtyard houses*

Generally, houses consisted of two parts, one is a closed and built space and, the other is an open and unbuilt space, known as the courtyard. This expression is based on the remains of ancient pre-Islamic houses in central parts of Iran. This climate of this regions is cold for half of the year and warm for the other half of the year. Hence, inhabitants do their daily activities in outdoor when the weather is suitable. While the influence of geographical and environmental phenomena on the formation of open spaces or courtyards is evident, culture, tradition, beliefs, philosophy, identity, and human values can be identified as the main factors in the formation of these courtyards. Houses have undergone an evolution over an extended period to reach the complete form of the courtyard house. This form is visible in the courtyard houses of the *Qajar* and *Pahlavi* eras. The *Tagh boland-ha* (*Hosseinian*) house in Yazd is one of the oldest surviving houses from the pre-Islamic period in Iran. Through an examination of this house, the

antiquity and historical importance of the courtyard pattern became evident. Unfortunately, the historical importance of this pattern has been unnoticed in the design of contemporary houses. Thus, the structure of the courtyard has been completely removed [75].

Ayvan is one of the lasting elements of Iranian architecture that has found various forms and compositions from the first millennium BC to the present day. The evidence from the pre-Islamic period shows that *Ayvans* were used in governmental, religious, and aristocratic houses. In Islamic period, *Ayvans* were used in various types of architecture such as palaces, mosques, tombs, schools, *Caravanserais*, and courtyard houses. There existed a significant correlation between the dimensions of *Ayvans* and the status of the ruling authorities. In other words, more powerful rulers constructed high *Ayvans* with numerous ornaments. *Ayvans* are divided into three types based on their shape, determining by the type of roof covering. The first type are *Ayvans* with flat roofs and gabled roofs, which date back to the first millennium BC in the *Hasanlu* area. The second type are *Ayvans* with curved roofs and arched roofs, which date back to the *Parthian* in *Seleucia* area. The emergence of these two types of *Ayvans* can be attributed to variations in materials and the development of construction techniques over time. The third type of *Ayvans* are a combination of columnar and arched type. In this configuration, a row of columns, known as *Tarma* or *Tarmeh*, is positioned in front of the arched space. This type of *Ayvans* date back to the *Sassanid* era. *Ayvans* with *Tarma* are popular in the Islamic period, especially in the *Qajar* era. The common characteristics among all three categories of *Ayvans* include their position, function, dominance, and interaction with the external environment. *Ayvan* has been implemented in various architectural designs and combinations. In pre-Islamic period, buildings were constructed with one *Ayvan*, Two

Ayvans, and four *Ayvans*. In Islamic period, the design of four *Ayvans* became a standard and perfected element of architecture [74].

The entrance of the historical courtyard houses experienced alteration with the advent of Islam in Iran. In pre-Islamic courtyard houses, the entrances were situated in the middle of the house, and they were symmetrical. In Islamic courtyard houses, especially during the *Qajar* and *Pahlavi* era, the entrances shifted to the corners, due to two reasons.

- The first reason is the social transformations that took place by the arrival of Islam in Iran, and its impact on architectural principles.
- The second reason is that architects avoided marking the entrances on the courtyard's facades by placing them along the two axes. In other words, at the intersection of the axes with courtyard's facades, closed and semi-open spaces such as *Sedari*, *Panjdari*, and *Ayvan* are located. These spaces were considered more valuable than entrances.

Moreover, the accessibility of the entrance to the courtyard transformed with the advent of Islam. In pre-Islamic courtyard houses, these paths were straight, allowing people to reach the courtyard through a direct corridor from the entrance. In Islamic courtyard houses, these paths are not straight, they are winding and designed with hierarchy. The design pattern for entrances was influenced by religious beliefs of the inhabitants. They aimed to keep the courtyard space, which is the private part of the house, separate from the outside space and not to be visible from the exterior. Some of courtyard houses from the *Qajar* and *Pahlavi* era in Yazd consisted of two houses, or with two entrances they are divided into two houses. This feature is taken from pre-Islamic courtyard houses, where various halls with different functions existed. For

instance, there were separate halls for women, men, and for different occasions (Figure 91).

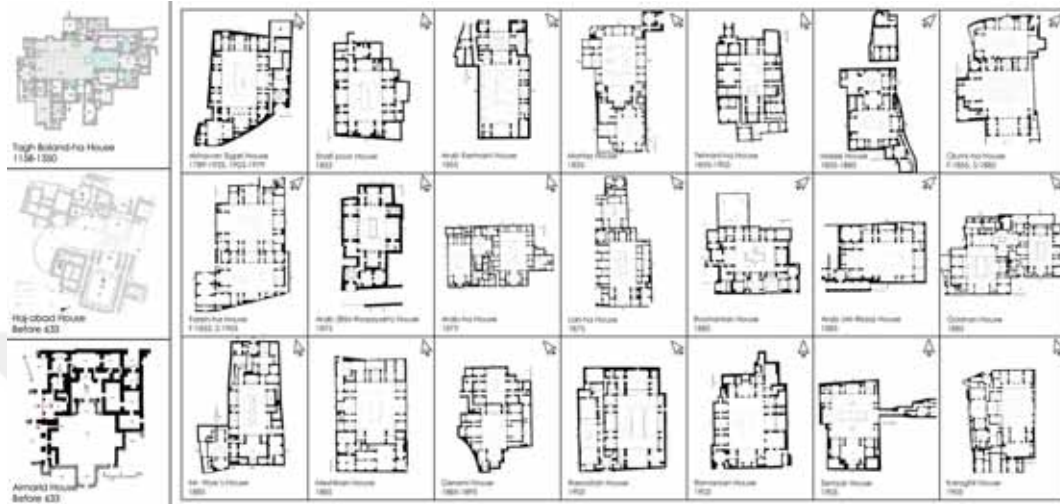


Figure 91. The drawings of the historical courtyard houses. Author's elaboration using [68], [70], and [71].

2.3.5 The Architectural Structures Associated with the *Qanat* Systems

This research investigated the *Zarch Qanat* in Yazd as a case study, aiming to examine the architectural structures associated with the *Qanat* systems, such as watermills, *Payabs*, and cisterns. These structures are directly related to the daily life of the residents in cities or villages [76].

The *Zarch Qanat* originates from the mountainous areas of *Shirkuh* in the southeast of Yazd city. It passes through the villages of *Khavidak*, *Deh Now*, *Qasem Abad*, and *Akramieh* before entering Yazd. This *Qanat* crosses under the various sections of the city of Yazd, including the *Amir Chakhmaq Complex*, *Jameh Mosque*, and Bazaar. Subsequently, it leaves Yazd and continues its route towards the city of *Zarch*, and it reaches the ground level in this city. In this city, the *Qanat's* water is used for agriculture. The agricultural lands benefiting from the water of the *Zarch Qanat* cover an estimated area of around 300 hectares, which indicates the historically effective irrigation provided

by the *Qanat* within this region. Crops such as wheat, alfalfa, pomegranates, and pistachios have been cultivated within these lands. The *Zarch Qanat* has three branches, *Shur*, *Shirin*, and *Ibrahim khovidaki*. Currently, only the *Shur* branch is active, while the other branches have dried up due to the drop in the underground water level (Figure 92).

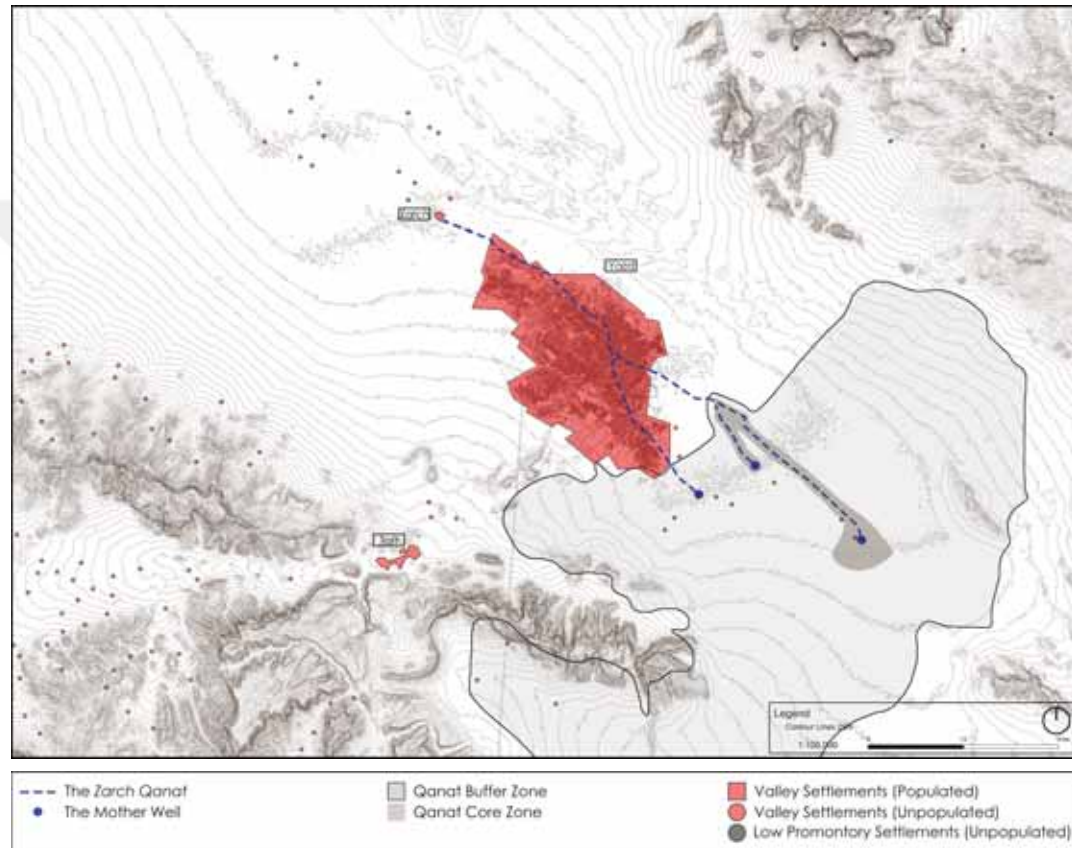


Figure 92. The *Zarch Qanat*, 1:100,000. Author's elaboration using QGIS 3.26 and OpenDEM datasets, [77].

The *Zarch Qanat*, considering both active and inactive branches, has an estimated length of about 80 kilometres. The depth of its mother well in the *shur* branch is 85 meters. The diameter of the circular wells of this *Qanat* is between 75-80 centimetres. In addition to circular wells, this *Qanat* has several wells with a rectangular cross-section, measuring 60*100 centimetres. The conduit of the *Zarch Qanat* has an average height of 180 centimetres and a width of 60 centimetres. The *Zarch Qanat* enters the city of Yazd

at a depth of 28 meters and continues underground for approximately 30 kilometres. In Yazd, several architectural structures have been built in association with the *Zarch Qanat*, such as watermills, *Payabs*, and cisterns [1], [78] (Figure 93).

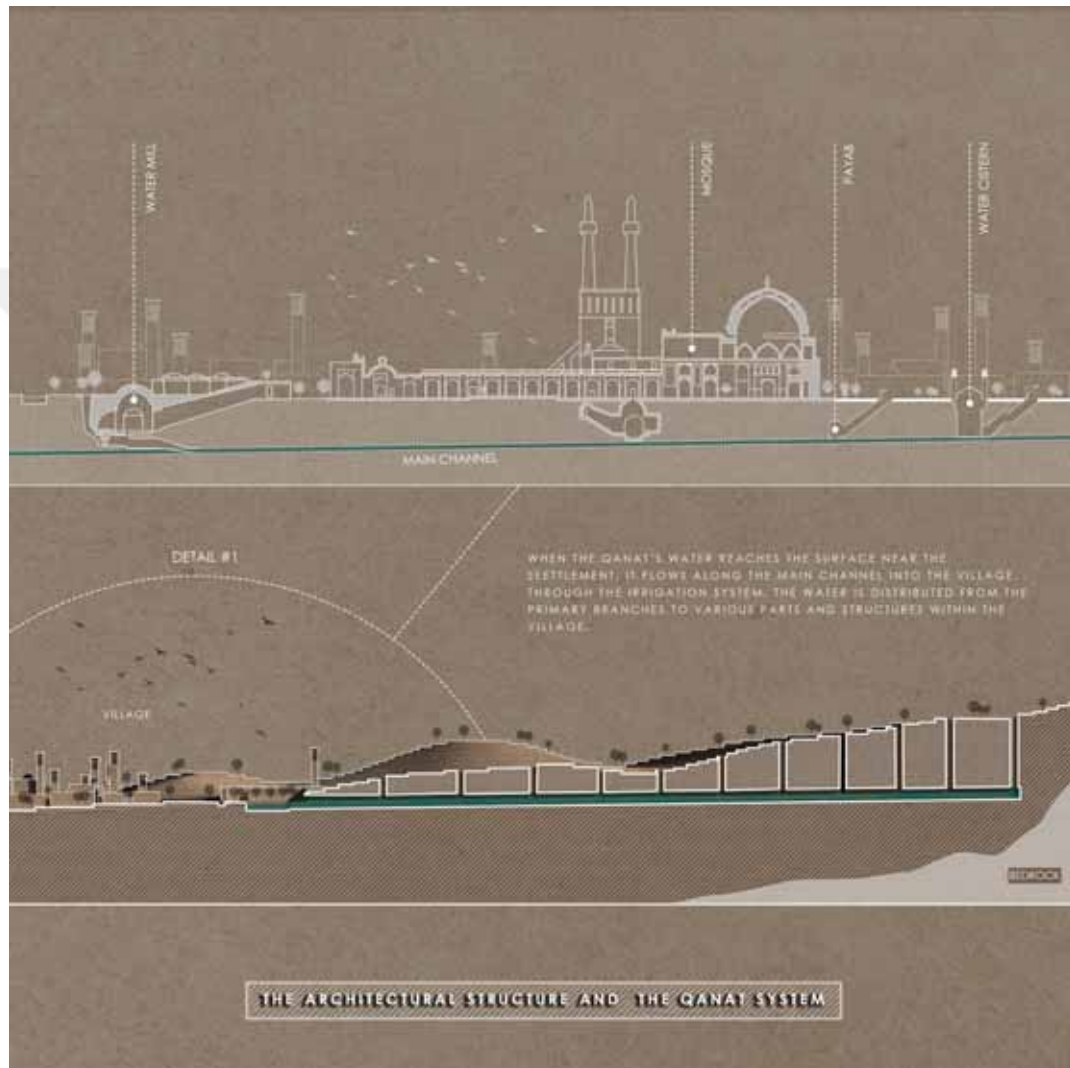


Figure 93. The irrigation system diagram. Author's elaboration using [76], [79].

These architectural structures are situated in the historical context of Yazd (Figure 94).

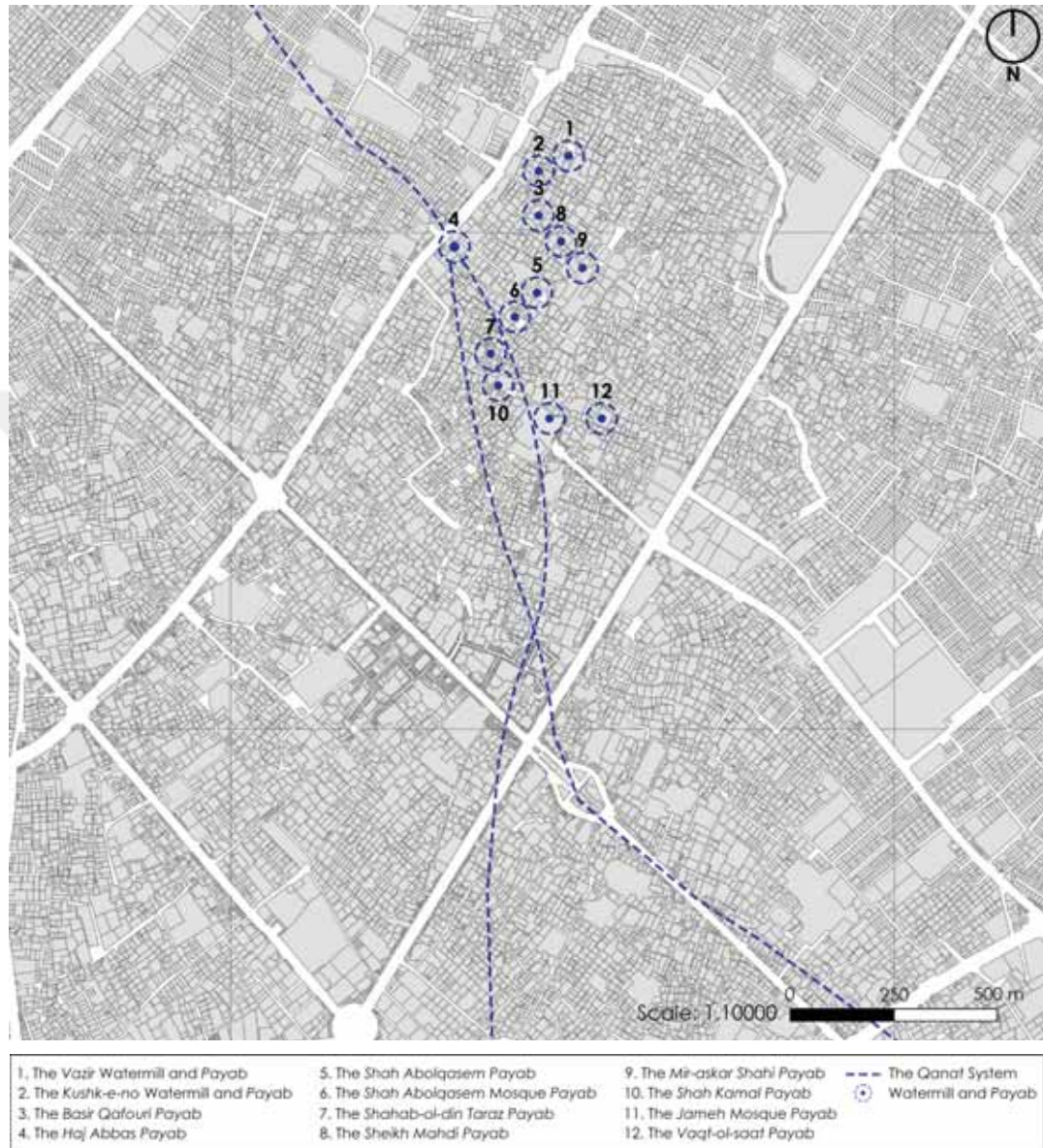


Figure 94. The location of the architectural structures associated with the *Qanat* systems within the historical context of Yazd. Author's elaboration using QGIS 3.26 and NCC datasets, fieldwork on November 2023.

2.3.5.1 *The watermill*

In regions where alternative energy sources were not viable or cost-effective, inhabitants utilized water energy from *Qanat* systems. In the city of Yazd, watermills powered by the *Qanat's* water were the main means for grinding flour used by the residents. The watermill's operation relies on the energy obtained from the water pressure accumulated in the mill's well. The *Qanat's* water was directed into the mill's well, creating pressure that pushed the blades of the mill into motion when it exited from the end. Hence, the top millstone rotates and grinds the grains that are placed between this stone and the bottom stone. After the millstone has been set in motion, water enters the channel. This channel is connected to the conduit of the *Qanat*, or it is poured into the well of another watermill. The watermills were constructed at two points along the route of the *Qanat* system. Their locations are determined based on the needs of the region, including population and the number of villages. Several watermills were built near the *Qanat's* outlet. They got access to the *Qanat's* water through the open streams or water storage pools. This type of watermills is commonly located in the vicinity of gardens and agricultural fields, where water flows on the surface of the ground. The ceiling of these watermills is positioned at ground level and most of their architectural components situated underground. Furthermore, service buildings such as warehouse, client waiting area, and the miller's resting place are built at the ground level. Several other watermills, such as *Vazir* watermill and *Kushk-e no* Watermill in Yazd, were built deep in the ground. Access to these watermills was facilitated by a sloping road designed to accommodate not only pedestrians but also the passage of cattle. Generally, the watermills are divided into three categories.

- The first category is situated in rural and sparsely populated areas. They are consisted of an entrance, a corridor, a court, a millstone area, and a well.

- The second category is situated in areas with medium population. They are consisted of more facilities such as warehouse.
- The third category is situated in populated areas. In addition to the mentioned spaces, they have a client waiting area, and the miller's resting place.

[79] (Figure 95)-(Figure 110).

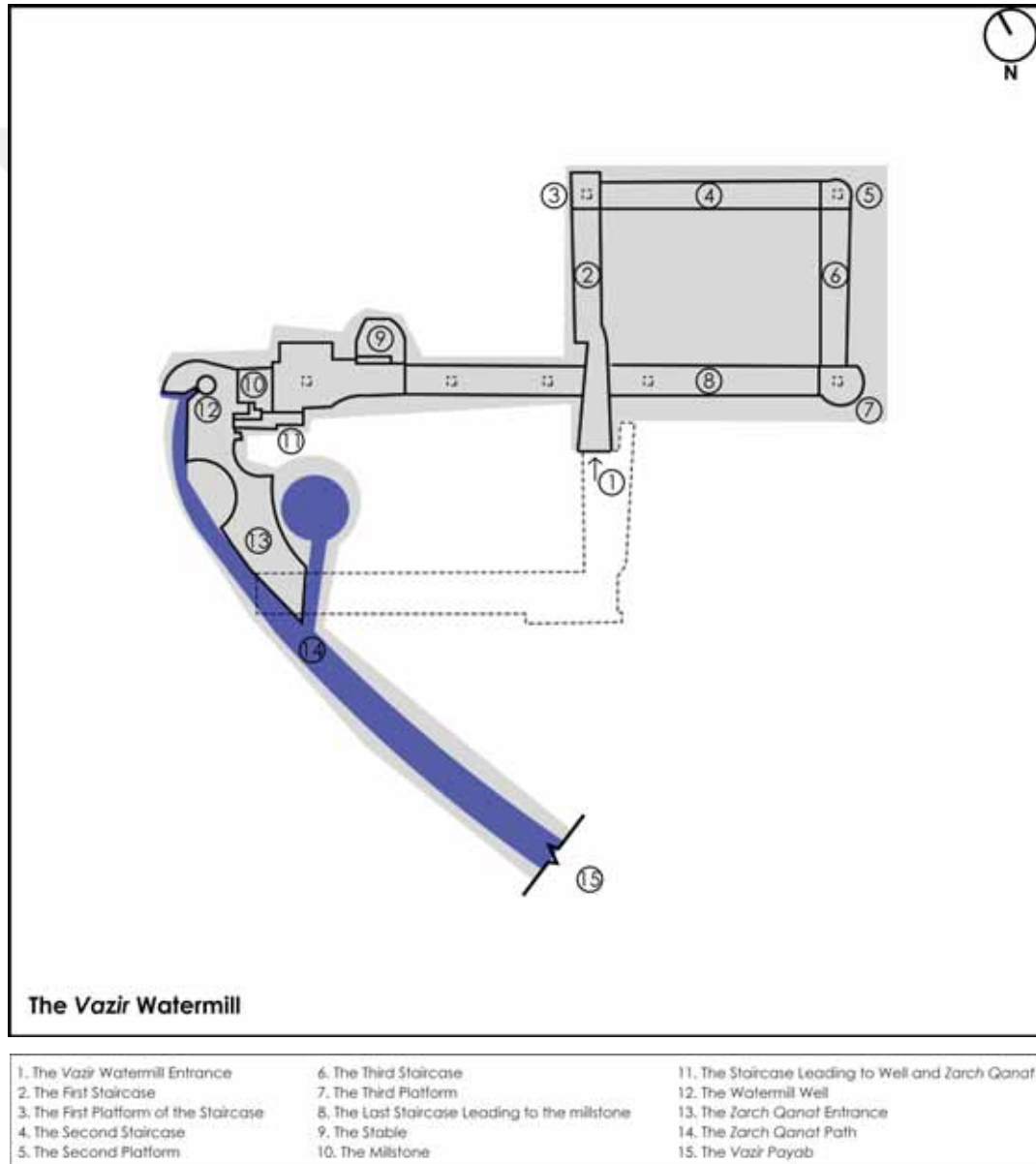


Figure 95. The *Vazir* watermill and the *Zarch Qanat*. Author's fieldwork on November 2023.



Figure 96. The *Vazir* watermill entrance (8). Photo by author in November 2023.



Figure 97. The *Vazir* watermill entrance (8). Photo by author in November 2023.



Figure 98. The *Vazir* watermill stable (9). Photo by author in November 2023.



Figure 99. The *Vazir* watermill stable (9). Photo by author in November 2023.



Figure 100. The *Vazir* watermill millstone (10). Photo by author in November 2023.



Figure 101. The *Vazir* watermill millstone (10). Photo by author in November 2023.



Figure 102. The *Vazir* watermill millstone (10). Photo by author in November 2023.



Figure 103. The *Vazir* watermill skylight. Photo by author in November 2023.



Figure 104. The *Vazir* watermill well (12). Photo by author in November 2023.



Figure 105. The *Vazir* watermill well (12). Photo by author in November 2023.



Figure 106. The *Zarch Qanat* entrance (13). Photo by author in November 2023.



Figure 107. The *Zarch Qanat* skylight. Photo by author in November 2023.



Figure 108. The *Zarch Qanat* path (14).
Photo by author in November 2023.



Figure 109. The *Zarch Qanat* path (14).
Photo by author in November 2023.



Figure 110. The *Vazir Payab* (15).
Photo by author in November 2023.

2.3.5.2 *The Payab*

The *Payabs* are architectural structures situated within the urban tissue, designed to provide residents access to *Qanat's* water. This structure is consisted of a long staircase leading underground and a court. The *Payabs* are associated with the *Qanat* systems that cross under the city. Generally, the *Payabs* are divided into two categories.

- The first category is public *Payabs* that are situated within the urban context of the cities, such as *Vazir Payab* and *Kushk-e no Payab* in Yazd. These public *Payabs* are the urban points for the ordinary people to utilize and gain access to the *Qanat's* water. Furthermore, within various important public buildings such as *Jameh Mosque* in Yazd, there is a *Payab* that is specific to that structure and provides direct access to water (Figure 111)-(Figure 116).



Figure 111. The public *Payab* entrance. Photo by author in November 2023.



Figure 112. The public *Payab*. Photo by author in November 2023.



Figure 113. The *Jameh Mosque Payab* entrance. Photo by author in November 2023.



Figure 114. The *Jameh Mosque Payab* entrance. Photo by author in November 2023.



Figure 115. The *Jameh Mosque Payab*.
Photo by author in November 2023.



Figure 116. The *Jameh Mosque Payab*.
Photo by author in November 2023.

- The second category is private *Payabs* that are situated within the private buildings, such as courtyard houses. These private *Payabs* provide direct access to water for wealthy people in their houses. To establish these *Payabs*, a secondary branch is separated from the main conduit of the *Qanat*. Subsequently, after passing through the considered courtyard house, it is reconnected to the main conduit (Figure 117)-(Figure 124).

The ordinary people used to go to *Payabs* during early morning and late evening hours to get access to clean water. During other times, the *Payabs* were used only for washing [76].



Figure 117. The private *Payab* entrance.
Photo by author in November 2023.



Figure 118. The water inlet to the private *Payab*. Photo by author in November 2023.



Figure 119. The *Qanat* path leading to private *Payab*. Photo by author in November 2023.



Figure 120. The *Qanat* path leading to private *Payab*. Photo by author in November 2023.



Figure 121. The private cellar entrance.
Photo by author in November 2023.



Figure 122. The private cellar entrance.
Photo by author in November 2023.



Figure 123. The private cellar. Photo by
author in November 2023.



Figure 124. The private cellar. Photo by
author in November 2023.

2.3.5.3 *The cistern*

The cisterns are architectural structures situated within the urban tissue, designed to store *Qanat's* water, especially during the winter when agricultural water requirements decrease. This structure is consisted of a long staircase leading underground, a court and tank, and *Badgir*. The *Badgir* keeps the coolness of water and prevents it from spoilage. The cisterns are constructed along the *Qanat's* route because the source of their water supply is the *Qanat* systems [76].



CHAPTER III

CONCLUSION

3.1 The Impact of the Qanat System on the Formation Process of Yazd

Interpretation based on the reconstruction of the formation process, leads to a design of reality that represents the entirety of associations among the urban components. This method of interpretation is guaranteed by the homogeneity of a system of differences that arises from historical expansions. This homogeneity represents the inherent organization that exists among structure and history [6]. This study has sought to interpret the connections between the urban components of Yazd by reconstructing the city's formation process. Furthermore, the research has examined the influences of the *Qanat* systems on the formation process of Yazd. In this approach to the structures of environment, this study has reached a broad comprehension of the built environment in Yazd by studying its components based on a decreasing scale [6]. Moreover, the research has explored the impacts of the *Qanats* on the city's components on each scale.

Initially, the study has investigated the *Qanat* systems, including their construction methods and main components. Subsequently, the research has considered the water supply system facilitated by *Qanats* and their hierarchy. Consequently, to comprehend the correlation between the formation process of Yazd and the *Qanat* systems, this research has examined the components of the city in four decreasing scales.

The first scale is the territorial scale. In this scale, the study has analysed the way the existence of the settlements and urban cores initiated from routes and productive structures in the central Iranian plateau. Hence, it has explored the territorial organism which is the broadest scope and comprises the most components. Through the analysis of the formation process of the territorial organism map of Yazd, it can be said that a crucial factor in positioning the city of Yazd between two parallel series of top ridge routes is its utilization of the *Qanat* systems to fulfil water requirements. The *Qanats* originate from the underground water table located on the hillside. This system uses the natural slope of the land to transport water within its conduit from upstream to downstream. Therefore, valley settlements can benefit from this irrigation system. In this scale, the *Qanat* system has impact in determining the location of the city of Yazd in the valley.

The second scale is the urban scale. In this scale, the study has analysed the way the urban organism which includes basic tissues, transformed within historical periods. Through the analysis of the transformation process of the urban organism maps of Yazd within five historical stages, including the chronology of the *Qanats*, it can be said that there is a strong connection between the urban growth of the city of Yazd, oriented along the main slope and towards the south and southwest, and the *Qanat* systems. Indeed, Yazd has expanded in such a way that there are favourable conditions, such as appropriate slopes and soil conditions for the construction of the *Qanats* to meet the water requirements. The correlation between the direction of the city's growth and the *Qanat* systems is a back-and-forth relationship, with each influencing the other. When inhabitants wanted to expand the city, the construction of the *Qanats* was considered as a vital issue. In contrary, when there was the potential of constructing a *Qanat*, the matter of expanding the city was considered. In this scale, the *Qanat* system has impact on the urban growth of the city of Yazd (Figure 125).

The third scale is the urban tissue scale. The study has analysed the typological process of the urban tissue of the city of Yazd throughout history by decreasing the scale into the aggregates that form the basic tissues. Furthermore, the research has examined the influences of the transformation of aggregates on routes and buildings. Through the analysis of the transformation process of the urban tissue maps of Yazd within three historical phases, it can be said that there is a strong connection between the urban configuration of the city of Yazd and the *Qanat* systems. In each phase, the urban tissue of Yazd follows a distinct urban planning methods based on diverse cultural sources. Each of these methods has its own planning logic. The *Qanat*'s act as a dividing line between three phases of the city. In addition, the main streets within the road network are parallel to the route of the *Qanats*, while the secondary streets in this network are perpendicular to the *Qanat*'s path. In this scale, the *Qanat* system has impact on the formation of the urban tissue of the city of Yazd and its road network (Figure 126).

The fourth scale is the building scale. The building type is the outcome of a diachronic process that begins with basic buildings [80]. The study has analysed the typological process of historical courtyard houses in Yazd throughout history by decreasing the scale into the building that is the smallest component of the aggregates. Through the analysis of the documents of the historical courtyard houses within the historical zone of Yazd, it can be said that there is a strong connection between these houses, which owned by wealthy individuals, and the *Qanat* systems. These courtyard houses have direct access to the *Qanat*'s water. Consequently, in this scale the study has analysed the architectural structures associated to the *Qanat* systems. According to the analyses, the formation process of city of Yazd is influenced by the *Qanat* systems, which is a part of irrigation system [9], [43].

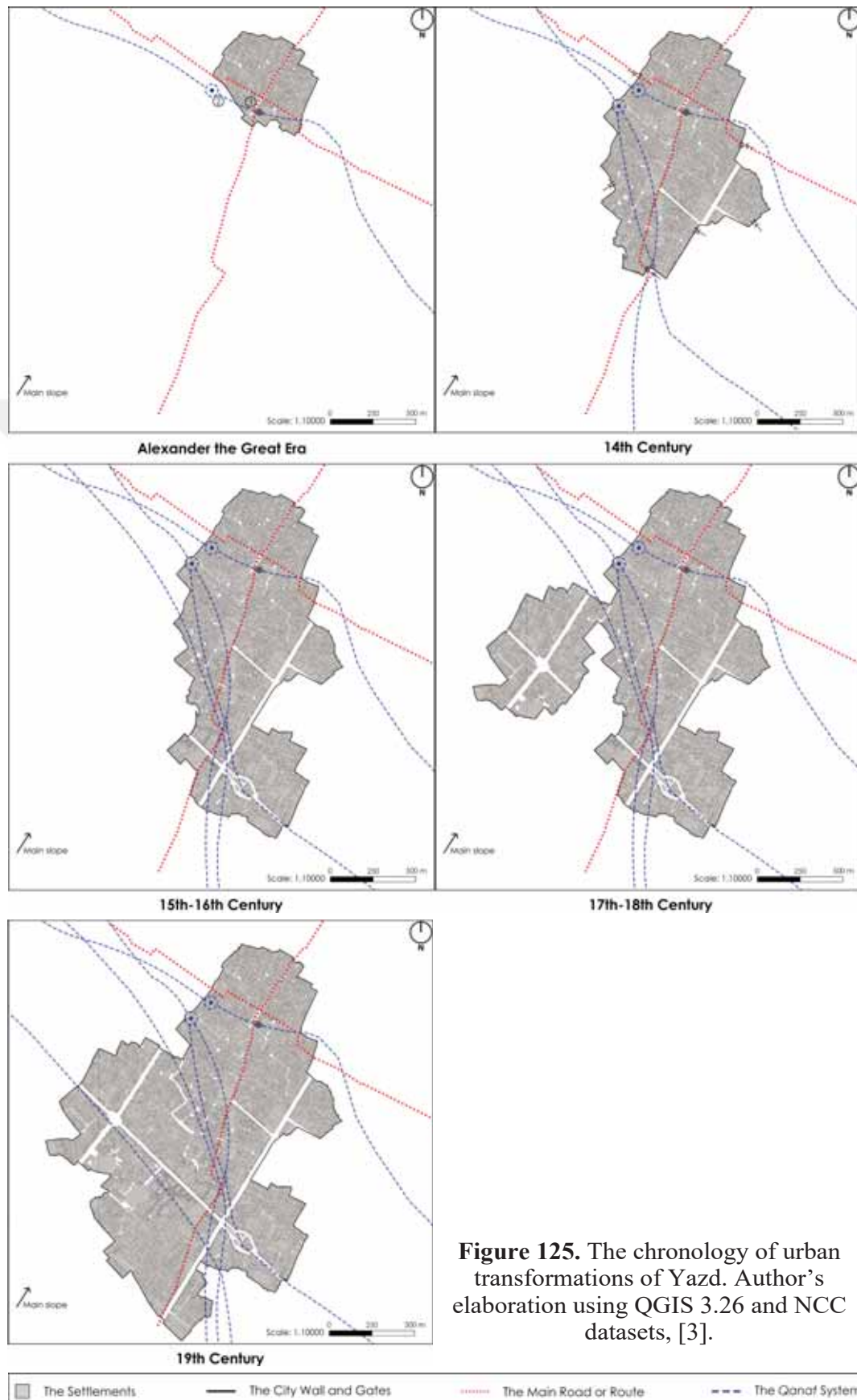


Figure 125. The chronology of urban transformations of Yazd. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

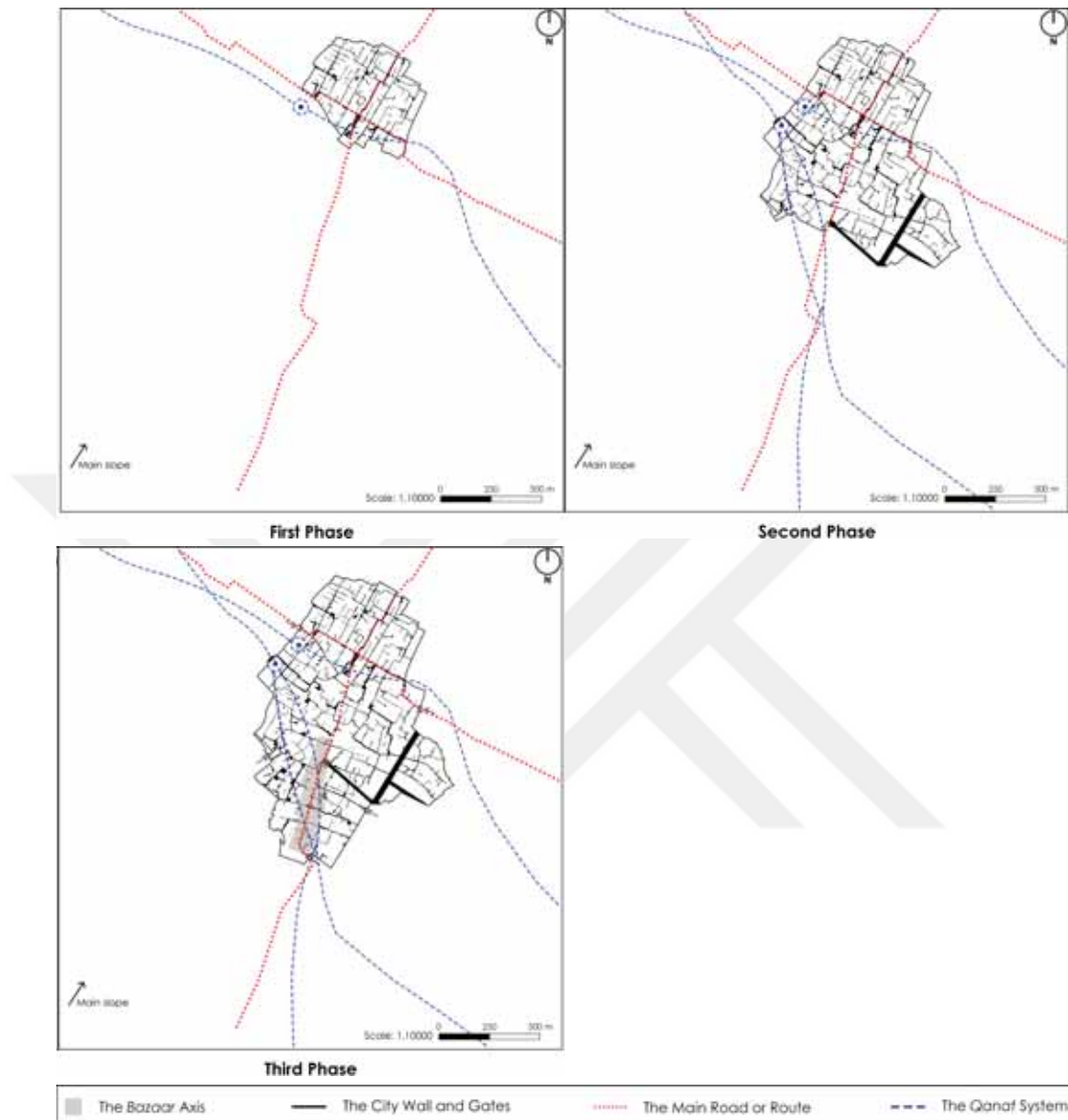


Figure 126. The transformation process of the urban tissue of Yazd within three historical phases. Author's elaboration using QGIS 3.26 and NCC datasets, [3].

3.2 Conclusion

In conclusion, the hot and arid climate with low rainfall in Yazd, and the absence of permanent streams, necessitated utilization of underground water, direct through *Qanat* technology. The *Qanat* systems of Yazd had an infrastructural role in the settlement. Hence, the formation and transformation of the city of Yazd have been dependent on the *Qanats* as the only supplier of water. The influences of the *Qanat* systems on the formation process of Yazd include their impact on the positioning of the city. In the city of Yazd, the connection of its topography and natural features has made it possible to direct underground water by *Qanat* technology. Moreover, the *Qanats* have influenced the development of the urban organism, the formation of the road network and communication routes, the construction of residential buildings, and architectural structures related to this system. Consequently, this study has analysed the correlation between these buildings and the *Qanats*, and the structural differences in the elements of water access in each of them. Following examination of the influences of the *Qanat* systems on the urban configuration of the city of Yazd, it can be said that the *Qanat* with its division system is a multi-functional network. This network has remained stable over centuries and is still standing today despite various changes. This infrastructure network has ensured the stability of economic, social, cultural, and political functions within the settlement.

APPENDIX A

Marco Polo's Travelogue to Yazd

“Yasdi is a beautiful and novel city, with rich manufactures. The people make silk cloths called by its name, which the merchants carry into various countries. When a man departs from that city, he rides seven days over a plain, where in three places only there are habitations and inns for the traveller. There are many forests filled with partridges and other birds, which afford excellent sport, also beautiful wild asses. At the end of these seven days a country called *Creman* presents itself.” [21]

APPENDIX B

Pliny the Elder's Natural History

“The *Parsae* have always inhabited the shores of the Red Sea, for which reason it has received the name of the Persian Gulf. This maritime region of *Persis* has the name of *Ciribo* or *Syrtibolos*; on the side on which it runs up to that of the *Medi*, there is a place known by the name of *Climax Megale* or Great Ladder, where the mountains are ascended by a steep flight of stairs, and so afford a narrow passage which leads to *Perspolis*, the former capital of the kingdom, destroyed by Alexander. To the east is the fortress of *Passagarda*, held by *Magi*, at which spot is the tomb of *Cyrus*; also *Ecbatana*, the capital of *Media*, the inhabitants of which were removed by *Darius* to the mountains. Between the *Parthi* and the *Ariani* projects the territory off the *Paraetaeni*.” [23], [24]

APPENDIX C

Table 6. Glossary. Source: [81].

Term	Class	Definition	Persian
<i>Qanat</i>	noun	The underground water channel	قنات
<i>Karez</i>	noun	The underground water channel	کاريز
<i>Muqanni</i>	noun	The person who digs and maintains the <i>Qanat</i>	مقنى
<i>Havabin</i>	adjective	The <i>Qanats</i> characterized by variable and seasonal water flow	هوابين
Non- <i>Havabin</i>	adjective	The <i>Qanats</i> characterized by constant water flow	غير هوايين
<i>Koure</i>	noun	The underground channel of the <i>Qanat</i> system	كوره
<i>Mazhar</i>	noun	The outlet of the <i>Qanat</i> system	مظهر
<i>Shaft</i>	noun	The vertical well of the <i>Qanat</i> system	شفت
<i>Pushteh</i>	noun	The distance between two vertical wells	پشته
<i>Tar-e kar</i> (<i>Taroun</i>)	noun	The first main section of the <i>Qanat</i> system	تره كار (ترون)
<i>Tar-o khoshk</i>	noun	The second main section of the <i>Qanat</i> system	تر و خشك
<i>Khoshk-e kar</i> (<i>Khoshkoon</i>)	noun	The third main section of the <i>Qanat</i> system	خشكه كار (خشكون)
<i>Corte</i>	noun	The agricultural field	كرته

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VITA

Nahal Khorrami received her bachelor's degree in architectural engineering from Tehran University of Art, Faculty of Architecture and Urban planning, Tehran, Iran, graduating in 2021. Her dedication to innovative design concepts was prominently featured in her bachelor's thesis, "Designing Pottery Cultural Complex in Yazd, Iran."

Expanding her knowledge and skills, Nahal pursued a comprehensive master's program in architecture at Özyeğin University, Faculty of Architecture and Design, Istanbul, Turkey, graduating in 2023. Throughout her master's studies, she demonstrated her research prowess by contributing to various research papers, including the *Typological Process of the Historical Courtyard Houses in Yazd, Iran*, and *Urban Morphology and Identity Crisis: The case of Yazd, Iran*. Currently serving as a tutor and a participating member of the DRUM (Dynamic Research on Urban Morphology) research group at Özyeğin University, where she actively contributes to academic events, conferences, and summer schools.

In 2018, Nahal founded the Tile Design Studio, specializing in Iranian ancient architectural decoration. Her passion for design and dedication to craftsmanship are evident in the studio's focus on designing and manufacturing handmade tiles. Moreover, she co-founded Done, an architecture and construction studio, in 2023, further solidifying her impact and influence in the architectural and construction domain.