Generative Morphology: Establishing Relief Networks in the Dynamic Taklamakan Desert

by

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Submitted in partial fulfilment of the requirements for the degree of Master of Architecture

at

Dalhousie University
Halifax, Nova Scotia
July 2013

CONTENTS

ABSTRACT

Desertification, the deterioration of productive and fertile lands into barren and desolate deserts, usually occurs as a result of deforestation, drought, or improper planting and agriculture. This thesis investigates ways to provide reliefs such as water and shelter in a continuously desertifying landscape (Taklamakan desert, Xinjiang, China) for locals, pilgrims, travelers and expedition caravans. To create diverse experiences in the desert, both temporary and permanent structures are considered in this project to minimize further land degradation. Movements of historical trade routes, oasis towns, and modern population fluctuation are examined to determine strategies and locations for intervention. The progressions of architectural, environmental and cultural decay are revealed in three selected sites: the Kapakaskan Village, the Jafar Sadiq Shrine, and the ancient ruined city of Niya. The design and the primary area of study seek to explain and incorporate passive or low energy building systems, form, cultural community, and technological innovations.

LIST OF ABBREVIATIONS AND SYMBOLS USED

Abbreviations

AVMC	Atmospheric Vapour and Moisture Condenser
BCE	Before the Common Era/Current Era/Christian Era
CE	Common Era/Current Era/Christian Era
CFD	Computational Fluid Dynamics
d/m	Days per Month
h/d	Hours per day
K	Kelvin
km	Kilometre
m	Metre
m^2	Metre squared
m^3	Metre cubed
m/s	Metres per second
m/s^2	Metres per second squared
mm	Milimetre
mm/d	Milimetres per day
PETB	Polyethylene mixed with titanium oxide and barium sulfate
RH	Relative Humidity

Symbols

Ta	288 Kelvin (15° C)
α	Angle
°C	Degrees Celsius
Δh	Dew gain or relative dew yield
Tc	Mean condenser surface temperature
%	Percent
ΔT	Temperature gain or cooling factor

ACKNOWLEDGEMENTS

I would like to thank Roly Hudson, my supervisor, and Catherine Venart, my advisor, for their guidance, feedback and interesting idea suggestions.

I would also like to thank Clement Wong for giving me good advice to help develop and progress my designs.

Finally, I would like to thank my parents and families for their help and complete support.

CHAPTER 1: INTRODUCTION

Area of Study

How can architectural strategies provide relief networks that are responsive to local culture and the environment in the Taklamakan desert within Xinjiang, China?

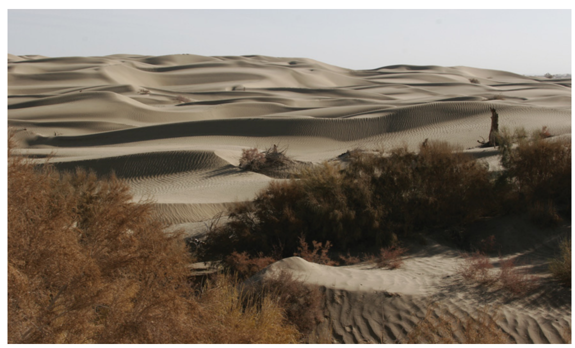
Currently, there have been massive afforestation projects in China such as the Three-North Shelterbelt Program, also known as the Great Green Wall of China. Started in 1978, the afforestation project is expected to take over 70 years to complete, with around 4480 km of shelterbelt trees to be planted in China's deserts. The project aims to reduce sandstorms which are encroaching upon major cities (BBC 2001). This project has received criticism from researchers, which pointed out the survival rates of saplings are low while costs are high. According to Wang Man, the head of the Forest Bureau, trees must be replanted every 3-4 years since they cannot guarantee the continued survival of the trees. Cao Shixiong from China Agricultural University estimated that only 15 percent of all trees planted on dry land since 1949 have survived. One of the main consequences, stated agro-botanist Zhang Yan is the rapid exhaustion of soil and water resources (Jiang 2009). Since groundwater in the Taklamakan desert - Tarim Basin is the only major source of water for irrigation and drinking purposes, extensive ground-water pumping was considered as the major human-induced factors influencing the groundwater decline (Sun et al. 2011, 254-263). With the rapid decline of groundwater, investigating different water collection systems provides the background for one aspect in this thesis.

Workers irrigate desert vegetation belt.
(Behring, 2006)

Takalamakan Desert pumping station
(dmcooper_onechib, 2006)

Shelter and human comfort are important factors to consider as well. Regional architectures in the basin are designed around heat retention and wind breaks due to the extreme day/night temperature difference and sand storms. Most of the structures are insufficient in dealing with the heat loss and since the southern rim of the Taklamakan Desert does not have coal, “peasants used to uproot the desert vegetation and burn it as firewood during the winter months,” said Zhang Tao, deputy director of the Afforestation Department. This amplifies the effect of desertification in addition to the use of ground water to the region with the poplar trees logged to near extinction (Bezlova 2006). Bringing better technology along with effective and efficient architecture to the area can help release some of the stress placed on the regional environment. Through the studies of various forms, materials, details, systems, and environmental factors, an appropriate architectural strategy will be developed to take advantage of Xinjiang’s desert environment and climate to provide the necessities for relief and regrowth.

Wind break fence to restrict sand movement and wind errosion.

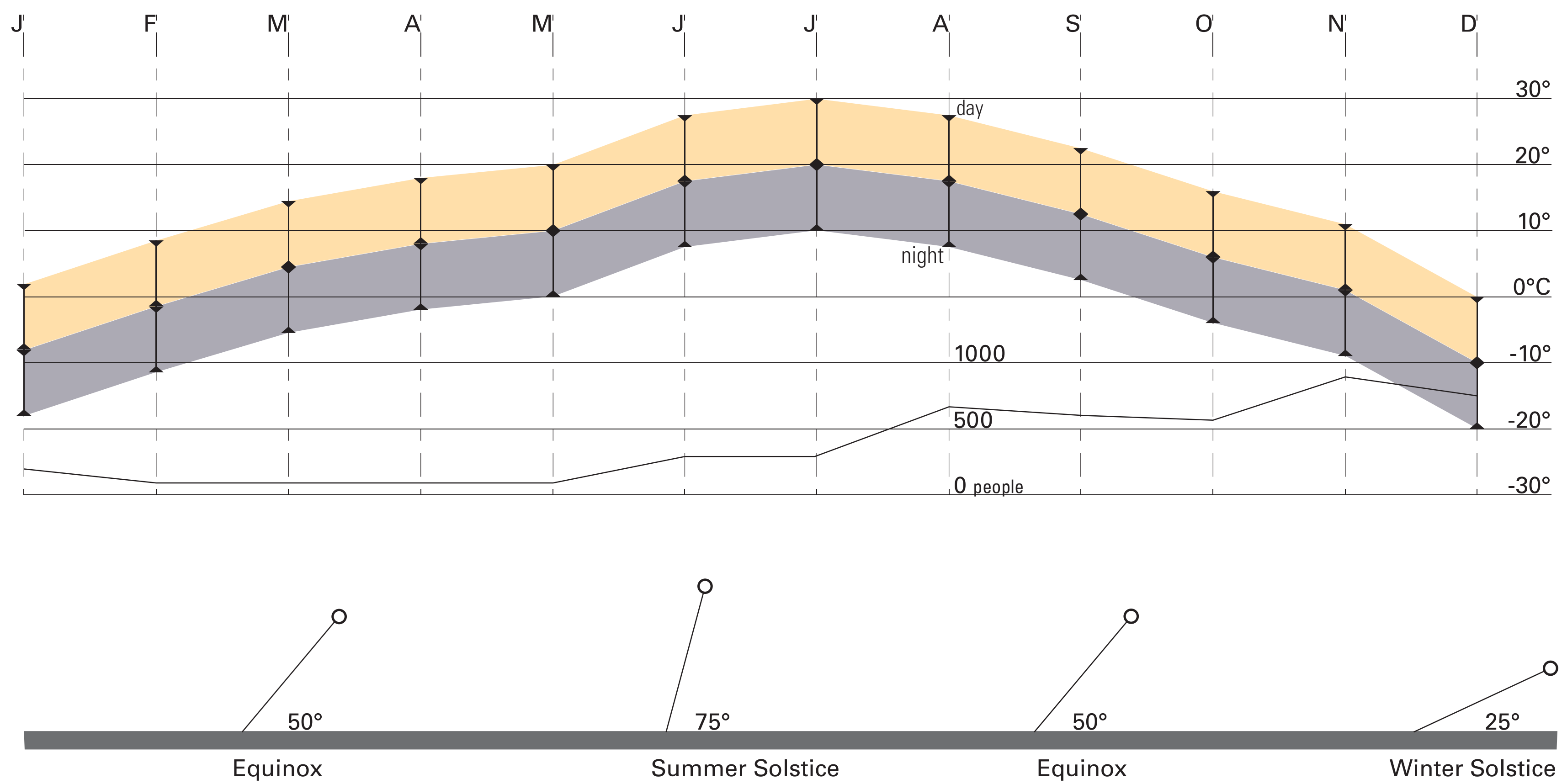


Desert shrubs are planted to reduce surface soil evaporation.

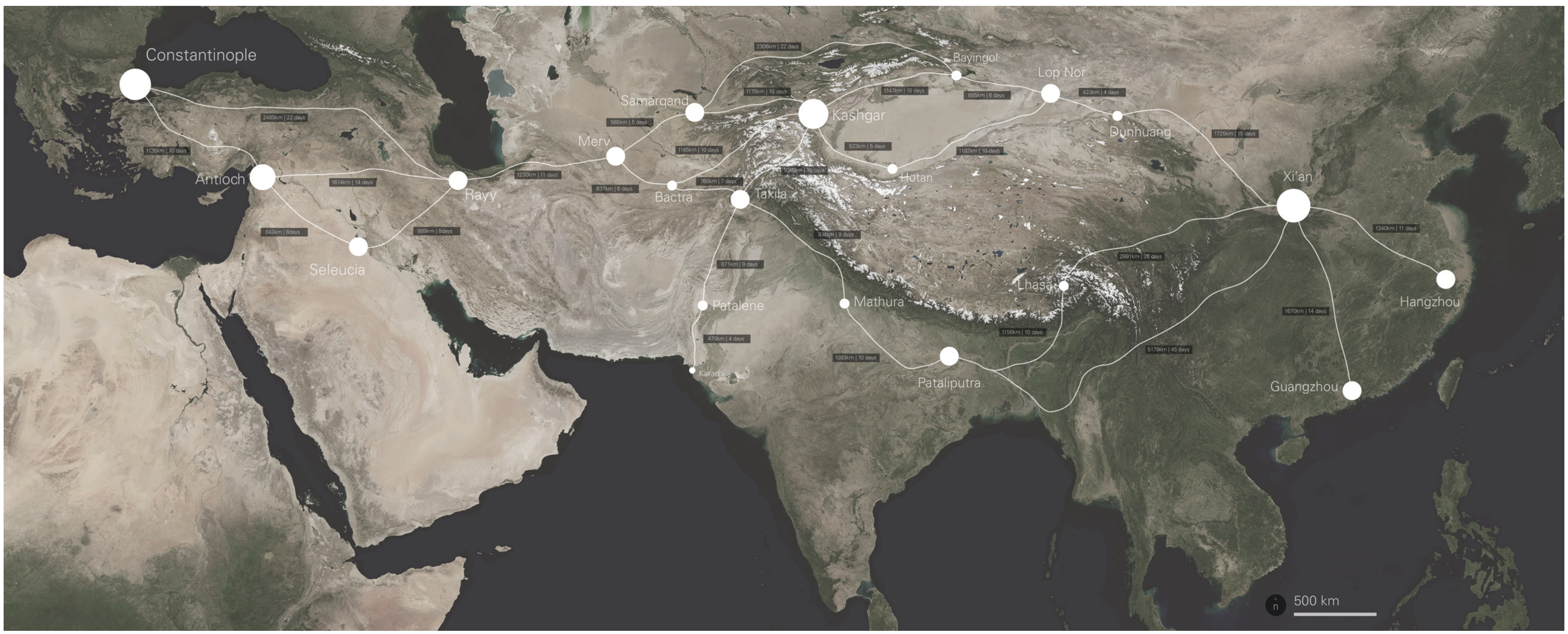
The cross desert highway, also known as the Tarim highway with desert vegetation planted on either side of the road helps reduce wind and soil erosion as well as restricting sand dunes from shifting onto the highway.

Site: Taklamakan Desert - Tarim Basin, Xinjiang, China

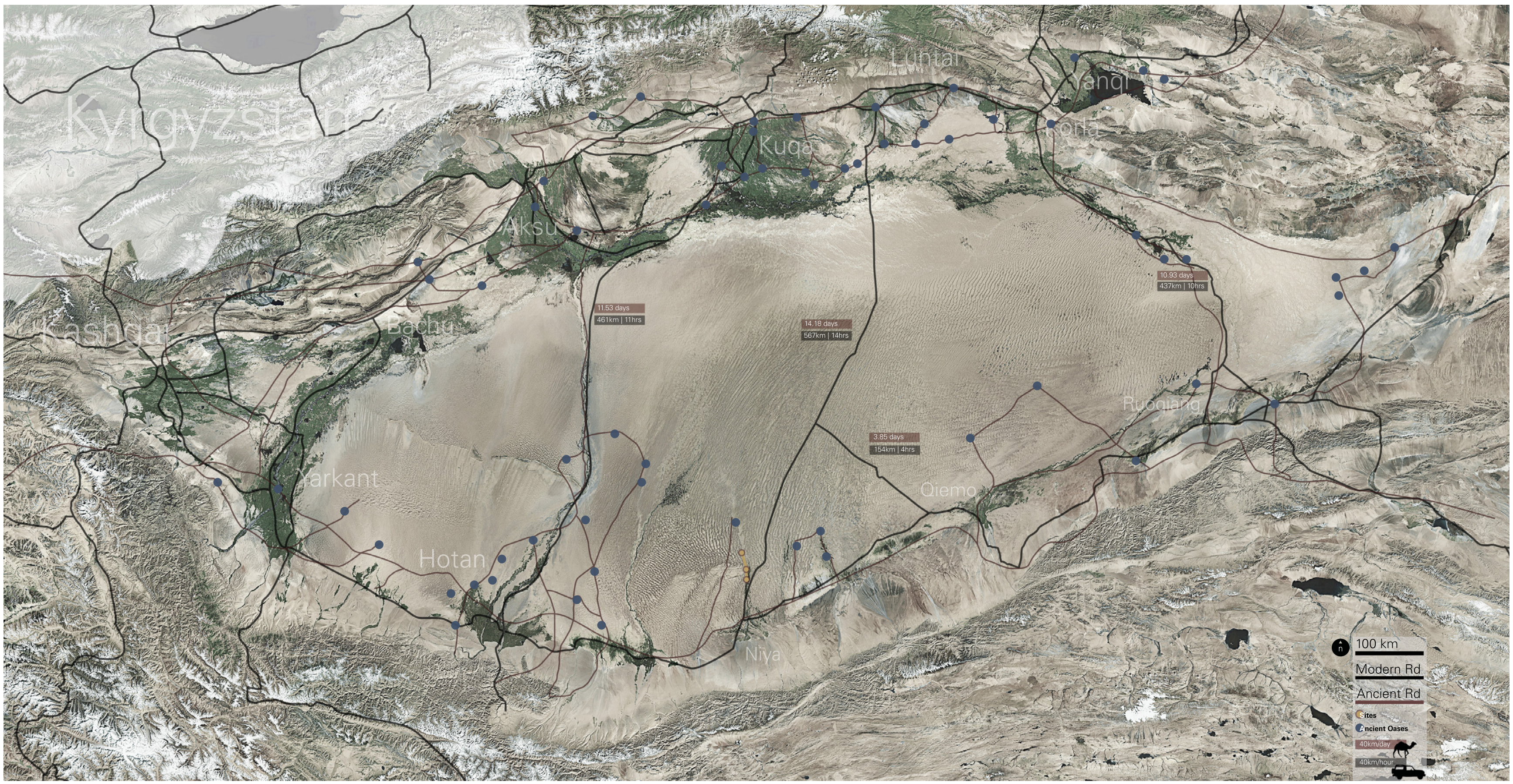
There are around four big deserts in the Xinjiang province in China: The Guerbantuggut desert, Kumutage desert, Chaidm desert, and the Taklamakan desert. Situated in the northwest region of China, with an area of approximately 337,000 square km, the Taklamakan desert is the world's second largest shifting sand desert. The sandy desert's dominant dune morphology comprise of compound/complex linear dunes, crescent dunes, and star dunes, which about 85% of the desert is made up of shifting sand dunes. The annual precipitation varies between 100-400 mm at the southern fringes and the annual potential evaporation is 2450-2902 mm with the mean annual temperature of 11.6°C. Summer temperature ranges from 10°C to 35°C while winter temperature ranges from -20°C to just above 0°C (Zu et al. 2003, 639-644). Historically, the Taklamakan desert is crossed by the famous ancient Silk Road trade route at the northern and southern fringes along oases and rivers. More detailed studies examining the changes of the trade routes through history and understanding node influences can be found in Appendix 1. Archaeological research has shown that there have been human activities in the southern part of the basin as early as 10,000 years ago, especially from the Han Dynasty to the Tang Dynasty, which the increased economy shaped the Silk Road (Xi 1988, 132-141). Oasis towns along the desert edge were vital to the survival of merchant caravans traveling on the Silk Road. These towns, such as Kashgar, Niya, Yarkand and Khotan (Hetian) in the south, and Turpan and Kuqa in the north, still remain relevant today. However, with the adverse effects of desertification and climate change, the desert is expanding and oases are drying up, thus many of these towns, such as ancient Niya and Gaochang, became desolate ruined cities or historical relics.



Annual temperature variance + Population fluctuation + Mid-day solar angle (data from Climatemaps 2013, Greenstream 2013)



Historical trade routes and cities in Asia with travel time and distance. (base image from Bing 2013, data from The Silk Road Project 2013)

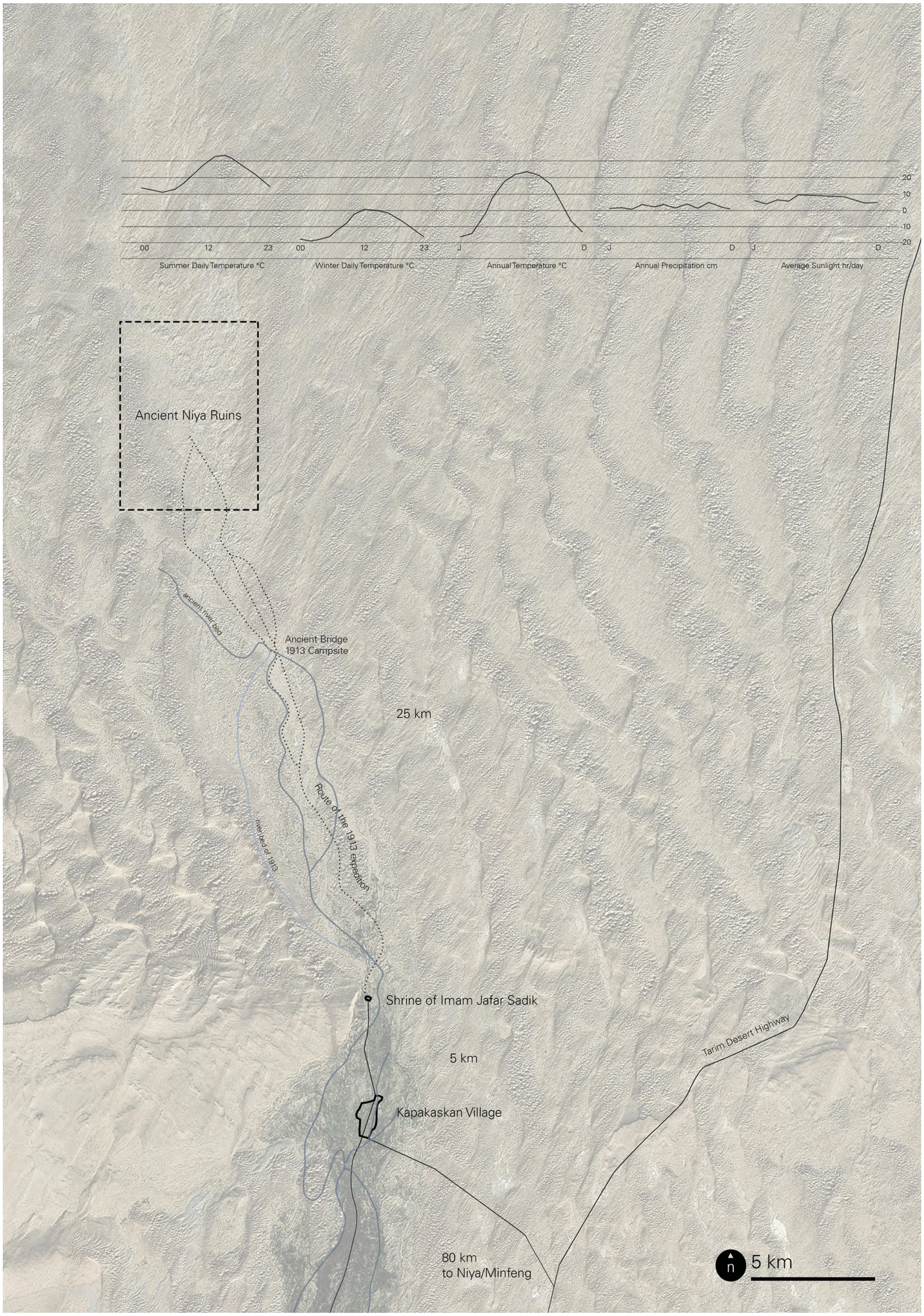


Taklamakan desert road network, ancient oases, and site (base image from Bing 2013, data from Hou et al. 2007)

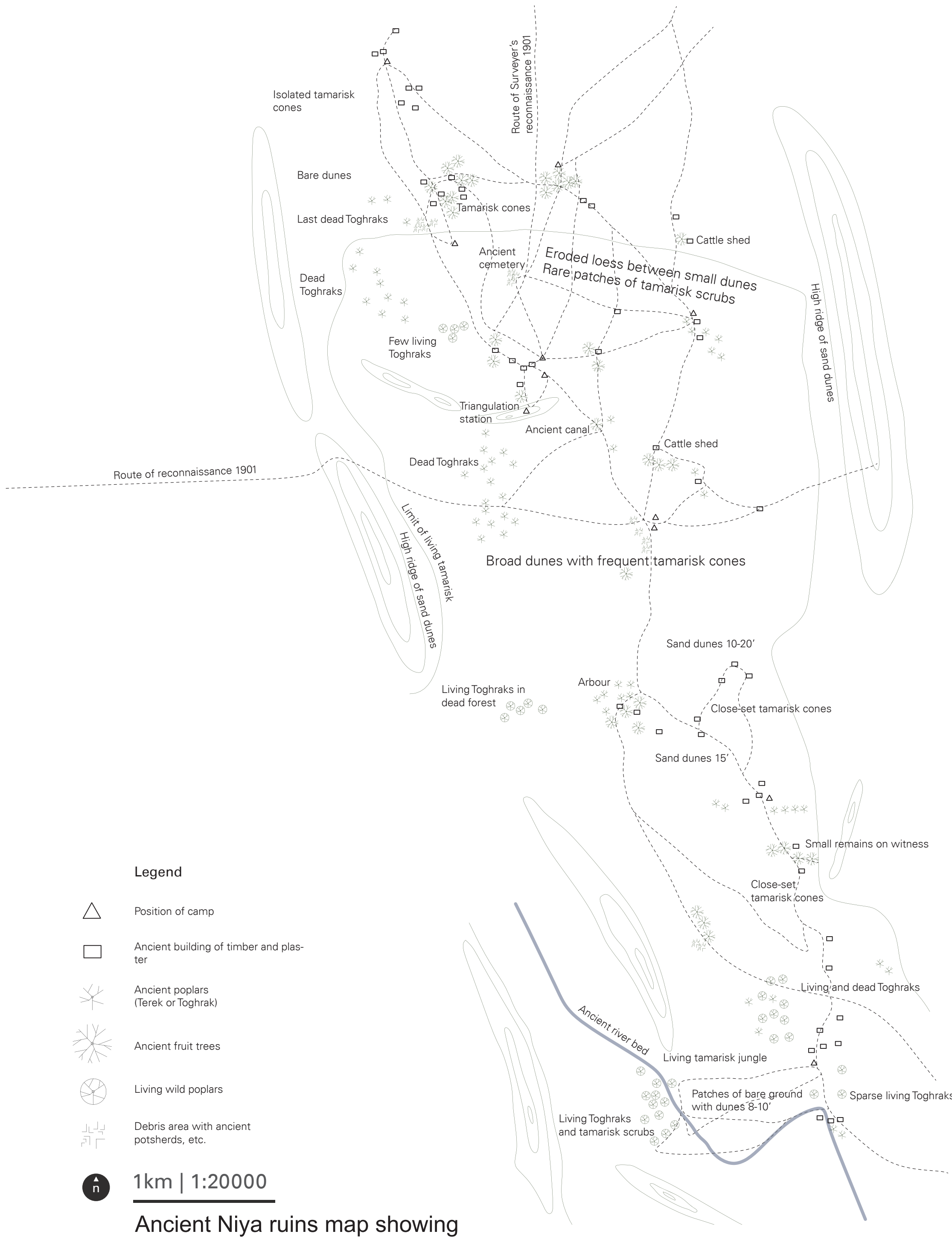
Site: Ancient City Ruins

Research into ancient city ruins in the deserts by Hou Ren Zhi (1985, 241-252) indicates many of the present day problems faced by one-sixth of the world's population living in arid regions. Zhi found that during the first century BCE cities were built along the Hexi corridor as a way to prevent raids by Huns on the ancient Silk Road. To reclaim grasslands in that region, the people had to harness melt-water that flows from the surrounding mountains as well as from oases. Zhi discovered that over cultivation of the land allowed the wind and water to erode and expose the earth. Eventually, the blowing sand encroached on the cities and over time, the ruins of former cities are covered by drifting sands. The same mistakes are being made again today with over cultivation and deforestation, and it has been shown that the deserts are expanding towards the modern cities. To emphasis the progression of decay and desertification, this thesis proposes a site fragmented into three zones; the ancient ruined city of Niya, the Jafar Sadiq shrine, and the Kapakaskan village. All these sites act as important nodes and halting points for travelers venturing into the desert.

In the heart of the desert, over 100 km from the nearest major city of modern Niya, is the ancient city of Niya. Ancient Niya was originally inhabited by Bronze and Iron Age people who left traces of settlements in the area in the first millennia BCE. These inhabitants as well as other people throughout the Tarim Basin were understood to be agricultural societies that practiced animal farming. The semi-nomadic pastoral economy in the region was a result of the hypothesized climate change causing the Tarim Basin to become more arid. Niya was abandoned by the fifth century CE (Mair 2012, 3-19, 122-155).



Site map of Kapakaskan village, Jafar Sadiq Shrine, and ancient Niya ruins. (base image from Bing 2013, data from Climatemaps 2013)



Ancient Niya ruins map showing research sites, and camp locations. (redrawn from Whitfield et al. 2012)

Sir Aurel Stein, a British explorer and archaeologist, located Niya in the early twentieth century where he found, extended deep into the desert, the fragments and ruins of a once flourishing and prosperous city. With an area of about 45 square km, Niya was one of the largest city oases on the Southern Silk Road. Stein concluded that the area had been abandoned quite abruptly in the fifth century and was never inhabited from then on. Along with more than 40 ancient structures identified by Stein from his three expeditions, a further 30 buildings and two graveyards were discovered by a Sino-Japanese team since 1993. The city had remnants of an irrigation system which once supported vast orchards, vineyards and gardens. The ruins are scattered in an area of about 25 km north to south and 7 km east to west, along the ancient Niya River. Among the many archaeological finds at the site, there are hundreds of wooden tablets inscribed in the rare Kharoshthi script and several official Kharoshthi documents on leather, a dozen wooden tablets with Chinese characters, ceramics, lacquer work pieces, coloured silk cloths and coins (Whitfield et al. 2012).

The main program for the ruins site will be a comfortable temporary shelter for archaeologists and expedition teams to stay overnight. The main characteristic is the temporal aspect of the site, thus, the projected structure are only to be used when people are there to diminish ecological impact and preserve the excavation site for further research.

Ancient Niya ruins and remnants photos taken by the expedition team. (Whitfield et al. 2012)

Site: Jafar Sadiq Shrine

The Jafar Sadiq Shrine (Mazar in Uyghur language) is located around 25 km south of the ruins of ancient Niya, along the dried oasis of the retreating Niya River. The Niya River once flowed beyond ancient Niya over 10 km to an older Stone Age site, but during Stein's expedition in the 1900s, the river only reached a few kilometers past the shrine. Today, the river does not even extend to the Kapakaskan Village, 5 km south of the shrine.

The shrine includes a mosque complex at the end of the road, some ruined structures, a pilgrimage path, and tombs on a hill to the west. The mosque structure was built with wood and bricks, with carved columns, a porch for outdoor prayers, and rooms for prayer during the winter. To support the shrine, visitors are required to pay a fee to enter, and stay overnight in small, basic rooms east of the front courtyard. Behind the mosque are structures that lie in ruins from weathering and decay. At various places along the pilgrimage path leading out towards the tombs, there are symbolic arches, graves, and trees. A tradition at the shrines is to attach onto these symbolic relics, pieces of cloth or amulets with religious significance, as representations of prayers; and animal skins, feathers or skulls, as symbols of sacrifice. Archaeologists have dated the tomb to the 16^{th} or 17^{th} century (Centralasiatraveler 2006).

Ziyarat, the pilgrimage to a holy tomb (literally "visit"), takes place at various times of the year and celebrate a variety of occasions. People usually gather around religious festivals such as *mawlid* (a birthday celebration for a holy figure; in January), *qurban* (when an animal sacrifice is made during the Great Festival; in October), *Ramadan* (the fasting month; between July - August), *muharram* (the sacred month; between November and December), and *barat* (a night of worship during the eight month of the Islamic calendar; around July). These popular pilgrimages are attended by hundreds of visitors each year. Local communities often set up trade fairs and festivals, where the shrine is surrounded by bazaar booths and food stalls, and featuring activities such as camel riding, wrestling, tightrope walking, magic shows, storytelling, and musical performances (Ross 2013, 11-16).

Jafar Sadiq shrine site map and prevailing wind (base image from Google 2013)

Desert Flora

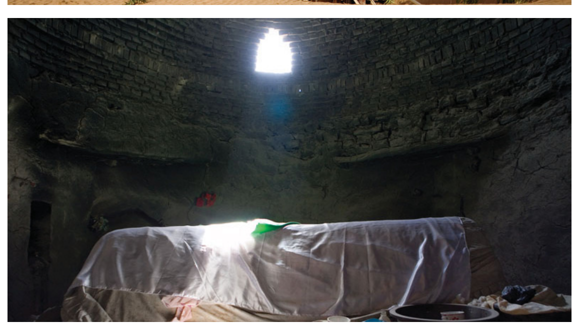
Tamarisk Shrub
Tamarix, salt cedar
Max root depth: 2 - 9 m
Average height: 1 - 18 m

Black Saxaul
Haloxylon ammodendron
Max root depth: 2 - 5 m
Average height: 1 - 8 m

Diversiform-leaved Poplar
Toghrak Poplar
Populus diversifolia
Max root depth: 20 m
Average height: 15 - 30 m

The structure and program on this site will relate to the activities that take place during these festivals, but will also frame a path into the desert, allowing visitors to experience the transition and effects of desertification. The relationship of semi-permanence to the site and the fragmented structures are also important factors to consider, and the proposed architecture should reflect that. The main feature will be providing shelter from the sun and wind during the day for relative human comfort, and a system of water collection during the night that removes the stress of groundwater from heavy pumping. This shrine also acts as the threshold that connects the past and the present, the ruins in the north to the village in the south.

Jafar Sadiq shrine site photos
(Centralasiatraveler 2006)



Pilgrimage mementos, relics and offerings

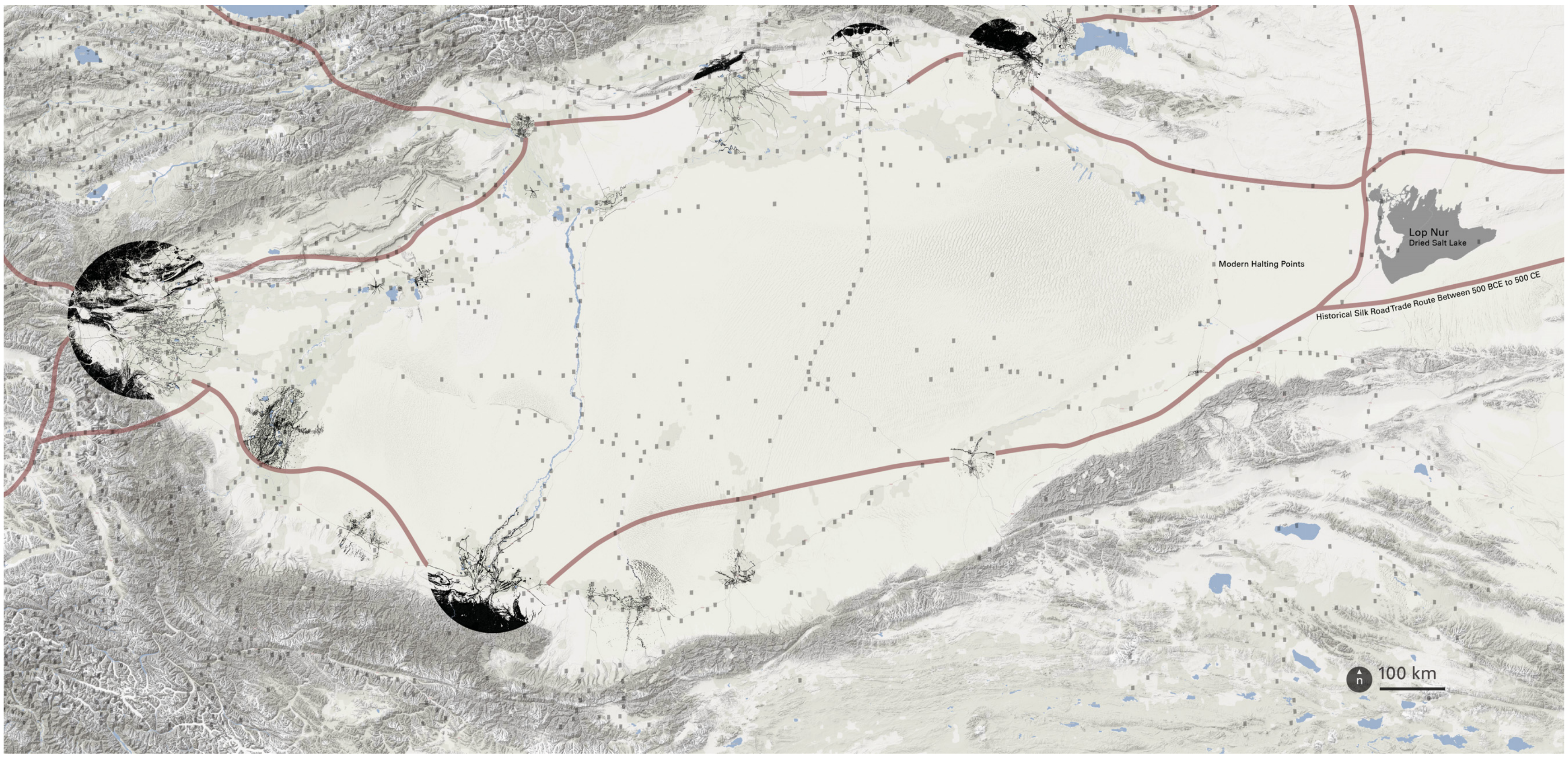
Tomb (Ross 2013)

Site: Kapakaskan Village

The village is called Kapakaskan (the hanging gourd in Uyghur) or just Mazar, because of the nearby shrine. Located 80 km north of modern Niya, and 5 km south of the shrine, Kapakaskan village is now home to 110 farming families. The village was once an oasis town but now relies on wells and groundwater pumping for its water source as the Niya River has retreated throughout the years. Kapakaskan recently became a base of expeditions to the shrine and ancient Niya ruins since the time of Stein's archaeological discovery. Similar to many other villages of the region, the homes there are constructed of wood, wattle (poles intertwined with twigs, reeds, or branches, used for fences and roofs), mud plaster, and bricks, which are built much the way they were in the days of ancient Niya 2,000 years ago. Farmers would store fodder on their roofs both for the added insulation as well as food for their donkeys and camels (Centralasiatraveler 2006). The only modern building in the village, constructed of bricks and concrete, was Kaysar Mahmut's guesthouse. The staple agriculture in this village consists of wheat, corns, and cotton, in addition, watermelons and Hami melons are grown as well.

In the modern day, with the expansion in the petroleum industry and the need for fast shipping across the Taklamakan desert, the cross-desert highway also known as the Tarim Desert highway was constructed to link the cities of Hotan and Niya at the southern desert edge with Minfeng and Luntai in the north. Approximately 446 km of the 552 km highway crosses uninhabited areas covered by shifting dunes. Along with many new ruined sites discovered near ancient Niya, the Tarim highway has allowed better accessibility into the village, bringing in more tourists, researchers, archaeologists, and pilgrims than ever before. There had been many expedition teams ranging from 10-40 people throughout the year, both local and international, have stayed in Kapakaskan village (Whitfield et al. 2012).

Therefore, the focus on this site will be to provide permanent comfortable accommodations and shelter from the extreme desert climate. Main features of the architecture will be the efficient use and collection of water, wind and solar to deliver suitable human comfort to its inhabitants. The building will serve as a base camp and a place of rest before travelers head into the barren landscape.



Historical Silk Road and modern halting points (base image from Google 2013, data from The Silk Road Project 2013)

Kapakaskan village site map and prevailing wind (base image from Google 2013)

Staple Regional Agriculture

Cotton
Gossypium herbaceum
Water required: 5000m³/hectare

Corn
Zea mays, Maize
Water required: 5600m³/hectare

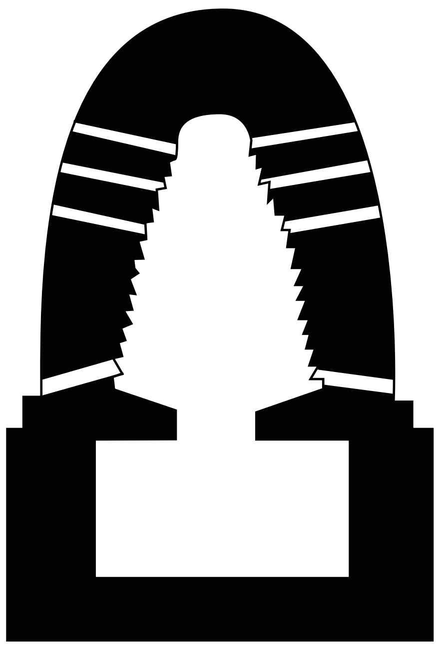
Wheat
Triticum aestivum
Water required: 2100m³/hectare

Watermelon
Citrullus lanatus
Water required: 4000m³/hectare

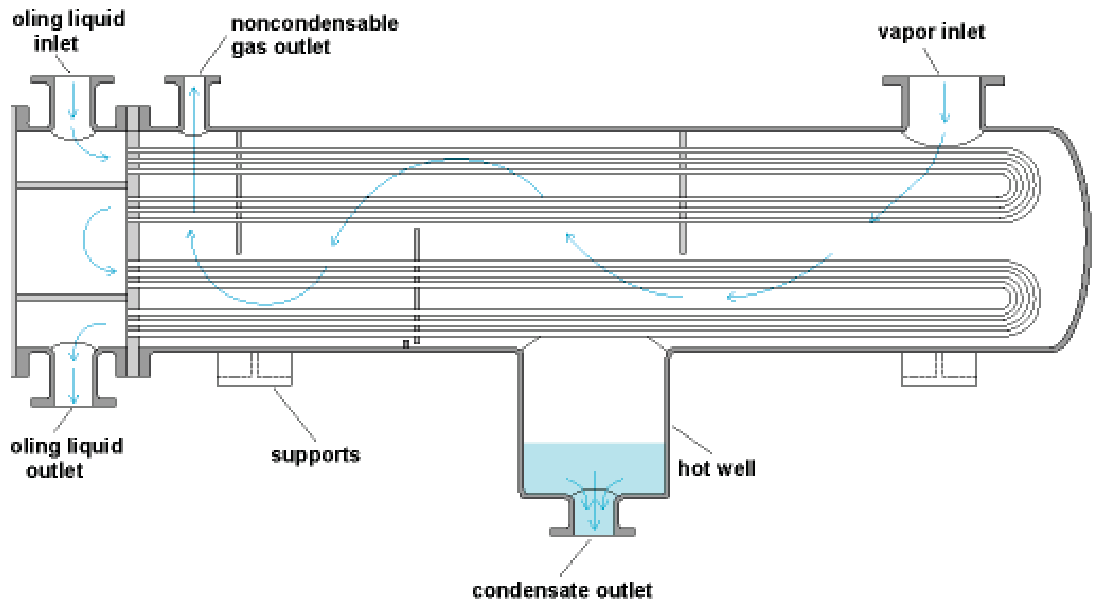
Kapakaskan village site photos (Rach 2011)

Technologies: Water

Water is a key aspect for surviving in the desert. Therefore, how can water be harvested? How can these harvest nodes survive in the desert and provide travelers with water and shelter? To determine this, different technologies of water collection and shelter archetypes in an arid environment are examined. While there are many methods for to generate water in this harsh and unforgiving condition, atmospheric vapour and moisture condensers (AVMC) are both efficient as well as low maintenance. AVMCs utilize the high temperature differential to condense the moisture in the air to water droplets. There are many types of these condensers such as high mass, active mechanical, and passive radiative designs. The high mass design, proposed by Kogan and Trahtman (2003, 231-240), is based on a pyramid-shaped structure built in 1912 by a Russian forester and engineer, F.I. Zibold, in Feodosia, Ukraine. Zibold designed his dew collector from his discovery of an ancient stone pile in the city of Theodosia, Byzantine, which he believes to have produced over 55,400 litres of water a day (Nikolayev et al. 1996, 19-35). However, while both of these high mass designs worked, they could not generate the thousands of litres per day as they claimed (Beysens et al. 2006, 9). Active mechanical designs, on the other hand, are costly to maintain, prone to failures and consumes massive amounts of energy to be viable in this situation.



Typical passive high mass air well
(redrawn from Nelson 2003)

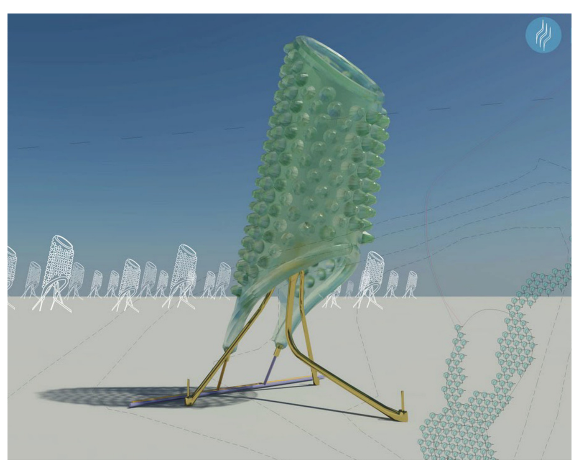


Typical active vapour condenser (AccessScience 2012)

Passive radiative systems are used far more common in other deserts due to their light weight structure, fast and easy assembly, and high water yield to capital investment ratio. Additionally, creating an integrated structure of shelter, shading, light, and ventilation using a radiative design can have multiple manifestations in terms of form, material, and orientations depending on the site. Girja Sharan (2005, 1-10) has investigated passive systems that use a radiative exchange design which performed much better than their high mass counterpart. Sharan conducted tests on six different materials, including aluminum sheet, galvanized iron sheet, polyethylene mixed with titanium oxide and barium sulfate, polyethylene, fiber reinforced plastic plain and corrugated. Sharan concluded that the condenser made of polyethylene mixed with titanium oxide and barium sulfate (PETB) gives the highest yield than the other materials (Sharan 2007, 2-14). The study is confirmed by a self-conducted test in Appendix 2.

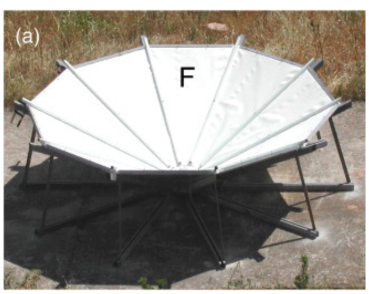
Passive radiative dew condenser in Satapar, India (Girja 2007)

Passive fog collector (Lummerich 2010)



Passive DEWelectric condenser (Brevoort, Chun, and Campbell 2010)

Sharan’s team conducted another study, using Computational Fluid Dynamics (CFD) software to simulate and compare the dew yield and the cooling rate between various radiation-cooled dew condensers. “The following four shapes were studied: (1) a 7.3 m^2 funnel shape [F], whose best performance is for a cone half-angle of 60°. Compared to the reference condenser, the cooling efficiency improved by 40%, (2) 0.16 m^2 flat planar condenser (another dew standard)[A], giving a 35% lower efficiency than the 30° 1 m^2 inclined reference condenser [B], (3) a 30 m^2 30°-inclined planar condenser (representing one side of a dew condensing roof)[C], whose yield is the same as the reference collector, and (4) a 255 m^2 multi-ridge condenser [D] at the ground surface provided results similar to the reference collector at wind speeds below 1.5 m/s^2 but about 40% higher yields at wind speeds above 1.5 m/s^2 “(Clus et al. 2009, 707-712). More data points and graphs can be found in Appendix 3. If the same can be applied to the Taklamakan desert, there could be enough water generated to sustain vegetation growth and for human consumption.



[F] 7.3 m^2 funnel shape


[A] 0.16 m^2 flat planar

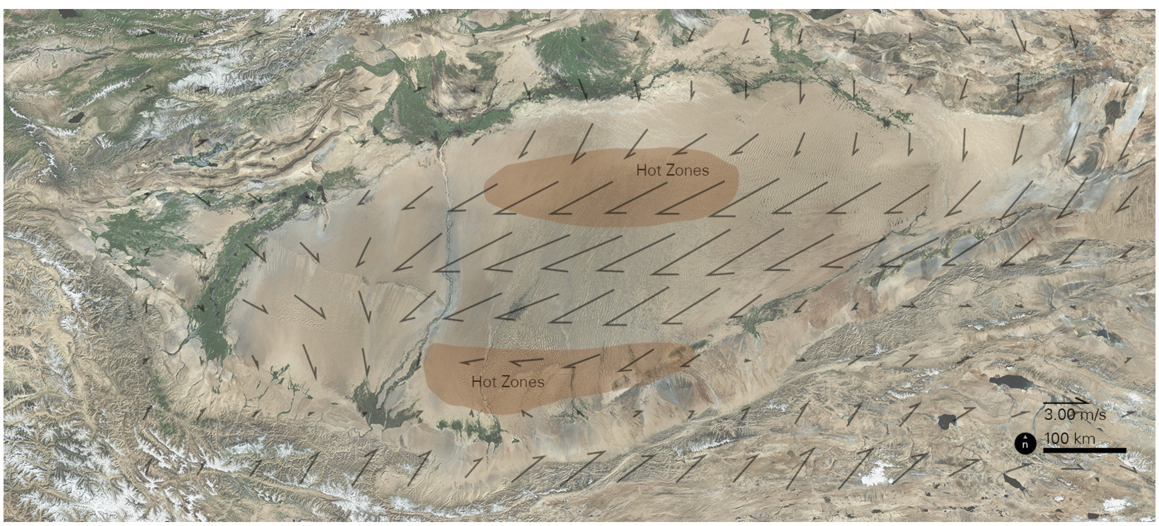

[B] 1 m^2 30° inclined reference


[C] 30 m^2 30° inclined

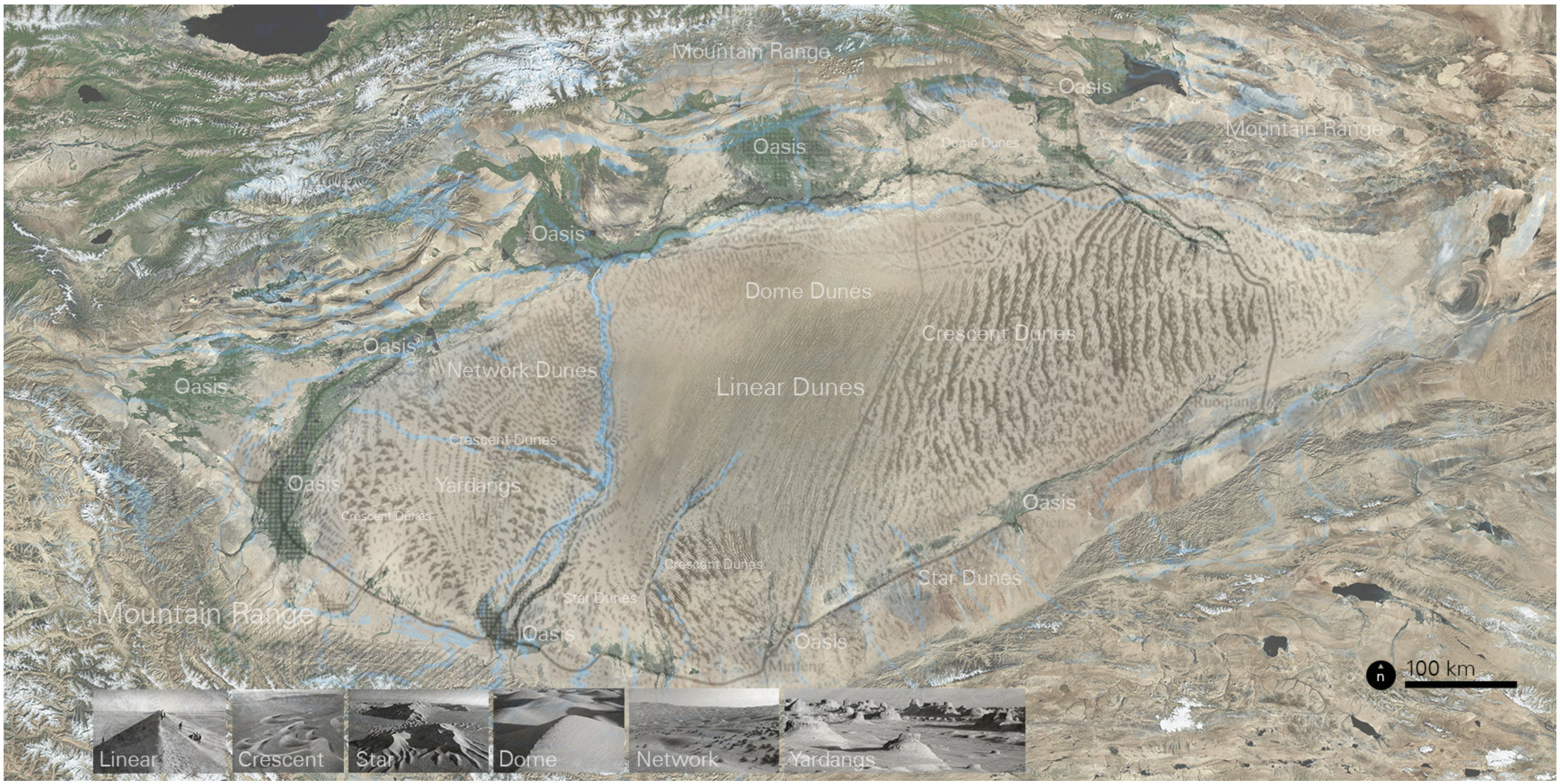

[D] 255 m^2 multi-ridge (Clus et al. 2009)

Technologies: Wind + Ventilation

Understanding the prevailing winds and the different types of sand dunes of the region are important factors to consider for inhabiting the desert. There are 5 types of dunes in the Taklamakan desert: linear, crescent, star, dome, and network dunes. The linear dunes are formed by winds blowing from opposite directions to each other; the crescent dunes are formed by constant winds from one direction; the star dunes are formed by multidirectional winds; the dome dunes are formed upwind near the edges of the desert; and the network dunes, which are multiple types of dunes that are linked together. Preliminary tests of structures with relation to sand dune forms can be found in Appendix 4. The wind conditions at the village, the shrine, and the ruins site are all mostly unidirectional; therefore, wind can be used most efficiently.

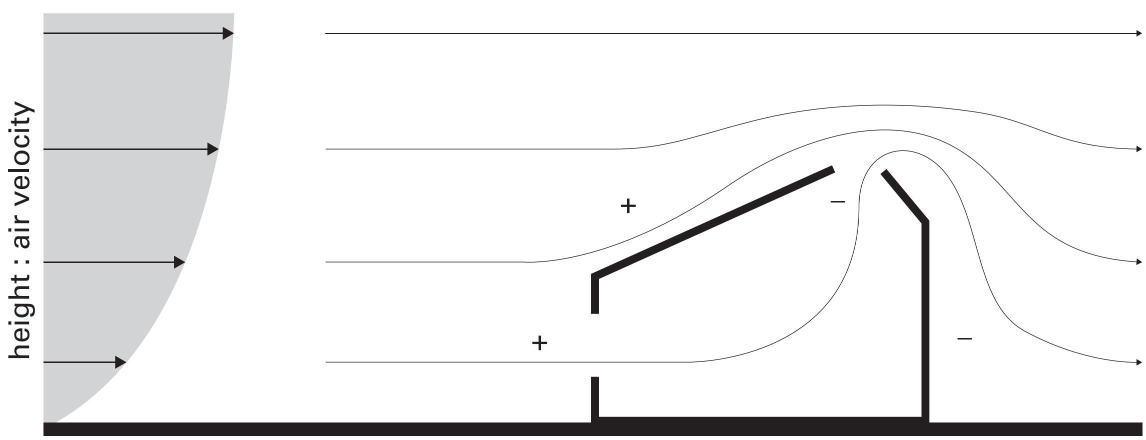


Hot zones, wind speeds and wind directions in the Tarim Basin (base image from Google 2013, data from Gao and Washington 2009)



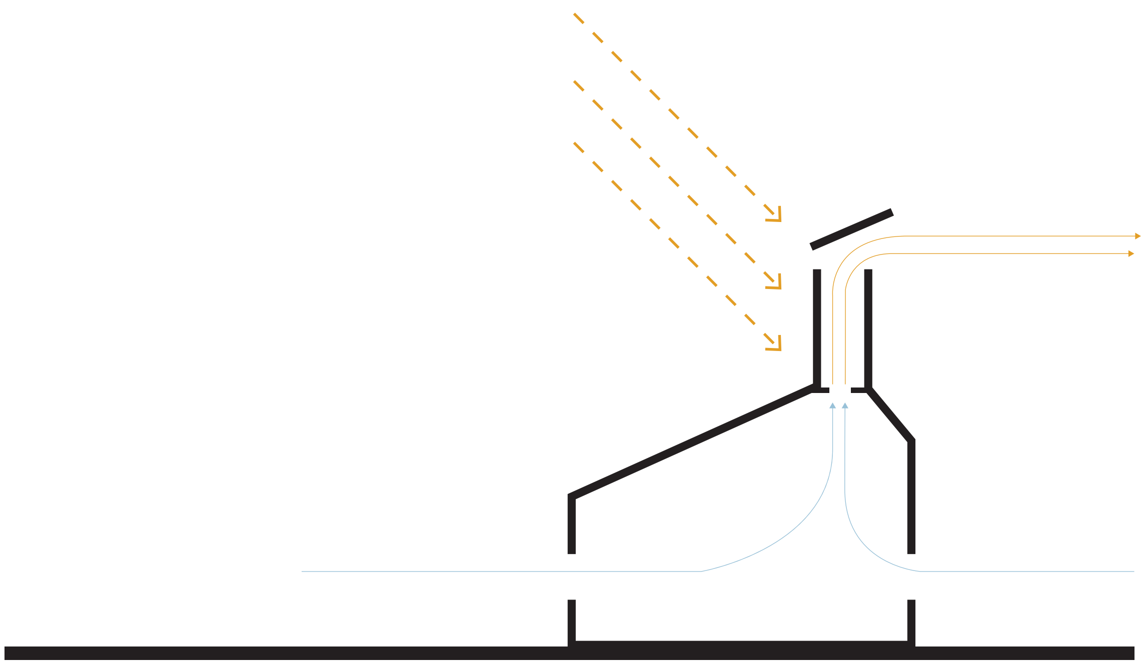
Sand dunes types and locations in the Tarim Basin (base image from Google 2013, data from Dong, Wang, Chen 2000)

The basic principles of air flow must first be understood before it can be effectively utilized. The movement of air is a result of differences in temperature, pressure, or density. Laminar and Turbulent are two basic types of air flow. Laminar flow refers to a fluid that flows in a parallel layers with no lateral mixing while turbulent flow is chaotic and irregular. Air flows from positive to negative pressure when it collides with any solid or dense object such as a building. The windward side creates a positive air pressure due to the compressive force while the leeward side creates a negative air pressure due to the vacuum. In addition, an increase in air speed will result in a decrease in air pressure, known as Bernoulli's principle; and the Venturi effect or jet effect means that air travelling through a constriction will increase in speed to satisfy the principle of continuity and conservation of energy (Lechner 2009, 267-274).



Bernoulli's principle and venturi effect (redrawn from Lechner 2009)

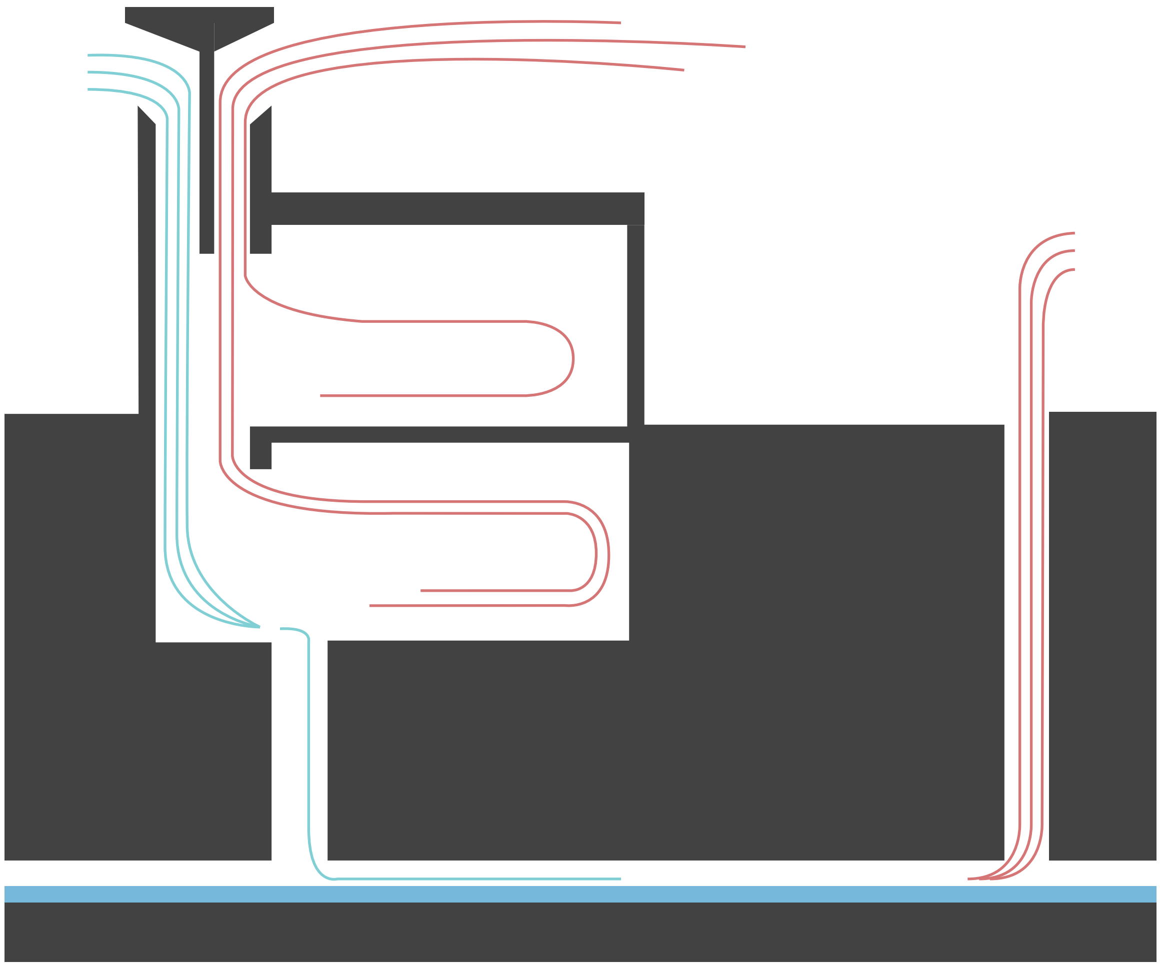
The stack effect is another basic passive ventilation principle that utilizes the movement of air driven by the difference in air density, also known as buoyancy, between the exterior and the interior of a building. By itself, the stack effect is a weaker force for driving ventilation since it does not rely on the wind, but solely on pressure differentials. For example, a building will naturally have a positive pressure near the roof and a negative pressure near the ground with a neutral axis somewhere in between. Thus, to increase the air flow or buoyancy force, either the neutral axis must be moved higher by increasing the height of the structure, or by increasing the thermal difference. The solar chimney is a deviation of the stack effect that makes use of the thermal difference by heating the interior air to increase air flow after the air leaves the main living area of the building (Lechner 2009, 278-281). Using these basic principles, a building can be designed to passively ventilate.



Stack effect demonstrated with a solar chimney. Solar chimney are painted black to absorb heat and increase the thermal difference.

Susan Roaf (Beazley and Harverson 1982, 58) described that in hot climates and windy deserts like the Taklamakan, wind-catchers can contribute greatly to the comfort of those living there. It is known that even in the 17th century, travelers through the Persian Gulf and other trade routes through hot regions have documented these wind catchers. As described by Thevenot: “they have upon the tops of their houses, an invention for catching the fresh air: It is a Wall one or two fathome high, and bout the same breadth, to which at the intervals of about three foot, other Walls about three foot broad and as high as the great Wall, join in right Angles; there are several of such on each side of the great Wall, and all together support a Roof that covers them: The effect of this is, that whatsoever corner the Wind blows, it is straight betwixt three Walls, and the Roof overhead, and so easily descends into the house below, by a hole that is made for it” (Thévenot and Lovell 1687, 87). The performance of these wind catchers is primarily affected by the height and intake volume, since air resistance and air temperature decreases with height. However, it has to be noted that if the wind speed is not high enough, these wind catchers will essentially become ventilators since the heat stack effect will override the down draft create be the wind. Therefore, many wind catchers work best when there is only unidirectional wind creating a positive pressure on the windward side drawing air down the shaft and a negative pressure on the leeward side drawing air up and out the shaft. It is also common to have a pool of water directly beneath the wind catcher towers to cool the water and humidify the rooms in dry desert climates (Beazley and Harverson 1982, 58-85). In rural and extreme environments, wind catchers are cheaper and require less maintenance than their expensive mechanical counter part of ventilation and air-conditioning.

Comparable to the wind catchers which uses underground waterway to cool the incoming air, earth tubes, also known as indirect earth coupling, utilizes the earth to either cool or heat the air depending on the deep earth temperatures. Since the earth has a much higher heat capacity or thermal storage than air, it will experience a more gradual temperature change whereas the air temperature difference will be more extreme. The earth tubes should be buried as deeply as possible since the increase in depth means an increase in the temperature stability. The surface area the pipes cover will also determine the heating or cooling efficiencies (Lechner 2009, 257-293).



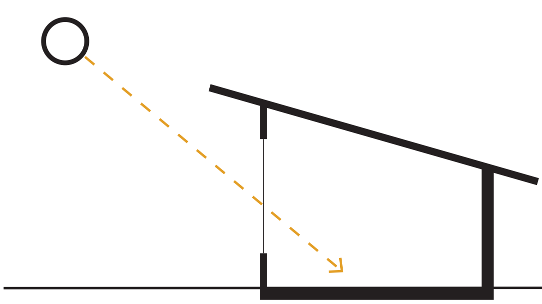
Basic wind catcher and indirect earth coupling design section (redrawn from Williamborg 2010)

Technologies: Solar

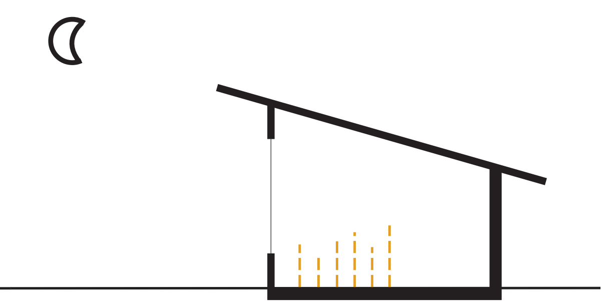
Solar is of abundance in the Taklamakan desert, and it can be easily utilized to benefit its inhabitants. The region receives between 2500-3500 annual sunshine hours and around 311 average June sunlight hours. Passive solar is an effective method to provide human thermal comfort in the desert climate. Basic principles of passive solar techniques make use of heat or thermal exchange. Thermal transfer occurs through convection, conduction, and thermal radiation. Convective heat transfer is described in the previous ventilation and wind section to cool interior spaces. The major source for heating an interior space will rely on solar radiative heat transfer and through ground conductions. The three primary passive solar configurations are direct solar gain; indirect solar gain; isolated solar gain (Bainbridge and Haggard 2011, 45-46).

Direct solar gain refers to the amount of sunlight entering the building or living area. In the winter, the sun will be at 25° to the horizon; during spring and autumn, it will be at 50°; and 75° in the summer. Therefore, adequate shading such as louvres will be required to prevent overheating in the summer while still providing radiant heat in the winter when the sun is low. Roof designs, building openings, and building orientation can control the direct solar gain as well (Kwok and Grondzik 2007, 69-270).

Indirect solar gain refers to the heat that is transfer to adjacent areas through thermal mass. Thermal mass or thermal capacitance is the ability of a body or material that can store thermal energy. It works by absorbing solar energy during the day and releases thermal energy at night to stabilize temperature variations (Bainbridge and Haggard 2011, 68-70). For example, water tanks, masonry wall or concrete floors can radiate heat into the building after it has absorbed direct solar energy.



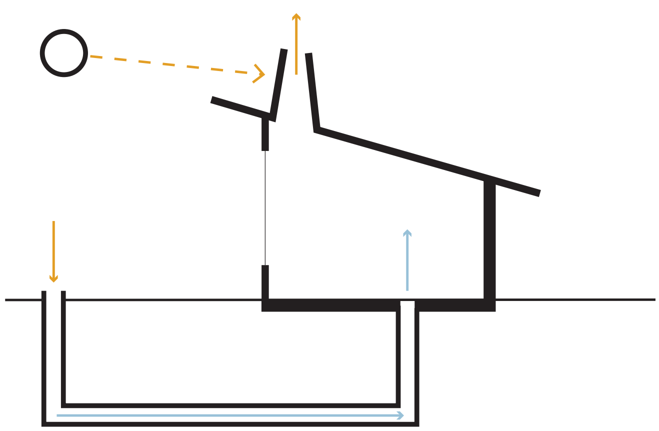
Direct solar gain



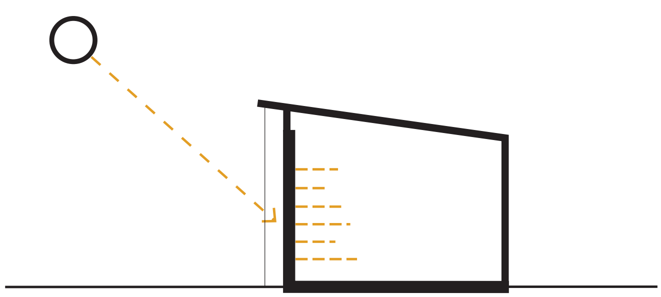
Indirect solar gain

Isolated solar gain involves the movement of heat through the use of solar energy. Some examples include solar chimney which make use of the stack effect; thermo-siphon which uses passive heat exchange based on natural convection currents; and ground-coupled heat exchanger that captures or dissipates heat using the earth's more stable and constant temperature changes (Bainbridge and Haggard 2011, 72-74).

A combination of these passive cooling systems can be seen in the Trombe wall system. First designed by Edward S. Morse then fully developed by French engineer Felix Trombe and architect Jacques Michel, a Trombe wall is passive solar design that collects thermal energy during the day and releases it towards the interior at night. It is based on the principles of not too dissimilar from greenhouses, where the solar energy is absorbed by the inner thermal mass while the exterior glass panels prevent the absorbed heat from leaving the structure through convection. At night, the thermal mass will radiate the collected heat back into the room (Bainbridge and Haggard 2011, 66). The modern designs have included use the stack effect within the air space between the exterior rain screen and the wall to improve ventilation. With no moving parts, passive solar Trombe walls are essentially maintenance free and well suited for the desert.



Isolated solar gain



Basic Trombe wall

Precedents: Shelters

The form of the architecture will play an important role in how well the structure will adapt to the environment. Magnus Larsson's Dune project (Larsson 2009) proposes a 6000 km long solid sand dune structure that will create a shelterbelt of trees to combat desertification. To achieve this, micro-bacteria are utilized to solidify the sand into structural elements, creating a network of nodes and paths which can also be used to harvest water and be inhabitable. The bacteria, according to Larsson research, are non-pathogenic and will die after solidifying the sand. Larsson's Dune project also derives its form from erosion patterns of rock structures to create shelter from wind and temperature differentials. While his project provides an interesting point of view on how to design large scale massive structures in the desert, there are other aspects that have to be considered such as human comfort, local program, and building details.

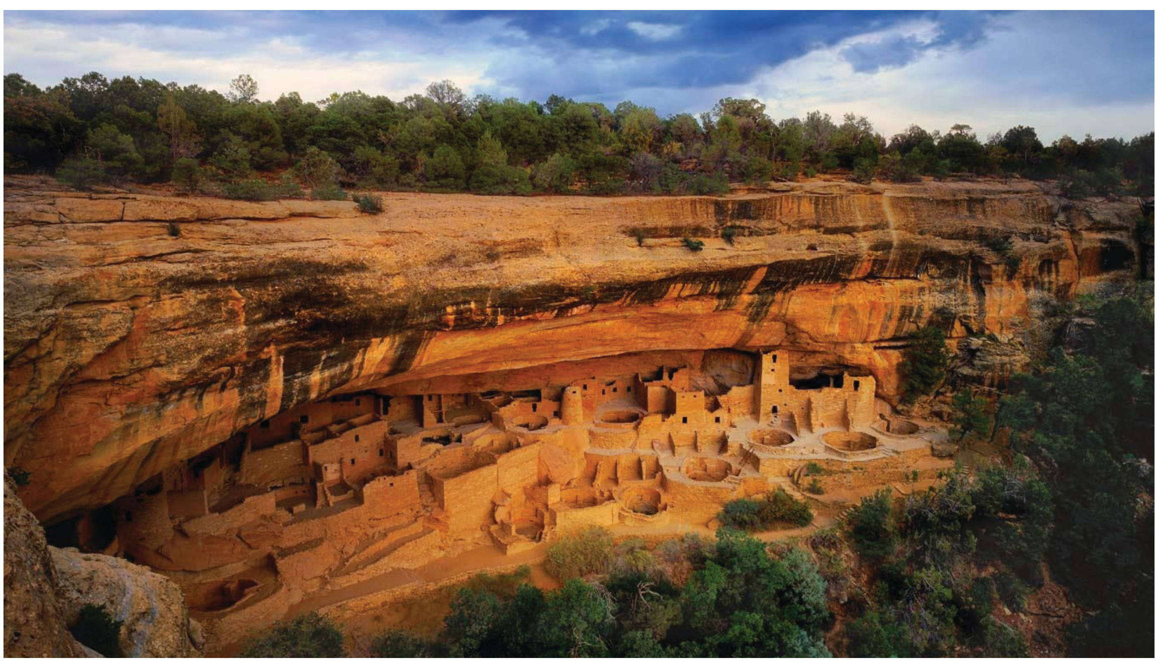
Dune Project: Sahara Desert (Larsson 2009)

In *Living with the Desert*, Beazley & Harverson (1982, 89-102) described the various challenges and impact these minor details can have on the inhabitants. Buildings in the Iranian desert have traditionally been designed with thermal comfort and ease of maintenance in mind. Walls were usually thick and built with mud bricks to retain as much heat as possible at night during the winter months. But in the summer, the thick wall is disadvantageous since it is retaining too much heat for the inhabitants to comfortably sleep indoors; for that reason, it is usually a custom to sleep on the roof. These desert structures are designed to be maintained regularly due to mud's poor performance against rain, snow, and earthquakes. Thus, all of these buildings have either exterior or interior steps to reach the roofs. Roof forms are another important aspect of their building design. Flat roofs are common because it is easier to build, light, cheap, retains more heat, and provides a surface to sleep on during hot summer nights. Domes and vaults, while being harder to build and heavier, radiates heat faster due to its large surface area and through convection. Domes are normally built with openings at the crown to give better ventilation, especially when the exterior temperature is lower than the interior. Other advantages of the dome are that the height protects the occupants from direct outdoor glare and heat while providing self-shading by reducing the surface area directly perpendicular to the sun. The opening crown also lets in soft daylight similar to that of a light well. Both the flat roofs and dome roofs have their respective advantages and disadvantages, thus understanding which one to use will depend on the different sites, situations and climates.

Iranian desert building with dome roof design (Minerva 2007)

Buildings like the Poeh Cultural Centre in New Mexico use thick adobe walls as thermal mass to regulate human comfort, while dwellings at Mesa Verde, Colorado, take advantage of the heat sink capacity of the rock cliffs and stone walls to establish an earth coupling effect. In addition, the south facing, overhanging cliffs provides adequate shading during the summer months. As a result, these structures maintain a stable temperature throughout the year.

Poeh Cultural Centre: New Mexico (PoehCenter 2013)



Cliff Dwellings: Mesa Verde (Huey 2013)

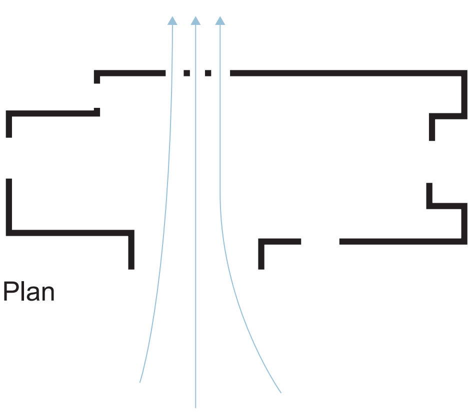
In regions that are hot and humid, building designs tend to focus more on ventilation where lightweight structures are preferred over thermal masses. While the sun is not as intense as dry climates, any additional heat added to the humidity can be discomforting. Traditional buildings in Southeast Asia or Japan, for example, use post and beam construction with lightweight wall panels that can slide open for maximum cross ventilation. Large overhanging roof is another feature of these building types where they not only act as protection for the wall panels but also create an outdoor shaded space.


Traditional Japanese house with sliding screen walls. (Olson 2009)

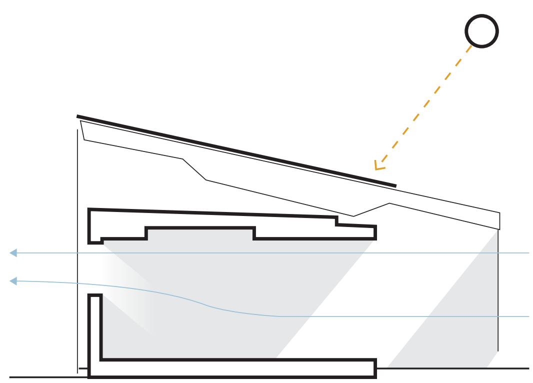

Modern Southeast Asia design with large overhanging roof. (Gfab Architects 2010)

Although it is not completely passive, the Cornell house at Cornell University integrates some of these basic technological principles really well. With a semi-independent canopy structure, it showcases the idea of natural ventilation, solar angle, day lighting, and shading. The house core and the sloped roof make use of the Venturi effect where air is forced through a narrow opening thus increasing its velocity. The 13 degrees slope of the roof also expands the solar surface area to power photovoltaic panels. Day lighting and shading are automatically controlled by daylight sensors that move the exterior louvers, vegetated screens, and the light canopy. This system allows the house underneath to operate independently and adapt when newer technologies becomes available. However, the downside to this is the cost of constructing and maintaining the two independent systems as well as any upgrades in the future (Zaretsky 2010, 96-103).

“Light Canopy” Cornell house (Koplinka-Loehr 2007)



Plan



Section (redrawn from Zaretsky 2010)

CHAPTER 2: DESIGN

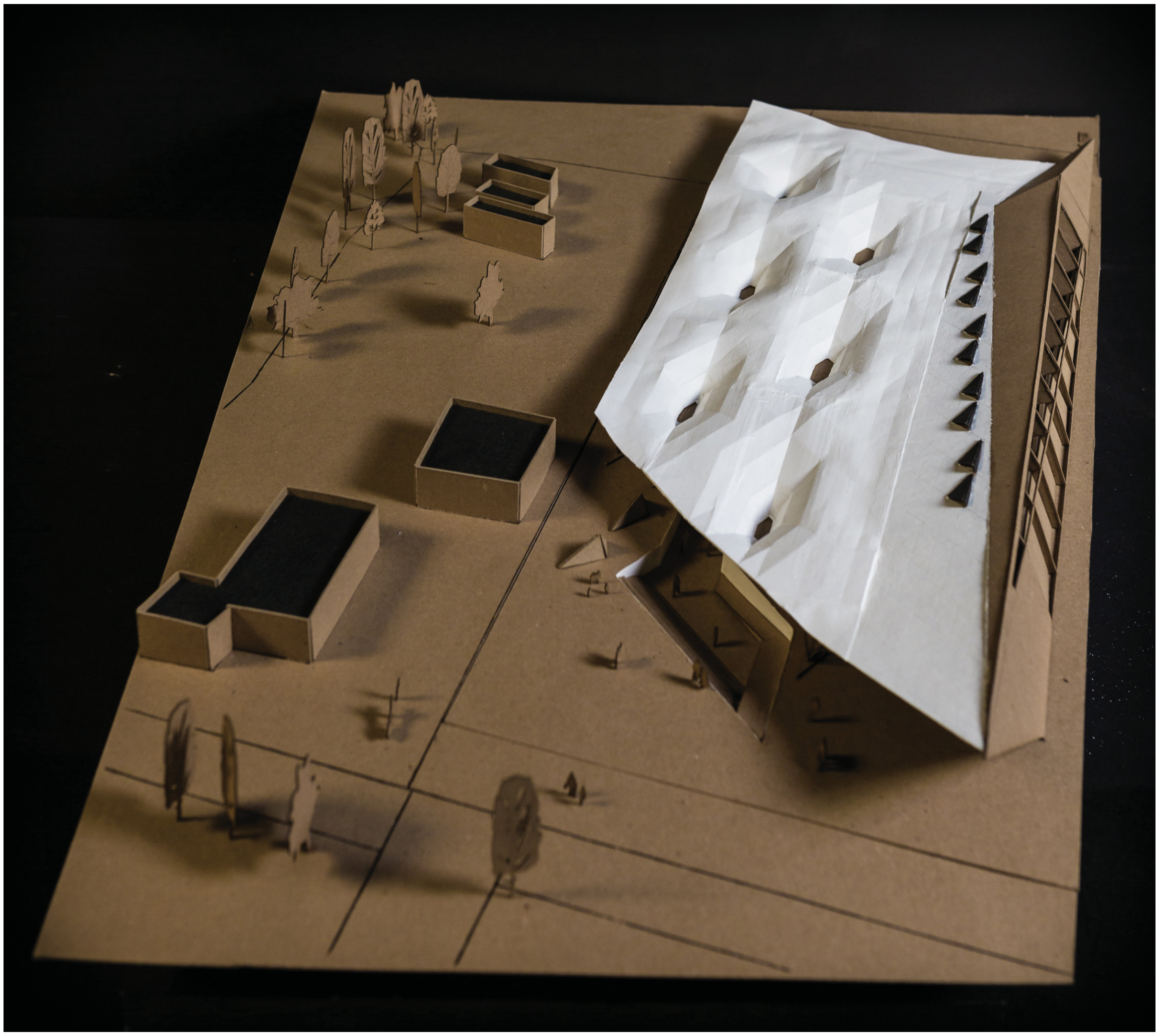
Village

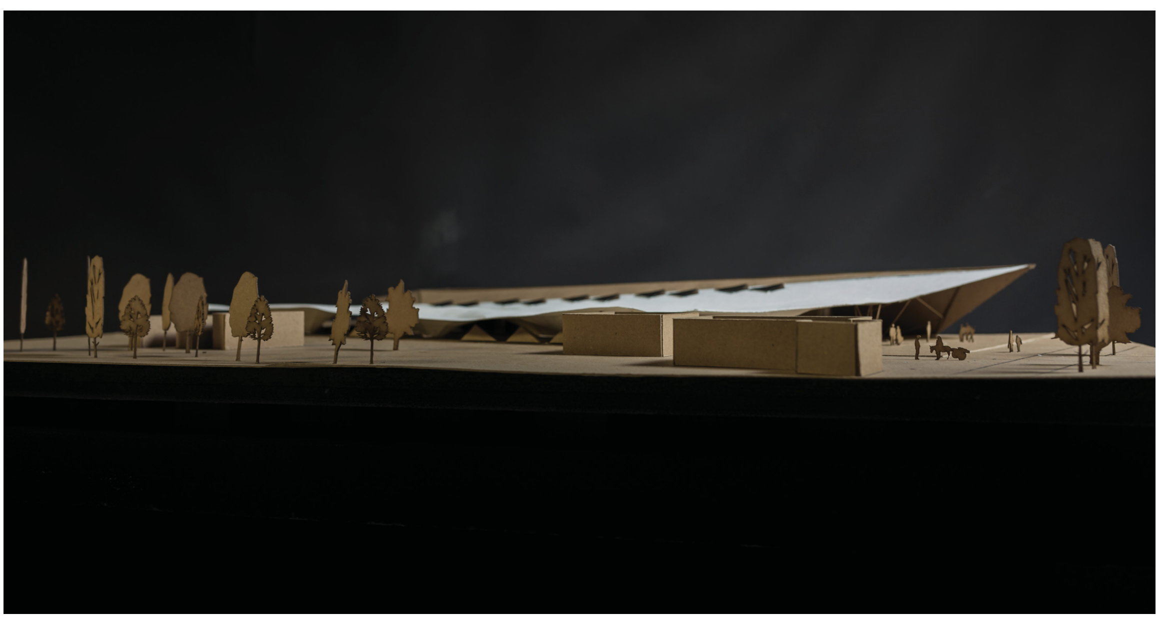
As the starting point and gathering place for all kinds of travelers, from scientific expeditions to solo explorers to the annual pilgrimage, the village serves as an important node in their journey. It is a place where travelers can rest and gather up supplies before heading into the desert.

Therefore, the conceptual and formal strategies for the village structure centres around the basic principles of passive radiative water collection, solar energy collection, ventilation, and shelter.

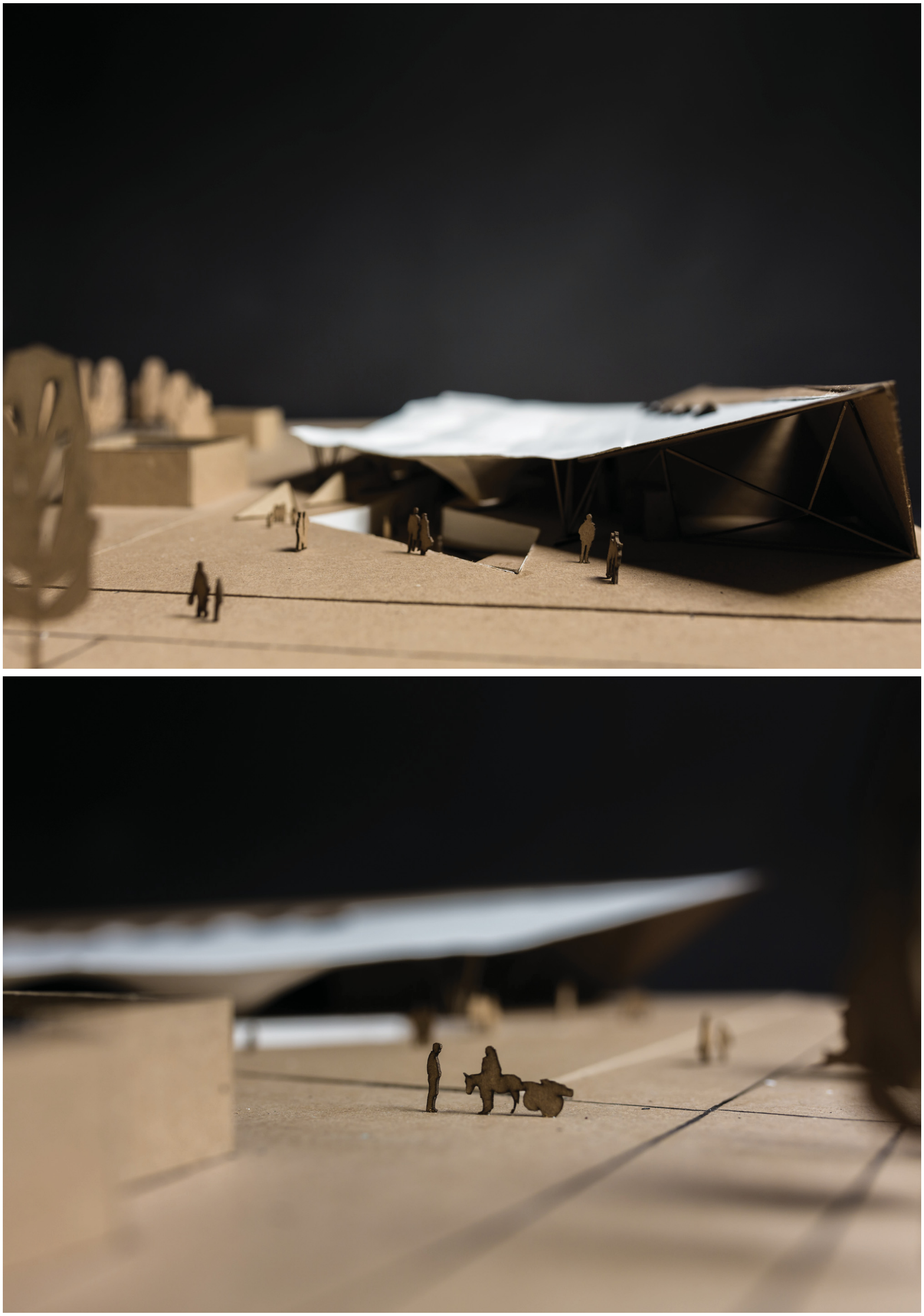
The proposed design will focus on creating both public gathering spaces and private dwelling spaces on the site. The sunken public courtyards shelter the occupants from the cold winds in the winter months while the direct earth coupling provides stable thermal comfort year round. The difference in elevation result in the separation of the public and private area, where the public will gather in the sunken courtyards and the ground level corridor in front of the rooms becomes a semi-private space for the occupants.

To accommodate the fluctuations in traveller groups throughout the year, private rooms gradually get smaller whilst the southern glazing gets bigger the further away it is from the main road. By doing so, individual travellers who wish to keep to themselves can have secluded rooms while the bigger rooms, for large caravans or expedition teams, are more connected to the public spaces near the main road.



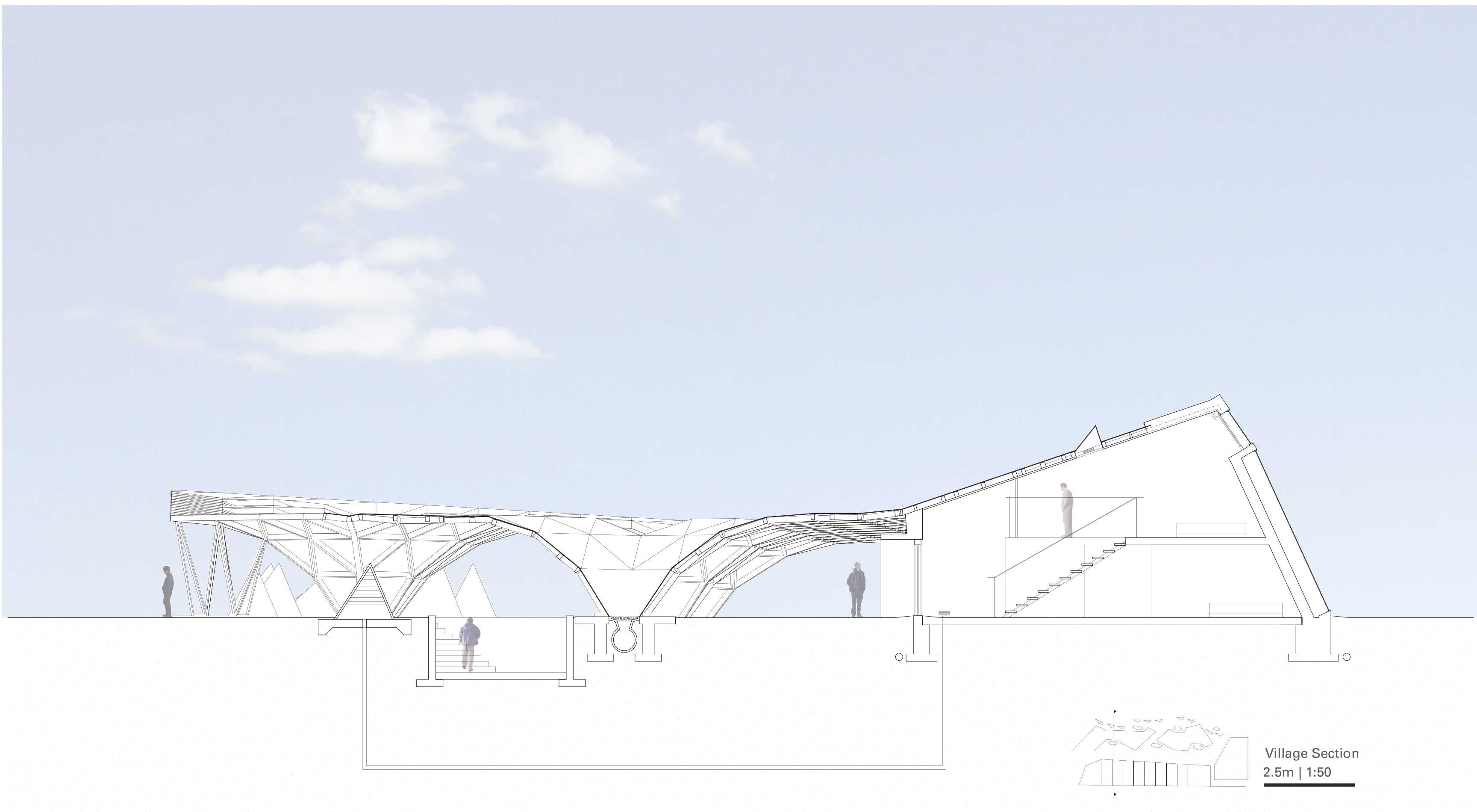


Village structure physical model



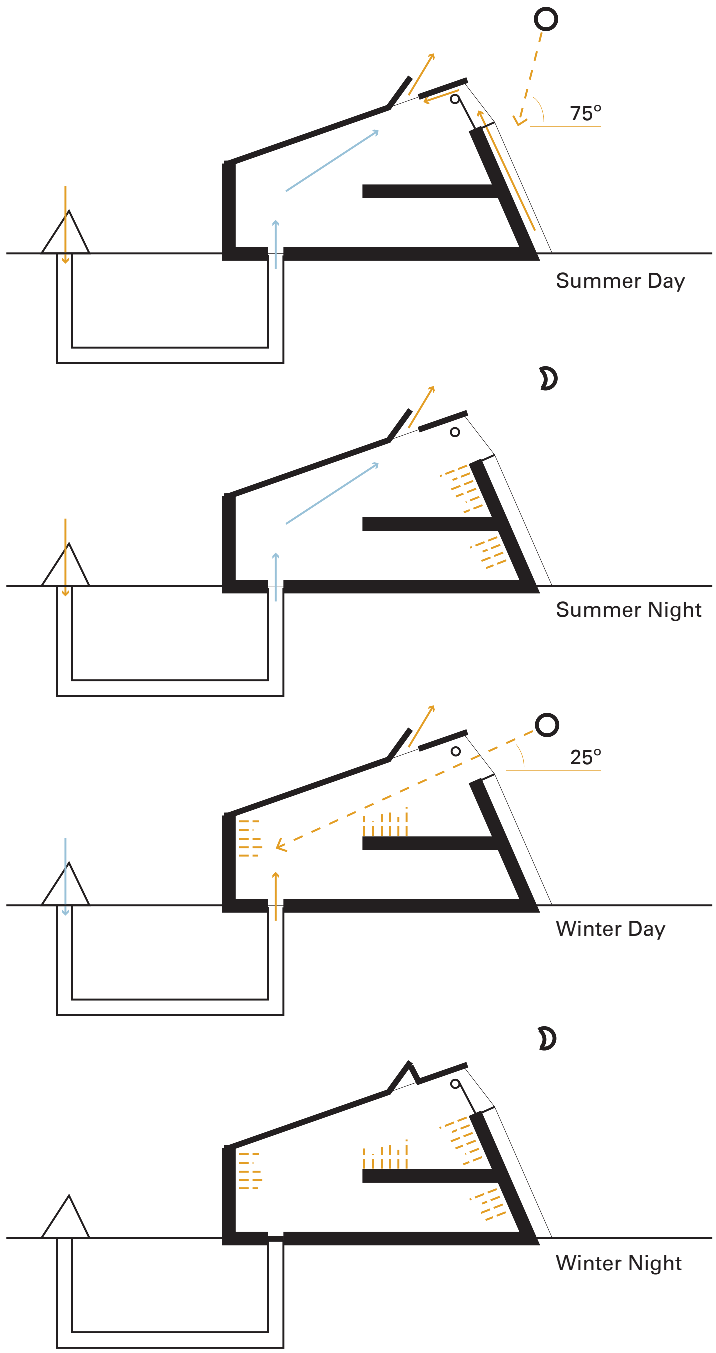
Village structure physical model

Village structure site plan (base image from Google 2013)

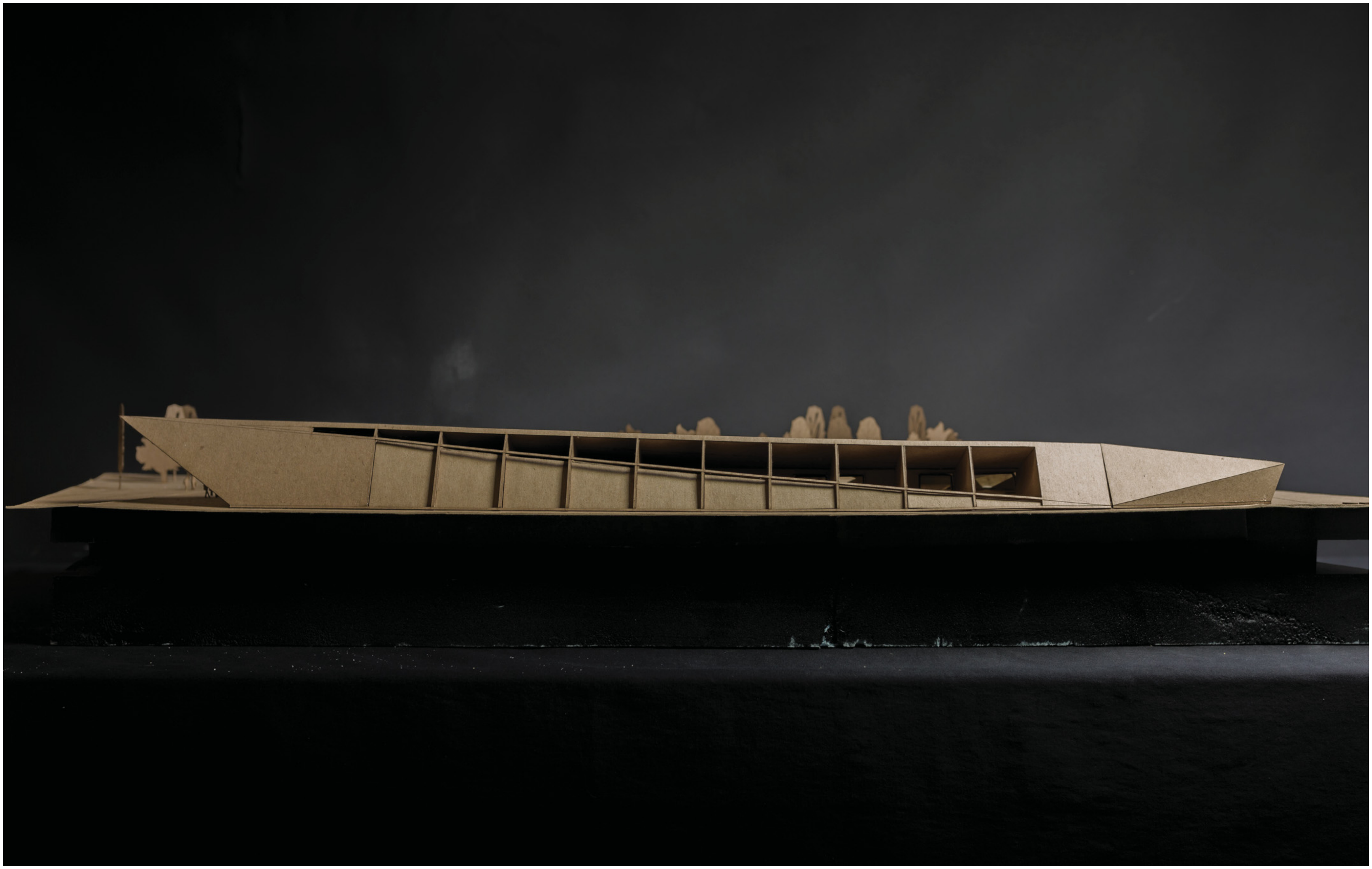


Village structure section

One of the main features of the building is the south facing Trombe wall that passively absorbs solar energy during the day and radiates heat during the night. The wall is tilted at a 25 degrees angle to increase solar gain during the cold winter months. In the summer, interior blinds turns the Trombe wall into a solar chimney, thus increasing the air flow along with the passive ventilation from the earth tubes. This system lets occupants control and maintain their optimal thermal comfort.



Trombe wall diagram

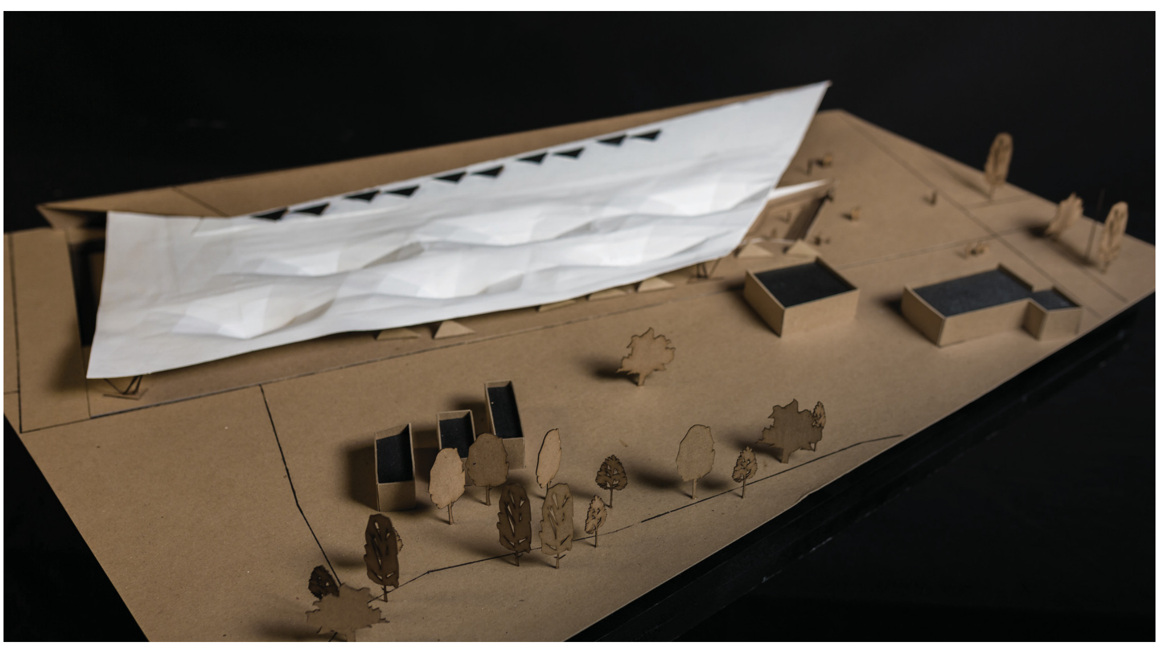


Physical model showing the south facing Trombe wall

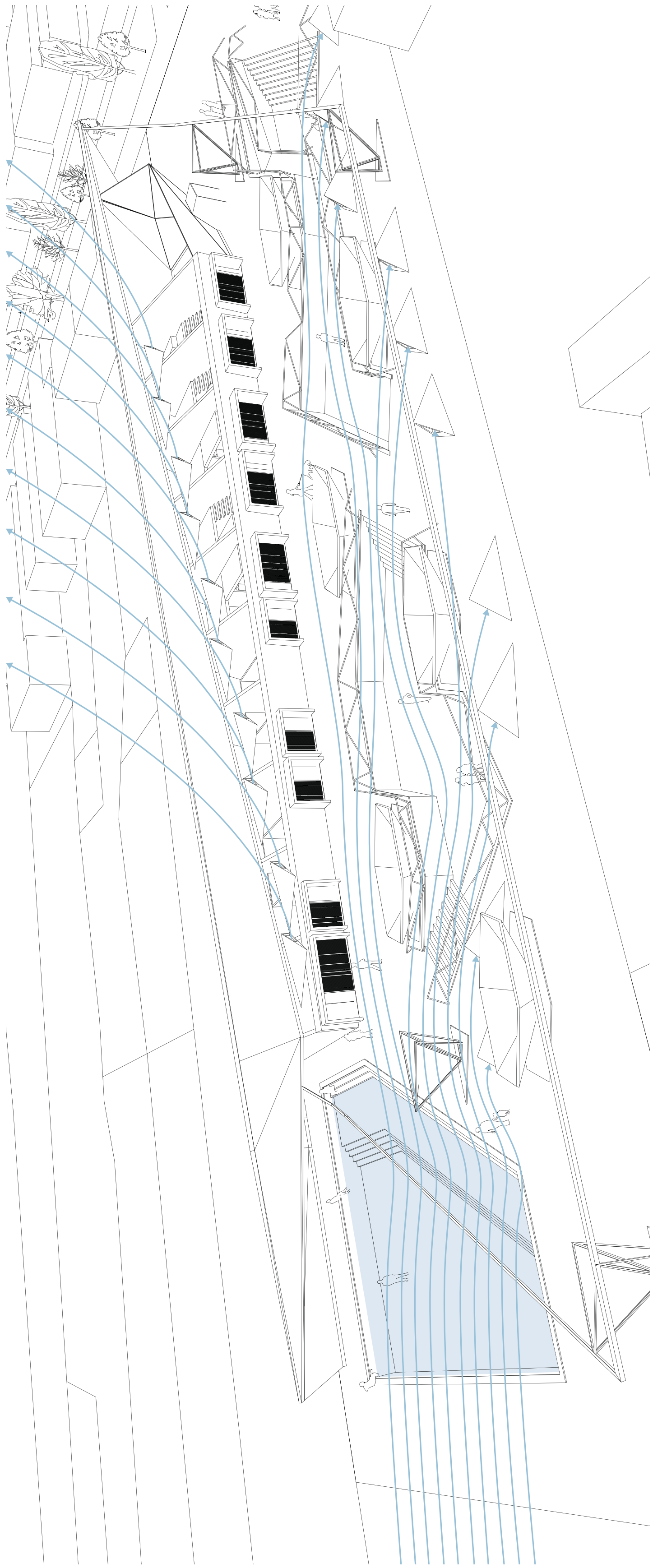
The primary building form is dictated by the south-eastern prevailing wind as it angles to maximize the airflow and ventilation. The large overhead canopy takes advantage of the Venturi effect to increase air velocity under the canopy passively. The increase of air pressure under the canopy in conjunction with the decrease in pressure over the roof exhausts generate a siphoning effect from the ground level wind catchers through the earth tube system to passively ventilate and regulate the temperatures in the dwelling spaces.

Moreover, the canopy form provides a large 1800 m² of passive radiative vapour and moisture condensing surface for an average of 120 litres of water collection per day as well as shading the public courtyards from direct sun exposure. The water collected drains to a holding tank which then feeds into an evaporative cooling pool. As hot dry air passes over the pool, it will turn into cool humid air that flows into the courtyards.

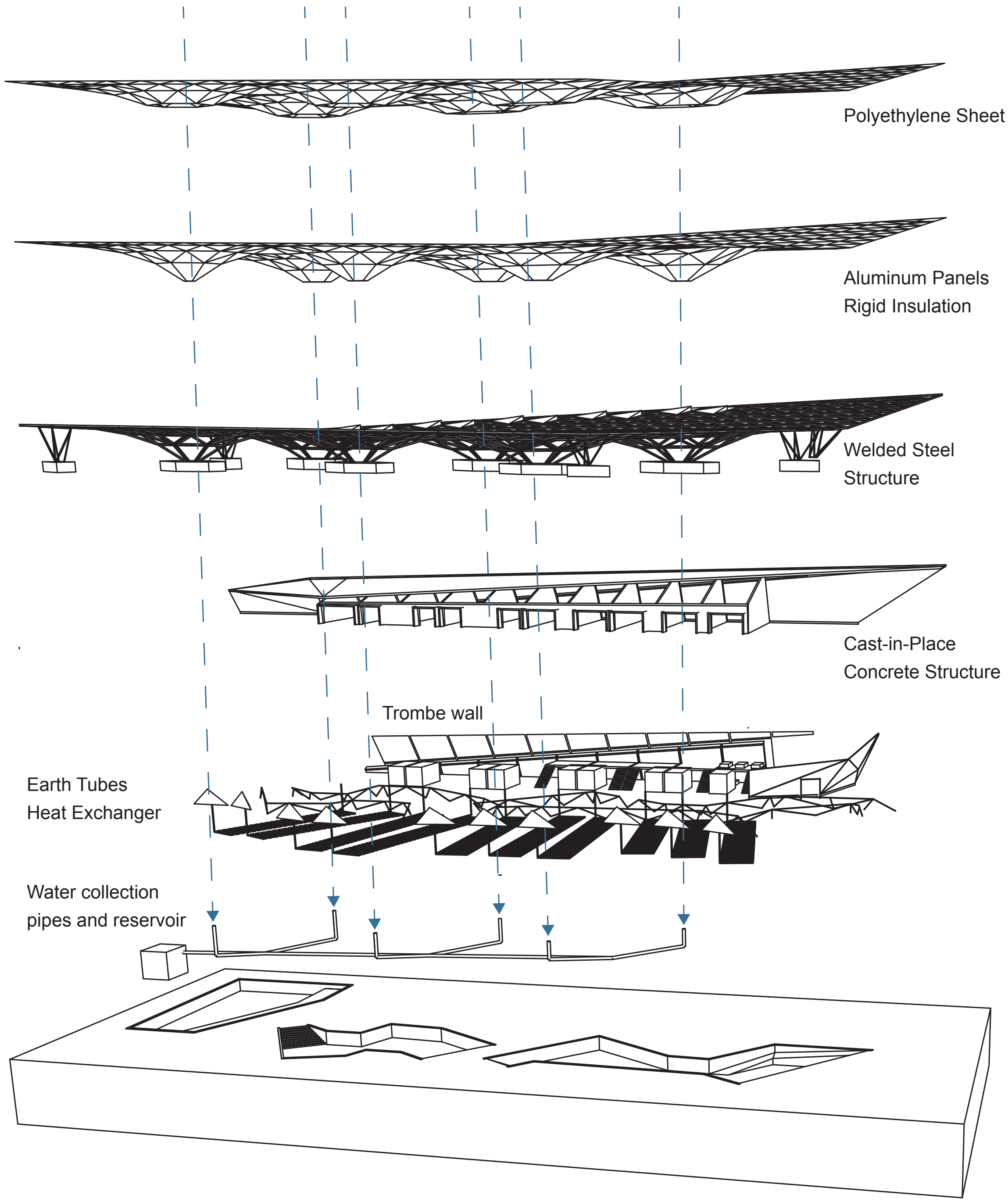
The materiality of the building structure also corresponds to the public private zone divisions. The private dwelling areas use heavy cast-in-place concrete structures that invoke a sense of weight but also benefit from being exceptional thermal masses. The canopy over the public space uses a lighter steel structure, aluminum panels, and poly-ethylene sheets for ease of construction and maintenance, as well as yielding greater water condensation results and has superior radiative effects.



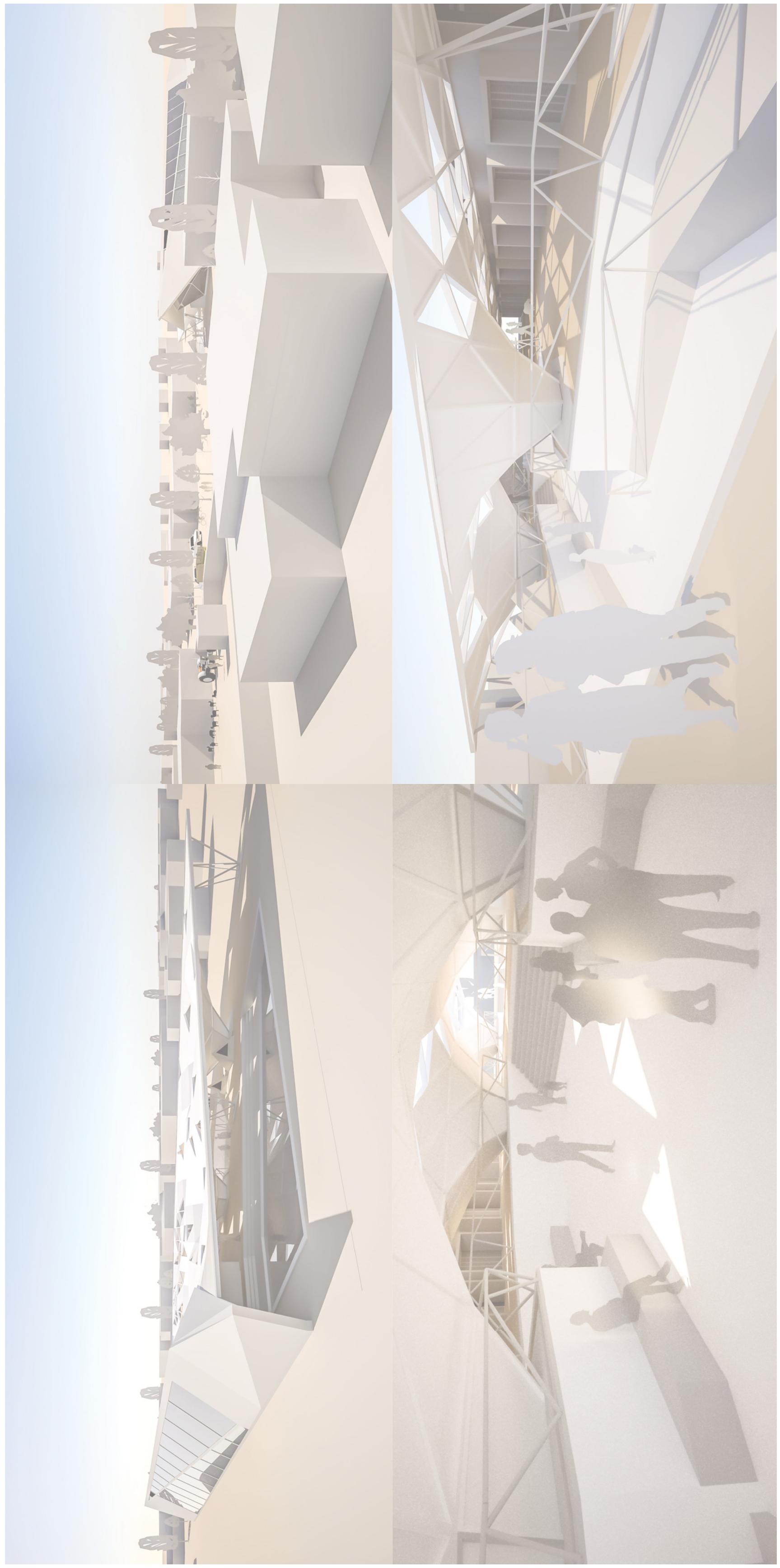
Physical model showing the canopy form



Airflow and ventilation diagram



Exploded perspective diagram of the village structure



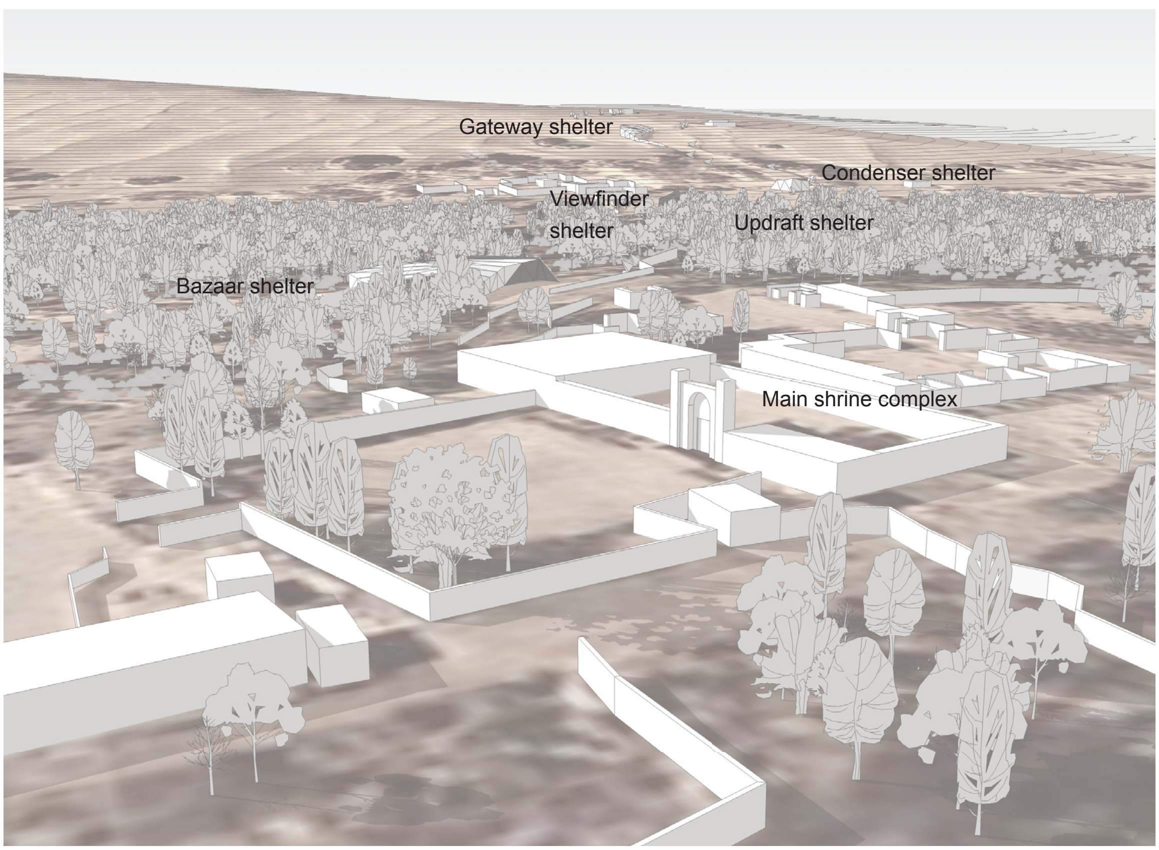
Perspective renders

Entrance perspective render

Shrine

The shrine is the transition point where the forested expanse meets the desert. The pathways leading from the shrine into the desert are worn down by seasonal pilgrimages. The design for this site acts as markers leading travellers and pilgrims through the historic path with various shelters along the way, each creating a unique experience.

The idea is for these semi-permanent, light-weight structures to adapt with the users and environment. Made with steel structural tubing and skinned with heavy tarpaulin (tarp), these shelters can be set up with relative ease and are essentially maintenance free. Each shelter will serve a different specific purpose with the primary function being protection from direct sun and wind exposure. Every shelter also has pumps to replenish the travellers' water supplies.

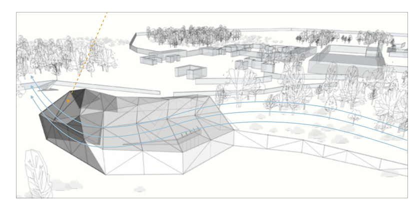


Shrine site aerial perspective

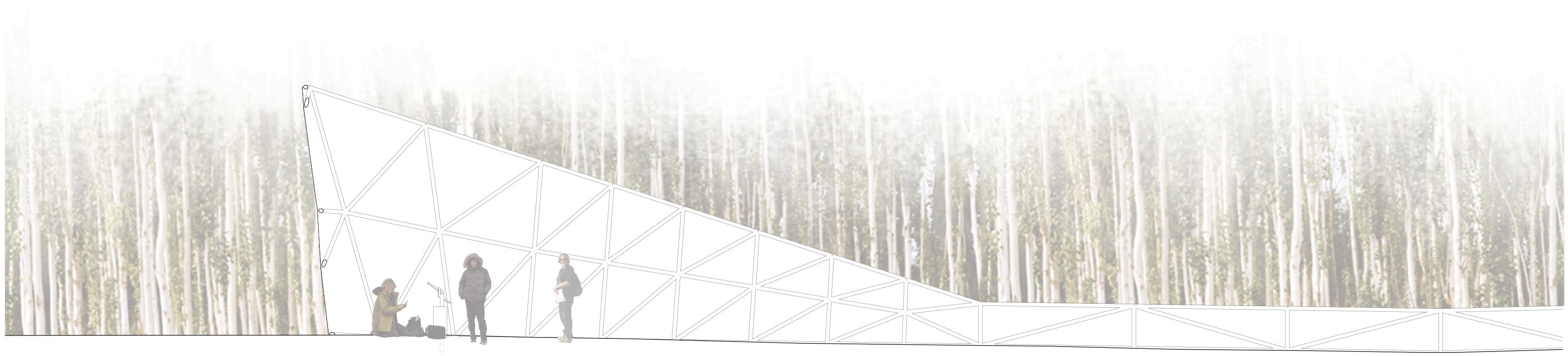
Shrine site plan (base image from Google 2013)

Pumps draw water from nearby water collectors

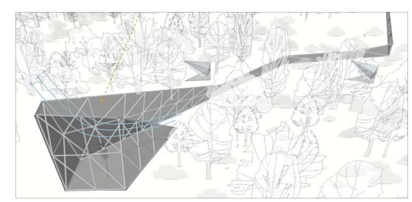
Bazaar Shelter
2.5m | 1:50



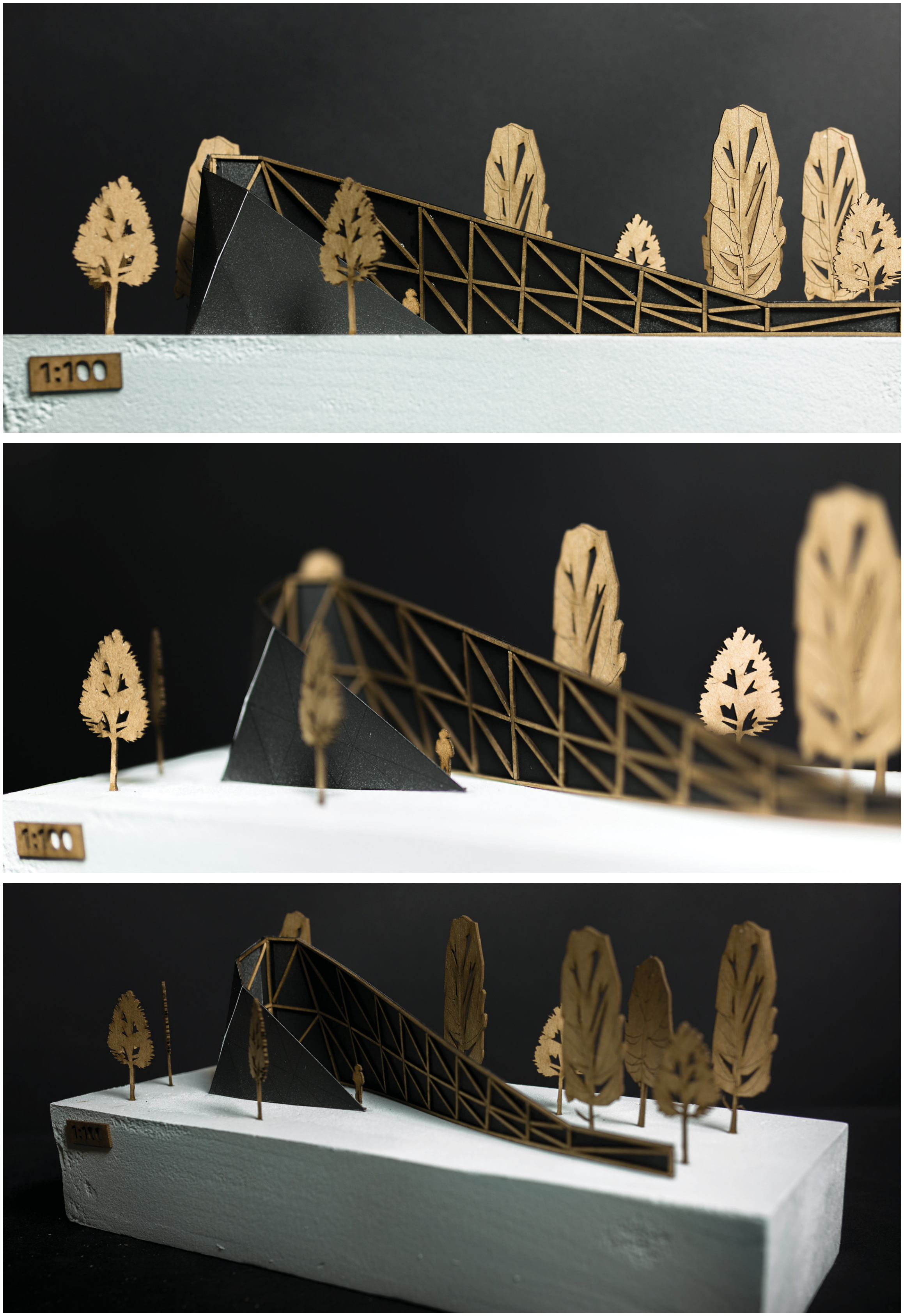
Moving along the pathway, visitors will first encounter a larger bazaar or market like shelter near the main shrine complex. It has multiple water pumps for large gatherings and provides a shaded space to set up booth for trade, food, or entertainment during the festival seasons. Since it will be used by a larger group of people, the space is well ventilated with a solar chimney to improve air circulation.



Updraft Shelter
2.5m | 1:50



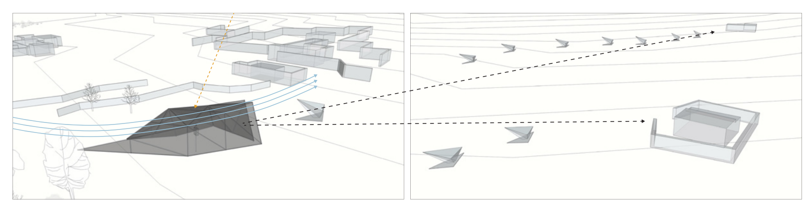
Traversing into the forested area of the route, visitors will come across the solar updraft shelter. This shelter is painted black to increase the solar gain thus increasing the stack effect. The idea is to cool the temperatures of the dense forest floor where the winds cannot reach. The structure gradually morphs into a low wall that guides the travellers through the forest.



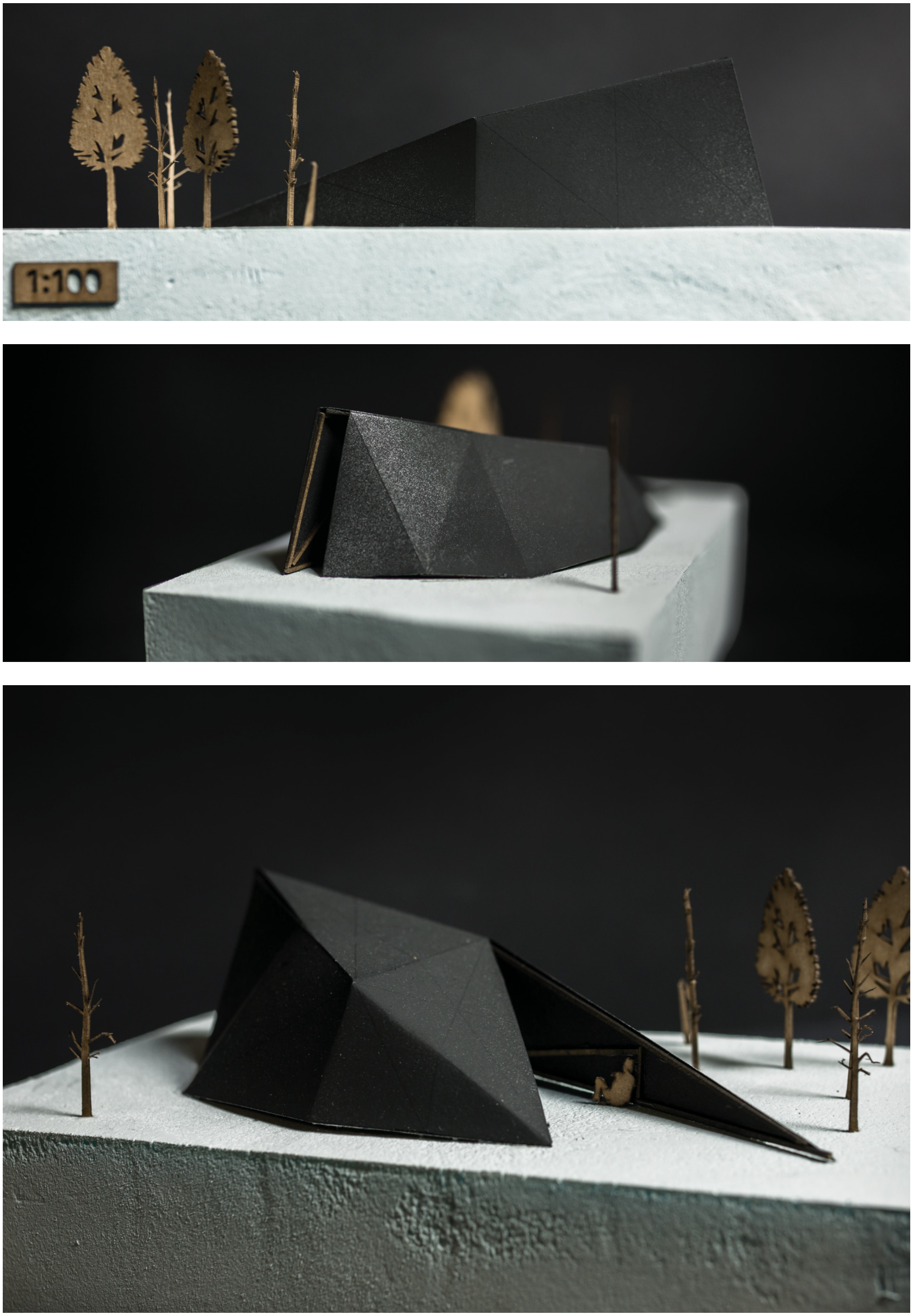
Updraft shelter physical models

Viewfinder Shelter
2.5m | 1:50

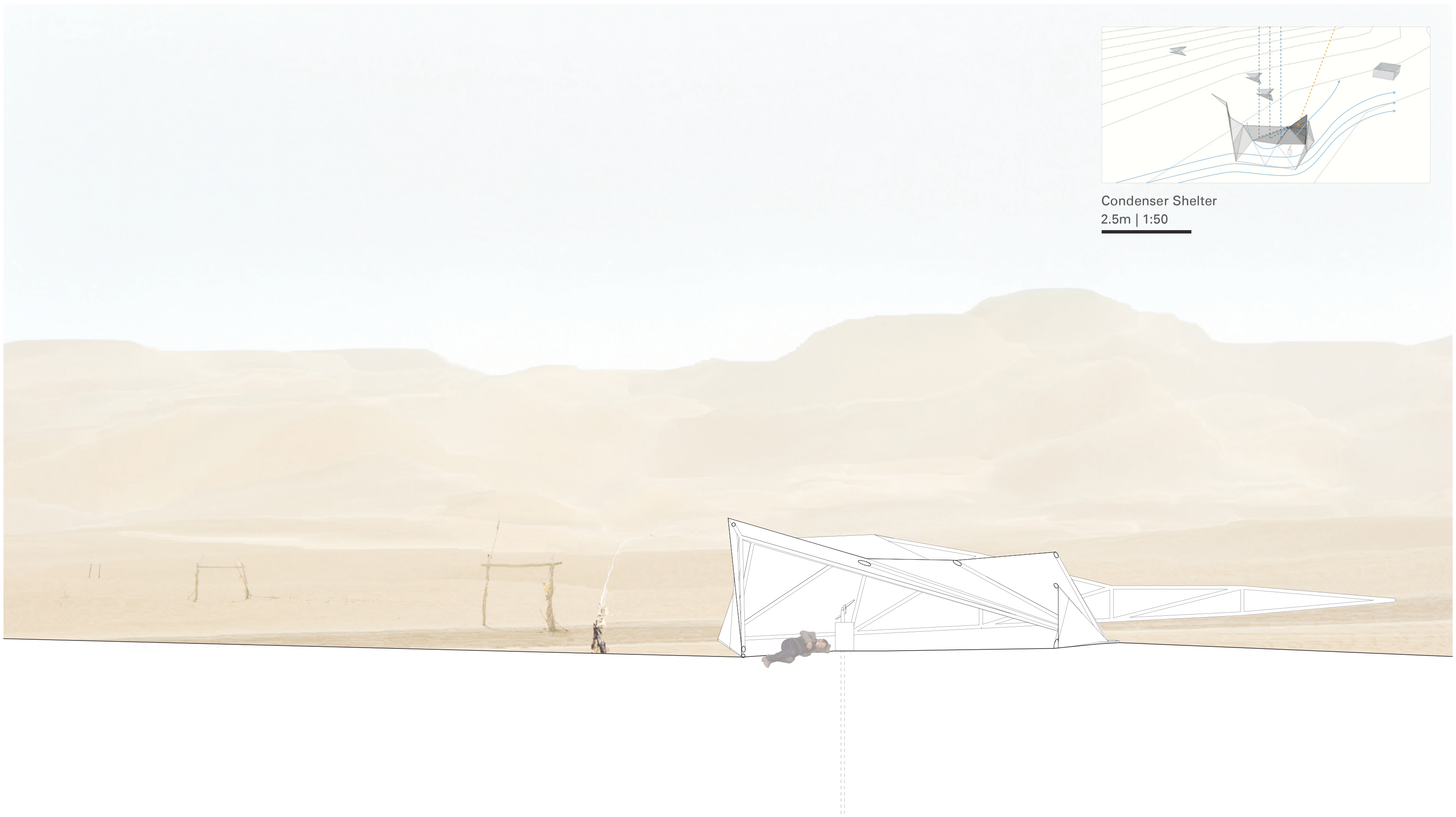
Desert Tombs



Advancing out of the forest, travellers are presented with a viewfinder shelter. This shelter aligns the view towards the direction of the tombs in the desert. Due to the orientation and form of the structure, it will have increase airflow inside the shelter. While it is optimal in the summer, the skin of the shelter must also be painted black to stabilize the cold winter temperature and winds.



Viewfinder Shelter Physical Model

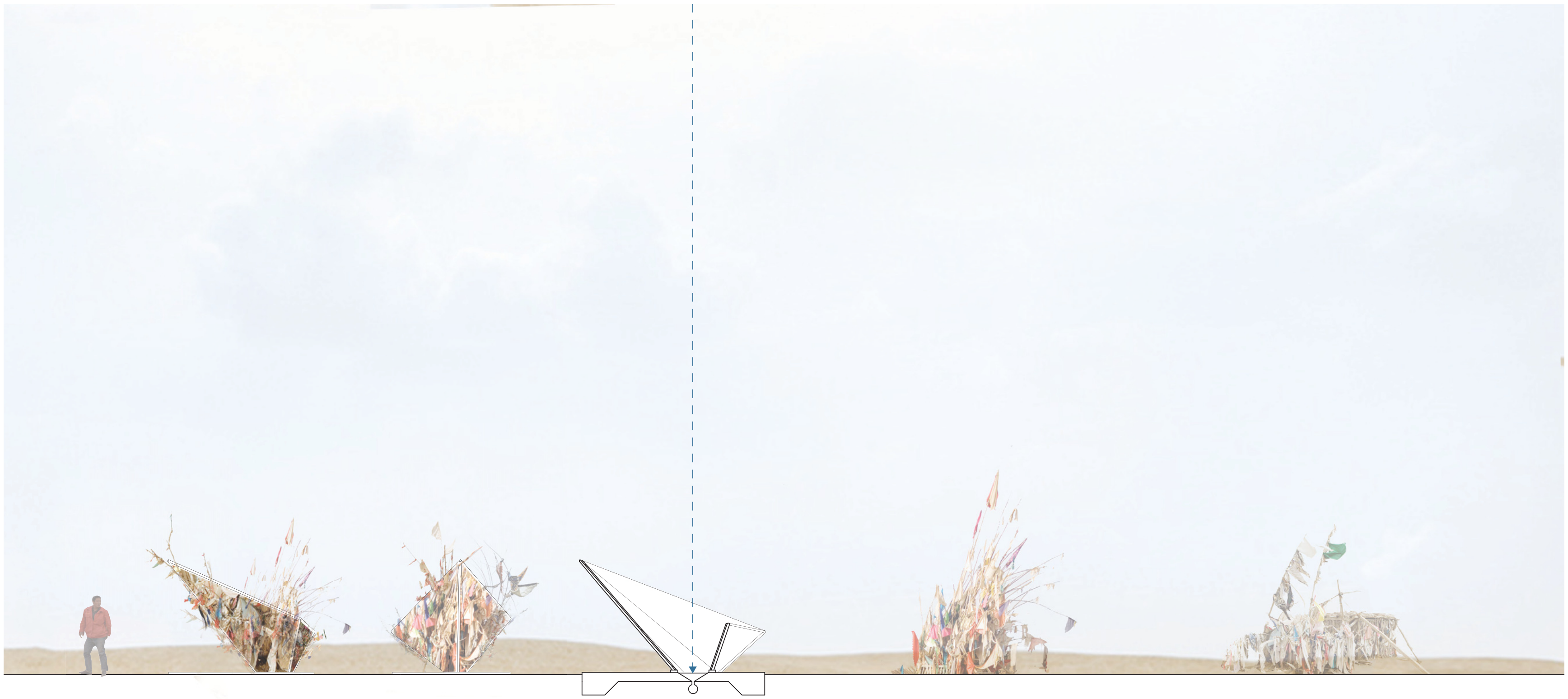


At the base of the sand dune lies the condenser shelter. The large surface area and low angled roof makes this an excellent water condenser. On average, it can condense 5 litres of water per day. This shelter will act as a supplement to the smaller water collectors but also provides an enclosed ventilated resting area.

The last shelter is located on top of the sand dune functioning as a gateway to the tombs and the vast landscape. It is also the last location where travellers can replenish their water supplies before heading into the Taklamakan desert.

Aside from the shelters, there are water collectors scattered along the route leading to the tombs that maintains the shelters' water storage. Each of these structures can collect approximately a litre of water per day. These water collectors are designed with triangulated steel structural frames to improve lateral bracing and wind resistance. In addition, each of these water collectors provide a framework for pilgrims and travellers to attach their own offerings, relics, or mementos to mark a prayer or visit, akin to the existing shrines that are representations of collective memories.

Water collector physical model



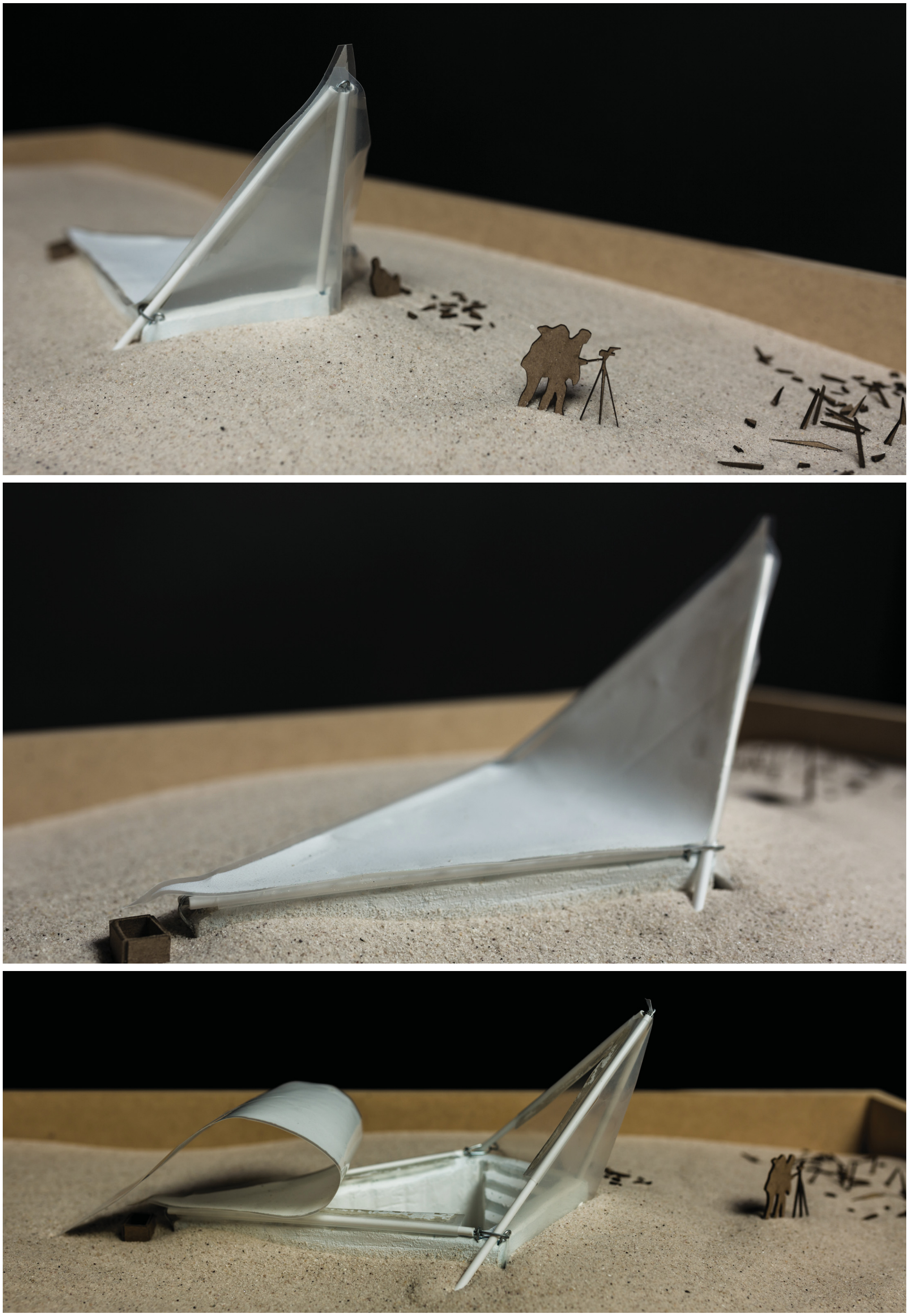
Mementos + Offerings

Water collector elevations (photos from Ross 2013)

Ruins

The ruins site is located far into the depth of the desert. The dispersed and temporal natures of the site are expressed in the characteristic of the design. The program is simply to provide the occupants, mostly archaeologists and expedition teams, an overnight shelter and a source of water in the morning. Taking formal strategies from previous sites, the shelter relies on a simple triangulated steel frame to support the canopy. The 40 m^2 sloped canopy can collect about 2-3 litres of water overnight, which is enough for the three or four occupants to last a day. The dwelling area is sunken into the ground, with sand bags as retaining walls. By using sand as an insulator and building material, it will keep cost down and significantly reduce the environmental impact. The sunken sleeping area can benefit from the effects of direct earth coupling to regulate interior temperatures. A dug trench at the end of the sleeping area will act as a cold air sink and catch any leaks from the canopy. As the expedition moves from site to site, they can bring the tarp canopy along with them and leave the steel structure behind. These protruding structures from the sand mark the location of the shelters with the rest of the fragmented ruins for others to rediscover. In time, these structures will be buried by the sand, melding into the desert.

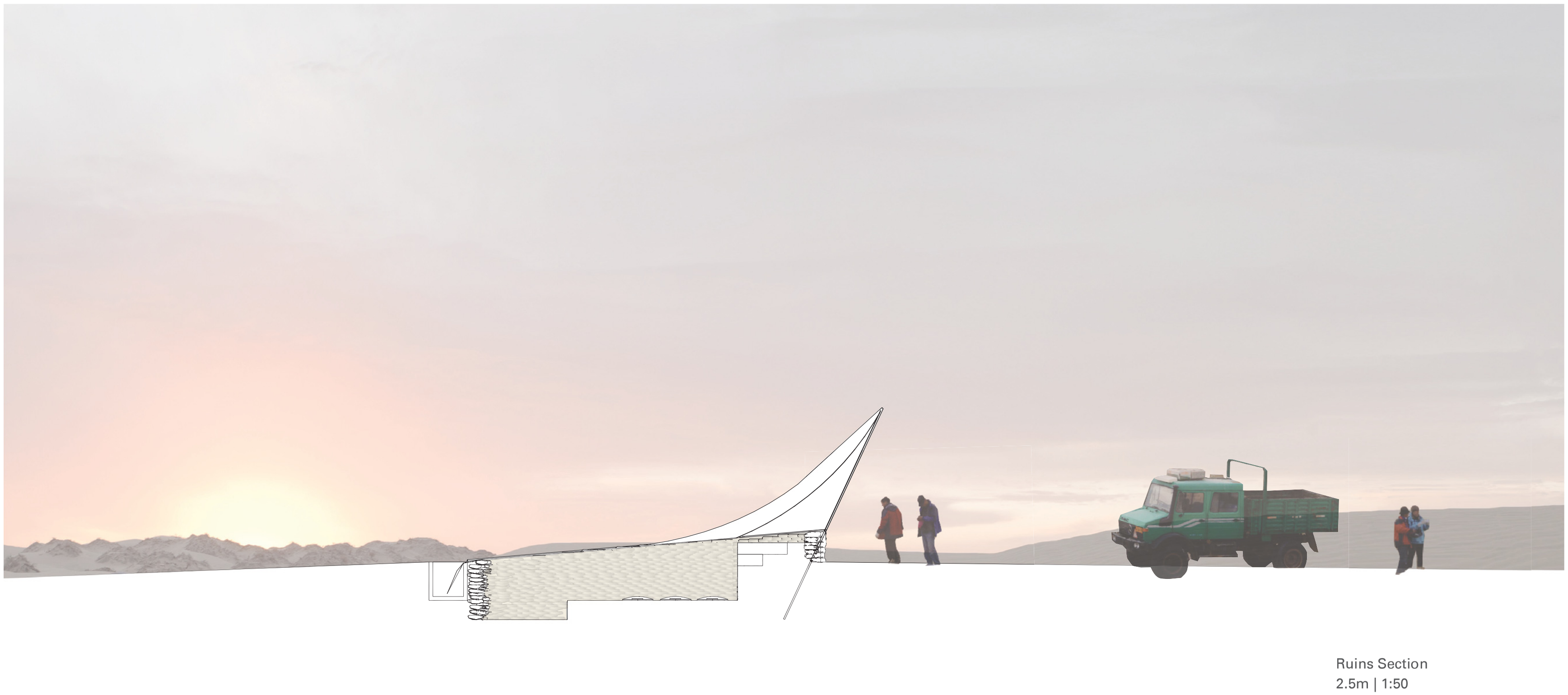
Ruins structure physical model



Ruins structure physical model

Ruins site plan

Ruins section and site photos (photos from Whitfield et al. 2012)



Ruins structure section

CHAPTER 3: CONCLUSION

The aim of this thesis is to set up a relief network for explorers, pilgrims, archaeological and scientific caravans in the desert that is responsive to both the local culture and the environment. The main issue was to resolve the decline in the regional ground water supplies and the advancing desertification of the landscape. However, this study has shown that it is more beneficial and successful to work within the environment and conform to the local ecosystem by introducing gradual changes rather than to forcibly and radically change the desert landscape.

With the dynamic landscape of the Taklamakan desert and the shifting sand dunes as the backdrop, the idea of movement and transformation have to be translated into the overall design. Movement and flow are directed through the village, the shrine and the ruins site, as each site generates a different unique experience of desert culture and atmosphere for the travelers. By examining the structured village site, the fragmented shrine site, and the scattered ruins site, it is evident that all of the proposed designs share similar formal and material strategies for the shelters, integrated with the basic principle of solar, wind and water. As travelers move through the three sites, they should perceive not only a decay of the landscape, but also decays of program and architecture while those core concepts and ideas remain constant. This achieves interconnectedness and establishes a relationship between the sites.

The design does not end with these structures in the desert, but it can grow and accommodate both the ephemeral landscape and cultural fluctuations. Transforming and shifting amidst the Taklamakan desert, some will be buried while others will be revealed.

APPENDIX 1: NODES

A network of structures in the desert can create important nodes not unlike a distributed network. By distributing the nodes, every node will have connections with multiple other nodal points, thus, if a node were to fail, the flow can be directed through other nodes instead of getting cut off. This redundancy is critical in the extreme desert environment where failures are common and repairs/regenerations are tedious and time-consuming. By studying the history of how these trade routes changes and moves, one can see where the critical nodes are since they will probably have access to a constant supply of water to support the settlements or cities, as well as how the water movement and the edge conditions of the desert changes through time. Another benefit to having a distributed network is that the flow can take a path of least resistance through the network from multiple starting points through the many paths created by the node connections. With multiple nodes serving and interacting for a common goal, it can also allow for faster expansions of the entire system, thus creating even more routes and more refined paths of least resistance. This is similar in nature where the organism with a higher metabolism will go through their evolutionary cycles faster and therefore adapt to the environment better.

100-800 CE

800-1400 CE

1400-1900 CE

1900-1950 CE

Trade route changes through history (base image from Google 2013, data from Ciolek 2007)

In a group building systems integration project, we have conducted several tests to better understand nodes and flow. In a local farmers market, we've studied the stalls as nodes and people movement as flow. It was concluded that flow rate (customers) have a direct correlation to the node (stall) growth (number of customers); nodes that engages the senses will attract more customers; location and function of a node will affect the success of surrounding nodes; and the pauses caused by people can create new path-way in the market. This study is very helpful in understanding how nodes and pathways can be created.

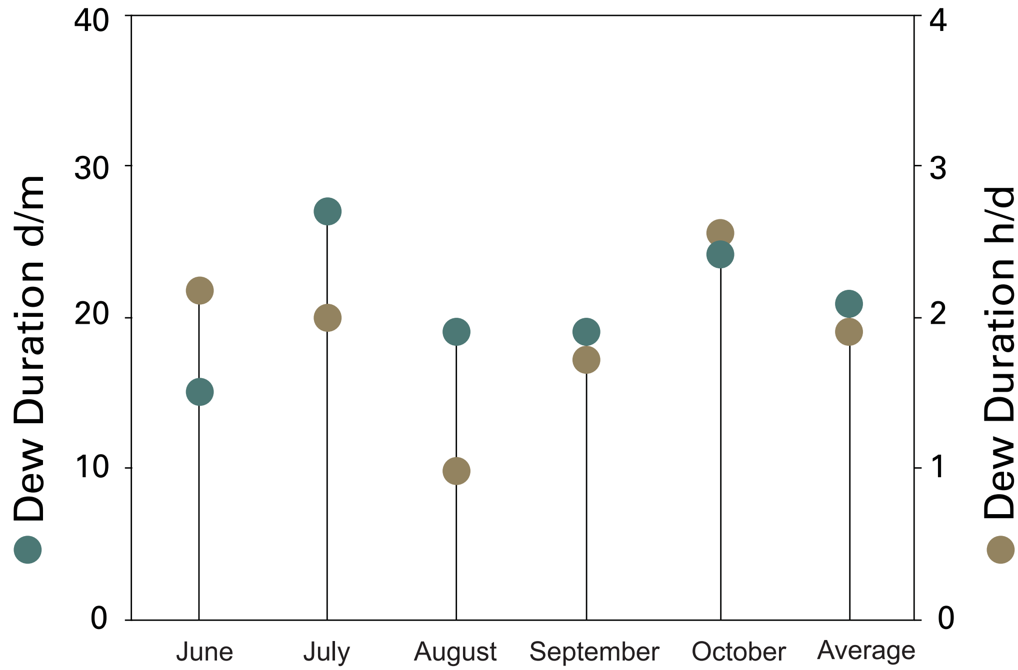
Stall influence diagram showing where people tend to gather and how it affects flow.

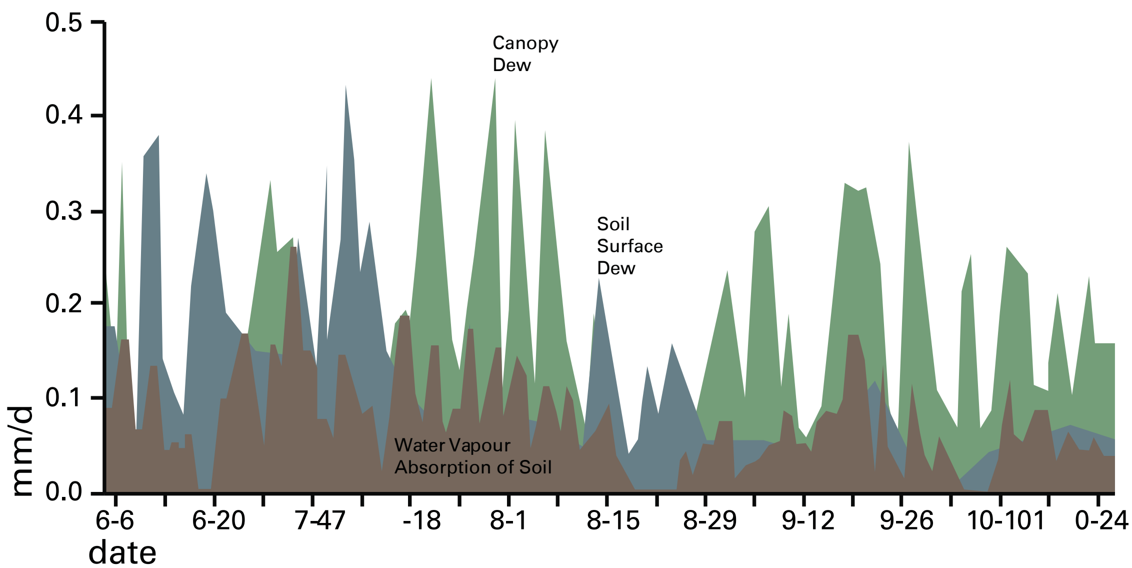
APPENDIX 2: MATERIAL + FORM TEST

Different materials will be tested to determine the best water vapour condenser in terms of yield and speed. Through a time based trial by putting each material in a controlled environment, I have concluded that galvanized steel, aluminum were the best performers in speed while the polyethylene and the ceramic tile produced the largest droplets. From this, I conducted a series of form test to see how they perform relative to each other. To do this, I have created several designs, layered, cone, and folded, to be left outside overnight and see how much water can be generated. Of all the designs, the cone shaped design condensed the most water since all its surfaces are open and subjected to air flow. With this information, I created a hybrid design which utilizes steel mesh as outer the shell to speed up the radiative process and a polyethylene backing to capture the dew droplets. The water will then be directed down into a underground reservoir where it can be kept clean and not evaporate away.

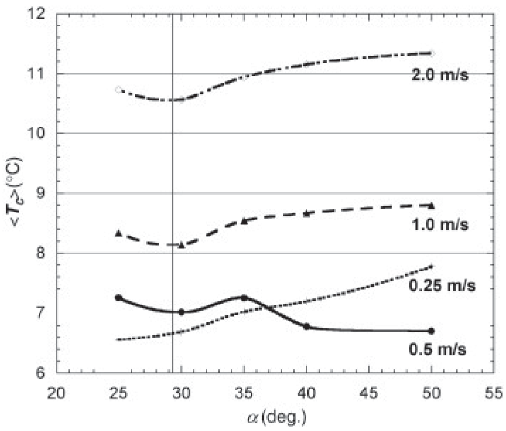
Different materials and forms tested for their condensation rate and yield.

APPENDIX 3: WATER COLLECTION DATA

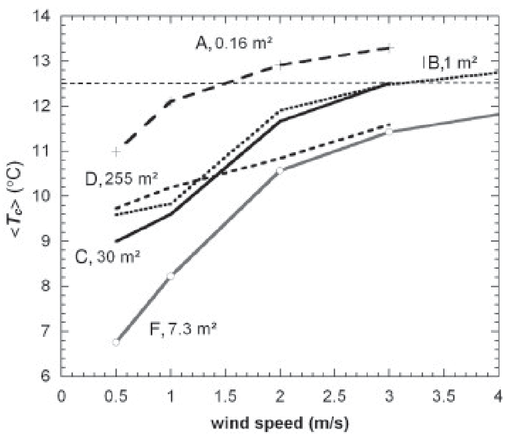




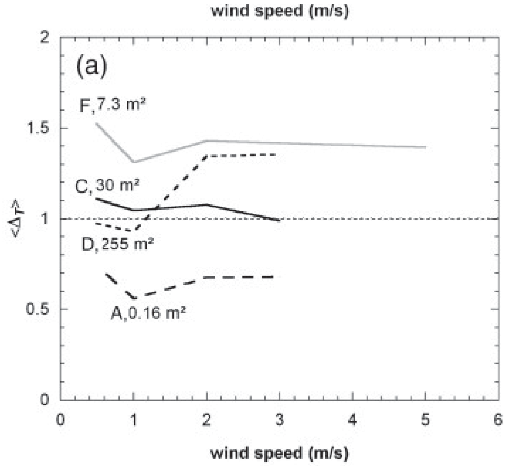
Dew formation statistics (data from Hao et al. 2012)



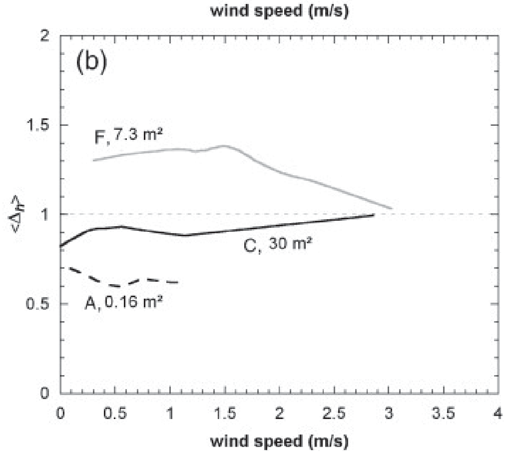
Funnel type [F] mean surface temperature <Tc> with respect to the angle α from horizontal (90° – half cone angle) at various wind speeds. The angle α ≈ 30° gives the best cooling efficiency (vertical line).



Averaged surface temperatures obtained by numerical simulation and related to wind speeds at 10 m elevation. No condensation occurs above the broken line <Tc > = Td = 285.5 K (12.5 °C), corresponding to Ta = 288 K (15 °C) and RH = 80%.



(a), "Temperature gain" (also termed the cooling factor) ΔT as obtained by numerical simulations for four condensers with surface areas ranging from 0.16 to 255 m² (Ta = 288 K and RH = 80%). The 1 m2, 30° inclined planar condenser is taken as a reference.

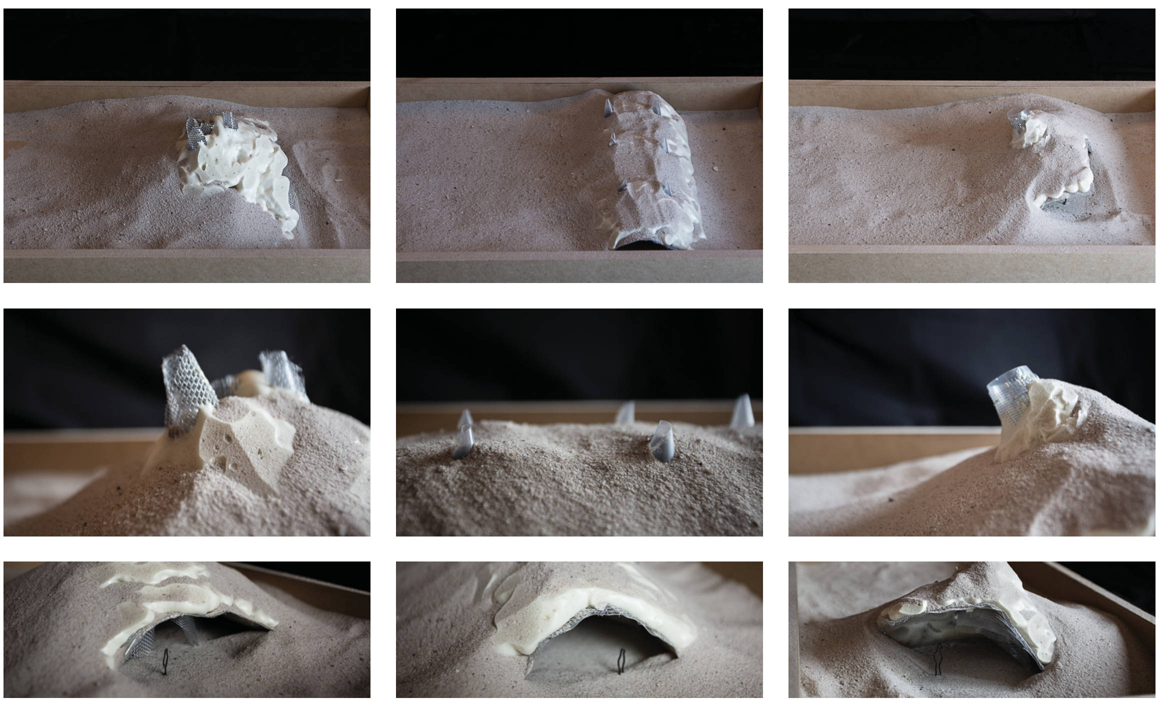


(b), "Dew gain" (also termed the relative dew yield) Δh for three types of condensers (not available for the 255 m2 condenser). Data are smoothed by a 70% weighing function.

(Clus et al. 2009)

APPENDIX 4: WIND

With the wind and sand dune data, I designed a few structure types that deal with the different condition in different areas of the desert. The first type has almost all the sides enclosed with a cluster of condenser cones in the centre so it is more suited to multidirectional winds. The second type is a linear/tubular design with condenser cones running down the middle in rows. This design is more suited to areas where winds are blowing from opposite directions. The third type is smaller in scale compare to the other two, but there could be more of these built that can deal with one directional winds. From this, I made some modifications to the structural envelope to lighten up the mass with a diagrid shell design. It has an outer layer with pockets that can capture the sand to use as insulation and protection, and an inner layer of polyethylene that is set back from the structure to create a thermal break as well as to allow heat to radiate at a faster rate.



Multidirectional wind condition Parallel wind condition Linear wind condition

Sand coverage + form test

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