Lessons From Yazd

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Rethinking Iranian Traditional Courtyard Houses for Indoor Climate Comfort in Educational Buildings

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Illustrations cover, left and right page made by author.

Abstract

In current times sustainability is a major priority in the building industry which contributes largely to country's total energy consumption. Additionally, educational buildings make up a large part of building stocks around the world and these buildings are responsible for large part of energy consumption especially by heating, cooling, and ventilating these building. To reduce energy usage, we must look for preservation and sustainable new designs, especially for solutions relying on renewable and natural sources and passive systems. Besides, thermal comfort in educational buildings is important since it significantly impact student's physical, mental health and productivity. Therefore, this research aims to investigate whether we can learn from the passive climate responsive architectural elements invented millennia ago, which form the traditional courtyard house typology of Yazd, for sustainable solutions regarding thermal comfort in educational buildings.

This thesis starts with introducing the features by examining the different elements that play an important role in providing comfortable indoor climates of the residents. To find out the usability of these architectural typology and its features and whether we can learn from it for current times, a case study analysis was conducted which investigated the adaptive reuse project of the faculty of Arts and Architecture in Yazd.

The results showed that it is evident this architecture and its knowledge has been of great importance for livability and will persist to be of great usefulness in times we seek for passive indoor climate solutions because climate will become more similarly to Yazd. To realize thermal comfort in educational indoor spaces innovative, adaptive, climate responsive, socio-cultural context and local material inspired solution should be implemented.

keywords – Yazd, thermal comfort, indoor climate, natural ventilation, adaptive reuse, traditional earthen architecture, courtyard house, sustainability, educational needs

Figure 1. Example of greenery in central courtyard of adaptive reuse project Kohan traditional boutique Hotel (The Adventures of Nicole, 2020).

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Figure 2. Adaptive reuse project of traditional courtyard house in Yazd's historic city (Harandi & Harandi Architects, 2022).

Introduction

This research explores the architectural typology of the traditional courtyard houses of the historic city of Yazd, Iran. This millennia-old city is well known for its windcatchers, courtyards, and thick earthen walls contributing to its living environment, and is entirely built out of adobe. The central courtyard plays an important role in terms of air circulation and cooling process. It enhances quality of living in an arid region by features like greenery, water, materials, lighting, and shadow. This research addresses the benefits of these features for climate issues. It aims to investigate what we can learn from the features of these traditional courtyard houses. Specifically, how we can benefit from the climate features to increase the quality of the indoor spaces of educational buildings. The research question is:

To what extend can we learn from the adaptive reuse of traditional courtyard houses in the historic city of Yazd in terms of thermal comfort for educational buildings?

This thesis focusses on educational buildings since the indoor climate is of greatest importance, as it affects the health and study progress of students who these days spent more time indoor especially at schools. These buildings require high demands of energy for cooling and heating. In current times preservation is priority in the building industry, thus we must look for passive solutions. Additionally, due to climate change the extent of arid and dry areas increases. Therefore, the case study of Yazd will be investigated, as it is an important world heritage site which is the vastest area almost completely built out of natural elements. Its solutions that are responsive to climatic issues can be an example for sustainability needs due to climate change.

Various previous studies have been conducted mainly by architects and designers, on the technical aspects of the features, such as calculations on the wind circulation (Vaezizadeh et al., 2016). There is more research done by social scientists and historians on the history of this building typology and the influence of religion and culture (Memarian & Edward Brown, 2003). Other research is conducted from a comparative perspective, comparing traditional courtyard houses of Yazd to other countries' traditional courtyard houses (Soflaei et al., 2017). Furthermore, on how this typology and its features can be used to solve the energy problem (Maleki, 2011). The new ground this thesis is covering is what we can learn from this ancient old architecture in other contexts, especially for the application in current educational buildings. Besides, this research focusses on the reuse of the traditional courtyard house for educational purpose.

The methodology of this thesis is a combination of different implemented methods. To explore the geographical and historical context and the architecture, various research papers regarding the region and the architectural typology are studied. The important features regarding the indoor climate comfort are explained through personal analytical drawings. To expand the information of this typology, a specific case of an adaptive reuse project of a courtyard house is examined through illustrations and photographs from archives. This case study analysis is supported by productions of maps. The investigation of current needs and comparison with Delft will be conducted through personal experience, supported by academic research. Lastly, the adaptability of the feature of the windcatcher will be discussed through various examples of contemporary applications, examined by summarizing the opportunities and challenges of the feature retrieved by academic research investigation.

The first chapter of this thesis provides a brief historical context of the area to explain the development of the architectural typology. The second chapter explores the typology to understand the architecture and its components that influence indoor climate. The third chapter examines the case study of the adaptive reuse of courtyard houses in Faculty of Art and Architecture in Yazd. The houses that accommodate the faculty of Art and Architecture are built around hundred and fifty years ago and will be investigated to proof whether usage of these traditional and passive features and climate solutions provides comfortable indoor climate for current educational use. The faculty was moved to the historic city of Yazd in 1989, because of its historic values and benefits for its students and researchers and professors, who are investigating, reviving, and learning from this architectural heritage and its features. To answer the research question this case study is relevant, since it shows current adaptation and their approach to issues they are facing today, using the building typology and its features for educational function. The fourth chapter investigates the current need for better educational building's thermal comfort.

Definitions selected for terms *indoor climate* and *thermal comfort* need to be described. *Indoor climate* is a broad term, which according to World Health Organization includes thermal environment (dryness, humidity, heat, cold), atmospheric environment (e.g., air quality, fresh air supply), acoustic environment (e.g., perception of sounds), actinic environment (e.g., lighting, radiation), and lastly, mechanical environment (ergonomics etc.) (Indoor Climate, 2021). Indoor environmental quality is determined by factors including thermal comfort. This thesis focusses on thermal comfort and air quality provided by natural ventilation, cooling, or heating. According to research of Kurvers and Leijten (2021) the definition for *thermal comfort* can be described as "thermal comfort is that state of mind that expresses satisfaction with the thermal environment and is established by subjective evaluation" (p. 4).

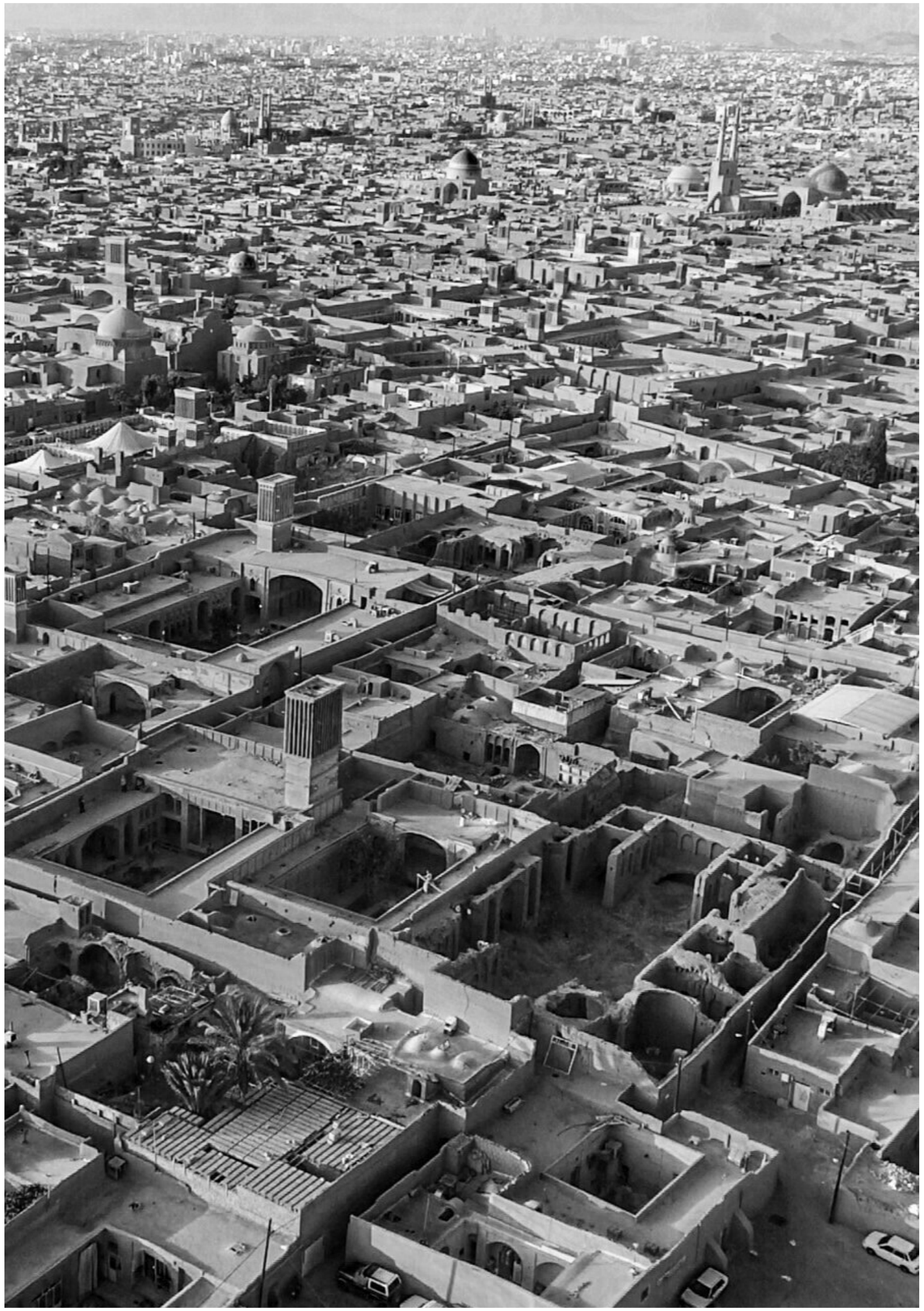

Figure 3. Overview on the historical city of Yazd urban context (Lari House, nd).

In order to get to know the architectural typology of the traditional courtyard house, first a brief historical context of the city of Yazd needs to be provided. This chapter will investigate the background of the city in terms of geographical, historical, socio-cultural characteristics, economic and political impact. This will explain the relation with the context and in what circumstances this architecture is emerged.

1.1 The emergence of the Historic city of Yazd

This research will investigate the vernacular architecture of the city of Yazd which is in a dry region. Thus, some information about the geographical and historical context will be provided first.

Geographical situation

The city of Yazd (Figure 2-3) is an ancient city in the center of Iran, located in the province of Yazd close to the Silk Roads. The city is located at an altitude of twelve hundred meters above sea level (Iran Meteorological Organization, 2009). The current climate is a desert and semi-desert climate along cold and dry winters, and hot and dry summers. Until the seventh century there was a quite pleasant climate together with green countryside and forests. Nevertheless, because of atmospheric change and irregular use of land, the area gradually changes to an infertile desert region. Consequently, this region faced less comfortable living environment and people responded to these climate changes in the way they built and orientated their houses. This resulted in the vernacular architecture this research investigates. Furthermore, the fact that the area lacked rain caused it to be not suitable for vegetation, therefore farmers used subterranean waterways to transfer water to farmland (Jodidio, 2006). The still existing waterways in the historic part of the city played an important role in the living comfort of the houses.

A broad area of the world faces same conditions of arid and hot climates. At least 20 to 30 percent is categorized as hot and arid areas. Besides, this percentage will increase by approximately 15 percent due to climate change (Foruzanmehr, 2019, p.20). Through designs and residential life, traditionally lessons are learned by locals over hundreds of years of seeking climate solutions to cope with these environments (Figure 4-5). The ensuing vernacular residential architecture symbolize meaningful richness of traditional technologies based upon climate-responsive designs (Fardeheb, 1987).

The Establishment

According to Afshar (1966) records show that the city of Yazd was known as Issatis in the pre-Islamic and Achaemenid eras 550-330 BC. However, no valid and reliable documents have remained as prove. Another record mentioned by Afshar (1966) states that Yazd, which was called Kasah, dates to the era of Alexander the Great. However, another report shows according to Afshar (1995) that the city dates to the Sassanid empire and was established by prince Yazdgerd, which declares the name of the city. Yazd's first extension and development into a prestigious, integrated city dates to the 11th century AD, when huge castles and gates were built, which created new identity for the city (Jodidio, 2006) (Figure 6).

Figure 4. Historical aerial photo neighborhood in historical city (Yazd World Heritage Research Center, 1957).

Figure 5. (left) Windcatcher Garden Baghe Dolat Abad after restoration (Yazd Kohan Archive, n.d.). (right) Six windcatcher, water reservoir Yazd (Ecochard, 1960).

Figure 6. A piece of the fortress wall Yazd - old fort (Yazd Kohan Archive, n.d).

Figure 7. Zoroastrian people celebrating religous holiday in the Province of Yazd (Yazd Kohan Archive, n.d.).

The development of the fundamental part of the historic city of Yazd enclosed by the city walls mainly resort to the ecological context, such as climate, the suitability of lands for construction but also importantly, the direction of the underground waterways (Masarrat, 1997) (Figure 4). All settlements in the historic area of the city had directly or proper indirect access to the waterways which are called Qanats. According to the research by Rahbarianyazd (2022) the development of the fundamental part of the city till the end of the 14th century contains four phases: the Sassanid period (224–651 CE) the Early Islamic period and the Kakuyid era (662–1141), Atabakan-e Yazd (1141–1319) and lastly the Muzaffarid Era (1319–1393).

1.2 Social, Cultural and Religious Background

Socio-cultural context

Before the Islamic conquest in the seventh century AD, the national religion of Iranian people was Zoroastrianism[1]. The Zoroastrian belief is one of the world's oldest faiths that is still practiced. The worship of fire is central in this belief, and this is still visible in the city by fire temples. Religious events are still celebrated by the small number of Zoroastrians (Figure 7). The city of Yazd was the central, most important place of this religion, and its religious architecture characterizes the city. After the conquest most of Yazd's citizens converted to Islam (Mollayousef, 2015). Additionally, the city had economical regional importance, it was the center for administration, industry, and markets, which is visible today in the architecture of indoor markets (bazaars) (Foruzanmehr, 2019 p.21).

On the level of the city scale, the historic city shows its strong traditional character by a unity of beige colored architecture spread over the city, which material reflects its context (Figure 8 & 9). On the level of the public space, the socio-cultural impact is visible. The city exists of narrow alleyways which provides shadow and coolness for a pleasant route while moving through the city. Besides, the adobe closed high walls blocks the sight on the houses and the courtyards which creates desired closed of private spaces as a subsequence of the architecture's climatic solutions (Pirnia, 2005). On the scale of the residential interior spaces, social obligations imposed by Shia Islam religious influence had significant impact on organization of this architectural typology. The aspect of privacy has an evident influence on the development of the centrally located courtyard and high earthen walls between public space, by orientating dwellings towards private courtyards. (Memarian & Edward Brown, 2003). The structure of family life and relationships determined the structure of the house. The courtyard house was a social reaction to extended family organizations (Afshar et al., 1975) (Figure 10).

To conclude, as well the geographical aspects as the socio-cultural and religious aspects have played an important role in the development of the cityscape and the vernacular architecture of Yazd. Besides, about half of Iran's built heritage is in the province of Yazd, which stresses the significance of Yazd's architectural and cultural value (Fakouri, 2021).

1. Zoroastrianism is a Persian religion which finds its origin around 4000 years ago. The prophet was Zoroaster, or Zarathustra in old-Persian, and believers refer to themselves as Zartoshtis or Zoroastrians, the name of the god is Ahura Mazda. Fundamental is the contradiction between good and evil. The holy elements are water, earth, and fire (Hintze, 2019).

Figure 8. Overview of high density and connected houses in the historc city (Gerster, 1977).

Figure 9. Neighborhood overview with water and vegetation within the courtyards (ICHHTO, n.d.).

Figure 10. Overview on a traditional courtyard house and courtyard within the context (van Dijk, 2016).

1.3 UNESCO World Heritage Values

As mentioned above, the city has an extensive historical background, regarding culture, religion, city planning and vernacular architecture. Due to local knowledge, it became livable despite of its unfavorable geographical context. The aspect of being the oldest and the largest city completely constructed by adobe, was the decisive factor for UNESCO to recognize this site as world heritage in 2017 (Figure 11). The latter allows it to be one of the most phenomenal cultural heritage sites in the world (Figure 12) (Fakouri, 2021).

Values of the Historic City of Yazd

However, more values played a part in the nomination as world heritage site. What makes this city stand out, is that the vast area of the historic city is still intact, and many residences are still in use as dwellings. This is different from other cities where historic parts are demolished for modern constructions. The city maintains its traditional character and historic neighborhoods which are still used or adaptively reused for education or tourism. This shows present-day usability of the dwellings, the ability to adapt to different functions and the interest and reviving of this typology. Other aspect that sets this city apart, are e.g., the still existing Qanat system for water supply, traditional courtyard houses, mosques, synagogues, fire temples, bazaars, hammams, and historic garden Baghe Dolat Abad (Figure 11) (UNESCO World Heritage Centre, 2017). These are remained due to cultural importance, national and international valuation, and strong, durable construction materials that enabled survival in its environment.

Furthermore, Yazd is an excellent example of traditional human settlements that represent man made and natural interactions in desert context. Accomplished by using local resources as earthen construction materials and by the clever Qanat system. Additionally, to create a pleasant living environment, minimal amounts of materials are used which could inspire architects to meet today's sustainability challenges. Another aspect characterizing the city is that three different religions coexist together. Zoroastrianism (Figure 7), Judaism, and Islam. The architecture of the city reflects this peaceful coexistence. It incorporates a variety of structures such as houses of worship, mausoleums, residences, that represent the various religions (UNESCO World Heritage Centre, 2017).

To conclude, this vernacular architecture, which is strongly related to the historical context of Yazd, is a representation of adaptation of humans to environmental circumstances and social needs. Studying this vernacular architecture therefore can be considered valuable to understand the ideas of these generations. Understanding, and expanding abilities of these vernacular environmental systems to meet today's needs are crucial for development of sustainable architecture. As mentioned by Foruzanmehr "vernacular design is considered as a treasure house of human experience, of successes and failures, of ways in which built environments have interacted with ecological settings and cultures" (p.17). Thus, historic environments are fundamental aspects of what contemporary architecture must be today and in the future.

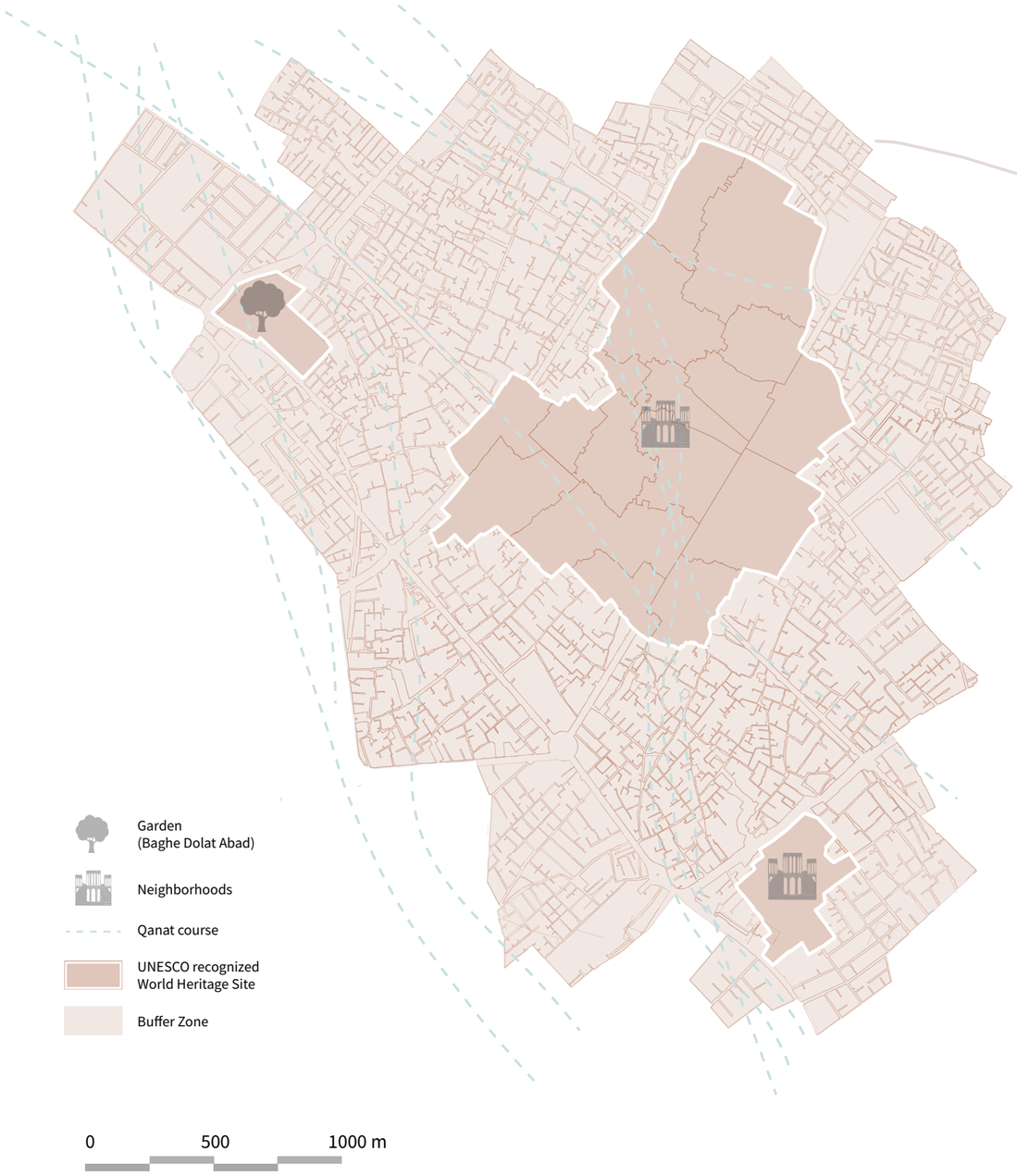

Figure 11. Highlighted parts of the city nominated as UNESCO heritage site in 2017, surrounded by a Buffer Zone, illustrated by author (UNESCO, 2017).

Figure 12. Overview of the low-rise buildings and the windcatcher towers (Badgirs) (Almasi, 2019).

To determine whether we can learn from the traditional courtyard houses in terms of passive indoor climate solutions, this chapter investigates the architectural elements of the traditional courtyard houses that has significant impact on the indoor climate and thermal comfort. The different elements are interrelated to each other and therefore explained to understand the total passive climate system. The reason for establishment of this architecture is investigated by its socio-environmental impact.

The city's vernacular architecture exists of, besides the religious buildings, 5 different building typologies shown in Figure 13. The different typologies are connected by its context by the Qanats, which provides water and contributes to the cooling effect of the city (Figure 13).

2.1 Architectural Features of Traditional Courtyard Houses

The main objective in building this typology was to create comfortable living environments by climate responsive design. So, dwellings are built this way because of society's exigences. However, comfortable living environments are also created by social aspects as family and socio-cultural behavior of residents. For instance, private live has always been an essential aspect in Persian households, caused by religion and culture. This aspect had significantly influenced the way this architecture is used and developed, as divisions are visible within the indoor spaces. Also, the use of indoor spaces is divided into two spaces. First is to welcome guests, and is located near the entrances, thus easily accessible, later the host invites guests to spaces with most comfortable indoor climate since they are located adjacent the courtyard. Secondly, there are more private indoor space for family purpose only.

The important architectural features regarding the indoor climate of the traditional courtyard house, can be divided into man-made and natural elements. A man-made element is the windcatcher tower (Badgir). Another man-made feature is the 'summer room' (Talar), and the last important aspect is the Courtyard (Bagh) itself. The natural elements that play an important role are the earthen clay materialization, shadow or sun, and the nature within the courtyard (Figure 14&17). This residential architecture's thermal comfort is ensured by three methods: by usage of shadow, wind, and water and by decreasing solar radiation influence (Golkar, 2001, p. 80).

2.2 Aspect of Windcatcher Towers (Badgirs)

Within the cityscape the windcatcher tower is a very prominent feature and is a component of the courtyard house (but also other typologies[2]) that plays significant part in the quality of indoor climate. Every domestic building exists at least of one windcatcher tower. Even though, several types and shapes of windcatcher towers are observable in the city, they are categorized by three main types. I.e., the one-sided, two-sided, and four-sided tower. In the first one, the windcatcher and the chimney are divided and situated on different places within the building to contribute to an improved air circulation and to be least vulnerable for storms. The two-sided and four-sided types are generally higher and here the windcatcher and the chimney are combined in one tower. The difference in tower type in the domestic buildings is result of the difference in wealth of the initial owners (Fakouri, 2021).

2. For example a water reservoir exists of four to six windcatcher towers (Fakouri, 2021)

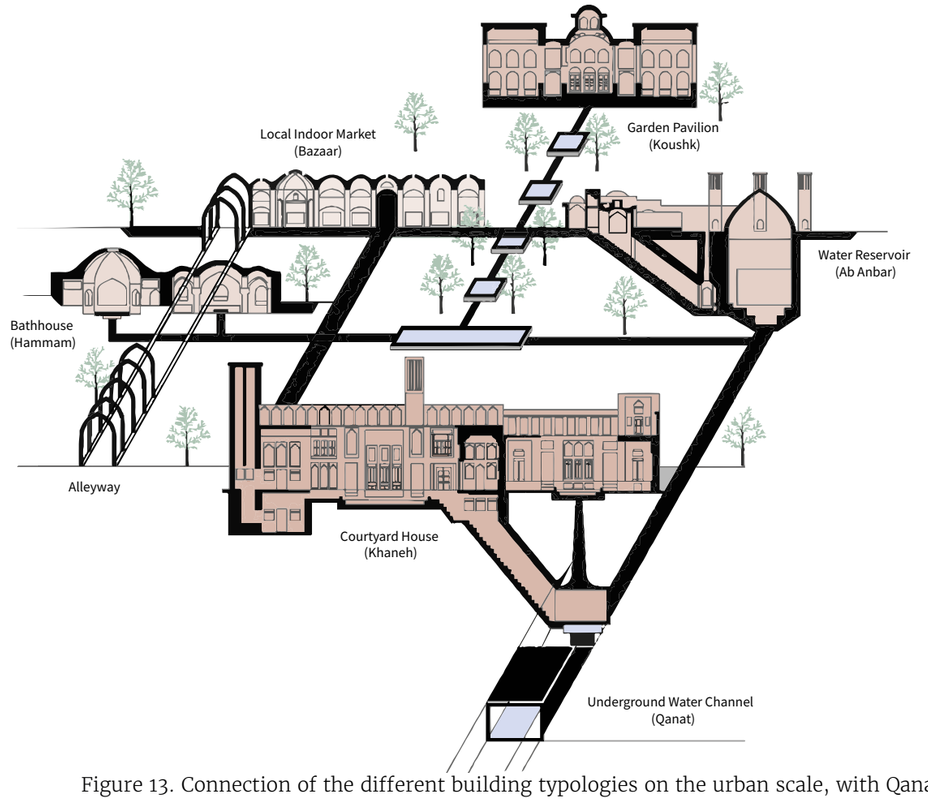

Figure 13. Connection of the different building typologies on the urban scale, with Qanat system, illustrated by author (Fakouri, 2021).

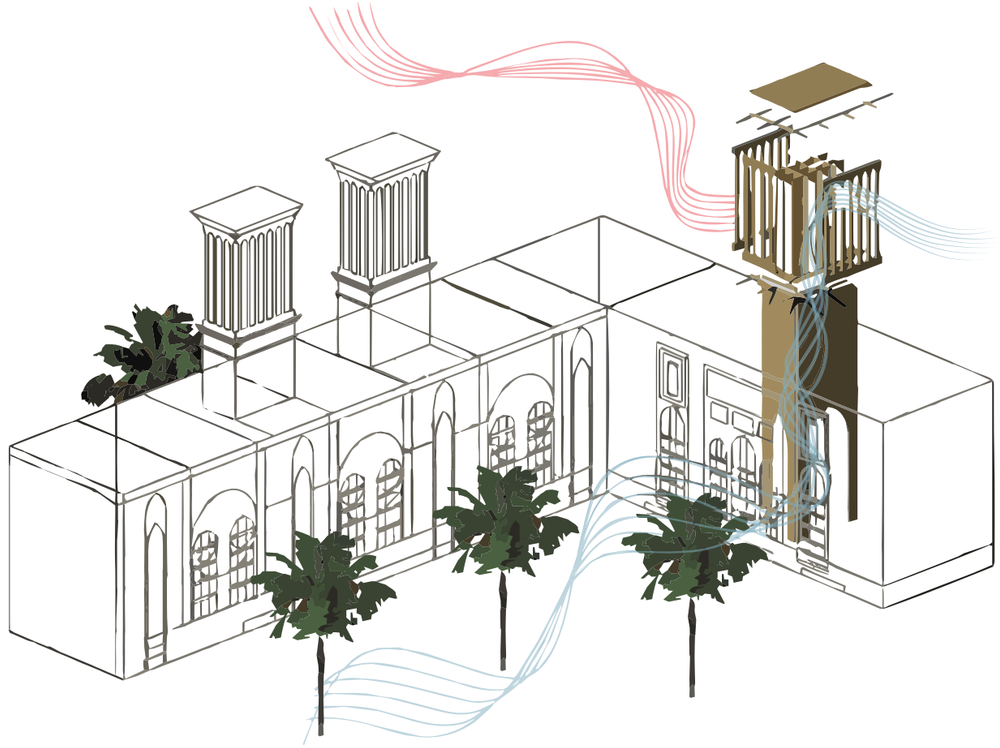

Figure 14. Explanation of the wind catchers in combination with courtyard in a traditional courtyard house, illustrated by author (Fakouri, 2021).

The different type of windcatcher towers generally consists of several elements that enables an improved functioning in transferring fresh air and lowering the temperature of the air flow through the building. Several elements provide reduction of temperature of the air flow (Figure 16). In general, the windcatcher tower functions as following; the head *catches* the wind and brings fresh air into the tower, after that the main structure performs the cooling function and lastly, the bottom structure provides transportation of the cooler air through the interior of the building (Fakouri, 2021).

According to the research of Hosseini et al., the functioning of the towers is as following; while wind moves around the windcatcher, it generates strong positive air pressure on the windward side[3] and fresh air will enter via the windcatcher. This fresh air goes down the windcatcher since the air is cooler and lighter. Within the tower, different clay divisions generate small shafts which creates surface contact. When the air is in this shaded inside area, touching the material, the clay absorbs the heat, and the temperature of the airflow decreases (Figure 15). This flow generates then a negative air pressure (suction) within the top of the windcatcher that transfers more air into the tower. On the other side of the tower, which is the leeward side[3] a negative air pressure (suction) will be generated, and hot air will go out of the building via the tower which produces air circulation. Continual movement of the airflow generates the cooling and ventilation system of these buildings (Hosseini et al., 2020) (Fakouri, 2021).

The windcatcher towers, show a passive system for ventilation and cooling. When considering application of windcatchers in educational buildings the primary wind direction of the context plays an important role in efficiency. For application in designs the location of windcatchers and the rooms adjacent to the tower must be well considered, also other features, like greenery must be present since they are linked.

2.3 Aspect of Water and Greenery

The performance of windcatchers in enhancing indoor climate got improved by the adjoining courtyard that is connected to the tower. Humidity and dryness of the region's climate negative effect got countered by the courtyards that consist of greenery and water. These features implement moisture to the fresh air that is entering the courtyard through the windcatcher towers and lowers the temperature of the air. Airflow that moves over the water ponds allows the water to vaporize resulting in decreasing the temperature and dryness of the air that enters interior spaces. When the airflow moves through trees' leaves, they absorb its heat, the wind speed will be reduced, and moreover the surrounding's dust will be decreased resulting in healthier and livable environments. Additionally, the courtyard consists of shadow because of trees, shrubs, and flowers. This feature of shade has also significant impact on lowering the temperature of the air and indoor spaces and reducing solar radiation (Basir et al., 2017; Soflaei et al., 2016). Lastly, the colors of nature and experience of greenery adds value to quality of these living spaces.

The central courtyard finds its origin in ideological, social, and cultural components. According to Soflaei et al. (2017) there is a difference in number of courtyards based on owners' wealth. Wealthy families owned three courtyards, varied from external (semi-public) for guest and strangers and internal (private) courtyards where woman could walk uncovered. Islamic cultural influence is noticeable in the courtyard being a symbol of Paradise and the fact there were various entryways to divide courtyards, providing privacy since there was no direct view on private courtyards.

Looking at water and greenery, for educational buildings, it could be a good addition to the passive cooling effect in summer times to create a comfortable and healthier indoor climate for students. The impact of this aspect on students results and well-being will be explained in chapter 4. Moreover, to have properly functioning windcatchers for indoor climate comfort, this feature of greenery and water cannot be missing.

3. Windward side: the side that has the opening against the wind direction
Leeward side: the side that has the opening in the same direction as the wind direction
(https://en.wikipedia.org/wiki/Windward_and_leeward#References)

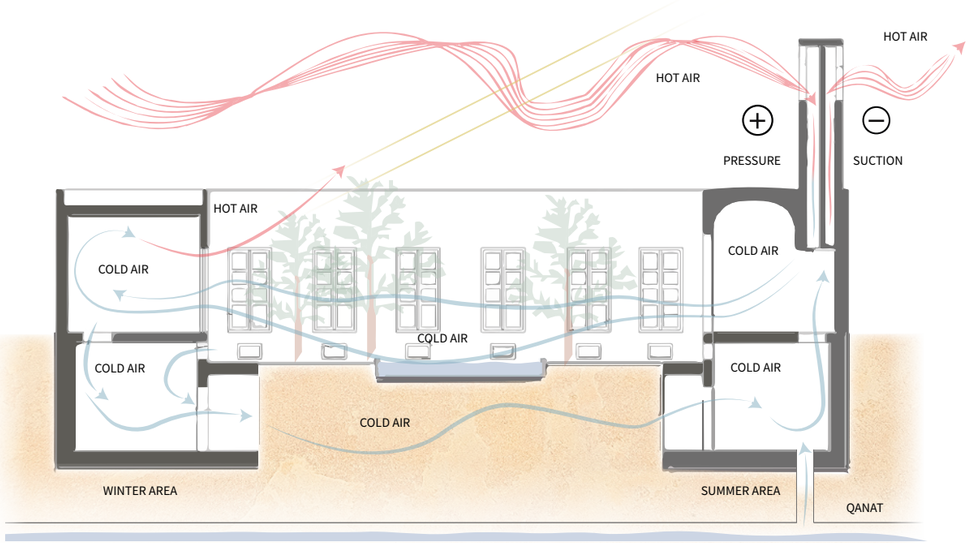

Figure 15. Functioning of windcatcher in relation to courtyard and indoor climate, illustrated by author (Hosseini et al., 2020)

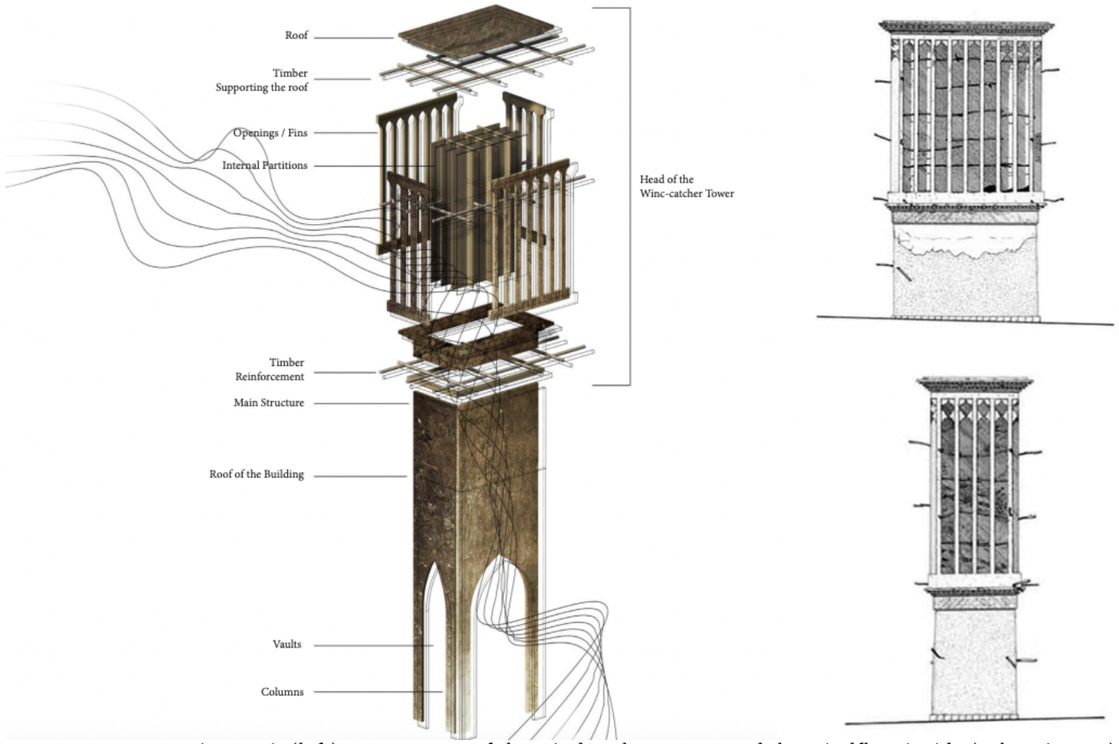

Figure 16. (left) Components of the windcatcher Tower and the windflow inside (Fakouri, 2021)
(right) Windcatcher elevations (ICHHTO-archive, n.d.)

2.4 Aspect of Orientation and Time

Another relevant element of this architectural typology is the aspect of time and orientation. The architecture contains areas with seasonal usage (Fakouri, 2021). To profit passively from the climatic situation, courtyards are orientated in the middle and are designed in a way they are narrow enough to block the sun and create shadow in summer periods but still deep enough to admit warmth and light from solar radiation in wintertime (Bonine, 1980, Givoni, 1976, Dunham, 1961). According to the research of Soflaei et al. (2016) several earlier research show that the influence of natural factors as solar radiation and wind, on indoor thermal comfort, are strongly related to orientation (Almhafdy et al., 2013; Meir et al., 1995; Meir, 2000; Reynolds, 2002; Soflaei et al., 2016).

Summer vs. Winter

According to Keshtkaran's (2011) research, traditional courtyard houses are separated into summer, and winter areas. The buildings in historic Yazd are mostly east-west orientated to benefit from maximum shadow coverage and the houses' main part is north-east orientated. This part enjoys most shadow during the year and functions as summer area. Opposite, beyond the courtyard is the winter area, which benefits from the heat and light received from solar radiation in wintertime. Some houses consist of four areas. Two spaces are added next to the central courtyard facing south-east and north-west. (Keshtkaran, 2011). As a subsequence of this orientation, the direction is convenient regarding Qibla, the praying direction for Muslims. The Zoroastrian courtyard houses are also orientated based on the sun, i.e. the four cardinal directions, to benefit from most exposure of sun during prayer towards the sun (Karimian et al., 2020). The houses' centric shape, closed of high walls and courtyard orientation created very private domestic spaces as a subsequence of climate solutions and forced the residents to live conservatively, therefore these houses are today more attractive to religious people.

Due to the orientation based on the sun and temporary use of spaces, people's life was determined by moving through the house based on the season during the year. This aspect of multifunctional use of space, and temporal function of rooms could be a solution for thermal comfort issues in educational buildings since some functions are not dependent on a specific interior space. This requires however flexibility in floorplan, but also in adaptability of users, to change their work or study environment during the year. Considering educational buildings, it exists of large spaces such as halls and lecture rooms, which are beneficial when it must change its function, since it can be considered having more flexible floorplans, compared to residential buildings, where floorplans are more fixed.

2.5 Aspect of Earthen Materialization

The architecture consists of one earthen building material, namely adobe (mud brick). The traditional houses and their components as windcatcher towers, interior walls, facades, floors, and ceilings are made of adobe. The thick facades were constructed without openings for privacy from the sidewalks and to create shadow (Fakouri, 2021; Memarian 1999; Moradi 2005; Yazdanpanah & Walker, 2010). This natural material is locally available, in-expensive, sustainable, and when implemented in thick walls reduces temperature fluctuation. Besides, this mud material has a strong ability to protect against solar radiations because of its light color. Furthermore, it exists of a high thermal capacity, that allows slowing down the process of warmth transferring through the walls and roofs into interior spaces by eight hours. Because of this material characteristic, the heat collected in the walls and roofs during the day warms the house at night when the outside temperature drops (Meamarian 1999; Moradi 2005) (Keshtkaran, 2011). This feature impacted people's lives since the roofs were used at nights because of the pleasant temperature due to warmth absorption.

In terms of religious impact regarding materialization, in the courtyard houses of Zoroastrians adobe floors have been covered with stone to prevent the underground water from filth. They believed materials as adobe are transmitters of dirt and pollution to subterranean water. Due to governmental and socio-cultural restrictions enforced on Zoroastrians, their houses were only one-story high. This impacted lives of residents and thermal comfort of their living environment since this resulted in lower quality of ventilation and less light. In response, the residents invented clever adaptations, as adding extra courtyards and openings toward them (Soflaei et al., 2017).

To conclude whether this can be an example for educational buildings, characteristics, the origin, and implementation of the used material in this typology must be considered. The use of natural building material adobe of the context makes this feature sustainable. For current designs and existing educational buildings due to their large volumes, a lot of insulation materials is required to provide indoor climate quality. Regarding preservation, less materials should be consumed and instead regional materials that are broadly available could be applied in thick walls to benefit favorable material properties in terms of thermal comfort. The aspect of shadow created by high walls can be relevant for educational buildings to create comfortable indoor and outdoor spaces.

Figure 17. Four important natural and man-made elements that play a role in thermal comfort of the courtyard house, illustrated by author (van Dijk, 2016)

This chapter investigates the case study of the Faculty of Architecture in Yazd, which is situated in traditional courtyard houses of the Rasoulian block. By analyzing this adaptive reuse project, the aforementioned architectural components will be investigated in current educational use of the courtyard houses. The Architecture Faculty will be described, and the aspect of the revived earthen vernacular elements will be investigated to see if they are relevant today.

3.1 Historical background of the Rasoulian Complex

The Rasoulian complex which houses the faculty of Art and Architecture, is in Sahl-ibn-e-Ali in Yazd, which is in one of the oldest neighborhoods in the historic city. One of the reasons for relocating to this complex is the aspiration of the Art and Architecture faculty to revive and preserve the historic and valuable context and urban fabric (Kazemi & Akbarian, 2014). The Rasoulian complex is part of a larger campus, located outside the historic city. The complex is part of two main zones, zone A and B (Figure 21). The block consists of one main house and 11 smaller houses. The most prominent building is the centrally located and former building, Rasoulian house. The latter belongs to Yazd University since 1989 (Figure 22) (Basir et al., 2017; Haji Ghasemi, 2004). This chapter investigates this courtyard house.

The houses located in the Rasoulian block are built more than 150 years ago. The Rasoulian house was built by Mohammad Rahim for Haj Abdorrasoul Rasoulian (Amini & Rafiei, n.d.). After the establishment of the school of Art and Architecture in 1989, facilitated by endowments, and official opening in January 2000, other houses were endowed as an extension. The fact that the faculty is in the historic city, is in interest of the students, the school, and the neighborhood. Relating to education the school benefits from the context and historical fabric of this ancient town as a foundation for its educational study program. The location is a base for learning, research, and training program of the university. Moreover, since the school of Art and Architecture is located at the historic fabric of the city, the school has contributed to retainment of the city's vernacular earthen architecture, by teaching their vision about the importance of preserving heritage buildings (Ayatollahi et al., 2018) (Figure 18-20).


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Figure 18. Meeting between proffesors of the faculty and an important traditional architect at Rasoulian House in 1989 (Mohamadi, 2019).

Figure 19. Teachers room Pirnia house around 1990, the man sitting and talking in the chair is important architect and professor Pirnia (Mohamadi, 2019).

Figure 20. Courtyard of Rasoulian house with outdoor summer room (Talar) functions as a stage for performance and the audience is in courtyard's open space (Mohamadi, 2019).

Figure 21. Overview of the Sahl Ibn Ali neighborhood and different zones of the faculty of Art and Architecture (General Directorate of Cultural Heritage of Yazd Province, 2007).

Figure 22. Overview of zone A (Rasoulian Block) with names of houses and date of first use, illustrated by author (Yazd World Heritage Research Center, 1957; Kazemi & Akbarian, 2014).

3.2 The Functions of the Traditional Courtyard Houses

The buildings that form part of the faculty of Architecture houses various functions (Figure 23). For example, the Rasoulian house, exists primarily of offices, classrooms, and study spaces (Figure 25-30). The Shekari, former hunting house, e.g., exists of the workshop, and the canteen and kitchen are in the Rasoulian and Sima Rasoulian house. The library of the faculty is in the Elieien house. Based on the map which shows the usage of the Rasoulian house (Figure 24) can be concluded that the courtyards and the winter room (glass façade is facing south-west) which are classrooms are mostly used by students for instance to meet and get together for events. The next paragraphs will elaborate the location of these functions and the relation with the indoor climate features.

3.3 Impact of Architectural Features on Rasoulian House

Windcatcher Tower (Badgir)

To conclude whether the aspect of the windcatcher is adaptable for educational buildings, this feature will be investigated in relation to the adjacent porch and windcatcher room of the case study. The Rasoulian House consists of one windcatcher tower. As shown in Figure 32 the tower is not very high and connected to the closed of room underneath (windcatcher room) and the cellar space that is connected to the Qanat system. The windcatcher room is south-west orientated and initially the summer of the building. As a result of the change in function, this room is now designated as the faculty's Dean's office (Kazemi & Akbarian, 2014) (Ayatollahi et al., 2018).

Unfortunately, this architectural feature does not perform as a climatic system anymore and lost its role in the building. According to the research of Khajehrezaei et al. (2018) which analysis possibilities for the current usage of the wind catcher towers, the traditional functioning of the windcatcher will nowadays not meet demands for cooling and required thermal comfort. They suggest usage of the windcatcher tower for another purpose, which is suction of the cool air from the cellar to flow through the indoor spaces. This way the windcatcher can be revived in an efficient way (Khajehrezaei et al., 2018). Another research project by Ayatollahi et al. (2018) investigated the adaptive reuse of Rasoulian house's windcatcher tower. To totally exclude nonrenewable energy use, this project uses the windcatcher tower as a natural ventilation system. To realize this the humidity of the water in the cellar and the low air temperature in this cellar can be used to cool the indoor air quality, when the air will be sucked out of the cellar due to the windcatcher suction force (Ayatollahi et al., 2018).

Orientation and Light & Materialization and Vegetation

The building is built accordance the orientation of the city, north-east and south-west orientated, to benefit from as well summer as winter situation. However, considering the fact that the building is now used for educational purpose, the building is used by students during the whole year. Thus, the use of mechanical ventilation and cooling systems depending on energy sources are therefore necessarily needed. However, according to Kazemi and Akbarian (2014) the usage of nonrenewable energy can be reduced when the potential of the connection between the traditional and natural features of the building will be reconsidered. This contains the aspects of orientation, time, light, greenery, water, wind, and adobe.

To conclude, the fact that the building is usable for current function and climate is because of the earthen walls (in combination with the linked features) creating cool indoor spaces. Since summer area and indoor spaces allocated to the windcatcher houses educational functions, the importance of the relation between location and function of the tower is proved. The courtyard being important for gathering can be seen as evidence that greenery, water, light, but also the high walls create comfortable places to stay (Figure 31-37). Even though the windcatcher towers are not in use, it can be revived with improvements. The remaining features can be considered important for the indoor climate. When implementing the features, the location of the passive systems is of great importance in relation to the adjacent function, since e.g., classrooms and offices differ in requirements due to user numbers. Important, most used functions should be located nearest to the features. Besides, we can learn from reusing traditional cultural heritage as educational buildings to be able to see and research knowledge of the past, through the eyes of future designers that can change and improve the building industry.

Functions

Figure 23. Functions of the different houses within the Faculty of Art and Architecture, illustrated by author (Mohamadi, 2019).

Usage

Figure 24. Map shows usages through circulation and places of interaction and gatherings in the building of the Rasoulian House (Mohamadi, 2019).


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Figure 25-30. Exterior and interior images of the faculty of Arts and Architecture, the Rasoulian house (Bozorgi et al., 2000)


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Figure 31-37. Exterior images of the courtyard of the Rasoulian house, the educational function is visible by students and the lockers in the Talar (Bozorgi et al., 2000).

To find out whether we can learn from the architectural features for educational designs, the question, *why* we should learn from these features to improve the indoor climate should be answered. Therefore, the relevance of good indoor climates will be investigated for educational buildings. Furthermore, a comparative investigation will be provided to examine the current state of the faculty in Delft and the faculty in Yazd. This shows whether there are needs for improvement in terms of indoor climate of these educational buildings.

4.1 Importance of Indoor Climate Quality in Educational Buildings

The indoor climate, and therefore thermal comfort plays a very important role in the well-being of users and their experience of a building. According to the research of Zomorodian et al. (2016), in current societies, population spend almost all their time, namely 90 percent indoors. In addition, in these societies, students spend most times at school after their houses. This stresses the importance of comfortable and healthy indoor thermal environments in educational buildings. Besides, indoor thermal comfort has been found strongly correlating to student's productivity but also physical health. According to the article of Bluyssen (2013), which highlights the importance of a healthy indoor climate, a low-quality indoor environment could be cause of a wide range of diseases and disabilities. For example, aspects such as heating, cooling but also artificial light created health and comfort problems. Recently, a relation between bad indoor environmental conditions and obesity has been found (Bluyssen, 2013).

A factor that contributes to quality of indoor climate and user's comfort which is one of the features of Yazd, is the aspect of nature. According to the research of van den Bogerd et al. (2020), educational organizations like universities have been implementing more greenery into interior and surroundings of their buildings, considering the advantages for students and employees. Research in the past have shown evidence for health benefits due to being in natural environments or looking at nature. These aspects would be linked to improving general health, well-being including mental health and emotions (van den Bogerd et al., 2020).

Today's most important assignment for architects and engineers is to realize buildings that use less to no unrenewable energy and have comfortable and healthy indoor environments. Since educational buildings make up large part of country's building stocks, these buildings are accountable for large part of energy usage of total energy consumption. Besides, most part of the energy consumption worldwide is used for heating and cooling according to research of Soflaei et al. (2017). This will increase due to more extreme weather which required more heating or cooling capacity around the world. Therefore, reduction in energy usage by cooling and heating and energy efficiency in these buildings is essential to realize total energy reduction of countries (Zomorodian et al., 2016). Thus, educational buildings should use renewable energy sources as wind and sun and should be heated or cooled in locations and periods they are really used during the day. The use of passive cooling and heating systems for thermal comfort could help achieve this (Kurvers & Leijten, 2021).

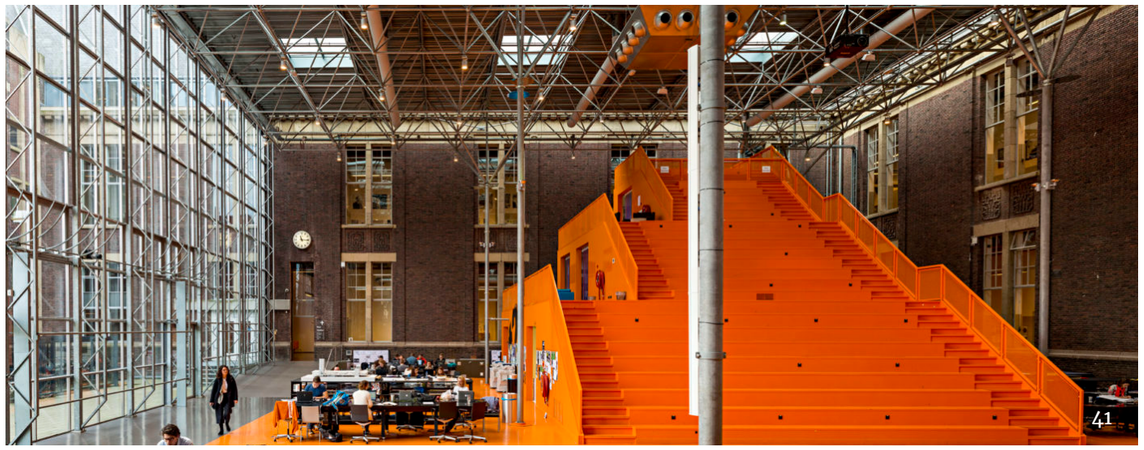

Figure 38. Old picture of former chemistry building, TU Delft (Braaksma & Roos Architecten, 2017).
Figure 39. Burnt down former faculty of Architecture, TU delft (Braaksma & Roos Architecten, 2017).
Figure 40-41. The Model and Orange Hall in faculty in Delft (Braaksma & Roos Architecten, 2017).
Figure 42. Faculty of Architecture and the Built Environment TU Delft (T' Hart, n.d.).

4.2 Comparison Faculty of Architecture and the Built Environment Delft

Looking at the university building in Delft (Figure 38-42), another adaptive reuse project is visible. This building, built between 1918-1923, at the edge of TU Delft campus, was the former chemistry faculty of the university. After the former Architecture and the built Environment faculty burnt down in 2008, this building was designated to be transformed to BK-city. After the renovation, the unrenewable energy consumption for heating is decreased by 50% due to preservation measures. The current Architecture faculty is one of the University's oldest buildings that is still used for educational purpose. Like the faculty in Yazd, this building is proof for students and society that sustainable renovation is also achievable for heritage buildings (Arkesteijn, et al.,2021).

While walking through the building, students experience the monumental building with exceptional storey-heights. Due to short timeframe and characteristics of the building, ceilings were not finished, resulting in high open indoor spaces, where ventilation ducts and pipes are visible, which emphasizes the buildings' adaptive re-use characteristic. In addition, by actively experiencing the climate installations, students are more aware and could explore this relevant component, for buildings. These high spaces create favorable impact on the summer situation of the building, since hot air moves upwards because it is lighter than cooler air, hot air will flow above human height level and improve thermal comfort. Interesting adjustments to the historical building are the Orange Hall and Model Hall additions located in between building parts that compose covered indoor courts by glass (figure 40&41). In winters, the storey-high windows and glass extensions allow sunlight entering the building and contribute to passive heating.

However, during winter and summer the building and its glass additions are experienced as too hot or too cold. In short, the building has a lot of historical values, like the faculty in Yazd, as Architecture faculty but it is lacking in its indoor climate quality. Thus, it requires improvements and sustainable solutions to meet the current comfort needs and the needs of the future due to climate change.

4.3 Current Climatic Issues in Faculty of Art and Architecture in Yazd

When looking at the faculty in the historic city of Yazd in current situation, an adjustment regarding improvement of indoor climate quality is visible. The faculty's professor Hossein Ghaem Maghami in cooperation with two students has realized the project of a movable roof above the faculty's library courtyard. It shows the traditional building function as an educational building needs an improvement for its indoor environment, since the roof on hot days will provide shadow and a cooler indoor space to the buildings bordering the courtyard. This courtyard is smaller comparing to the main courtyards and doesn't have vegetation or water inside. This demonstrates that traditional Yazdi temporary textile roof solution called 'Poosh' can be transformed into a modern solution, which is part of cultural heritage, and fits in its context, by using wood (Figure 43-45). When looking for passive thermal comfort solutions whether in Yazd or Delft context should be taken into consideration.

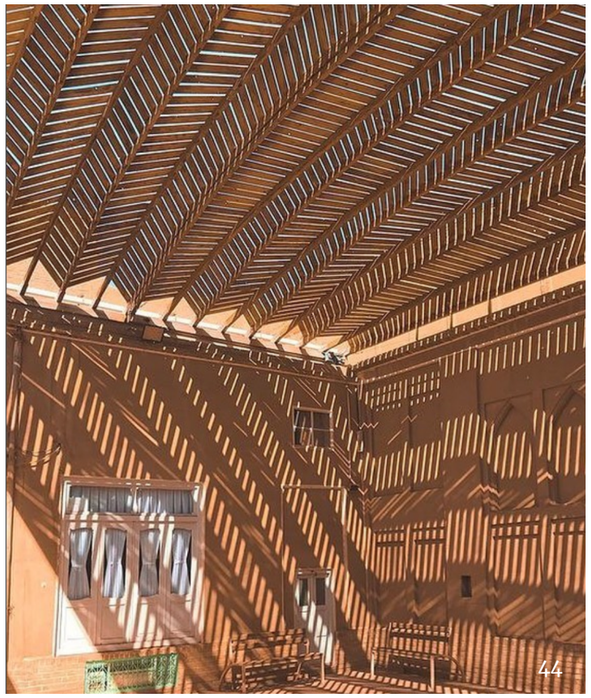

Figure 43-45. Wooden movable roof solution for better thermal comfort in the courtyard of the Elieien House, the faculty's library building (Ghaem Maghami, 2019).


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Figure 46 & 48. Jalal-abad Villa in Iran has windcatcher with water tank (Nasrabadi, 2018)
Figure 47. Windcatcher project in the American Midwest (Specht Architects, 2013)
Figure 49. Windcacther tower made of recycled cardboard designed by MAS (Ghinitoiu, 2019)
Figure 50. Regent College Library, Glass windcatcher tower, Vancouver (Hall, 2007)
Figure 51-52. Windcatchers in contemporary design of Qatar University (Qatar University, n.d.)

Discussion

This research examined the benefits and the functioning of the architectural elements, but to find out the potential of the architectural features for educational buildings several aspects need to be considered. The potential of windcatcher tower e.g., for contemporary applications is according to Fakouri (2021) determined by several aspects mentioned in Figure 53. The application of a windcatcher tower could possibly come with challenges. Besides, as mentioned in previous chapter the traditional feature needs improvements for current use. In addition, natural ventilation is inexpensive and sustainable when using sustainable materials available in the area. However, therefore the feature is reliant on contextual conditions as wind, wind velocity and temperature, thus the efficiency is dependent on its location. Besides, contemporary designs show that this feature can be adapted to modern and sustainable designs, however, the new versions also show that today smart or automatic elements are added, such as ‘‘sensor-controlled panels or solar-powered fans’’ (Stouhi, 2021) (Figure 46-52). These additions however are ‘semi-passive’ systems for cooling which is less favorable. Also, the aspect of materialization as one of this research main aspects could be reconsidered, as contemporary designs must adapt to their context, the natural elements of clay, brick or wood are replaced by stone, glass, steel, concrete.

The features of water and greenery, orientation and materialization are less arguable in terms of whether we can learn from Yazd’s historical use for educational buildings. These features are visible or considered in most of sustainable educational designs. However, the case study of Yazd shows that the system of greenery and water is connected to a larger eco-system and water channels which is strongly connected to its historical context and ancient knowledge, and usage of clay is linked to the context of the desert. To learn from the past for sustainability, the influence of both socio-cultural and environmental context is important, especially for sustainable indoor climates since these are subject to its environment. Instead of prevention of affecting the context by building new buildings or reusing heritage, we should also look at its historical context.

The city of Yazd shows durability of this architectural typology by its current livability despite of change in climate, lifestyle, society, and function. However, the mentioned social impact that influenced daily lives of the residents are more important when learning lessons for dwellings then educational buildings. The findings of this research are limited due to its limited extent. Therefore, it is restricted by only focusing on selected features and is the broad definition of indoor climate narrowed down. Further research could focus on different typologies or extending this research by continue focusing on improving other aspects of educational buildings then thermal comfort. In addition, the selection of data for this research was limited by the accessibility of Iranian sources online and via contact with researchers from Yazd University.

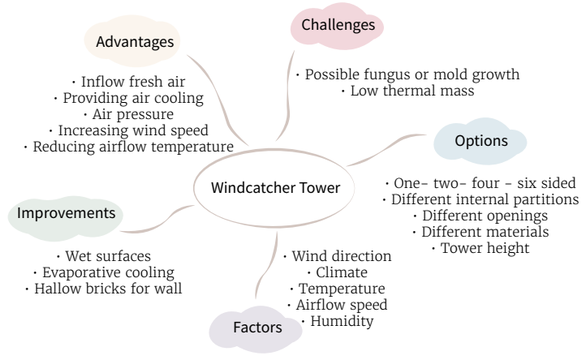

Figure 53. Factors that can be considered for possibility of application of windcatcher tower, illustrated by author (Fakouri, 2021).

Conclusion

Historic Yazd's architectural heritage demonstrates the persistence of ancient passive solutions related to climatic issues. The traditional architecture reflects the influence of historical, socio-cultural context of the city in correlation with climate responsive design. It proves that to build sustainable architecture besides environmental, as well social sustainability should be taken into consideration. By learning and implementing these passive and climate responsive solutions for indoor thermal comfort with respect to its context and by replacing current mechanic systems for heating, cooling, and ventilation, relying on unrenewable sources, energy consumption and carbon footprint can be decreased. These solutions could be very beneficial for educational buildings, since these buildings are responsible for a large amount of energy consumption. However, when implementing the features in educational buildings, the location of the passive systems is of great importance in relation to the adjacent function.

By analyzing the adaptive reuse project of the faculty in Yazd, this research has shown that use of this typology including its architectural features can be an example regarding indoor climate systems to provide thermal comfort for educational purpose. The faculty in Yazd proves the importance of the courtyard houses and the revival of these buildings by teaching and using this vernacular architecture. It shows the ability for current reuse. However, in terms of ventilation, the architectural feature of the windcatcher tower will not answer the demands for current indoor climate since it is not used for providing thermal comfort now. It can be concluded that when adapting the feature of the windcatcher improvements due to contextual conditions, new technologies and requirements need to be considered. In addition, the roof designed by Ghaem Maghami shows traditional temporary solutions are still inspiration for improvements in the faculty.

The aspect of orientation and temporary use of spaces based on the season can be very useful for educational buildings, since they mainly exist of larger open plans which allows change in functions during the year. However, this requires flexibility and adaptability by its users. Furthermore, this vernacular architecture proves that by creating a comfortable indoor climate for healthy study and work environments it is important to add greenery and water to enhance the indoor climate quality. In addition, being in natural environments or looking at nature has been linked to improving student's well-being and thus is beneficial for these buildings. With regards to materialization, we can learn from the application of thick earthen walls, in terms of using local materials and reducing the number of materials used today for insulations, by using the capacity of materials in exterior walls.

Despite the architecture's quality in providing thermal comfort for indoor and courtyard spaces, through several intelligent architectural elements examined in this research, the architectural features should not directly be copied in designs, since the research has proven that it needs connection with its context. While considering application in educational buildings, historical and socio-cultural background, habits, and customs should be studied. In addition, some features possibly could cause challenges due contextual factors, as climate or material properties. More research should be conducted on the adaptability of the features in specific context to find out whether these qualities can be useful for these educational buildings. The comparison between current states in Delft and Yazd proves that Delft lacks in providing pleasant educational environments and needs additional passive solutions.

Overall, based on the evidence found in this thesis, it is definite that this architecture and its knowledge has been of great importance for livability and will persist to be of great usefulness in times we seek for passive indoor climate solutions because climate will become more similarly to Yazd. To conclude, an innovative, adaptive, climate responsive, context and local material inspired solution should be implemented for qualitative educational indoor environments.

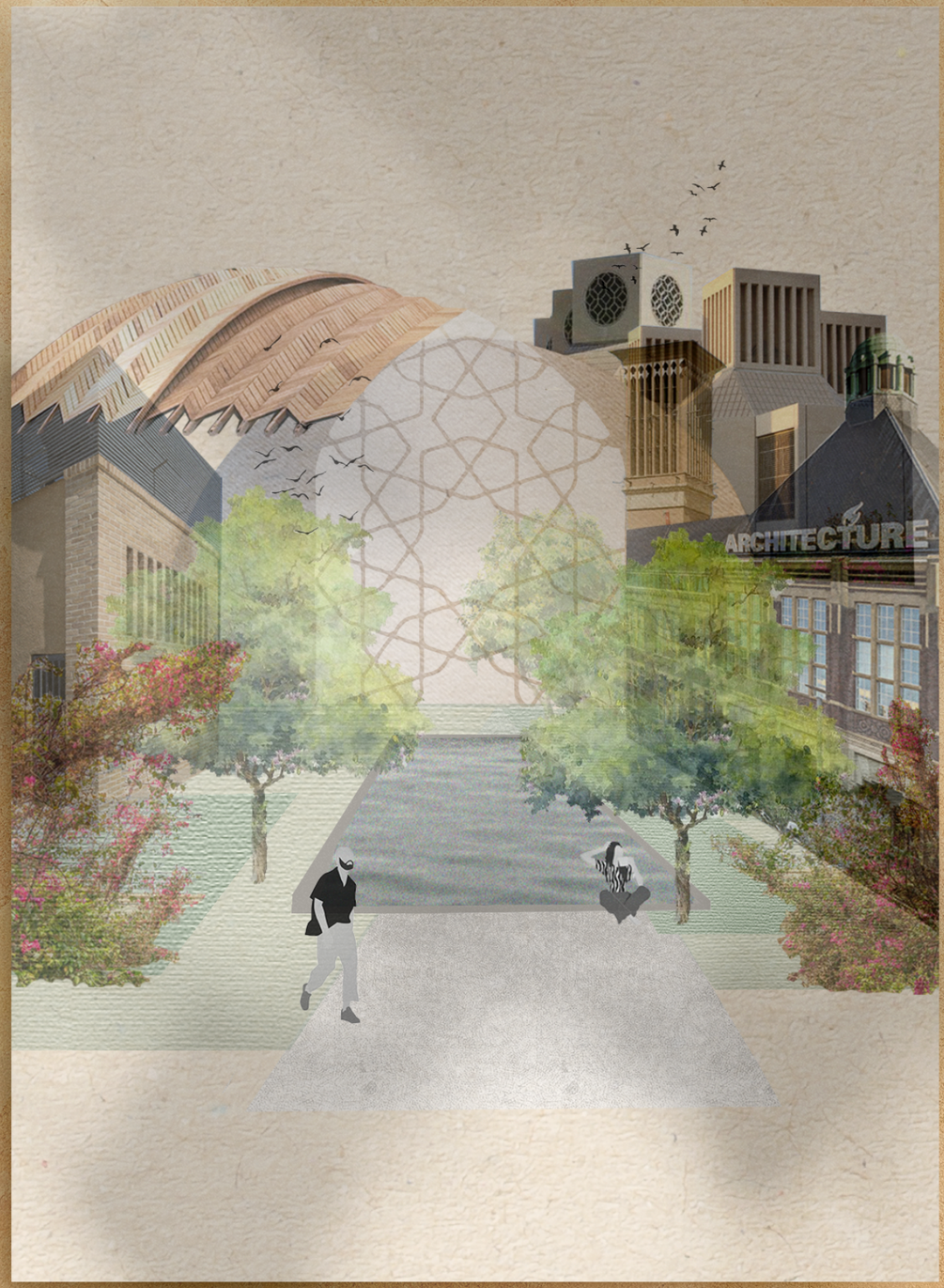

Figure 54. Architectural features in contemporary context, Yazd meets contemporary times, collage made by author (Abbassi, 2022)

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Biography

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