HOW TO APPLY VERNACULAR ARCHITECTURE PRINCIPLES INTO SHELTERS IN SEMI-ARID CLIMATE AREAS

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ABSTRACT
The purpose of this research is to find a solution for shelters in high-risk earthquake areas in the worldwide. A representative region has chosen as semi-arid climate area where have highly recorded earthquake history, and more extreme climate characters. Thus, to study the vernacular buildings in this climate zone can be helpful to understand the local material limitation, environmental influence, and the empirical building strategies. In this case, residential buildings in Kashgar, Yazd, Harran, cave dwellings of Northern China, and Middle Spain had been chosen. The principles of these vernacular buildings will be derived and especially in the aspect of thermal performance, ventilation, and heating. In the end of the paper, the principles of semi-arid buildings will be summarized and compared and give some design guidelines for shelters.

KEYWORDS: Vernacular Building, Semi-arid Climate, Principles, Shelter.

I. INTRODUCTION

The earthquake caused serious damage to human constructions and impacts human daily life, in a certain period after a severe earthquake, people need shelters to be settled and wait for the recovery of their homeland. In general, right after the disaster, people will be allocated into temporary shelters such as tents or public mass shelter for few weeks, and after that, before the permanent housing been rebuilt or resettled, the refugee will move temporary shelters to temporary housing from half to three years. In the stage of temporary housing, people are supposed to back to their normal life such as cooking, working and educating. (Félix, 2015) Furthermore, some high-quality temporary houses can evolve into permanent houses. (Abulnour, 2014)

The quality of the shelter provided by the government or relevant organizations plays an important role for refugees in the transition period. So far there are plenty of shelter solutions made by companies and architects. However, most of the shelter design provided by professionals and technicians are focused on standardized, mass-produced and pre-fabricated focused on structural safety, production speed, and supplying efficiency, but the issue about local context, climate difference, and cultural variations are always been ignored (Félix, 2015).
In order to provide comfortable shelters, it is important to understand the location and the climate of the post-disaster area and how its environment effect on the shelter. One of the best ways is to study the vernacular architecture. Because the features of these buildings not only reflecting the on-site material resources and local climates, but also they are keeping modified by the empirical experience inhabitants (Crespo et al. 2015). Through the study, the principles of the vernacular buildings can be extracted, and the principles can be guidelines for shelter design for the same area.

II. LOCATION AND METHODOLOGY

2.1. Semi-arid Climate

References study the vernacular building, a specific region should be pointed out. The first step is to mapping the high risk of earthquake places with world climate regions. The method is to overlap the World Recorded Earthquake Map (Figure 1) and the World Köppen-Geiger Climate Classification Map (Figure 2), the most Earthquakes happen in semi-arid climate zones, cold desert climate zones, Mediterranean climate zones and humid subtropical climate zones. The second step is to narrow down the research scope from these four regions by comparing the climate characters in the aspect of temperature and precipitation. As a result, except the annual rainfall in humid subtropical climate zone is much larger than other three climate areas, the Semi-arid climate has the most extreme temperature and rainfall differences. The vernacular building study and the design target thus can be narrowed in semi-arid climate zone.

Semi-arid climate usually at the boundary of the desert, it is a buffer zone from the desert climate to humid climate. Thus it has little precipitation and large temperature fluctuation between day and night as well as summer and winter. Even though the environment is harsh for the human being, indigenous culture nourished and evolved in these areas through history from Asia to Europe. Many vernacular buildings exist till now that reflecting the wisdom of surviving in semi-arid climate by simple building technologies. In this case, five representative places are chosen from Asia and Europe in semi-arid climate zone: Kashgar, Yazd, Harran, Northern Chinese cave dwelling and Tajuña Valley.

Figure 1. Recorded earth world map

Figure 2. World map of Köppen-Geiger Climate Classification
2.2. Method

The main research method on vernacular buildings is based on literature, through the findings, the study from the aspect on geography, climate, city/village context, building scale, form, material, opening, and heating. The principles will be derived from each location. In the end, through the comparison and analysis, principles can be applied or translated into the modern technique which suits temporary houses.

III. VERNACULAR BUILDINGS

3.1. Gaotai Residence, Kashgar, China

Kashgar is the most western city in China. The city located at 39°30’ north latitude (Yu, 1996), an altitude of 1288.7 meters (Liu, 2014). The city is situated between the basin and mountains, it has a significant arid land climate which is at the border of semi-arid climate and cold desert climate zone showed on the Köppen climate classification. Kashgar has long and hot summer at an average temperature of 38.8°C and it has shot but cold winter at an average temperature of -6.7°C, diurnal temperature fluctuation is dramatically high at more than 12°C. The rainfall in Kashgar is rare, the average annual precipitation is merely 121mm. The northwest prevailing wind is relatively high at 35.4 km/h and sometimes with sand in it. (Yu, 1996)

Gaotai is a 2000-years-history residence zone in the southeast of Kashgar. The building in the area is close-knit with narrow and winding streets (Figure 3). The width of the street varies from 2.2 to 3 meters (Liu, 2014). The most of the residence has 1 to 3 floors, and some higher floors are cantilever or cross over the street due to the development generations and limited building space. (Liu, 2014) The shadow created by the narrow streets and the cross-street buildings effectively cooling down the public area in hot summers and also protecting people from strong wind and sandstorm.

Due to the geography limitation, the building materials are mainly extracted near the site: raw earth and sometimes poplar wood. Mass walls are commonly built by the rammed earth, adobe or earth bricks. Plaster can be seen in some of the buildings. The thickness of the wall can be reached to around 1 meter (Liu, 2014). The material and the thickness of the building provide an ideal thermal mass for the indoor environment.

Figure 3. Kashgar City, Xinjiang, China
The roof is flat in Gaotai, it caused by dry and windy climate, and it is easy to add another storey to the roof. Balconies are popular on the top floor, it connecting rooms on top floor and people also growing plants there (Liu, 2014). The balcony provides a place for people to have more outdoor activities in higher place, and the plants can provide shades reducing the solar radiation on buildings. Sometimes the balcony had eaves on top to provide extra shade.

Courtyards are core space for Gaotai residences, they are private space used as family rooms and also as climatic modifiers (Yu, 1996). The sizes of the yards vary from 20m² to 100m². Grape trellis is usually built in front of the rooms, it providing shade in summer times. (Liu, 2014)

The principles of Gaotai residence can be summarized:

1. Weave the building mass close enough to create shading for outdoor activities in hot summer;
2. Use local material – soil - as thermal mass and thermal insulation;
3. Flat roof make building flexible and possible for further adding;
4. Using courtyards to create microclimate for ventilation and buffering the building temperature;
5. Growing plants create more shading and fresh air.

3.2. Yazd, Iran

Yazd city in the centre of Iran, the latitude is at about 31°90’ north. Similar to Kashgar, it is at the border of the semi-arid climate zone and cold desert climate zone. The city is well adapted to the desert surroundings. The features of urban morphology, building orientation, material, courtyard and openings in Yazd are similar to Kashgar. (Mohammadabadi & Ghoreshi, 2011)

Differently, The sidewalks in Yazd are mainly in direction of east-to-west, most of them are narrow and curved, some of the sidewalks are even roofed or with arch constructions called sabat. The shadows provided by sabat make people’s daily outdoor activities less harsh in hot summer. (Keshtkaran, 2011)

The wind catchers are the most significant feature in Yazd, the tower construction are higher than surround buildings to catch the wind. (Figure 4) The wind catchers open to the direction of the favorable winds in hot seasons that it leads cool air into the building while sucking the hot and exhaust air from the other side of the wind tower. An integration of the wind tower and a pond is commonly used technique in Yazd, the pond is in the middle way of the intake, the air flow effectively accelerates the evaporation and bring the cool and moist air into the living area. (Keshtkaran, 2011)

Roof in Yazd are flat and protect by high shelter wall, the high shelter wall provides not only safety and privacy for people, but also shading the roof surface from sunlight. Dome structure is also common in the city applied to mosques, water reservoirs, ice houses, and passages. (Figure 5) The curved surface exposed to direct sunlight in different levels, and the direction of the sun
changes through the day, which makes the dome surface hard to accumulate the heat. (Keshtkaran, 2011). Evidence also indicates that domed roof has better thermal performance in hot windy places better than flat roof (Faghih & Bahadori, 2011);

In Yazd, people move to different areas in according to seasons. The summer area is on the south side of the yard where the rooms are back to the south and have more shade in front of the room in hot summer. The winter rooms are on the opposite of the yard which facing the south to gain more sunlight to warm up the room in cold winter. (Keshtkaran, 2011)

The principles of Yazd vernacular buildings:

1. Shade the public places for hot summer;
2. Using favorable wind for ventilation by wind catcher;
3. Evaporation can be worked together with the ventilation for cooler and more humid air;
4. Domed roof with opening on top brings heat away;
5. Changing rooms by seasons for comfort.

3.3. Harran, Turkey

Harran is an ancient city in southeast of Turkey, near the border of Syria. The city lies in the hot semi-arid climatic region. The temperature fluctuation between day and night in summer are significant. The mean temperature in July was recorded at 31.9°C (Başaran, 2011). The extraordinary feature of residence in Harran is the using of existing local material and the dome-shaped building typology. (Figure 6)

The wall of Harran houses is mainly built of stone brick and mortared by mud. The average wall thickness in Harran is around 50 to 60 centimeters. The thickness of the wall plays a role in thermal insulation and storage. The wall also is the base of the roof structure. The roof of Harran residence using the similar principle of Yard’s dome structure, but it shows more clearly on the idea of the special shape. The roofs are shaped in parabolic cone, the total height of the houses can reach to 3.5 to 5 meters. A 20-centimeter hole is opened on top of the cone, it discharges hot air. The cone roof construction plays a role as a solar chimney. A thermal analysis was experimented by Başaran in July that even the outdoor temperature reached above 40°C at the daytime and drop 20°C at night, the indoor stays stable at around 30°C, and the
indoor humidity stays between 30% and 50% which met the relatively comfortable condition. (Başaran, 2011)

Harran houses suffered numerous destroyed and rebuilt through history, the buildings evolved to fit the local temperature to minimum the energy consumption, besides the usage of material is reflecting another way of sustainable. The bricks and stones are recycled from ancient ruins. It saves energy to make new materials as well as saving transportation cost. The dome can be built very fast by local people, usually, a dome consists 1300 bricks and it can be finished in half day by one person (Bekleyen et al., 1998).

The principles of Harran houses see below:

1. High domed roof as solar chimney;
2. Using on-site natural material as well as recycling manmade wastes to save energy and time.

3.4. House Cave, China

House cave (Yaodong) is a common dwelling type in Loess Plateau, Northern China. Most of the house cave distributed in Northern Shaanxi, Gansu, Ningxia, Western Shanxi, Western Henan and some part of Hebei provinces (Xu, 2011). These areas are from 31°23’ to 37°39’ north latitude (Zhao, 2010). The climate condition of Chinese house cave are different, they are mainly distributed in semi-arid zones, continental zones and oceanic climate zones from north to south. The temperature is more extreme in the northern part, and cave dwellings in facing more moisture problems.

Cave dwelling is one of the original living styles of human being, but this tradition inherited in northern China. Frequent warfare in history is one of the reasons for these hidden-type buildings exists till now, however, the comfort is the main reason for people to keep living in the soil. For example, Mizhi is one of the most famous house cave village in northern Shaanxi, the monthly averages temperature range from -9.4 °C to 23.4°C in July, recorded high at 38.2°C and low at -25.5°C. While in the house cave, the indoor temperature is between 10°C to 22°C without extra heating, the relative humidity is between 30% to 75%. (Ren, 2011)
There are three types of house cave: sunken cave, cliff cave (Figure 7), and Guyao (manmade house-like cave built on the ground). The common technique is to dig a 4 - 12m depth, 2.5 – 4m width arched hole in the massive soil (Zhao, 2010). The soil thickness on top of the cave is from 3m to 8m depends on the local soil condition (Ren, 2011). Due to the opening of house cave is only able on one side, the orientation is important. Except for the limitation of cliff caves and Fengshui theory effect on some cave owners, most main house caves facing south for maximum sunlight.

The principle of cave dwelling is:

1. Using large amount of soil as thermal mass;
2. South as the orientation for the main room.

Kang is a bed that can be heated up by an adjacent stove which commonly used in house cave, also widely used in most northern part of China. It uses the remaining heated smoke from cooking stove to heat the Kang plate before exhaust expelled. The Kang usually made of the high thermal mass material that it can store the heat and release to the bedroom by convection. However, it is not a very efficient way to heat the entire room, the improvement called elevated Kang had been designed in recent years that heat transfer area increased 50 to 100%.(Zhuang et al., 2009) Meanwhile, the similar principle can be applied to the wall or floor such as Chinese wall heating (Bilow, 2012) and Korean Ondol.

In well-designed Kang, the smoke flow driven by buoyancy force and assisted by wind, when the air exhausted through the chimney, the new air are dived into the stove.(Figure 9) It helps the indoor airflow and ventilation. Otherwise, bad Kang design will cause smoke backflow and pollute the room. (Zhuang et al., 2009)

The principle of Kang system is to utilize the energy for multiple uses in cooking, sleeping, domestic heating and ventilation; and also utilize air flow to heat building parts, use mass to store (Bilow, 2012) and conduct the heat to the room.
3.5. Tajuña Valley, Spain

Similar to Loess Plateau in China, cave dwellings also exist in Spain. Semi-arid climate domains the most area of the central and east part of country. The average daily temperature is about 40°C in July and August and drops to 15°C at night, and minimum average temperature in winter is about -2.5°C. (Barbero-Barrera, 2014) The extreme weather meets the perfect physiognomy. In the southeastern region of Madrid, cave dwellings settled densely in Tajuña Valley. The soil formed by limestone and gypsum, which indicated that the hill or the ground can be easily extracted and stays stable in sense of shelter.

The principle of using nature topography as thermal mass for dwelling in Tajuña Valley is same as China’s house cave. However instead of independent caves facing to the courtyard, the cave rooms in Tajuña Valley are connected inside the hill or underground with one room as entrance also as main room – kitchen. It connects all other rooms as well as the first bay to act as the thermal mattress. (Barbero-Barrera, 2014)

IV. CONCLUSIONS

The principles in semi-arid climate in China, Iran, Turkey, and Spain have similarities and also have their own special strategies. The principles summarized above can be applied or improved into the shelter in different aspects:

The principle of urban weaving building context with narrow and winding streets in refugee camp can be designed as clusters that a number of dwelling unit can be designed close to each other in sense of shading each other and protecting avoid the strong wind for inner area; Besides small courtyard design inside each clusters to improve the microclimate; Avoid straight streets to slow down the wind; Shading the public area by fibre or canvas awnings similar to the shading system in Seville, Spain (Taylor, 1997) to provide more chance for outdoor activities;

The principle of using thick earth, adobe or bricks as thermal mass is major thermal solution in semi-arid climate, the construction method can be replaced by use sand bags or box-like bricks
to contain the soil to accelerate the building speed; Or replace the soil by phase-change materials (PCM); Or using combination of thermal mass material together with insulation materials and/or PCMs; According to recycle tradition in Harran, shelter enclosure wall material can be made by recycled wasted material such as bricks and concrete shivers from ruined buildings.

Flat building top with thick thermal protection is the main roof principles in semi-arid climate, domed roof as the solar chimney is the strategy of some areas in middle and west Asia. The flat-roof shelter unit can be the prototype of the design, it has flexibility for use as a balcony, or be possible to add another storey or other adding such as sun shield, dome, wind catcher, solar panels or plats.

Using prevailing wind to ventilate the indoor spaces, rotatable wind catcher can be designed as an add-on to shelters to adjust the direction themselves by different location; Solar chimney can be a secondary solution for places have no clear prevailing wind; A simple mechanical system can assist with ventilation by using a fan and air duct. If the water supply is sufficient, integrate the air passage with water storage for evaporating cooling.

The south orientation is tradition for many places in 30° to 40° north latitude.

The principle of Kang system is to utilize the energy for multiple uses in cooking, sleeping, domestic heating and ventilation; and also utilize air flow to heat building parts, use mass to store (Bilow, 2012) and conduct the heat to the room. In case of shelter tradition stove is much practical if electronic heating is not available in some places. Leave space for stove as well as intake and exhaust openings for possible stove installation, and use fireproof material for shelter design.

Plantings can provide shade and improve air quality, growing fruits in front of the building to provide shade in summertime which also provide foods.

Moreover, the shelter design in the semi-arid area also can be applied to similar climate regions such as cold desert climate zone and Mediterranean zone, and the same prototype can be used in the subtropical area with small changes or adding.

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