Housing Practices in Gujarat
For centuries now, buildings constructed by the local people continue to be the primary and most significant mode of production of housing in India. These practices are well rooted socio-culturally and economically in local artisanal practices. Most of the construction undertaken by the communities is based on traditional materials and local skills [fig 1]. Within the socio-economic and geo-ecological context of their habitation, traditional wisdom has led to evolution of housing typologies that are the most appropriate and sustainable [fig 2].

While these building practices may be climatically and ecologically more suitable, the traditional ways of building are not validated and recognised. New methods developed by analytical sciences and industrial production systems are increasingly replacing traditional ways of building [fig 3]. As a result, these traditional building practices are being lost. However, it is also becoming quite clear that changing patterns, particularly shrinking natural resource base, increasing housing needs, rapid changes in traditional occupations and other socio-economic circumstances have led to poorer and unsafe quality of construction in recent times. It is, therefore, pertinent to study, document, relearn and further develop traditional building practices. This documentation is a step forward in this direction.
Households using traditional building materials in Gujarat

Traditional building materials like mud, bamboo, thatch and grass are more prevalent in rural parts of Gujarat. According to the Census of India Survey (2001) these building typologies account for 43 per cent of the total rural housing of Gujarat [fig 4]. Earth based construction alone accounts for more than 34 per cent of rural housing in Gujarat. The data also reveals that rural areas of Ahmedabad, Anand, Banaskantha, Bharuch, Dahod, Kheda, Narmada, Panchamahals, Sabarkantha, Surat, Dangs, Vadodara and Valsad districts have more than 50 per cent houses built with earth or bamboo as the main construction material.

These building practices have their roots in the way the traditional societies functioned and organised themselves. The climatic and geological conditions, social and economic aspects, along with religious beliefs were interwoven, resulting in the outcome of these practices as a cultural expression. This was reflected in the buildings, dance forms, songs, stories and other cultural expressions. While trying to understand the building practices we realised that the seasons, availability of materials and skilled artisans all had a bearing on the way construction was carried out, which in turn influenced the house type. The source of construction material, season for construction, building practices and materials varied to accommodate these factors and lent a socio-cultural expression, representing that region. Such construction practices though not rigorously followed are still found in many regions of Gujarat. Very good examples of these building practices are amply found in different regions. Of the traditional building materials used, earth based construction practices are most promising as they were found to be sustaining, affordable and wide spread. Further details regarding earth-based construction practices are discussed in the following sections.
Use of Earth in Construction
Similar to many other parts of India, Gujarat also has a long
history and tradition of building with earth [fig 5]. Mainly three
types of construction practices using earth as predominant
building material are found in the state. They are cob, adobe and
wattle and daub constructions. Cob wall constructions are still
found and practised right from north Gujarat and Kutch up to
Bhal region covering the Gulf of Khambhat as well as Vadodara
and Padra in central Gujarat. Similarly, adobe construction
(and its more popular variant using unburnt bricks) is widely
used all over Gujarat. Traditionally, adobe blocks were used for
construction in Kutch, north Gujarat, villages near Nal Sarovar
in Bhal region, in central Gujarat and a few places in coastal
Bhal near Bhavnagar district. Wattle and daub construction
is a tradition that is very much alive in eastern and southern
Gujarat, especially in the tribal region where the penetration of
cement-based construction is still in its nascent stages.

fig 5. Earth is one of the main materials in traditional construction in Gujarat
Building with Earth
Past Perfect - Future Tense?
Building with Earth
Past Perfect - Future Tense?

Recently, it is observed that the earth-based building practices are on decline, as is the case with most other traditional practices. Buildings with so called ‘modern’ materials are becoming more popular. There is a reluctance to continue the traditional earth based building practices. So it is appropriate to ask whether it is still relevant to continue these practices.

**Why are people abandoning traditional earth-based building practices?**

A large proportion of the rural population of India still lives in houses made out of earth. However, due to various reasons people are abandoning earth-based building practices and moving towards materials like brick and concrete.

Social status of a ‘pucca’ house as opposed to a ‘kutcha’ house is preferred by people. ‘Pucca’ is associated with brick and concrete while mud or bamboo is ‘kutcha’. This encourages the owners to build houses with brick and Reinforced Cement Concrete (RCC) slab, despite poor construction quality due to lack of properly trained and skilled labour, poor climatic performance, high use of energy and consumption of water and high costs.

Houses constructed using earth as a wall material are classified as ‘kutcha’ houses and get lesser compensation as compared to a ‘pucca’ house recognised by the government in case of damage or collapse due to natural disasters. Indira Aawas Yojana (IAY) and other government housing schemes do not encourage these traditional earth-based building practices. The houses built under such schemes end up promoting houses without consideration for local culture, climate or environment [fig 1]. Also, there are no public structures that utilises earth construction to demonstrate a good example of traditional building practice.

Lack of practice results in loss of knowledge about the soil and technique of construction; leading to poor quality of buildings. Due to various reasons like lack of commissions
and popularity of brick and RCC slab houses, the practice of traditional earth-based building construction is slowly declining. There are very few practising earth artisans left.

Weathering effects, specially rain and flooding damage earth buildings unless proper surface protection is applied. Salinity is a major issue in coastal Bhal, Kutch and north Gujarat. Due to the spread of salinity, it is harder to find good quality soils for constructing walls. Salinity causes erosion of walls, especially at the base. This can potentially result in collapse of the structure. To avoid such failure, these buildings require frequent repair and constant maintenance. This is labour-intensive and thus not preferred by people.

Traditional earth wall houses have tiled roofs with wooden under-structure. Increased prices and lack of availability of timber has had impact on the use of wood in these houses [fig 3 and 4]. Similarly, country tiles and Mangalore tiles are also slowly becoming unavailable.
Why does it still make sense to follow earth-based building practices?

Earth is an easily available and accessible material eventhough the availability is reduced. Earth based building practices are truly environment friendly options as they use locally available materials such as earth, agricultural and animal by-products like husk, straw, stock, cow dung etc. Most part of the construction process is not energy intensive and has low carbon footprint. Using these technologies can prove to be a low cost option as compared to brick walls in the areas where good soil is easily available.

Walls made out of earth have excellent thermal properties to ensure comfortable living conditions without resorting to external means. Houses with earth walls remain cool in the hot climate of Gujarat. In comparison, cob walls and adobe walls are thermally far superior to brick walls due to the material properties and thickness [fig 5]. This fact is acknowledged and greatly appreciated by house owners who live in earth wall houses.

The earth buildings can be constructed, repaired and maintained within the local socio-economic system. Thus, it does not depend on external and inaccessible systems, but only calls for revitalisation of the system. At the same time, it provides greater control of the house owner in material procurement, design, construction, maintenance and cost management. Adobe blocks, cob and wattle and daub walls construction require less technical expertise. The skill level required to construct these is already available in the region [fig 6]. Untrained villagers can also learn how to do it in a short time period.

Some of the constraints were already addressed by good traditional practices which are diluted now and others can be resolved through further research and learning from other building practices and applying existing knowledge base.
Understanding the Context
Understanding the Context

Gujarat takes pride in having the longest coastline in the country, a desert in the northwest, one of the oldest mountain ranges in the country towards northeast and forest in the south. Along with geological conditions, the climate and environmental conditions changes significantly across the state. Different regions are prone to different disasters posing severe to moderate risk to life and property. These conditions have translated into different traditional practices in the form of crafts, culture and built-form. The current section presents the geographical condition of different regions in Gujarat including terrain, soil conditions, agriculture practices etc. It also describes climatic conditions and disasters affecting the region. The section briefly discusses different materials available for the construction in each of these regions.

Based on original map prepared by Gujarat Ecology Commission
Understanding the Context

Geographical Conditions
This study encompasses traditional earthen construction practices followed in different regions of Gujarat covering Bhal region, which includes central Gujarat and parts of Saurashtra with its flat plains and coastal landmass, north Gujarat with its arid inland areas, hot and semi humid climate in the east and south Gujarat, and Kutch with its desert landscape and grasslands. The geographic diversity seen in the regions reflects in the architectural practices of the state.

Bhal Region in Central Gujarat
Bhal\(^1\) region consists of landmass stretching along the coast from the Gulf of Kambhat in Anand district to the Creek of Bhavnagar covering several talukas\(^2\) in Bhavnagar, Ahmedabad and Anand districts. The Bhal region is a flat alluvial plain. It is a mix of croplands, saline wastelands, grasslands and marshes. Sabarmati, Bhogavo, Sukhbhadar, Ghelo, Kalubhar and Mahi are the major rivers of Bhal region, which terminate in the Gulf of Kambhat.

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1. Bhal in Gujarati literally means forehead, a flat land where nothing grows
2. Taluka is a subdivision of a district; a group of several villages organized for revenue purposes. It is also known as ‘tehsil’ or block in different states of India. It is derived from urdu word ta’ alluk meaning estate.
Water retention capacity of the soil in Bhal is very high and terrain is flat. This is suitable for wheat cultivation during the winter. Hence, Bhal is known for its wheat. Often, the fields are kept fallow during the monsoon and wheat is grown in the winter.

fig 1 and fig 2. Farms in Nani Bhal, before and after harvesting.
The gulf of Khambhat divides Bhal region into two areas – moti Bhal and nani Bhal. Moti Bhal comprises of Bhavnagar and the western coastal region of Ahmedabad district. The eastern coastal part of Ahmedabad district along with Anand’s coastal area is known as nani Bhal. As the name suggests moti Bhal is larger than nani Bhal [fig 3].

Bhal is largely a saline wasteland. The salinity problem in coastal Bhal is two-folds: primary or inherent sediment salinity and secondary surface salinity. Surface salinity is mainly visible in the coastal zones under tidal influence, including low-lying areas where high tide water as well as monsoon water stagnate and evaporate, leaving behind a salt-encrusted surface. The land is flat, close to the sea, and susceptible to periodic inundation, which leads to the soil becoming even more saline. Saline land is a major concern in moti Bhal compared to nani Bhal [fig 4]. The land of moti Bhal region has very low agricultural productivity due to the salinity, salt-water ingress, wind erosion and lack of fresh water sources. Potable water is major concern in this region [fig 5].

Crops are mostly dependent on rain. The land around Anand region has better agricultural productivity with wheat, cotton and tobacco being the major crops. Wheat is mostly grown in interior Bhal and not in the coastal area. The coastline of Bhavnagar and Ahmedabad districts has seen a decline in its mangrove cover, Salvadora and forage grasses over the years. This has a negative impact in salinity-ingress and degeneration of land.
The region around Anand district has more trees and vegetation compared to Bhavnagar and Ahmedabad districts. *Gando bawal*, *pilu*, *deoi bawal*, *khijado*, *sajal*, *haldarvo* and *amli* are commonly found trees in the region. A few *neem* trees are also found in this region. Other shrubs and bushes in this region include *kerda*, *marjadvel*, *ber*, *gokbru*, *gadar*, *akdo* and *ikdo*. Grasses found in the Bhal region are *kans*, *chhaj*, *sukbali*, salt grass and *gha bajariyu* of which some are used for roof covering.

**Sandy Plains of North Gujarat**

The region bordering Kutch on the west, valley of river Banas to the south and border area of Rajasthan in the north are part of north Gujarat. Sandy plains are characteristic of this region. [fig 6]. The major rivers of this region are Banas, Saraswati, Rupen and Sabarmati. Sabarmati is the only perennial river. Many rivers from the region disappear into the Little Rann of Kutch.

As the region lies between the saline desert of Great Rann of Kutch and the sand dune desert of Thar in Rajasthan, it is an easy target for desertification. Tharad and Vav talukas situated on the border of the Great Rann of Kutch face severe salinity ingestion through water and salt-laden winds. This region also faces issues related to water shortage. [fig 7]

The main crops of this region are *bajra*, wheat, gram, maize and cotton. The husk from wheat, and stocks
from *bajra* and wheat are used for smearing and making weather protection mats, respectively.

The trees commonly found in this region are typical of semi-arid climate - *gando bawal, robida, desi bawal, ber, pilu* and *kerdo*. The different varieties of grasses are characteristic of this region. *Shegatra* and *mujari* are the common grasses in north Gujarat and also in the desert regions of Rajasthan and Kutch.

**The Desert Region of Kutch**

Kutch is the largest district in Gujarat and third largest in the country after Leh and Barmer. It is surrounded by the Gulf of Kutch and the Arabian Sea to the south and west, while the northern and eastern regions are surrounded by the Rann of Kutch. It is a seasonal wetland; therefore, it justifies the name of the region Kutch literally meaning ‘something which is intermittently wet and dry’. A large part of this district is a shallow wetland known as Rann of Kutch. It is submerged in water during the monsoon season and becomes dry in the other seasons [fig 8]. These marshy flats are also known for its salt production, which become white after the shallow water dries up in the summer heat. Land salinity is a pressing issue in most part of Kutch [fig 9].

Geographically, Kutch can be divided into the coastal zone demarcating the southern fringe, the Kutch mainland, the Banni plains and the Ranns. The Banni plains are the grasslands with their seasonal marshy wetlands forming the outer belt of the Rann of Kutch [fig 10]. Pachham is part of the northern hilly range.

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3. Wetlands are the transitional zones between permanently aquatic and dry terrestrial ecosystems. International Convention on Wetlands at Ramsar (1971) defines wetlands as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters”.

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fig 8. Kutch landscape after the monsoon rains

fig 9. Kutch landscape after the monsoon rains

3. Wetlands are the transitional zones between permanently aquatic and dry terrestrial ecosystems. International Convention on Wetlands at Ramsar (1971) defines wetlands as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters”.

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fig 10. Dry landscape near Banni
Kutch has many seasonal rivers including Khari, Magh, Tara and Rudramata[fig 11]. Rudramata is bunded for irrigation, while the others are small rivers with very less water. The rivers flowing towards north disappear in the Rann of Kutch while rivers flowing towards south and southwest meet the Arabian sea.

*Bajra, jowar*, wheat and pulses are the main agricultural products of this region. However, water shortage has had an adverse effect on the agricultural produce of this region and only southern and central parts of Kutch are used as agricultural land.

Due to the diverse geographic conditions, there is a lot of variation in the vegetation in this region. *gando bawal, desí bawal, kerdo, pilu, lai* and neem trees are commonly seen in Banni and Pachham regions. In the Kutchi local language, grass is generally called *Gha* and there are at least 28 varieties of grass in Banni. Some of them include *darbh, khīp, shaniyo, valo, baru, phulio, khari, adhau, kanj* and *vans*.

*fig 11. Rudramata River in Kutch after Monsoon*

*fig 12. Gando Bawal is one of the few vegetations that grows in Kutch*
The Saurashtra Region

Saurashtra peninsula, in western Gujarat, is defined by the Little Rann of Kutch to the north, the Gulf of Khambhat to the east, the Arabian Sea to the southwest, and the Gulf of Kutch to the northwest. From the northeast, an ancient sandstone formation extends into the peninsula. Most of the sandstone, however, is underneath the volcanic stone [fig 13]. According to the records of the Irrigation Department of Gujarat Government, there are 72 rivers in Saurashtra. Bhadar, Ozat, Aaji, Machchhu are the main rivers of the region. Yet, proportion of irrigated land is very little [fig 14]. Most of the land under cultivation depends predominantly on rainfall, thus land which can yield more than one crop in a year is very less [fig 15].

Saurashtra has approximately 33% of total coastline of Gujarat. A part of Bhal region also overlaps with coastal Saurashtra of Bhavnagar district. The coastal regions are flanked in the west and east by clay and limestone and in the south by alluvium and miliolite, a limestone formed though littoral deposits reworked with sub-aerial processes, known as Porbandar stone. Limestone quarrying is common activity in Porbandar and Junagadh districts[fig 16].

The area flanking the Gulf of Khambhat is largely alluvial. The eastern fringe of Saurashtra is a low lying area marking the site of the former sea connection between the Gulf of Kutch and Gulf of Khambhat. An elevated strip of land connecting the highlands of Rajkot and Girnar forms the major water divide of Saurashtra. Veraval is an important port for the region.

Much of the inland Saurashtra is less than 600 feet (180 metres) above sea level, but the Girnar Hills and the isolated Gir Range reach elevations of 3,665 feet (1,117 metres) and 2,110 feet (645 metres), respectively.
Groundnut is the main monsoon crop while wheat is the winter crop. Cotton is grown almost throughout the year. Sugarcane is also prevalent in some districts of Saurashtra. Seasam, cumin and pulses are also grown in Saurashtra. Junagadh and parts of Rajkot are also well known for mango (Kesar) and other fruit orchards.

The natural vegetation of the dry, hot region is mainly thorn forest, but mangroves are common in low lying areas near the sea. desi bawalal, gando bawal, pilu and neem are the main trees seen in the region. In coastal Saurashtra, casurina and coconut are also commonly seen.

fig 16. Lime quarry in Porbandar district
The South and East Gujarat
South and East Gujarat is formed by the hilly regions of Vindhya, Satpura and Western Ghats. Interior of Valsasd, Surat, Dangs, Bharuch, Navsari, Narmada and Panchamahal districts are part of this region. [fig 17 and fig 18] This is also a part of the region known as the tribal belt of Gujarat, and is predominantly inhabited by Chaudhary, Dubda, Rathwa, Gamit, Naik, Kotwalia, Koli, Bhil etc. tribes. Traditionally, these tribes did not have clearly defined division of work and the community was self reliant. This was reflected in their construction. People would make their own house with help of the neighbours and relatives, and in exchange will help others build their houses when required. Though, due to increasing interaction with other population these practices are slowly vanishing. In coastal parts of south Gujarat, fishing and sea faring communities form majority of population.

fig 17. Hilly terrain of the Dangs during winter
The east and south Gujarat region is rich with natural resources of forests and rivers. Narmada, Mahi and Tapti (also known as Tapi) are the main rivers. The western border of the region merges with the plains of Mahi, Narmada and Tapti River and touches the Arabian sea. The soil is more silty and clayey fertile soil. The salinity is mild to severe as one goes from east towards coast. The region used to have thick forest cover, which in recent times is receding.

The fertile land produces rice, wheat, bajra, jowar, maize, gram, tuar, millets, cotton, groundnut, castor as well as some condiments and spices. Vegetables and fruits are also grown in the region. South Gujarat is known for its alphonso mango (Hafus) and sapota (Chikoo) orchards. Apart from this, bamboo, teak, lacquer and other forest products are also found in this region.
Climatic Conditions
Gujarat lies in the transition zone between the arid region of Rajasthan in the north and the wet Konkan coastal region of Maharashtra in the south. The climatic conditions vary across the different regions within Gujarat. The climate in the northern region is similar to that of Rajasthan - hot and arid, while the climate in the southern parts of Surat and Valsad is closer to the Konkan sub-humid climate with heavy rain falls. Climatic conditions form the basis for construction practices and hence are important factors determining the type of construction in the region. The following section is based on the data available from different departments of Government of Gujarat and meteorological department.

Kutch and north Gujarat form an arid zone, where the climate is characterised by extreme temperatures and low rainfall, generally not exceeding 400 mm. Central Saurashtra, and central Gujarat are semi-arid regions with extreme temperatures similar to arid regions, but have relatively higher annual rainfall ranging from 400 to 800 mm. Coastal Saurashtra lies in the warm and humid zone. The rainfall increases from the coast to the higher interior areas, ranging...
Understanding the Context

from 500 to 800 mm. In terms of temperature, the extremity is reduced, both, in terms of the daily and annual range. The Sabarmati-Narmada belt has extreme temperature with moderate rainfall, which ranges from 800 mm in the north to 1000 mm in the south. Areas along the Gulf of Khambhat have high humidity. The sub-humid zone lying to the south of Narmada has lower summer temperatures than that of central Gujarat, and the winters are milder. The region has high rainfall ranging from 1000 to 2000 mm annually.

Most of Bhal region falls in the semi-arid zone with day temperatures ranging from 37° to 44°C. However, it could be as low as 1°C in winter and as high as 48°C in summer. The average annual rainfall is 510 mm. Hot winds called ‘loot’, dust storms and whirlwinds are common.

In north Gujarat the maximum daily summer temperature is 43.5°C and during winter, the minimum temperature can be as low as 4.5°C. The average annual rainfall of the
region is 400 mm and relative humidity is low, ranging from 60 to 65 per cent. Within the region rainfall decreases while aridity increases, from east towards west.

Kutch falls in the arid zone with temperature ranging from 2°C in winter to 45°C in summer. This region has an average annual rainfall of 340 mm. It also has low relative humidity which remains under 60 per cent for most of the year.

The rainfall in the southern part of Saurashtra including the area near the bay of Khambhat is approximately 630 mm while other parts of Saurashtra have even lesser rainfall. The temperature near the coastal region is moderate with a minimum of 12°C to maximum of 30°C near Dwarka, while temperature increases towards inland Saurashtra, in Surendranagar. South Gujarat is a semi humid zone, with high summer temperatures and heavy rainfalls during monsoon. The temperature in southern Gujarat ranges from 12°C to 37°C, while in east Gujarat it usually ranges from 14°C to 42°C. Temperature in the hilly region of Dangs ranges from 9°C to 31°C. The average rainfall is 1500mm or more in south Gujarat, while it is 800mm to 1000mm in the northern regions like Panchmahal, Vadodara, Bharuch and Narmada.

All the regions other than south and east Gujarat share certain climatic characteristics, including extreme temperatures, relatively low rainfall and arid conditions. South and east Gujarat have relatively higher rainfall.
Natural Disasters
Different regions in Gujarat face threats from various disasters. Some regions are prone to multiple disasters while some face possibility of disasters more severely or frequently than others.

Traditional communities responded to different natural disasters using available techniques and materials in their own ways. The Vulnerability Atlas prepared by TARU for the Gujarat State Disaster Management Authority forms the basis of this section.

Earthquakes
Earthquake PGA zonation considering a 100-year return period shows the vulnerability of Kutch towards earthquakes. Many moderate to very high-intensity events were recorded in Kutch in the past. Central part of Kutch falls under zone 5 for earthquake risk, meaning that possibility of severe earthquake at 50 year interval is very high in this region. Most of the remaining part of...
Kutch, north coastal Rajkot and Jamnagar districts are highly vulnerable and fall under zone 4 with reference to earthquake hazards. Areas of Bhal and north Gujarat fall under the moderate-risk category, however Bhal region has a history of relatively more earthquakes than north Gujarat. South and East Gujarat have relatively low risk of earthquakes.

**Cyclones and Storm Surge**

The estimated mean taluka-wise basic wind speed zonation (in m/sec) for a 50-year return period shows a maximum wind speed class of 45 to 47 m/sec along the Saurashtra coast facing the Arabian Sea, which is exposed to the highest intensity of cyclone and storm impact. The south western coast of Kutch has wind speed class of 40 to 44 m/sec while the rest of Kutch, Bhal and south Gujarat fall under the wind speed zones of 34 to 39 m/sec. North Gujarat region falls into the speed zone of less than 33 m/sec. Thus, the cyclone risk is highest in coastal Saurashtra. The interior Saurashtra and Kutch coastal areas face moderate risk from cyclones. Bhal and interior Kutch face comparatively low risk from cyclones while rest of the state faces very low risk of cyclones.
The coast of Kutch and Bhal near the gulls can be severely affected with high proportion of inundation during storm surges. Also, towards the southern Gujarat, areas near the coastal zone do face the risk of storm surge.

Floods
The flood risk in north Gujarat, Bhal and Kutch is much lower than areas of south Gujarat. Surat and Valsad have a known history of annual floods during the monsoon. However, parts of central Gujarat, Kutch and Saurashtra can also face a flood risk if there are very heavy rains. This is possible as the peak rainfall in Kutch and Saurashtra regions can be as high as 1,000 mm or more, against an average rainfall of less than 600 mm. Areas vulnerable to flooding in Bhal region are along the Sabarmati and Mahi rivers and in north Gujarat along the Banas river. Yet, lack of drainage due to flat land surface and low permeability of soil in Bhal causes floods during the monsoon every year. Many villages in the gulf of Khambhat and along the coastal Saurashtra face annual flooding. The hilly regions of south and east Gujarat face the risk of flash floods, while the coastal villages face a higher risk of floods due to heavy rainfall combined with high tides in the sea. In the villages of Valsad and Surat, flood is an annual phenomenon due to lack of adequate drainage.
Regions of Kutch, north Gujarat, and Bhal face severe periodic droughts. Rainfall in these areas is low and unpredictable while the agriculture is mainly dependent upon the monsoon.

**Availability of Construction Materials**

Traditional building practices used earth, stone, wood, various grasses, animal and agricultural by-products etc. for construction. Materials like burnt bricks and cement are slowly replacing these traditional materials. However, in economically poor areas people cannot afford the cost for construction and maintenance of the newer materials. In some remote areas, transportation of bricks and cement is difficult, especially during monsoon. Hence, people utilise whatever resources are locally available. In areas like Banni in Kutch, and Bhal, where stone is not available and bricks are expensive, earth is an easily available and accessible material for everyone. Thus, many people are still building houses with earth. In south and east Gujarat, the availability of good quality of timber prompts for its ample use in traditional construction practices. Hence in the southern regions of the Dangs, Valsad, Surat and Tapi, and eastern regions of Panchmahal and Vadodara, which are known for its teak wood, it is used
for construction purposes. At the same time, good quality soil is also easily found in the region. Here people combine timber with earth for the purpose of construction. In general, earth was found to be the most commonly used material, either in its pure form or mixed with other organic materials such as cow dung or husk and straw etc. depending on the availability and quality of the soil.

While salinity is a severe issue in Kutch, Bhal and north Gujarat regions it is not such a severe issue in south and east Gujarat. In Kutch, coastal Bhal and north Gujarat, the traditional practice is to extract earth from village ponds after monsoon to avoid saline soil. However, the soil in some parts of these regions (especially in Bhal region in Anand district where salinity is relatively less and soil is more appropriate for construction), is sourced from the Gamtal (village area). East and south Gujarat has more clayey soil, which is appropriate for application as surface rendering. Depending on the sand, clay and silt content in the earth and the technology used, additional proportion of sand, pure clay or *kuval* (wheat stems) are added.
In most areas for the roof under structure and openings, people traditionally used hard wood like teak, sajar and baldarlo. Nowadays, hard wood appropriate for traditional construction has become expensive and difficult to procure. People have started using woods like eucalyptus, neem, kerdo and bawal as a replacement. Bamboo is also being used for roof under structure. Similarly, traditional country tiles were replaced by Mangalore tiles reflecting the industrial production of the latter. Currently, Mangalore tiles are being replaced by CAS sheets or asbestos cement sheets.

In the villages of Ahmedabad and Bhavnagar districts, timber was not easily available for construction. However near Anand, one still finds many old structures with extensively carved hardwood elements, which is due to proximity to port towns such as Dholera and Khabhhat from where imported wood was procured for construction of houses for wealthy traders. In the absence of timber for construction, both gando baval and desi bawal were used in construction as roof under-structure. However, gando bawal, which is primarily used in wattle-and-daub construction, rots easily and is not preferred for construction. Akdo is also sometimes used in wattle-and-daub construction, and ikdo is used in making wall protection elements. Sometimes, local grasses are also used for roofing. Wheat husk and stems are utilised for smearing and dried wheat stock is used to make the elements for wall protection.

In north Gujarat, wood from the robida tree, found in abundance, is extensively used for construction. gando bawal and desi bawal are also used for construction due to non-availability of other woods. Grasses like Segatra are commonly used for roofing, while Mujari is used for making weather-protection mats as well as rope to tie roof members.

In Kutch as well, both desi bawal and gando bawal are used for construction purposes. Different grasses are used for thatch roofing, but none are as long lasting as darbh. Unfortunately, darbh is not easily available anymore. Agricultural by-products like husk and the stock of bajra, jowar and wheat are extensively used for smearing and making weather-protection elements.

In south Gujarat teak was amply used in construction along with timber from desi bawal and other trees. Rice husk is used in surface rendering on the walls. Stock from tuar is also found in wattle and daub construction.

Evolution of Building Practice
Apart from Saurashtra, good quality soil for construction is available in most other regions. The sand as well as clay content of the soil is between 40% to 60%, which is appropriate for construction. At the same time, areas like Bhal, north Gujarat and Kutch do not have much timber for construction, but local wood is available for roof construction. Here cob and adobe constructions are commonly found which used only earth for construction. In east and south Gujarat along with soil, good timber was also available. Hence, wattle and daub is common construction practice which utileses earth along with timber. In Saurashtra, good lime stone is much easily available and hence random rubble and lately courced rubble and ashler masonry is much common in Saurashtra, apart from Bhal region.

Local climatic conditions and disasters play important role in development of designs and details of construction. The single room and verandah was minimum a house would consist of. In response to hot climate, larger houses would have courtyard, while houses in Kutch, which faced risk of earthquakes developed its unique circular typology with Bhunga construction. Thus each region adapted different design and details while using the earth as main construction material.
Prevalent Earth-based Building Practices
The present section discusses different building practices observed in Gujarat that utilises earth as main construction material. Each practice is described with examples and detailed description of construction methodology.

As discussed earlier, three earth-based construction methods were being practiced in different regions in Gujarat.

- Cob construction
- Adobe construction
- Wattle-and-daub construction

Map based on field visits and secondary sources
Cob construction which uses only earth is most common in those areas that traditionally did not have other building materials and resources, but had soil suitable for construction. Houses with cob construction are seen throughout north Gujarat, central Gujarat including Bhal region up to Padara in Vadodara district and parts of Kutch where no other construction materials are available [fig 1]. Though examples of cob constructions are commonly seen in most of these regions, it is increasingly becoming a non-practiced method of construction.

Adobe construction, which is very similar to brick or stone construction, was traditionally being practiced in areas where the scarcity of construction materials was compounded with unavailability of water source near the construction site. Although not a very common practice in most regions in Gujarat, it is seen in a few areas near Nal Sarovar in Bhal and in Kutch [fig 2]. A few examples of adobe are seen in Banaskantha and near Dholka in Ahmedabad district as well. However in Bhal or north Gujarat region there was no construction going on using adobe blocks. In Kutch, a few recently built houses had used adobe blocks. Unburnt bricks1, a variation of traditional adobe blocks often seen in most regions across Gujarat, may be termed as continuation of adobe construction.

1. Unburnt bricks are found all over the state in rural areas. They are of the same size as burnt bricks, while adobe blocks were traditionally much bigger. These bricks were found to be very weak since deterioration of brick making process. These negligence are overcome in normal bricks by burning the bricks, which then does not require much care in other processes. The curing and drying is also not well done in unburnt bricks. For these reasons, adobe construction does not take into account constructions using unburnt bricks of recent times.
Earthen Buildings

Wattle and Daub Construction

Wattle and daub wall in Isar village, Narmada district
Wattle and daub used for boundary wall in Kutch

Adobe Construction

Adobe houses in Bhirandiyara village in Banni region, Kutch
Open space between adobe houses in Bhirandiyara village

Cob Construction

Cob house in Pandad village of nani Bhal region in Anand
Cob House in Pandad village of Nani Bhal region in Anand
Jhompa made with cob in Uchapa village, north Gujarat

Cob house in Tunda Vadh, Banni area, Kutch

Small room and kitchen in a village in Banni

Adobe is used for rectangular as well as circular bhunga houses

Wattle and daub house in Isar village, Surat

Wattle and daub Malegaon village of Dang district

Prevalent Earth-based Building Practices
Wattle and Daub construction is most commonly seen in regions where in addition to suitable soil, timber or bamboo for construction is easily available. It is one of the most practised construction methods that use earth. Many houses in tribal areas of east and south Gujarat have been utilising wattle and daub construction [fig 3 and 4]. Kutch also has substantial number of wattle and daub constructions. However in Bhal region, wattle and daub construction is not very common, it is found mainly in the construction of additional structures, like the kitchen or bathing area, which does not form part of the main house. In all these regions, wattle and daub construction is an on-going construction practice still being followed by many people.
Cob Construction

Cob construction can be defined as a stack masonry system composed of individual lumps of mud which bond together, creating a semi-homogenous layer. Each layer is built up to a certain height and allowed to dry partially to attain sufficient strength so that one can stand on it to build the next layer. The top of each layer, except the last, is rounded on the top in section. The wall is built in layers so that the shrinkage cracks in each individual layer can be filled in before building the next layer. This method controls the extent of shrinkage cracking in these walls.

Cob construction may have been in use since prehistoric times in different regions and climatic zones across the world. England and Wales have an old tradition of building with cob. This is where the words cob, cobb or clom are derived from. The word cob has its roots in the old English, meaning “a lump or rounded mass”. Instead of purely soil and water combination, cob in England, as well as in many other parts of the world was prepared by mixing straw and clay based subsoil with water. Significant historical buildings in Afghanistan were also built using cob construction. Many traditional constructions in central Europe and western Asia region were built using cob. Many old cob buildings can still be found in Africa, the Middle East,
Wales, Devon, Ireland, Cornwall, Brittany and some parts of eastern United States. New Zealand also has a number of cob buildings from the mid-19th century.

Cob wall constructions are commonly found in the following regions:

- Bhal region
- North Gujarat
- Kutch

Cob walls and gabled roofs with a wooden under structure was the most prominent building system in many regions of Bhal and north Gujarat, until two decades ago. Even today, many examples of cob wall houses are found in rural areas of north Gujarat, Bhal and few areas in Kutch. People still make their houses using cob, though in recent years cob wall structures are gradually being replaced by brick walls and RCC slab structures.

Oad- a nomadic community is very famous for practising cob construction in Bhal and north Gujarat region [fig 5]. Throughout the construction season Oads used to travel from one village to another in a group usually consisting of members of the extended family. When they got enough
construction assignments in a village, they would camp outside the village. If they worked to construct one layer of wall in one house on a particular day, they would return to the same house only after a few days. Meanwhile, they worked on other houses in the village. As this rotation was necessary for drying of cob walls, they would take up a few construction assignments together and stay at the same place for more than a month. Construction of the walls of one house would take up to two months. The whole Oad family worked as a team to construct the house. The man did construction while women fetched water and mixed the material for construction. The women also brought the material from the mixing area to the place where wall is being constructed. The children helped the women in all their tasks. During construction, the food for the entire family was provided by the villager whose house was being constructed on that particular day. Apart from food, they would also charge some nominal fee in terms of cash or food grain or both. Oads built both, small - single room houses as well as large houses with courtyards some of which were even two to three storeys high. Most Oads could not afford a house and travelled in search of work.

Till now, most cob houses in Bhal were constructed by the Oads. Today, most people are averse to cob construction. Hence, very few Oads are practicing cob construction. Due to lack of work in construction they are now taking up labour work in brick kilns across the state, as it pays marginally better. Interestingly, most of the on-going cob constructions are being executed by house owners who do not have specific skill in cob construction. These self-made constructions vary significantly in methodology and use of material. Oad builders never use organic additives in soil, while the self-built constructions are often using grass or wheat stocks [fig 5]. There is deterioration in building practice and hence finesse.

In Kutch, the cob construction is done by the people themselves. While it is not as popular as adobe construction, some examples of cob construction are found in Kutch. Cob walls in Kutch are utilised to construct bhunga houses. A bhunga is an independent structure, circular in plan and has a conical roof usually made of wood and thatch. Several bungas form a house.
Typical Cob Houses
A typical cob wall cluster is shown here [fig 6]. This settlement called ‘Oad vas’ in Dhima village has houses with verandah facing the street or a common open space. Many houses have an external open space contained within the compound wall [fig 7]. This forms a threshold leading from the public space to smaller street into the more private space [fig 8]. In traditional rural settlements, many families of the same community stay in close proximity and share open spaces as well as common utilities.
Rectangular, single storeyed houses are the most common type of houses constructed with cob. The earthen walls are constructed on earthen foundation. They usually have gable roof with a wooden under-structure. Country tiles which used to be very common are gradually being replaced with Mangalore tiles. Trusses are very rare in residential building roof, but are found sometimes in north Gujarat [fig 9]. Usually, the tensile members of the truss, the cross bracings are missing [fig 10]. In Bhal region, there were some two and three storey buildings using cob construction which were all built by the Oads [fig 11].
Circular houses, known as Bhunga are mainly found in Kutch, many of them dating back 50 to 70 years [fig 12]. Often they are built on stone foundation. The cob walls support the wooden under structure of the roof, with thatch as roofing material. Houses of well-to-do families sometimes have tiled roof. The circular plan and conical roof allows the walls at the periphery to be low, and still achieve sufficient height towards the centre of the room. Similar constructions found in north Gujarat and Rajasthan are locally known as jhompas. The north Gujarat jhompas are smaller and not as well evolved as bhunga [fig 13]. Often used as the kitchen or storage, they are separate structures, detached from the main house.

Most of the circular houses in Kutch and north Gujarat are self or community built structures. The women play a significant role in the construction. They help in material (soil and thatch) procurement and construction. Wall and floor rendering and finishing called Kol and Lipan are carried out entirely by the women.
A variation was found in north Gujarat, where a combination of rectangular and circular plans was utilised in a single house of an Oad family [fig 14 and 15]. The entrance area and one room are orthogonal while the inner room is circular in plan. The thatch roof is of conical shape above the circular part which became a two way sloping roof above the orthogonal portion. This house demonstrates the flexibility of cob as building material. As this is not very common it cannot be classified as a separate type.

In addition to houses cob construction is also used for building cattle sheds, grain storages etc. [fig 16] These structures do not have a foundation and usually have thatch roof. Of late, CGI sheets are increasingly used to cover such additional structures.
The spatial layout of a rectangular house typically consists of a semi-covered verandah in the front and a series of parallel rectangular covered spaces or rooms opening up into the verandah [fig 17]. Towards the end of the verandah, a small room acting as kitchen is also often seen. Though cooking activities happen in the open, this is useful during extreme weather conditions. The verandah sometimes has another layer added to one more roof supported on wooden columns or RCC precast posts [fig 18]. In some houses a porch also exists behind the house. A well-defined element of the cob houses is an otla (raised and extended plinth) which had multiple uses [fig 19]. People sit here in the mornings and evenings; use it to sleep at night and the women carry out some of their household chores like cutting vegetables, stitching and knitting etc. The otlas are mainly found in the front but may also be located on the side or rear of the house [fig 20].
In north Gujarat, the houses are defined as one khand or two khand houses, meaning one or two rooms arranged parallel and opening into the verandah [fig 21]. The openings are very small in these load bearing structures. An indispensable part of any house is the grain storage or kothar. This is found usually in the main room [fig 22]. In north Gujarat, separate circular grain storage is also found within the courtyard. Niches of different sizes, for storage are also present within the thick walls. Most houses have a niche separately demarcated as puja space. Bigger houses have one room of the house dedicated as puja space [fig 23]. Smaller houses open into a common public space or street through the verandah while bigger houses usually have courtyard created within the compound wall. The compound walls are covered on top with broken country tiles to protect them from the rain. These houses have an elaborate entrance porch with storage and sitting for guests, from where entry to the courtyard is defined.

The kitchen is located either at the end of the verandah, or separately in the open space outside. Traditionally there was no toilet but a small construction with low walls towards side or at back acts as the bathing space. The opening of this area is covered with jute or cloth. The drainage system is missing altogether. Sometimes,
a cattle shed is located within the same compound either along the side or back. Sometimes, the cattle shed are constructed as separate structure.

The cob walls in Bhal and north Gujarat are usually constructed upon an earthen foundation. Though often, the foundation is very shallow or missing altogether\textsuperscript{6}. Where present, the depth of the foundation varies between 6 inches to 3 feet. The width of foundation was the same as the width of the base of the wall. The walls were usually 18 to 26 inches thick depending on the height of the wall. The wall height varies from 6 to 12 feet in a single storey house and a maximum of 25 feet in a three storey house. The higher walls are thicker at the base and tapers to 10 to 12 inches at the top. There is no intentional use of horizontal elements like lintel bands or sill bands that provide resistance to earthquake or floods. Sometimes wooden elements are inserted within the walls or connecting the perpendicular walls, but they do not provide sufficient resistance against horizontal thrust [fig 24]. The roof under-structure, made of wooden elements is directly resting on earthen walls, at times applying point loads on gable walls [fig 25]. Cob houses usually have tiled sloping roof with a wooden under structure. Since country tiles are hard to find, Mangalore roof tiles have gradually replaced the country tiles in many buildings. More recently, people are replacing the tiles with galvanised iron or asbestos cement sheets.

\textsuperscript{6} In example of construction of Lakhabhai’s house, the same earth that was dug out for the one-foot-deep foundation upto one foot was refilled in the to make foundation. Many artisans said that the foundation was not needed since they were building with earth upon the earth. Though However, at very few places the artisans said that mentioned up to 2.5 to 3- feet- deep foundation was laid. In Kutch, usually there is a round 3- feet foundation is found in cob construction, details of which are discussed farther in this section.
Stage 1
Stage 2
Stage 4
Stage 5: Final layout of the Vandh

fig 26. Development of Vandh in stages
7. According to some old artisans, the practice of building circular houses was introduced in Kutch after the great earthquake of 1818 A.D. This was done in a meeting of construction artisans organised to discuss and find measures for risk reduction during any future earthquake.

8. In pastoral communities of Kutch, seasonal migration is very common and, hence, land ownership was collective. The population was sparse and, hence, there was enough land available. People built as much was required for their family requirements. After winter, the people followed the cattle and left their houses and migrate with their cattle after winter in search of grass. They usually travelled through various regions and returned in during monsoon where there would be enough grass available for their cattle in Kutch. Sometimes later, women started staying back to keep their houses well maintained. Now, the seasonal migration now is reducing and people are slowly settling down.

Circulr Cob Wall House

Houses with a circular plan are found mainly in Banni and Pachchham areas of Kutch as well as in parts of north Gujarat (Banaskantha district). The villages in Kutch are a conglomeration of different vandhs. Each vandh is constituted of a few vaases. Vaas is a united family unit where the entire family shares one or more common open spaces. A typical plan of a vaas in Kutch is shown here [fig 26].

A vaas is usually established by a family elder who constructs a large plinth on some vacant plot. This plinth usually covers the future expansion of the vaas. Initially, a randhaniu or kitchen and some bhungas for living, storage and sleeping are constructed. Sometimes, a semi open pavilion is also added as sitting or receiving guests. An earthen storage unit or kothar is present inside the bhunga and decorated with mirror work and chitrakaam, similar to the rectangular houses. A vaas is usually known by the name of the elderly person who constructed the first Bhunga. As the family grows, more bhungas are added around the earlier units. These units are added depending on the requirement of the family. They are randomly placed, yet form a central space for each smaller family unit. Thus, the overall configuration of the whole bhunga settlement creates well defined external spaces that are used by the families in their routine work. These are used more than the inside spaces, which are mainly earmarked for storage and shelter during high winds or rain storms. There were no toilets in traditional constructions.

Usually it is seen that human settlements are formed by building houses next to each other - in clusters and villages, but in desert areas of Kutch (and also Rajasthan), the vaas are located very far from each other. This can be attributed to the scarcity of water, pasture and other resources. The people seem to have understood that every family needed a certain area and resources within their reach to survive, hence, to avoid dividing the scarce resources; the next vaas is set up at a distance. Also, most of their daily activities are carried in open spaces outside the built structures. Therefore, the distance between the vaases gives some degree of privacy.
Construction of the bhunga is carried out by the family members. The bhunga is constructed either using cob, adobe or wattle-and-daub construction. For the cob construction, soil is sourced from the nearby pond and collected near the construction site. The foundation is usually laid with stone using the sand packing method instead of cement mortar. This method helps in saving scarce water resources and has the added advantage of being constructed over a longer period. The depth of foundation in Kutch is usually 3 feet deep and the width is approximately 2.5 feet, which is equal to the base of the cob wall. The soil is not mixed with any additives and the construction is done by men, while women help in preparing the soil mix, bringing it to the place of construction and sourcing water too.

A bhunga is built on an earthen plinth that extends around the built structure [fig 27]. The plinth is made such that the water drains out well into surrounding low-lying area, without damaging the cob walls. The walls are comparatively low height. Each bhunga usually has one or two small windows [fig 28]. The roof is constructed with local wooden members, usually Desi Bawal, Neem or other local wood. Two very unique elements of this conical roof with radial beams are the mann and biladu. Mann, a carved
A piece of hardwood, is the central element of the roof that acts similar to a key stone in arch construction. Many times, it is intrinsically carved and painted as it comes right at the centre of the room [fig 29]. It holds the radial beams of the roof in place at the top of the roof. The mann may be supported by vertical column which transfers the load of the roof downwards. In smaller bhungas, which are less than 10 feet in diameter, this column is usually not present. In some houses, the central column is supported by a beam spanning the diameter of the bhunga. It is at the level of the wall and hence there is a clear space in the centre [fig 30]. The biladu is an element made of two arms with a longer wooden piece. It was placed towards the outer end of radial roof beams inside the cob walls [fig 32]. One arm was tied to the beam while the other is tied to the cob wall with the help of wooden pegs or nails so that it is anchored to the wall, thus resisting the downward thrust of the roof. The conical roof is covered with thatch using local grasses. The roof usually covers much of the wall from outside through overhang such that most parts are not exposed to the environment and hence preventing damage from rain water [fig 33]. The materials for construction are collected over a period of time, sometimes stretching over a few years.

fig 29. Central piece of roof wooden understructure, Mann is extensively decorated, showing the artisanal skills of the region. Here, a clock is represented on the visible surface.

fig 30. The stub column supporting the Mann resting on wooden beam

fig 32. Anchoring roof to the wall with Biladu

fig 33. Thatch roof overhang protects the walls from rains
fig 34. Construction process of cob building
Construction Method
To understand the traditional method of building cob walls, a sample construction was carried out at Pandad village in Anand district. An extension was added to the existing house of Lakhabhai Oad, a traditional cob artisan. Lakhabhai’s parents worked as cob builders and he had helped them while growing up. He had built the existing house about 10 years ago. His mother Gangaben is a skilled cob artisan. The family stopped building cob houses about 15 years ago since there were not enough assignments. They settled down in Pandad around the same time. Lakhabhai, his mother Gangaben and a few other family members worked on this extension. Three walls were constructed to add one more room beside their existing house of one room and a verandah. The verandah was extended to link it with the house. The two-way sloping roof was extended to cover the extension. The images and construction process described below were recorded during the process of extension.

The construction process carried out using traditional methods practised by Oads can be described in five steps.
1. Soil selection and water procurement
2. Preparation of the foundation and base layer construction
3. Preparation of soil mix for construction
4. Preparation and handling of lumps
5. Construction of the wall
Soil selection and water procurement

Oad artisans employed their intuitive knowledge to select the appropriate soil for cob wall construction. They gained this knowledge through experience and transfer of skills over generations. They normally find the most appropriate soil from the surrounding areas. They have some knowledge of the soils where the houses are being built because they worked in the same villages year after year. In cases, where they do not know about the soil, they use simple methods to understand the soil based on colour, feel (for sand and clay content) and water-absorption properties.

It was observed in Nani Bhal region that soil for construction was procured from the Gamtal within the village, which is usually a hillock in the flat terrain of Bhal or from nearby farm [fig 37]. Here, the soil composition is found to have the right proportions of clay and sand. In places where the soil is usually saline, like Moti Bhal, Kutch and north Gujarat, the soil for construction was procured from the village pond after monsoon or in the beginning of winter [fig 38 and 39]. This period coincides with the festival of Diwali and New Year. This time is appropriate as the salinity is washed away by rain and the receding water level, leaving behind soft soil which is easy to extract. For extension of his existing house [fig 40],

**fig 37. Construction soil from farm, in Sinor**

**fig 38. Soil extracted from pond, Sinor**

**fig 39. Soil borrow area Baluntri lake in north Gujarat**
Prevalent Earth-based Building Practices

Preparation of foundation and base layer of the wall

Traditionally, all cob houses in Bhal and north Gujarat were constructed on earthen foundations. The dimensions of the foundation were marked with ropes and pegs on the ground before excavation for the foundation started. In the case of Pandad village house extension, a 1 foot deep and 2 feet wide foundation was dug [fig 42]. The soil excavated from the foundation was mixed with water and poured back into the foundation and compacted.

Lakhabhai and his brother identified good quality soil from a nearby farm.

Mixing and preparation of mud for construction is easy if the soil is sandy and very difficult if it was too clayey. A good soil\(^\text{12}\) should neither be too easy nor too tough to prepare. If the sand content is high, the walls will easily be washed away when exposed to rain. If the clay content is higher than desired, there will be too many shrinkage cracks, thus making the wall weaker. In case of clayey soil, sand and/or straw may be added, though this was not a common practice.

Water from the village pond\(^\text{13}\) is used for construction. Traditionally, the water was brought in a pakhal\(^\text{14}\) carried atop a buffalo [fig 41]. However, water can be obtained by other means.

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12. Normally, sand content varies between 40 and 60% in good soil for cob or adobe construction.
13. The water used for construction should not be saline.
14. Traditionally made of leather, pakhal is a sack used to carry water. It has a bigger opening at the top from where water was poured in while the smaller opening is tied and kept closed. From the smaller opening the water can be poured out. Now, tarpaulin is used instead of leather to make pakhal.
The first layer of 6-inch thickness was constructed on top of the foundation. This demarcated where the wall should be constructed. The earth for construction was brought in small batches and mixed with water. With the help of a shovel, soil was placed on top of the foundation and shaped with hand [fig 43]. Women also participated actively in construction [fig 44]. Thus, a 6-inch-high layer was moulded with the hands. This did not demarcate the plinth level [fig 45]. The plinth is usually higher than this first layer. The plinth height depends on the usual water level during monsoon.
Preparation of soil mix for wall construction

Soil is mixed and prepared on a levelled ground\(^{15}\) close to the construction site [fig 46]. The soil prepared is used for construction on the same day. The required amount of soil of 10 to 20 centimetres thickness is spread on the ground. Water is added to the soil and mixed with a shovel [fig 47]. All the water is not added at once, but in batches during the mixing process. The approximate soil and water volume proportion for mixing is in 10:3 ratio\(^{16}\). This proportion is, however, varied slightly according to the soil and the time of the year when construction was done.

A buffalo is made to walk on the mix for about 15 minutes [fig 48]. Further, mixing and pugging\(^{17}\) is done by foot for another 20 minutes [fig 49]. This continues until there are no dry lumps of earth and the mix has gained the desired consistency\(^{18}\).

15. Preparing and mixing on the ground makes it easier to control the water content. If the prepared mix is softer than required, the surface below will soak the extra water over a short period and the mix will be ready to use soon. If prepared on a tiled or tar surface, the quantity of water needs to be very precise.

16. Six buckets of water were required for mixing 20 buckets of soil.

17. Treading on the material or mixture of materials.

18. As a rule of thumb, with good quality soil the pugging is stopped once the mix stops sticking to the feet.
Preparation lumps for construction
There are two or sometimes three people (traditionally, women of the Oad family) who carry the lumps of prepared mud. They hand those to the artisans (usually male members of the family) who build the wall.

Small portions of prepared soil are lightly pressed with the foot, compacted and then separated with the help of a shovel [fig 50]. This is then lifted and carried to the builder. It is important that the prepared mud lumps hold a shape and does not fall apart when they are being carried to the construction site [fig 51]. If the lump falls apart, the sand content is too high.

As observed during construction at Pandad village, at the beginning of the construction, the size of the lumps was roughly 1 ft.x0.75 ft.x0.5 ft. As the construction progresses, the height of the wall increases and the required wall thickness reduces due to the tapering of the wall. With this, the size of the mud lumps also reduces. The reduction in lump size is also due to the fact that as the construction progresses, the lumps need to be almost thrown like balls and caught by the artisans building the wall above lintel level.
Construction of the wall
The lump of prepared mud is thrown with some force on the wall [fig 52]. The artisan will then mould the wall by hand, ensuring that it is compact and the level is maintained. Bits of mud are adjusted and reshaped from the lump and worked upon to ensure that the desired shape, thickness and level are achieved [fig 53].

Cob wall is constructed in layers, each one coming just little below the eye level of the artisan working, and hence, it is roughly 12 to 15 inches high [fig 54]. This ensures that the artisan can see and determine the correct line and level from his position. A single layer is allowed to dry for about a week and then the next layer is constructed on top of it. The drying time depends on the season and local climate, as the mud dries faster during summer and it takes longer in humid climate. Drying of the layer also depends on the type of soil. If the moisture retention of the soil is more, it will take more time to dry. Thus, sandy soil dries faster, while soil with more clay content takes a bit longer to dry. This property of soil also has an implication on the cracking pattern.

The drying period of one week also ensures that the shrinking of the wall takes place before the next layer is constructed [fig 55]. Traditionally, Oads worked on a few houses simultaneously. They constructed one layer of a house on one day and then move on to other houses in the village, thus rotating the construction cycle. So, when they were back to work on the same house after a week or so, the layer had enough time to dry. At times, the artisan walked on top of the constructed layer after a couple of days to check whether it was dry or not. If his feet did not make any impression on the wall, the layer was considered dry.

19. If the next upper layer is constructed before the lower layer dries thoroughly, it will reduce the strength of the wall.
If one layer is constructed from one end point A to another end point B of the wall, the next layer is constructed starting from point B towards point A [fig 56]. Thus, the variations due to left and right-hand working are balanced.

Each layer is slightly rounded from the top. This ensures that the next layer anchors well on the curve of the previous layer [fig 57]. This provides better stability to each layer and, subsequently, to the wall. The wall is tapering in section with the thick base of the wall gradually reducing towards the top. This ensures balance and better load transfer. If the layer on top becomes wider than the layer at the bottom, there are cracks in the centre of the wall running parallel to the length of the wall. This will split the layer into two [fig 58]. This is considered an unsafe practice and therefore, avoided.

The shrinkage cracks in the construction depends on the clay content of the soil. If the soil has more sand content, it will not crack. But if such a wall is exposed to rain, it will easily get washed and lose its strength. According to the Oads, some extent of cracking is necessary. This also indicates that the layer has fully dried and the next layer can be constructed. If the layer does not crack, it will be difficult to judge whether the layer has completely dried on the inside. When using clayey soil, the cracks are natural. If the construction is done in winter, cracks are fewer as the layers dry slowly.

Using clayey soils like black soil will not make walls stronger because there will be too many cracks. Small pieces of wall will keep falling off, thus weakening it. If the soil is too clayey, there will be too many or big wide cracks, small wooden pieces are often placed onto these gaps before starting the next layer. This will stagger the cracks, thus stopping the vertical continuation. According to the artisan, cracks wider than 2 inches are considered problematic for the structure and these are fixed with wooden pieces.
If a cob wall has to be connected with an existing wall, a piece of wood\(^\text{20}\) is used as a connector at each layer [fig 59]. The piece is normally 1.5 to 2 feet long and half of it is hammered into the existing wall before the construction of the layer starts. The other half is encased into the new wall as it is built. This creates a bond between both constructions built at two different times. Similar connectors are also used when one layer is constructed in two parts. In this case, the connecting wooden piece is inserted into the first half of the layer while it is still wet. The remaining part is covered during construction of the second half.

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20. Woods like Pilu, Kerdo, Arani or Neem is used to connect the new wall with the old one. These woods are not easily attacked by termite or white ants and are also water resistant.
The niches and openings in cob construction
Niches are easy to accommodate in the thickness of cob walls. The wall thickness is reduced wherever the niches are desired. Usually, care is taken that the niches, combined with the openings, do not occupy a large wall surface area. If the niches are not decided from the beginning, they are carved out of the wall even after the wall has been constructed. However, this practice is not preferred. A wooden board is placed to provide lintel level support at the top of any niche larger than 18 inches. Smaller niches do not require such support.

Once the wall reaches sill level, the window frame is positioned on the dried layer before the construction of the next layer begins [fig 60]. Usually windows are not placed on gable walls. Thus, the roof overhang that provides protection to the window. The window frame is positioned with the help of bamboos or a rope with slipknot [fig 61].

The vertical level of the frame is adjusted as required with the help of a plumb and its knot. The horizontal level is adjusted with the help of the spirit level [fig 62]. A packing is placed under the frame for adjustment, if required. In absence of a spirit level, Oads use some drops of water in the centre of the lower horizontal member of the frame. If the water starts moving towards one side, it means that it is not aligned horizontally. Once the window frame is in plumb, the construction of the next layer begins [fig 63]. The sill of the window is shaped such that it slops slightly towards the outside to let the water flow out.

The next few layers are constructed near the window to encase the sill and lintel horns within the construction. This ensures the alignment of the window. If the window is taller than two layers, the lintel horns are not covered fully, but the window is partly supported by constructing next to the windows [fig 64]. After that, the construction is carried out till lintel level.

Once the construction reaches the bottom of lintel level, a wooden board called *dabaniyu* which acts as the lintel is placed on top of the frame [fig 65]. This is at least 1.5 to 2 inch thick depending on the width of the window. The lintel board is levelled and tied to the window frame with a rope. Once it is in position, the wall layer above it is constructed [fig 66].
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fig 61. Window frame is positioned securely with rope

fig 62. Levels are adjusted for correct placement of window

fig 63. Construction of next layer begins after correct positioning

fig 64. Lintel horns are covered to secure window frame in place

fig 65. Wooden slab for lintel is placed in bigger windows

fig 66. Cob construction continues above the lintel
On the gable wall, wooden nails are placed above the lintel level [fig 67]. On the outer wall, they hold the grass mats, which protect the walls from rain. These pegs are made of Kerdo or Pilu, which are resistant to water and white ants. The pegs are normally placed roughly at a distance of 3 to 4 feet [fig 68].

The gable is constructed as usual, but gradually the end portions on both sides are left incomplete. This makes the wall taper from the edges. Later, they are shaped to make a sloping edge for the gable. The angle of the roof is dependent upon this tapering. The village carpenter usually visits the place and consults the Oads for the slope of the roof before the gable walls are finished from top. Bamboo and string are used to determine the slope of the rope, but at times they are also intuitively decided by either the Oad artisan or the carpenter. It is easy to correct the angle in cob construction if the constructed one does not work well for the carpenter.
Roof construction
Traditionally, the wooden under-structure with country tiles was most common in cob houses. The roof is constructed by a local carpenter who is well versed with cob construction. When the house reaches the lintel level, the carpenter visits the construction site and helps fix the windows. Once again, when the house construction reaches roof level, the carpenter discusses the roof construction with the Oad artisan. At times, he starts placing the wooden roof members when the last layer of cob construction is being done.

The use of truss is not common in rural areas, but it has been observed at times in wealthier households or institutional constructions. The wooden roof members are placed directly on the cob wall without wall plates. Though some artisans informed that they would place a long wooden log where they feel the wall is weaker or wider cracks are found. To place the roof member in place, the wall is scratched at the required place and the member is adjusted in that place. Afterwards, the cob mixture is filled in and wall is repaired. The direct placement of roof member applies point load on the wall.

The traditional roofing was country tiles made by the village potter. These are slowly replaced by Mangalore tiles, manufactured mostly in Morbi. The tiles are placed from bottom to the top. Once in a year the roof tiles are opened and placed again as part of routine maintenance. Usually this maintenance is carried out before the monsoon. The broken tiles are replaced with new tiles and the old ones are cleaned so that water can drain out properly during the rains. The roof overhangs provide protection from the rain significantly, but it also means that the roof will be more susceptible to high winds. Hence, roof overhangs are not more than 1 to 1.5 feet towards gable walls as well as the verandah side.
Wall plaster and finishing

Wall rendering on cob walls are done in layers. The main ingredients for plaster are earth, animal (usually cow or buffalo, but sometimes donkey) dung and agricultural by-products like rice or wheat husk. The soil used for plastering has more clay content compared to the soil used for wall construction. The organic additives lend smoothness and bonding through the fibre content in them. The plaster is known as Kol in most regions and it is done in a minimum of three layers. To prepare the mix for plaster, the soil and organic matters are added in desired proportion on the ground [fig 69]. After adding water, they are mixed well with hands [fig 70]. Small lumps are made of the mixture and then applied on the wall [fig 71]. The first layer contains up to 30 to 40 percent of dung. This is usually cow or buffalo dung. This layer is 1 to 1.5 inch thick. The second layer has up to 60 to 70 percent dung. The thickness of the second layer is also around one inch. The last layer is mostly dung and husk. In Kutch donkey dung is also used as it gives smoothness to the finished surface. This is very thin layer. This gradual reduction in proportion of soil ensures good bonding between the wall and plaster. The final finishing is done with white clayey soil available in most regions. This has higher lime content and lends a white colour to finished walls [fig 72]. Sometimes different clays are mixed to give various colours to finished walls. The total thickness of plaster varies between 1.5 to 2.5 inches. If the plaster is too thick, it will separate from the wall while a very thin plaster will not provide enough protection to the wall surface.

Over a period of time when the surface of this plaster degrades, a surface layer of plaster is regularly applied. This is known as lipan. The base material for lipan includes clayey soil, agricultural by-products and animal dung mixed with water. Lipan is usually done in two thin coats. The finishing layer shows clear impressions of finger patterns and decorates the wall. Lipan is applied to walls as well as earthen floors. The frequency of lipan is different depending upon the region and severity of surface degradation. Lipan on walls is required less frequently than on the floor. In most areas, wall lipan is done once to thrice a year while floor lipan requires frequent cycles, ranging from 15 days to two months. At least once a year before Diwali and after monsoon, lipan is done on the walls and floors, to repair them after water seepage and damage due to monsoon.
Adobe construction can be defined as a masonry system composed of individually formed mud blocks known as adobe blocks, which are sun dried and bonded together with mud mortar. The basic unit of construction - adobe block is the most important aspect in adobe construction. The main difference between adobe masonry and cement mortar masonry is the materials used for construction. The basic principles of masonry construction remain the same in both.

An adobe block can be defined as air-dried brick made from a puddle mud solution and cast in moulds. The constituents of the mix have varying proportions of clay, silt and sand. Straw and stabilisers may be added for special performance enhancements. The adobe block is commonly referred to as mud brick as well. The advantage of using adobe blocks over other earthen construction is that the water source need not be very close to the construction site; hence, adobe construction was used in the areas where sweet water was scarcely available.

Adobe construction is one of the oldest construction practices found across the world. Its use dates back to 8000 B.C. The citadel of Bam, or Arg-é Bam, in Kerman province of Iran is the largest building made using adobe and dates back to at least 500 B.C. The use of adobe construction is seen in most hazard-prone regions all over the world, such as Latin America, Africa, the Indian subcontinent and other parts of Asia, the Middle East and southern Europe.
Adobe constructions are found in the following regions.
- Kutch
- North Gujarat region
- Nal Sarovar area in Bhal

Kutch has still kept the tradition of building with adobe blocks alive. People make adobe blocks themselves, with help from friends, relatives and neighbours. Rectangular as well as circular bhunga houses, made using adobe block as the construction unit are commonly found here. It has been observed that after the earthquake of 2001 the use of adobe blocks for construction reduced drastically, though it is also a known and well accepted fact that the bhunga houses constructed with earth withstood the earthquake reasonably well.

North Gujarat, specially the areas bordering the desert have circular houses. Some of them use adobe construction, though cob construction is more common here. Some examples of adobe construction are found in Bhal near Nal Sarovar area, but currently it is very rarely practised. Apart from these, some houses in Bhal region were built through NGO intervention as part of their strategy to provide better living conditions with minimum cost to people. For the project, house owners were trained to make adobe blocks and cannot be considered as traditional building practice.
Typical adobe houses

Usually adobe construction is very similar to cob construction\(^{23}\), the only difference being that adobe blocks are pre manufactured while cob is an in-situ construction. This has impact on the construction methodology and also on the consistency of the construction units. Most often, adobe blocks are casted by people themselves near the village pond, from where they source water and soil for making adobe blocks. The intensive labour and availability of other material options have led to significant reduction in number of adobe block constructions in Gujarat and deterioration of this building practice over the years.

Though very rarely found, rectangular single-storey house was the most common adobe house

\(^{23}\) Eventhough construction methodology is different for cob and adobe construction, visually it is difficult to differentiate adobe construction from cob construction once the lipan has been done. The material quality (earth) and, hence, structural properties (wall thickness, height and failure pattern etc.) are very similar.
type in Bhal region. Here, the usual practice was to construct the walls on very minimum foundation. At times, the foundation was altogether missing. The houses usually had gabled roof with wooden under-structure. Trusses are not very common, but are found in institutional buildings. The houses were rendered with hand plaster called kol and finished with lipan. Thus, the building practice is quite similar to cob wall construction in terms of typology and use of roofing and finishing materials.

Most of adobe construction in Gujarat is found in Kutch, where people are still practicing adobe construction to build houses. A typical example of a cluster with adobe construction is shown here [Fig 73]. A typical traditional settlement consists of rectangular as well as circular houses built on the same plinth and in the same compound. They may utilise combination of adobe, cob or wattle and daub construction practices. Usually some rectangular houses made with adobe blocks are found in Kutch, but circular houses known as bhunga are common and well known [Fig 74]. Occasionally bhungas are found in north Gujarat, where they were known as jhompa. In Kutch, adobe construction is more popular than cob wall construction. Houses in Kutch are usually constructed on sand packed stone foundation. The low height adobe walls are covered with thatched roof having a wooden under-structure.

Fig 74. Plan and section of a typical cluster of houses in Bhirandiyara, Kutch with circular and rectangular adobe houses
Rectangular adobe wall house

In terms of house layout, the rectangular houses using adobe blocks are very similar to cob wall houses. All the houses using adobe blocks are single-storeyed structures. In Kutch, as part of Vandh, the single structures made with bhunga usually don’t have verandah [fig 75]. Some independent structures were found with a verandah and one or two rooms arranged parallel to each other [fig76]. In all cases, the entry to the structure is direct and there are usually one or two small windows. Similar to cob construction, the external walls are low in height with minimum exposure to wind and rain. Despite the need for covering the walls for protection from rain, the roof overhangs are short. This is due to frequent winds and cyclones. The roof used to be a wooden under-structure covered with country tiles. The country tiles are now replaced by Mangalore tiles in most places.
Since the built spaces are utilised mainly as storage spaces, the niches in the walls and kothar occupy prominent places in the interior. Usually built outside the house in a corner, a small platform and storage below serves the purpose of providing cooking space [fig 77]. In some houses, the kitchen counter is covered and acts more like storage for cooking [fig 78]. Otla, a multifunctional raised plinth provides space for various daily activities like sleeping, resting and cooking etc.

fig 77. Kitchen is constructed outside the house

fig 78. Storage for outside cooking
Circular adobe wall house
Circular, low height construction with a conical roof is the most common building type in Kutch. It utilises both, adobe block and cob construction. As explained in the earlier section on cob walls, the bhunga formed part of the vaav which is an extended family housing unit in Kutch. This means that there is no significant difference between cob and adobe bhungas in terms of spatial arrangement. The external and internal spaces are almost identical. The construction materials for foundation and roof construction are very similar to cob. Sand packed stone foundation up to a depth of 3 feet is commonly used. The roof is made of wooden under-structure with thatch as roofing material. The presence of mann and biladu - wooden elements for conical roofs are also commonly found elements in both types of construction. The houses are hand plastered in two to three layers with a mixture of earth, dung from household cattle and agriculture by-products like wheat or rice stems and husk. The finishing layer constitutes coloured soil from the nearby region, which is usually white, brown, yellow or ochre. These houses are self or community-built structures and women play a significant role in house construction. Adobe block making is carried out by women and men together. Block masonry is mostly done by men with help of women. Maintenance, like cleaning and smearing, is mainly handled by women. Kol and plaster as well as decorative plaster with mirrorwork, called chitrakam is carried out by women only [fig 79]. Only long-term repairs are carried out by men and women together. Some women artisans are very famous for adobe work and plastering with earth.
Construction Method
Adobe construction includes two main activities – block making and block masonry. In Gujarat, it is only being actively practiced in Kutch region. The adobe blocks are casted where there is access to good quality earth for block making, as well as ample sweet water for construction. After the blocks were casted and dried properly, they were brought to the site for construction. The below details describe the process of adobe block making²⁴.

²⁴. The construction method described here is based on the interviews with different adobe artisans as well as first-hand observations of adobe block making by traditional artisans at Hunnarshala Foundation Campus, Bhuj, in March 2010. All the images of construction are from the construction site at Hunnarshala Foundation, Bhuj.
Making Adobe Blocks

The adobe block-making process is usually carried out from October to January, right after monsoon. This is the time when the salt content in the upper strata of soil is minimal and it is soft to work with. Also, there is ample water available for making the blocks. In Kutch, the soil is procured from the pond. The soil selection is based on traditional methods, by pressing and checking the wet soil with the hand and determining the sand and clay content. Since the soil and water for making adobe blocks are procured near water source, the storage is easy. The blocks are also made near the procurement site. Once the blocks are ready to be used then they are transported to the construction site. This construction is similar to brick or stone masonry, but usually utilises mud mortar.

The adobe block-making process can be further divided into the following steps.
1. Soil selection and storage
2. Preparation of soil for casting the blocks
3. Casting of adobe blocks
4. Drying of blocks
Soil selection and storage
For making adobe blocks, the soils available in the vicinity of the site are tested for proportion of various constituents like gravel, sand, silt and clay. In rural areas, the artisans already know the area where good quality soil is available for construction. Within the area, they check different locations for suitable soil, which has the correct proportion of clay and sand. Before casting the blocks in bulk, the artisans always try out sample blocks with the selected soil. It is important to study the shrinkage cracks in the blocks to make sure that they are not too many or too wide. If the shrinkage cracks in the test blocks are too many or if they are wider than an inch, it means that the clay content is very high. To balance the proportion, the right quantity of sand is added, which results in reduction of cracks in blocks. Sometimes, stone dust is also used in lieu of sand. But this is done only when it is cheaply available in the vicinity. If the soil has more sand content than required, the blocks will not withstand exposure to water for a long time and will get washed during rains. Usually in Kutch, no organic additives are added to the soil.

Once identified, the required quantity of soil is brought and stored in one place. Before making the blocks, the soil is kept moist with a wet cloth for at least two days to a week. This procedure allows for better integration and distribution of water within the clay. According to some traditional artisans, at times the soil was mixed with sand and water at the source, soon after it was procured. However, this practice does not allow for enough 'sleeping' time. The resultant block quality can vary greatly.

25. In newer constructions, the soil is tested in the laboratory for composition and salinity. The desired quality is achieved by adding sand whenever needed. Additionally, the compressive strength of the sample blocks is also tested.
26. If the proportion of clay is high, a layer of clay is formed on the surface of the lump. While pugging the mixture, a layer of clay will coat the lump and the inside of the lump will remain dry. This will prevent proper mixing of soil.
27. Artisans in Kutch opined that use of stabilisers like wheat or rice straw was not advisable as they attract termites. Though adobe block-making processes in many other places involve agriculture and animal by-products, they are not commonly found in Gujarat. This is similar to the opinion of Oad artisans who build cob houses using earth.
28. The water helps activate the cohesive properties of soil and is practised in many places all over the world where adobe construction is prevalent. This procedure is referred to as 'sleeping' the mud and it is done for one or two days.
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Preparation of soil for casting the blocks
Batches of moist soil are taken out and water is added in appropriate quantity to ensure easy pugging. Pugging is done for about four to five hours, depending on the soil. During the process, the soil is occasionally turned over with a shovel to ensure that all the soil is mixed thoroughly and there are no dry lumps. More pugging is then done to get a homogenous mix. The homogeneity of material ensures better bonding.

Casting of the blocks
The blocks are casted in wooden or aluminium moulds. In most traditional constructions, wooden moulds were used, which produced a single adobe block. The size of the adobe block is primarily dependent on the required wall thickness. Wall thickness is generally dependent on weather conditions - thicker for extreme conditions and thinner for moderate ones. The block size is also dependent on the weight and ease of handling the blocks. In Hunnarshala Foundation campus, block size was 18 inches X 8.5 inches X 3.5 inches. At Saroda village, blocks of 12 inches X 9 inches X 4 inches were used for constructing 9 inches and 12 inches thick walls. Here, the average dry weight of each block was about 12 kg.

29. The mixture will stick lesser on the surface of the aluminium form, giving the blocks a smoother finish as compared to blocks made with a wooden frame.
30. It was also observed that over a period of time, the wall thicknesses and, hence, the corresponding block sizes have reduced in most vernacular constructions. This may be resultant of increased pressure on land availability.
The mould is placed on a flat ground and the prepared mud is poured inside the mould. The mud is manually compacted by hand, pressing the lumps of soil ensuring that all the gaps are filled. With the help of a flat wooden stick, the mud is levelled and all the excess mud is removed. The top surface of the block is slightly moistened, levelled and given a final finish with hands. Fingers are lightly run on the surface of the block to give it a textured surface that will ensure proper bonding with the mortar. The form is gently slid up and taken out. The mould is washed before the next block is cast.

**Drying of the blocks**

Drying the blocks is a two-stage process. The prepared adobe blocks are first dried for two to three days in the shade on a flat surface. If there is no shed available, they are covered with a slightly wet jute or cotton cloth so that drying is not very fast. Rapid drying may develop cracks in the blocks. After initial drying, they are turned on their sides. The bottom is scraped clean. Again they are left to dry for a couple of days. Then they are stacked up to three layers and left to dry for another 15-18 days. The total process of drying takes about 20-30 days depending on the season and climate of the region.

Only after thorough drying, the blocks are moved to the stock pile, neatly stacked on their long narrow side protected from the rains. Once dried, broken blocks or the blocks with cracks are sorted and removed. These blocks can be crushed and the soil reused to make new blocks.

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31. Excessive exposure to direct sun can accelerate surface drying and cause cracking. The slow drying in shade or under a cover reduces the possibility of cracks in the blocks. A surface with natural soil is preferred for drying, since some of the moisture is also absorbed by the soil below.

32. Adobe blocks need to be well dried to avoid any further expansions or shrinkage, as this can result in damage of the structure. Once the bricks are dry, all the expansion and shrinkage will be visible. A few blocks are broken to check whether they have thoroughly dried.
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fig 91. Mould is gently removed

fig 92. The block is put dry at the same place

fig 93. The blocks are covered to avoid fast drying

fig 94. After few days, they are turned on the edge

fig 95. The blocks are stacked on each other for storage

fig 96. The broken blocks are discarded and reused
Adobe block masonry

Construction with adobe blocks is done like brick or stone masonry. In Kutch, sand-filled stone foundation was very common. Instead of cement mortar, generally mud mortar is used for adobe wall construction. The water content in mud mortar is lower than in cement content and due to reaction of earthen blocks with water, the blocks are not dipped in water before construction as usually is the practice during brick masonry. Instead, the block surface is moistened a little, just before construction. This is done to prepare the surface for better bonding with mortar. English or Flemish bond is used for masonry. Care is taken to avoid continuous perpendicular joints, as they can hugely impact the strength of the wall. A maximum of three to four layers are constructed in a day, then the wall is left to dry for a couple of days before the next layers are constructed. The openings are kept small and are well placed to ensure that the overall wall area is maximised.

The roof is installed using wooden members similar to cob construction. Finally, the floor and walls are finished with kol. Lipan is done regularly as part of routine maintenance.
Wattle and Daub Construction

Wattle-and-daub construction can be described as a composite wall construction system comprising timber or bamboo internal framing encased in mud. The woven lattice of wooden members is called wattle. Wattle is woven between the wooden frames and is daubed with a mixture usually made of some combination of earth. The mud used for this construction has relatively higher clay content with some proportion of organic additives. The additives in the soil may be animal dung and rice or wheat straw or husk. The surface is then rendered in multiple layers on both sides.

Wattle-and-daub construction is one of the oldest and widespread traditional construction method practised throughout the world. The usage of wattle-and-daub construction dates back to more than 6,000 years and is still an important construction practice in many parts of the world. Many historic buildings include wattle-and-daub construction and the practice is becoming popular again in more developed areas as a low-impact, sustainable building practice. Historical examples of wattle-and-daub constructions are found in central Europe, western Asia, North and South America. In India, Ikra construction found very commonly in the north east as well as many other Himalayan regions, where it is known with different names, is essentially wattle-and-daub construction.

Wattle and daub is easier to construct and does not require much specialised skills. Also, a greater flexibility is possible due to the frame structure. Moreover, a variety in size, position of openings as well as type of spaces can be produced with ease.
Wattle-and-daub constructions are commonly found in the following regions of Gujarat:

- East and south Gujarat
- Kutch

Simple single-storey houses with a verandah and one or two rooms are commonly found throughout the coastal as well as hilly terrains of south Gujarat [fig 98]. Houses in east Gujarat are often double storeyed, with space for cattle and storage on the ground floor and living spaces on the first floor. Use of local trees like teak, mango, neem as well as bamboo is very common in construction. The tribal people construct wattle-and-daub houses themselves with the help of their neighbours and relatives. Though in the coastal regions, the artisans traditionally working with wood or bamboo construct the frame structure. The wattle and daub are usually applied between the frame by people themselves, where women play important role in construction. Roof construction is carried out by the village carpenter. Hipped roof is also found in many places along with pitched roof. The roof is made of wooden under-structure with country tiles, moulded by people themselves or sourced from
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though, lately Mangalore tiles and CGI sheets are commonly used. The penetration of RCC and brick is not as widespread, but one can see the traditional structures being replaced slowly by brick and RCC structures.

Typical wattle-and-daub houses

In terms of the house layout, there are two distinct house types found in Gujarat using wattle-and-daub construction. The rectangular wattle-and-daub house is the most commonly found house type. The rectangular houses are subdivided into single-storey and double-storey houses. The single-storey houses are common in the plains; this includes coastal regions of Valsad and Surat districts as well as plains of central Gujarat in Vadodara, Narmada and Bharuch districts, up to Panchmahals and Dahod [fig 100]. The south Gujarat region—specially Surat and Valsad district being well irrigated, many tribal here have adopted agriculture as their main source of livelihood after the loss of their forest land and related economic activities. The houses

33. In continuation with the tribal traditions, many people in eastern Gujarat make burnt bricks for their own use. The quality, strength and fuel efficiency of the method adopted by the people is beyond the scope of this study.
in Valsad and Surat are bigger compared to houses in Narmada and Bharuch districts due to their economic well-being. Though, basic construction and typology of the houses remain the same. Deeper into the forests, especially in the hilly terrains of Dahod, Panchmahals and the Dangs, double-storey houses are more commonly found. These houses are occupied by tribals who still largely follow the tribal lifestyle. The houses are built on small farmland, which are demarcated by wooden hedges or wad.

In Kutch and some parts of Banaskantha in north Gujarat, circular bhunga constructions utilising wattle and daub are commonly found. In Kutch, these free-standing structures are part of a larger house, along with other bhunga structures. The bhungas belonging to single families are notionally connected through a common earthen plinth. The other bhungas of the same house could be built with cob, adobe or wattle-and-daub construction. A few houses are organised into a vaas, which is an extended family unit. A vaas is often enclosed by hedge or wad utilising wattle-and-daub construction. Circular constructions in north Gujarat are fewer and not usually part of the main house but act as additional structures for storage, kitchen or sit-out space. They are also very basic structures compared to the elaborate Kutch bhungas.
Rectangular Wattle-and-Daub House

A typical wattle and-daub construction is very similar to the cob or adobe construction in the plan layout, but it is immediately distinguished by its thinner walls. The surface of wall is distinct with its visible pattern of frame structure.

The typical house in south Gujarat is a single-storey construction that opens on a street or into a common space. The houses have a verandah that provided transition from outside to the inner rooms. The rooms are built parallel to each other opening into the verandah. The wall between the verandah and inner rooms is decorated with handmade paintings on the walls [fig 101]. These handmade paintings are rapidly being replaced with stencilled images. Sometimes, there is another layer added towards the back of the house which accommodates the kitchen or storage space. There is usually a backyard which acts as a kitchen garden as well as storage for fodder etc. Sometimes there is a small shed for cattle in the backyard, attached to the main structure of the house [fig 102]. Mostly, the houses are constructed with gable roof, but in coastal south Gujarat, the houses sometimes have hipped roof [fig 103], while the cattle-shed roof is separately constructed below the roof of the main structure and has a one-way slope. Creepers with local vegetables are often stored on the roof of the house.
In tribal regions of Narmada and Surat districts, the houses are measured based on the number of columns—thambhli\(^{34}\) in a house [fig 104 & 105]. Usually the houses are between nine and 18 thambhls. A nine-thambhli house is considered small while a 15-thambhli one is considered big. The distance between the grid points (and hence, columns) is determined by the span of the beams and is usually eight-\(\text{haath}\)\(^{35}\) (approximately 12 feet). Thus, the houses measure around 600 to 1200 sq. ft. In south Gujarat, sometimes whole tree trunks are used as \(\text{thambhli}\) and \(\text{patdi}\)\(^{36}\). Traditionally, good quality timber is used to construct the frame. Teak wood of approximately 8” X 8” sections for columns and 6” X 4” sections for beams is usually found, though this varies as per the case. The height of the \(\text{thambhli}\) is determined considering the roof level, plinth height as well as portion that is embedded under the ground. Between the columns on the grid lines, vertical members to support wattle lattice are placed approximately three to four feet apart. The wattle-and-daub walls are called \(\text{kamli ni diwal}\)\(^{37}\) in local terminology. Recently, the \(\text{verandah}\) is covered up with wattle-and-daub walls. This makes the main room very dark and inadequately ventilated. Though, this is found to be a recent phenomenon as people are adjusting to the changed lifestyle, addressing privacy and security requirements.

\(^{34}\) Thambhli literally means (leaner) column. It was made of either a single wooden member or two members tied together. Some rows of columns are given special names, like central raw of columns were called mobha ni thambhli, next rows on both sides are called podgai thambhli.

\(^{35}\) A \(\text{haath}\) was common measure before measure taps were easily available. Literally meaning hand or arm, it was usually an arm-length measure. It would roughly measure up to 1.5 feet, though varied depending upon the person who measured.

\(^{36}\) \(\text{Patdi}\) is local terminology for beams usually made of timber.

\(^{37}\) ‘\(\text{Kamli ni diwal}\)’ literally means wall like a blanket.
In plains of central-eastern Gujarat, the typical rectangular houses have a similar typology of verandah and one or two parallel rooms. Traditionally, wattle and daub was used to construct the houses, though today, bricks have replaced wattle and daub in almost the entire region [fig 106]. Mostly wattle-and-daub is used for extensions or temporary structures [fig 107]. A few interior areas still have wattle and daub constructions remaining. This region is famous for Pithora paintings, tribal art of Rathwa community. The paintings are painted right at the entrance on the wall between the verandah and main room. Lately, to keep their cattle secure from being stolen, the verandah with elaborated paintings is enclosed with wattle-and-daub walls without openings. Hence, one enters the house through a small door into what was earlier a nicely decorated verandah. This takes away the beauty of the semi open space of verandah that provides transition from an open space to an enclosed and defined entrance. The paintings are almost invisible in the dark and dingy space of the enclosed verandah [fig 108] and the inner rooms are neither well lit nor adequately ventilated. The lack of ventilation is partly balanced by the use of earthen walls and tiled roof.
House at Nargol village, Valsad
The house of Savitaben Nanubhai Dubda is situated in Bhavani Faliu, near Nava talav, Nargol [fig 109 &110]. The house comprises of a large verandah in front which serves partly as a kitchen and sitting space. Part of the verandah is enclosed to create a cooking space. The verandah space provides for transition between the outside and inside. The verandah connects the two rooms laid side by side. These rooms are used as sleeping and storage spaces. Both rooms are interconnected and one of the rooms is subdivided further by a wattle-and-daub partition to separate sleeping and storage space. Though lighting is minimal as there are no windows due to reasons of safety, wattle-and-daub walls and tiled roofs provide enough ventilation.

Savitaben’s house is made using primary structure of pre-cast RCC poles as columns and infill wattle-and-daub walls. This shift from traditional timber posts to pre-cast RCC post is the recent pattern as availability of timber has become difficult and expensive. Infill wall panels of wattle and daub are made with different materials. Bamboo is the best possible option. However, cost constraints make people use other materials such as date palm leaves or stalk of agricultural crops. These options have poor longevity. Bamboo if protected from wetting can last up to 10 years. Baru, Khajuri, Kasal, Bhendi are other local options. Traditionally, daubing is done in at least three layers. The first layer is black soil with high clay content, second layer is red soil
and final layer is a cow dung solution. The layers of soil also include certain proportion of cow dung in 4:1 ratio, where soil is four parts and cow dung is one part. The roofing is done with a mix of materials. The house was earlier covered with Morbi tiles but due to maintenance issues, the family has shifted to corrugated cement asbestos (CCA) sheets. So, one side slope of the gable roof is done with CCA sheets while the other slope still has Morbi clay tiles. The house floor is finished with mud plaster.
House at Kikla village, Valsad

Nooriben Gulambhai lives in Kikla village in Udwada. Her house though in a poor state now, reflects the quality it exuded in the past [fig 111]. This 75-80-year-old house is one of the few surviving traditional structures. The house is based on a grid of timber posts and has a hipped roof. A large verandah in front is primarily used as a sit out and transition space to the interior, more private spaces. A series of three rooms laid out side by side can be accessed through the first room. Towards the rear, an addition has been made for cooking. Another sloping roof has been added below the hipped roof slope to the rear to cover the kitchen space. The first room accessed through the front verandah leads to the kitchen on the rear and an adjacent room that is used primarily as a store. The space under the pitched roof is used as a large attic space for storage. The middle room, under the main ridge, has attic space. The size and layout of the room corresponds well with the overall structural layout of timber posts and roofing under-structure. The ridge beam of the hipped roof is supported on two main timber columns that are adjusted in the walls of the middle room.

Infill wattle-and-daub walls are then added to this structure of timber posts. Nooriben’s house shows how the timber frame structure provides a neat and functional architectural space for the house.
House at Mandva Kaprada village, Valsad
Rangliben Ramjubhai’s house in Mandva Kaprada village in Valsad district is another example of timber post and beam structure [Fig 112]. Here, 6” X 6” timber posts are laid out in a 2 X 2 rectangular grid, providing a two-room house with a verandah in front. This grid is further divided into smaller rectangular grids as per the roofing under-structure. A hipped roof under-structure is made on this timber frame. The sizes of posts, beams and roofing under-structure indicate the artisanal understanding of the structural system. The housing space is created by making infill wattle-and-daub panels in this timber frame structure. Wattle-and-daub walls were made using bamboo as primary material. Two varieties of bamboo are found in the region - solid bamboo and hollow bamboo. Solid bamboo is used mainly for posts and beams but hollow bamboo is split and woven to make wattle. The one with thorny needles around its culms is better for the post and the one without thorns is preferred for weaving. It was preferable to harvest bamboo for the wattle on a no-moon day as it will not be easily attacked by pests and insects. Usually summers or winters are considered the best seasons for harvesting.

According to Rangliben, for the daubing, reddish soil and silt clay deposited by the river is preferred in this region over soil from agricultural fields. Rice husk and dung are added to this soil and soaked for two days before applying as it as daub on the wattle. The last or top layer for daubing is primarily a cow dung solution.

Rangliben’s house measures about 720 sq. ft. The timber frame for the house was erected by a team of two artisans with help from one member of the family. It took 15 days; cost them Rs. 6,000 in labour along with tea and food for the working days.
Circulr Wattle and Daub House

Wattle-and-daub houses in Kutch are similar to the bhunga houses built with adobe or cob construction in terms of spaces and composition of house. It forms part of the larger house with some other bhungas. The plan of a bhunga is simple circular with similar arrangements of interior elements like kothar, niches and puja space in load-bearing construction. Interestingly, the windows are not very large even though the frame structure has the flexibility for larger openings. This is to protect the houses from frequent sand storms in the region. Due to unavailability of other wood for construction, Gando Bawal is used for the frame structure and also for wattle construction. Various grasses from the region are used for roofing. The bhunga is used as storage, cooking or sleeping space. These houses in Kutch are built by the family members. Though, lately, some specialised work like roof under-structure is assigned to carpenters. Women play a major role in constructing the house. Pre-construction activities like collection of wooden twigs, grasses etc. are done by women. During the construction, wattle and daub is mostly done by women while men prepare the main structure with columns and interwoven beams using thinner branches. Here too, women are very active. Women also do the thatch work on the roof.
Construction Method
Construction method for wattle and daub
Traditionally, wattle-and-daub infill is used with wooden or bamboo frame structure. But, this is not a necessity. It is possible to build wattle-and-daub within any frame using bricks, stabilised earth blocks or other material. Proper details should be well worked out to keep the lattice of the wattle securely attached to the structure. The construction of the whole system of wattle and daub consists of two main activities.
1) Construction of column and beam structure
2) Wattle and daub

1) Construction of column and beam structure
Traditionally, the process of wattle and daub construction begins with collecting the wood. The wood is collected over a period of time and, hence, it is usually well seasoned wood [fig 113]. In Kutch, mostly Desi Bawal is used for wattle and daub, but people have shifted to gando bawal lately due to unavailability of other options. In south and east Gujarat, teak, bawal, neem, mango or bamboo are used for frame construction.

fig 113. Collection of wood for construction in Kutch
The wattle and daub is applied to construct walls between two columns in column and beam structures. Usually in a rectangular construction, the columns are organised on a grid. First, the grid points on which the house is to be constructed are marked. In tribal houses of Narmada and Surat districts, the central columns of the house are erected first and then the mobh is placed [fig 114]. The rest of columns are then erected and horizontal beams are placed.

In most cases, there is no foundation for the columns. The wooden or bamboo columns are directly inserted up to two or three feet into the ground. The use of tar, burnt oil or a solution mixed with neem juice is applied as an anti-termite layer at the bottom of the column. Height of the columns vary based on the height of the floor, roof and plinth height. In case of bamboo or tree trunks, the diameter is at least 8 inches while timber members are approximately 8 inches by 8 inches. Often, the base and capital are nicely carved. Usually, eaves are 6 to 7 feet above the ground. In some smaller houses, the height of the lintel or roof eaves is even lower than 5 feet. In case of timber construction, the entire construction is usually done with wooden joinery details [fig 115]. In places where raw trunk or bamboo is used, sometimes rope is used to secure the members [fig 116]. Though mostly the wood for post is cut from near the branching, forming a ‘Y’ shape to support the beam[fig 117], sometimes wooden kumbhi is placed on top of the post to rest the beam [fig 118]. The use of nails is a recent phenomenon. The entire structure is erected before the actual wattle and daub is applied. The attic using bamboo [fig 119] and roof structure are also constructed before enclosing the walls with wattle and daub. Where there is attic constructed, the support for roof beams is either taken from the smaller column on top of the attic or a separate column is constructed next to the column for attic structure[fig 120].

fig 114. Central column supports the mobh
Prevalent Earth-based Building Practices

fig 115. Timber construction with wooden joinery

fig 116. Bamboo or tree trunk is tied with rope

fig 117. Trunk is cut near branching to get Y shape

fig 118. A separate member is added to support the beam

fig 119. Bamboo attic is often found in Gir and south Gujarat

fig 120. Separate column constructed to support roof and attic
Up to this level, the construction varies between the circular bhunga or rectangular houses of Kutch and the rectangular houses in east or south Gujarat. In Kutch, the height of the structure is much lesser and the columns are thinner, as the roof is made of lightweight thatch [fig 121]. At regular intervals, thin trunks of creepers or branches are horizontally woven into the vertical members to create tie members at different levels. The roof is constructed with local wood. Often due to smaller size of construction, the elaborate column-beam structure is much simplified. Yet, the application of wattle and daub is similar in Kutch and the south Gujarat.

2) Wattle and daub making
Process of wattle-and-daub construction comprises of the following steps.
- Soil selection and preparation of mixture for daub
- Preparation and treatment of bamboo for lattice
- Lattice work
- Daubing, finishing and plastering
a) Soil selection and preparation of mixture for daub and smearing

The soil used for daub is selected on the basis of clay content. Clayey soil (from 50 to 80% clay content) is preferred for daubing. Soil from certain areas (borrow area) usually near the village pond, is considered good for construction and the whole village collects soil from these places when they need to construct. In pond, the upper stratum of the surface consists of smooth clay. This clay is procured from the edge of the pond where water has receded after the monsoon. The soil is transported to the site of construction. Saline soil is avoided as it erodes very fast, exposing the wood or bamboo in the wattle to weather.

The soil is stored on clean flat surface near the construction site. Bigger lumps are crushed manually or with a shovel. The soil is then mixed with cow or buffalo dung and rice, wheat or jowar straws. Soil, dung and straw or husk proportion is maintained in 10:3:3 ratio. If required, sand is added to balance the excessive clay. Donkey and horse excreta can also be used in lieu of buffalo or cow dung. Traditionally, neem leaves were used as a stabiliser with

![fig 122. Soil based mixture is soaked in water](image)
plant juices. Also non-erodible mud prepared with coal tar is used in some recent practices. This acts as a waterproofing agent. Fibrous materials like cow dung, straw etc. act as stabilising agents and reduces the shrinkage cracks in the wall.

After all the ingredients are mixed well with a shovel, water is added to the mix. This mixture is left till all the water is absorbed [fig 122 on previous page]. This may take more than a day. After the water is absorbed, more water is added if required and mixed thoroughly. The mixture is kneaded by pugging to ensure proper mixing [fig 123]. Pugging is done once or twice a days. After the pugging is finished for the day, the mixture is covered with wet jute bags or thick cloth. This process is called *sadaanavu* - literally meaning rotting. This is usually done for 3 to 4 days and can go up to 20 to 30 days. After that, the material is ready for use.

39. For the surface finish (smearing) material, the same process is followed, though clayey soil is preferred and sand is not added at all to the mixture.

40. There were several types of bamboos in south Gujarat earlier, now there are three main types available in Narmada district. Kantas (with thorns) is thick bamboo between 9 and 12-inch diameter when fully grown, but is hollow, is used mainly for lattice work. Thinner but solid bamboo (called just ‘bamboo’ by locals) is often used for structural purposes. Maximum diameter of this bamboo is 6 to 8 inches. Desi bamboo called Manvel is not much used for construction but it is used for making decorative tribal artefacts. Now, most of the bamboo is imported from Assam or sometimes the Dangs.

41. Though some people knew about traditional way of bamboo treatment, it was not found actually being practiced.
b) Preparation and treatment of wattle

Depending on the material availability, wattles are made with bamboo, twigs and wood. The use of twigs to make wattle is usually seen in Kutch. In south and east Gujarat, bamboo is used commonly for wattle construction. At least three-year-old mature bamboo is used for construction, which traditional artisans identifies with their experience [fig 124 and 125]. Monsoon is not a good time for procuring bamboo as the bamboo has more sap and is prone to infection and attack of insects. Harvest in winter or summer also coincides well with procurement of earth for construction. Bamboo is cut preferably on a no-moon night, which according to traditional artisans, reduces the possibility of termite or pest attack. Sorted bamboos are sometimes treated with traditional methods to improve the lifespan of the structure. The most common method is to leave the freshly harvested bamboo in flowing river water for at least a month. The bamboo for wattle is checked for pores, which indicate termites or other pests attack [fig 126].
To make wattle, bamboo has to be split along its length and woven. Roughly two inch diameter bamboo is used for making lattice for wattle. The joints are smoothened and levelled before splitting the bamboo [fig 127] because the rough joints usually bulge out of the earthen surface of the wall, thus exposing the bamboo to weather. Bamboo is first split into two parts, which is then further split into smaller strips. The split bamboo pieces are smoothened and stored near the construction site.

c) Lattice work for wattle
Using twigs is the more basic way of construction and does not involve any weaving between the members. They are simply tied next to each other with help of a string [fig 128]. While using bamboo, the bamboo strips are interwoven with the bamboo or wooden members to make bamboo panels [fig 129]. At the edge of the panel, the strips are bent or tied together at loose end with a strong string [fig 130]. In some cases, this is done by assembling all the loose ends of the strips between two horizontal bamboo strips and then tying them. This makes an entire panel of
lattice with approximate dimensions of 3 feet by 3 feet. Wherever openings are required, the lattice is cut and tied at the ends with bamboo strips on the top and bottom of the opening. Usually the openings are adjusted such that the support structure member for lattice acts as lintel or jamb for the openings.

D) Daubing, finishing and plastering
Once the lattice work is completed, the process of daubing commences. The mix for daub is applied firmly over the wattle [fig 131]. The in-between gaps of bamboo mat are carefully filled with daubing material using a trowel. The daub is compressed properly to avoid formation of air pockets. While compressing from one side, the other side of the wall is supported by another person so that it does not crack open and fall out. This procedure is carried out till the wall is approximately 4-inch thick. If the daub wall has to be thicker than four inches, another layer of daub is applied only after the first layer is roughened. Women usually perform the daubing in traditional practices [fig 132].
The wall is left to dry for seven to 10 days or until it dries completely. During the wet season, the drying procedure requires more time [fig 133]. When the daub dries, it shrinks and develops finer surface cracks. These cracks are then filled with the same mix prepared for daub and allowed to dry once again. After drying for four to five days, the wall is inspected again for crack formation, and any remaining cracks were filled. After the daubed wall has no visible cracks and is completely dry, a thin layer of smear finishing is applied with a similar composition of daub, but without sand. The windows and door edges are covered well with daub [fig 134]. The front wall of many houses are decorated with traditional decorative motifs or patterns with daub. In Kutch it is called Chitrakam [fig 135].

The finishing of this surface is not entirely waterproof. Alternative finishes like non-erodible mud plasters, lime plastering and composite mortars with soil are used for the external surfaces to make it water repellent. At times, in recent constructions, cement and sand plastering are also seen on external walls.

*fig 133. In traditional construction, walls are let to dry for long period of time*
Techniques like lime plaster are cheap, well known and effective. Lime is crushed into small pieces and sieved. It is then mixed thoroughly with sand and water. This mixture is covered and stored for a day. It is then applied just like conventional cement-sand plaster. A mix of lime and gugal\textsuperscript{42} is applied on top of the lime plaster to give it a smooth finish. The plaster is then left to set and cured for about two weeks.

For interior surfaces in Kutch, a coating of white mud\textsuperscript{42} is applied on wattle-and-daub walls. One part of white mud and four parts of sand are mixed with water and kept aside for four days. Sometimes, stabilisers like gugal or neem juice are added to the mix. This mix is then applied to the wall with a trowel. For the next layer, white mud is mixed with water thoroughly. It is then applied with a cloth over the surface to produce a smooth and very thin finishing coat.

42. See http://www.gits4u.com/agri/agri5gugal.htm for further details.
43. White mud usually has a high percentage of clay and lime deposits. This is commonly found in many areas of Kutch.
Structural Properties and Disaster Resistance of Earth Construction
Structural Properties and Disaster Resistance

In terms of their structural behaviour, earth constructions can be divided into two types:
1) Load bearing structures
2) Frame structures.

In load bearing structures, the load of the roof or intermediate floors is transferred down by the walls directly. Here the wall acts as the main structural element and hence the walls are thicker in such constructions. Cob and adobe construction are essentially load bearing constructions where earth is used for structural purpose [fig 1].

In frame structures, the load of the roof and the intermediate floors is carried down by a frame traditionally constructed using timber, bamboo or sometimes a combination of brick or stone columns with timber, bamboo or stone beams. The walls are made of infill materials like bamboo, wood, earth or bricks. As the wall behaves like a screen and does not carry any load, the wall thickness and the self-weight of the entire structure can be reduced significantly. Wattle & daub is such a structure where earth is used traditionally as an infill material along with the timber or bamboo [fig 2].
Cob construction and adobe block construction are the commonly found load bearing structures in most regions of Gujarat including Kutch, north Gujarat and Bhal. Both these constructions use pure form of earth without any additives. However in some regions of Bhal, when people construct their own houses, organic matter like hey, cow dung and sand may be added to achieve the desired quality of soil appropriate for construction. Yet, when traditional artisans constructed the buildings such practice was not commonly found. Many artisans believe that adding agricultural by-products would attract termites and pests, which would damage the structure.

**Structure of load-bearing earthen construction**

The structural properties of the earthen buildings can be understood at two levels, one is inherent qualities of the materials and the other is when the construction behaves as part of a system within a building. The following section studies load-bearing walls at both these levels.

**Inherent structural behaviour of load-bearing earth construction**

In dry conditions, well-formed and well-constructed cob or adobe systems have significant compressive strength. Thus, in usual conditions, the earthen buildings are quite strong. But, they have very low shear and tensile strengths. Furthermore, the system is prone to moisture-based degradation. Hence, in wet conditions, the strength can deteriorate rapidly and significantly.

**Structural design ideology for cob or adobe construction**

As tensile strength is low for earthen load-bearing construction, it makes the system comparatively susceptible to bending stresses. Bending stresses reduce depending upon the section modules which are proportional to the square of the depth of the wall, while compressive stresses reduce depending upon the area which is proportional to the depth of the wall. The low tensile strength capacity is traditionally addressed by making thick walls. This reduces the bending stresses at a sharper rate than reduction of compressive stress, thus making the combined stress a compressive stress system or gravity system. As contact with water can cause serious degradation in strength, traditionally, this is avoided by using either renders on the wall or overhangs to reduce the damage caused by rain and storms. Another traditional solution is to extend the plinth to prevent ground water from splashing on the base of the wall. In some traditional practices like cob construction, the walls are tapered allowing optimal balances between strength requirements and material costs. As cob wall systems are moulded on site, they lend themselves easily to such procedures.
Performance of load bearing earthen construction in disasters
To understand the structural behaviour, especially disaster resistance of load-bearing earthen buildings, a sample case is taken to try and understand its behaviour during different disasters. It has been understood from previous case studies that both, cob walls as well as adobe construction are primarily load-bearing systems and in most cases, they have similar foundation and roofing systems. There are two basic typologies found - rectangular plan and circular bhunga shape. The implication of disasters on different typologies will vary but not so much on the type of construction as long as they are standard houses constructed either with cob walls or adobe masonry walls. The orthogonal houses were single or double-storey, with one or two rooms and verandah in front. The circular bhunga type houses were always single-storey houses with low walls and conical thatch roofs. The openings were always small in both these types of houses. To understand structural behaviour and disaster-resistant features, sample houses from both these typologies have been considered as described below and understood in context of disaster resistance properties.

House Type 1: Rectangular form single-storey house
Main features of the typology
• Two rows of rooms with a verandah in front
• Shallow foundation with earth construction
• Gabled roof
• Adobe/cob Walls - load bearing
• One window and single door in each room
• Wooden under-structure for roof
• Roofing of tiles – Mangalore/country tiles

- • Inherent advantages of load-bearing earthen construction
Inherent advantages of a construction system are listed below.
- It is easily repairable.
- It ensures thermal comfort since walls are essentially very thick.
- It can be done with locally available traditional systems and skills.
- In case of cob construction, the system is formed of individually moulded lumps; there is a very high degree of flexibility in the form of the wall. Tapering of walls and other variations are the advantages of this system, where optimal usage of material can be ensured.
- Of all the earth-building systems, since adobe construction constitutes individual blocks, it is easier to ensure a high degree of quality since individual blocks can be inspected before use. Also, the shrinkage is restricted to the mortar level as the blocks are pre-dried units.

- • Inherent limitations of load-bearing earthen construction
Inherent limitations of load-bearing earthen constructions are as follows.
- It needs constant servicing, lack of which reduces the lifespan of the structure significantly.
- At the traditional system base, it can only be used for reasonably modest structures.
- It gives significantly lower usable space versus built area as the walls are essentially thicker.
- In case of cob wall construction, each layer needs significant time to dry, this system is time intensive.
- All sites do not have the quality of soil needed for earth-based building systems.
- The traditional knowledge needed for such systems is a dying art and the availability of skilled craftsmen is declining.
Structural qualitative analysis

- The gabled forms are susceptible in cases of horizontal forces perpendicular to that direction. Unless there is a lintel band (at the point at which the gable starts) and a covering band on the gable, it is entirely probable that during high seismic activity the gabled end would fall off. The traditional system of having stone copings may not work too well in regions of high seismic activity as these would not be well anchored.

- In regions of high seismic activity, the corners of the walls would end up being subject to significant stress and, unless reinforced, would end up either dropping off entirely or being heavily damaged. In moderate seismic areas, the traditional method of embedding wooden corners in the walls at regular intervals may suffice.

- In high wind/cyclone conditions, the roof is susceptible to damage. This damage is of primarily two types:
  - Failure of roof supporting system: The supporting system may lose connection with the top of the walls unless tied down securely. In the traditional system, the way of connecting is by building an optional load wall over the gable end. This may not be sufficient at all. Also in the event of high winds accompanied by rain, the flying of the roof/tiles would be followed by vertical seepage of water from the top of the walls. This would completely destroy the structure.
  - Failure of tiles: The tiles may fly off unless securely connected with the under-framing system. The present system of connection where the last layer is the only layer connected using bamboo is totally inadequate for such purposes.

- Overhangs are very important to protect the mud walls from rain and storms, but they are not sufficient in all the directions. The traditional method is to paint the surface with tar before the monsoon. If this is assiduously done, it may be sufficient, but otherwise, the walls are subject to severe risks.

- The plinth in mud wall houses needs to extend on all sides of the house and be well drained to avoid splashing on the walls. The current practices do not do this and this is seen in a significant number of houses where the walls are eroded at the base. It is also a questionable practice to have mud walls right up to the ground. The ground seepage remains a clear and omnipresent risk which would erode the walls due to moisture ingress from the base of the walls.

To conclude, on the whole, the construction systems do not inspire any great degree of faith. The greatest risk to mud wall construction is moisture. In this system, the roofs, the overhangs and the plinth protection are vital, but poorly done. The risk is therefore significant. The houses are totally under prepared to deal with any form of disaster (seismic, cyclone or floods).
House Type 2: Circular bhunga with single room

Main features of the typology
- Circular plan – single floor
- Sand-filled stone foundation, up to plinth level
- No internal walls – single room
- Adobe/cob walls – load bearing
- Small window and single lower height door
- Wooden under-structure for roofing
- Roofing of thatch

Structural qualitative analysis
- In high wind or cyclone conditions, the roof is susceptible to damage. The risk is lower than the gabled roof, but it is still significant. This damage is of primarily two types:
  - Failure of roof supporting system: The supporting system may lose connection with the top of the walls unless tied down securely. Also in the event of high winds accompanied by rain, the flying of the roof or thatch would be followed by vertical seepage of water from the top of the walls. This would completely destroy the structure. In the traditional building system, the connection of the supporting system with the walls is with wooden collars, which are nailed to the walls. In most cases, due to the form of the roof, these may be sufficient, but a roof band is still advisable. Also, since the climate is one of relatively low rain, the associated risk for support system failure is low.
  - Failure of thatch: The thatch may fly off unless securely connected with the under-framing system. The present system of connection is that the thatch is securely tied to the under-structure with ropes. This detail seems adequate.
- Overhangs are very important to protect the mud walls from rain and storms. For the traditional systems here, the overhang is sufficient and the roof comes down fairly low reducing the risk due to storms or rain.
- The plinth in earthen wall houses needs to extend on all sides of the house and be well drained to avoid splashing on the walls. The current practices of making the foundation and plinth of stone, generally bypass these problems.
- The seismic risk of the structure could be moderate as the roof has a very light load. In times of significant lateral loads, the vertical loads are low, it is possible that there may be tensile stresses at some locations. As the cross section is circular, the bending stresses would be relatively low, so the risk may not be very high, but a circular band at the top would be advisable to ensure composite action.

To conclude, on the whole, the construction systems seem generally adequate to deal with the associated natural disasters but require certain additional measures to make it safer.
Climatic performance and weathering effects
Apart from natural disasters, the safety in a building is mainly dependent on the age of the building and how much it is susceptible to climatic and weathering conditions. Regardless of natural disasters, the building is exposed to these climatic conditions, and resistance to these factors determine the life as well as the durability of the building.

Exposure to water during monsoon is main the cause of direct and adverse effect on the life of any load-bearing earthen structure. This exposure to water is caused due to two reasons, direct splash of rain water on the exposed wall surface and contact of stagnant water at the base of the walls [fig 3].

Termite infection is frequently seen in wooden roof members. The termite penetrates easily through the earthen walls into the roof members and there is little resistance.

Salinity is becoming another major issue for earthen construction. A typical section of cob wall is thicker at the base as it tapers towards the top. Salinity ingress erodes the base of the wall, thus changing the typical section of the wall. This can eventually result in swaying of the wall and critical damage to the structure. The problem of erosion at the base is also found in adobe walls. Though it is difficult to attribute whether this is a recent phenomenon due to climate change or it has always been there, if the wall is not constantly maintained, it badly impacts the base of the wall over a period of time. During interactions with people in north Gujarat and Bhal, it was felt that the problem of wall base erosion due to salinity has increased in recent years.
A typical earthen load-bearing house tried to deal with these issues in a variety of manners as described below.

The base of the wall is extended with help of either an otla on the front or raised plinth on the gable wall. This increases the base of the wall and the erosion due to salinity or water stagnation is first felt on the extended portion before reaching the actual wall. Thus, the wall is protected for a longer period.

Regular maintenance of the wall surface is another way of dealing with erosion, and this is a very common practice.

Yet another way is sheltering the earthen walls with verandahs. Mostly front and at times back walls were covered with verandahs and, hence, their exposure to water and wind is reduced. At times, there are two layers of covered verandahs or animal sheds, further reducing the chance of rain water exposure to the walls or plinth.

To avoid rain splashing directly on the walls, protective mats prepared from local grass and stocks are hung on the exposed gable walls. These are found in all the regions where earthen walls are made, but the materials and technique vary marginally.

It is usual practice to extend the wall overhangs and reduce the exposure of high walls to rain and wind. This practice is occasionally employed at places, especially not in rectangular houses. This is due to the fear of high speed winds and cyclones. In bhungas, long roof overhang with lower walls is a usual practice.

To deal with termite attacks, local anti-termite solutions like neem juice or tar are applied. One interesting detail found in north Gujarat region is that the wooden under-structure, especially beams extending out of the house, are left jutting out without cutting them to exact size. Usually, termites infected the wood where there was a junction with the earthen wall portion. Soon after the infection, which was more severe in monsoon, the portion of the beam would be cut and the beam would be pushed inside to provide sufficient support to the roof after treating the infection.

Due to their inherent and applied structural properties as well as climatic and weathering effects, certain issues need to be addressed in the present form of application of earth as load-bearing structure. These issues are discussed further later. Some of these issues are common in frame structures utilising earth as one of the main construction materials too. The following section discusses the use of earth in frame structure.
Wattle and daub is a very commonly found example of frame structures in many regions of Gujarat. In east and south Gujarat, wattle-and-daub construction has traditionally been the main method of construction for houses. In Kutch also it is widely used as the traditional method of construction along with cob and adobe construction. In Bhal region, wattle and daub is not the most common way of construction for the main structure of the house. Yet, due to its simple construction methodology, people have lately started adopting it to construct additional structures like kitchen, storage and bathing space with wattle and daub. Unlike cob and adobe construction, wattle and daub utilises organic additives mixed with earth.

Structure of framed earthen construction

In essence, wattle and daub is a frame structure which utilises composite materials for construction. The frame made of wood or bamboo in traditional construction transfers load from the roof to the ground, while the in-filled lattice of wood or bamboo with earth daubing acts as a screen wall. Depending upon the nature of the main frame, it is debatable whether the wattle and daub acts as a structural member, but it is clear that still the wooden lattice and earthen daubing are not the main structural components.

The present section studies the frame construction using earth at two levels. One is inherent qualities of the materials and the other is when the construction behaves as part of a construction system within a building.

Inherent structural behaviour of framed earthen construction

In dry conditions, well-formed and well-constructed wattle-and-daub systems have significant compressive strength. Thus, in usual conditions, they are quite strong. Earth has very low shear and tensile strength. But the presence of lattice and frame makes the structure resistant to this. Furthermore, the earth is prone to moisture-based degradation. Here too, the wooden lattice work is better resistant, but constant and significant exposure to water and moisture results in rotting of wood, and hence, the aging of the building is faster than other modern materials, which are water resistant.
Inherent advantages of framed earthen construction

Inherent advantages of the wattle-and-daub construction system are listed below.

- It is easily repairable.
- It ensures thermal comfort since walls are made of earth, which is thermal resistant and has a cooling effect.
- It can be done with locally available traditional systems and skills.
- There is a very high degree of flexibility in the form of the wall and optimal usage of material can be ensured due to light weight.
- Since it is a frame construction, which can be made into the unit-based pattern, it gives flexibility to construct bigger structures in terms of span and height.
- It gives significantly higher usable space versus built area as the walls are essentially much thinner compared to load-bearing structures.
- As far as the construction is concerned, it does not take much time to erect the frame structure for wattle and daub. The wattle-and-daub infill walls are also not much time consuming and can be constructed while the structure is occupied.

Performance of wattle-and-daub construction in disasters

To understand the structural behaviour, especially the disaster resistance of framed earthen buildings, it is necessary to take an example and try to understand its behaviour during different disasters. It is also found that there are two basic typologies for the houses that use wattle-and-daub construction - orthogonal plan and circular bhunga shaped. The orthogonal houses are single storeyed with one or two rooms, a verandah and small windows. The circular bhunga type house are single storeyed with low walls. To understand the structural behaviour and disaster-resistant features, the example illustrates both these typologies. Following are the observations for these types.
House type 1: Rectangular form single-storey house

Main features of the typology

- Two rows of rooms with a verandah in front
- Shallow foundation with earth construction
- Gabled roof or pitched roof (both cases discussed where necessary)
- Wattle–and-daub walls - frame structure
- One window and single door in each room
- Wooden under-structure for roof
- Roofing of tiles – Mangalore/country tiles

Structural qualitative analysis

- The gabled forms are susceptible in case of horizontal forces perpendicular to that direction. Usually there is a continuous wooden member at the lintel level (at the point at which the gable starts), which acts as the lintel band and another member on the gable, which provides sufficient resistance against moderate to high seismic activity of the region. As the joint between two members is usually not well secured it may be vulnerable to earthquake or high-speed winds.
- Many houses built with wattle-and-daub have pitched roof. The pitched roofs do not face this problem severely as they do not have free-standing gable walls. The damage to the high wall is avoided in this case.
- During high-seismic activity, especially for houses with a double storey or attic, the thin wooden columns will need sufficient cross bracings. This is provided by the wooden element known as teer in some regions. The application of these cross bracings should be done properly.
- In regions of high seismic activity, the corners of the walls end up being subject to significant stress. In some cases there were cross bracings provided at the corner and these help in case of horizontal thrust. The frame structure, if tied properly will not open up at the corners. In moderate seismic areas, the traditional method of such construction will suffice.
- In high-speed wind or cyclonic conditions, the roof is susceptible to damage. This damage is primarily of two types:
  - Failure of roof supporting system: The supporting system may lose connection with the top of the walls unless tied down securely. Also, in the event of high winds accompanied by rain, the flying of the roof/tiles will be followed by vertical seepage of water from the top of the walls. This will damage the daubing and eventually the wooden structure. Because of the sloping surfaces on all sides of a hip roof, they are in effect self-bracing against side wind loads. The gable roofs with their square edges to the gables create greater uplift forces in high-speed wind conditions and are more vulnerable.
  - Failure of tiles: The tiles may fly off unless securely connected with the underframing system. The present system of connection, where the last layer is the only layer connected using bamboo, is totally inadequate for these purposes.

To conclude, on the whole, the construction systems are sufficient to provide a good degree of safety, if the construction is carried out correctly. The greatest risk to mud wall construction is moisture. In this system, the roofs, the overhangs and the plinth protection is vital but not very well carried out. The risk is, therefore, present but it is lesser than cob or adobe construction. Still, keeping the deteriorating construction practice in mind, the risk is becoming higher.
House Type 2: Circular bhunga with a single room
Main features of the typology
• Circular plan – single floor
• Sand filled stone foundation, up to plinth level (what is usual foundation for wattle and daub bhunga??)
• No internal walls – single room
• Low wattle and daub walls - frame structure
• Small window and single lower height door
• Wooden under-structure for roofing
• Roofing of thatch

Structural qualitative analysis
• In high-speed wind or cyclone conditions, the roof is susceptible to damage. The risk is lower than the gabled roof, but it is still significant. This damage is primarily of two types:
  - Failure of roof supporting system: The supporting system may lose connection with the top of the walls unless tied down securely. Also in the event of high-speed winds accompanied by rain, the flying of the roof or thatch will be followed by vertical seepage of water from the top of the walls. This will damage the structure. In the traditional building system, the connection of the supporting system with the walls is with wooden collars, which are nailed to the wooden elements on the walls. In most cases, due to the roof form, these may be sufficient. Also, usually there is a roof band made of twisted wooden elements. This acts as a band and helps in providing stability to the roof elements. As the rainfall in this region is relatively low, the associated risk for support system failure is low.
  - Failure of thatch: The thatch may fly off unless securely connected with the under-framing system. The present system of connection is that the thatch is securely tied to the under-structure with ropes. This detail seems adequate.
• Overhangs are very important to protect the walls from rain and storms. For the traditional conical roofs of bhunga, the overhang is usually sufficient and the roof comes down fairly low reducing the risk due to storms and rain.
• The plinth in wattle-and-daub houses needs to extend on all sides of the house and be well drained to avoid splashing on the walls. The current practices of making the foundation and plinth of stone, generally bypasses these problems.
• The seismic risk of the structure could be moderate. This is because the roof has a very light load and in times of significant lateral loads, the vertical loads are low and it is possible that there may be tensile stresses at some locations. These forces are taken care of by wooden members in the structure. Also, the cross section being circular, the bending stresses will be relatively low, so the risk may not be very high. The circular band at the top is helpful, ensuring composite action.

To conclude, on the whole, the construction systems seem generally adequate to deal with the associated natural disasters.
Climatic performance and weathering effects on frame structure

Apart from natural disasters, the safety in a building is also dependent on the age of the building and how much it is susceptible to climatic and weathering conditions. Regardless of natural disasters, the building is exposed to these climatic conditions, and resistance to these factors determine the life span of the building.

Exposure to water during monsoon has a direct and adverse effect on the life of the wattle-and-daub structure. This exposure to water is caused due to two reasons, direct splashing of rain water on the exposed wall surface and contact of stagnant water at the base of the walls. Salinity is becoming another major issue for wattle-and-daub construction. In a typical wattle-and-daub construction, the wooden members are in direct contact with the soil, and have higher chances of erosion. Another big threat to the wattle-and-daub structure is from termites. Since the wooden members are in direct contact with earth and also the mixture of soil is one of the main components of the construction, both these materials are highly susceptible to termite infection.

These are the main factors that have impact on wattle-and-daub constructions in the following manner.

Regular maintenance of the wall surface with lipan is a way of dealing with the surface erosion, which is very common. Regular lipan prevents the bamboo lattice as well as the frame from being exposed to the environment, thus protecting the structure from being weakened.

The plinth in earthen houses needs to extend on all sides of the house and be well drained to avoid splashing on the walls. The current practices do not do this efficiently. This is seen in a significant number of houses where the walls are eroded at the base.

Overhangs are very important to protect the walls from rain and storms. For the traditional pitched roofs, the overhang is usually sufficient. Lower wall height combined with sufficient roof overhands reduces the risk due to storms and rain.

The walls of wattle-and-daub constructions are comparatively lower. Use of pitched roof further reduces the possibility of exposure to rain. Combined with extended wall overhangs, this is an effective way to avoid erosion due to water.

It is also a questionable practice to have wattle-and-daub walls right up to the ground. The ground seepage remains a clear and omnipresent risk which will lead to the rotting of wooden members due to moisture as well as termites from the base of the walls.
Repair of the wooden structures involves continuous replacement. This means cutting the bottom member and replacing it. The same is done with the wooden beams. The case is similar in north Gujarat where beams are left extending out of the walls during construction. Whenever there is a termite infection, the beam is cleaned and the infected portion is cut. The extra portion of the beam compensates for the length required for replacement. This is common in the tribal regions of south Gujarat.

Yet another way is to shelter the earthen walls with verandahs. Mostly, front and at times back walls are covered with verandahs, hence, their exposure to water and wind is reduced. At times, there are two layers of covered verandahs or animal sheds, further reducing the chance of rain water exposure to the walls or plinth.
Limitations and the Way Forward
It is critical to understand limitations of earth building practices before the way forward can be discussed. Despite being one of the most preferred construction materials until a few years ago, earth based construction is rapidly decreasing in popularity. The detailed documentation of traditional earth practices undertaken in various parts of Gujarat provides a good insight into the limitations that one needs to deal with while undertaking earth based construction. While some of the reasons for decreasing use of earth construction may be within domain of socio-economic processes, some are due to the technical issues faced by users/owners in traditional earth houses. This section summarises main issues related to traditional earth construction.

**Availability:** Material for earth construction seems to be abundant everywhere. However, it is not so. In general, all natural resources have been exploited and are no more that easily accessible in desirable quantity and quality. One tends to assume the case to be different for earth. But its scarcity and deterioration in quality is not really a surprise.

Salinity of the soil in many areas has increased over the years. Compounded with increasing population and lack of open spaces even within the villages, this has resulted in decreased availability of good soil for construction. In north Gujarat and Bhal known for their earth houses, it is becoming increasingly difficult to find good soil for construction. Besides soil, traditional building typologies with earth construction require timber and clay tiles. Today, all these materials have become scarce. In the past, local communities had easy access to trees such as teak, neem and mahuda for construction. Due to deforestation, there is a limitation on timber procurement. Even bamboo from forests is not easily accessible to rural communities for their own house construction. It is now easier and cheaper for the local rural communities to make homemade burnt bricks, use CGI sheets or cast RCC slabs. Though brick and RCC construction may be of very inferior quality, it can be managed easily with less money. Country tiles, which were commonly found in villages only a few years back, have almost disappeared and with it the livelihood for potters has taken a setback. Instead, local communities are now turning towards CGI or asbestos sheets for construction due to easy availability and quick installation.
Eroding Skills: Today it is not easy to find artisans who can build with earth. The knowledge and wisdom gained through traditions of building with this material is on the verge of getting lost barring a few areas of Kutch that continue to survive in isolation. While industrial materials like CGI sheets and cement became more easily available and access to traditional natural resources is constrained, rural communities have shifted to other building practices. Due to lack of work, skilled earth artisans were forced to move away from their traditional profession. In the process, traditional knowledge and skills are being rapidly forgotten. Oads who were traditional cob wall builders have been now working at brick kilns [fig1]. People who cannot afford so called modern materials are still constructing their houses with earth, but find it hard to get skilled artisans. Buildings constructed without knowledge, skill and rigour in such a situation turn out to be very poor in quality and thus causing further loss of faith in earth construction.

fig 1. Oads now work in the brick kilns
Changed Social Aspirations: Inferior quality earth construction resulted in it getting tagged as a symbol of poverty. Aspiration of improved social status meant building with materials the rich used and therefore, shift to bricks, cement and steel. Technical issues associated with earth poorly managed in recent earth construction further accelerated the decline and strengthened aspirations of a brick and cement house. Unlike some of the distant and isolated communities in Kutch, most of the rural communities in north Gujarat, Bhal and Saurashtra made the shift in building typologies with easier access to markets. With current trends gaining strength, it seems only a matter of time for remaining areas of Kutch. Even though social aspirations may have led to this shift towards brick and cement buildings, it has not resulted in better quality of life or safer houses. Poor communities still have poor quality houses.

fig 2. Cob wall damaged at the base due to rain
Technical issues with earth as building material: Though earth walls may have advantage of homogeneity, one of the important limitations of earth as building material that needs to be well understood is its low tensile and flexural strength. Stresses during earthquakes can easily exceed the tensile strength of earth walls. Brittleness of earth walls can also cause out of plane failures due to flexural stresses during earthquake. Architectural configuration, slenderness ratio of walls, extent of openings in walls, roof and intermediate floors providing some flexible diaphragm and integrity of different building elements as one overall structure can greatly affect seismic performance of earth buildings.

Condition of earth construction at the time of earthquake can significantly affect its performance. Therefore, earth construction also requires frequent maintenance due to its vulnerability to vagaries of nature particularly wet conditions. Dampness or water seepages in earth construction can be devastating due to its quick erosion and loss of strength. If not maintained properly, the deterioration can severely affect the durability and strength of earth construction. Earth construction is also prone to burrowing by mice and cavities can affect soundness of walls.

Some of the common technical issues encountered in current practice of earth buildings are as follows.

Inadequate foundation and plinth: Many of the existing earth buildings in rural areas are inadequately built to deal with these issues. The situation is particularly poor in recent earth buildings of last one or two decades. Most of the traditional earth walls are constructed with inadequate foundations. In the case of load bearing earth walls, regardless of the soil conditions the depth of the foundation is usually very shallow. In case of exposure to floods shallow foundations are severely damaged due to scouring.

In wattle and daub construction, the wooden frame is efficient in taking the load of the construction, but due to lack of foundation, it is often in direct contact with the ground. This results in rotting of the frame as well as infill walls due to moisture, termites and mice. The treatment of wood against termite is not a common practice and no methods are used to separate the wood from the ground.

Inadequate water protection: In old earth buildings, the plinth or base of the wall was extended in the form of an otla. In areas prone to heavy rains and flooding this protected the wall from water exposure. However, earthen plinth is not effective in case of constant or long period of exposure to water [fig 2]. It eventually washes away the plinth and exposes base of the wall to water. Similarly poor roofing details often lead to water seepage from the top and thus eroding earth walls on which roof structure rests. The
prevalent method of applying kol and smear is not very effective in cases where there are leakages from the roof. The traditional plaster- kol is usually very thick. Over the years the thin lipan layers also add to the thickness of the kol, making the surface layer heavy, resulting in separation from the wall. This exposes the wall to water and moisture, resulting in severe damage to the wall surface [fig 3].

Similarly, no special details are observed at the windowsill or overhang at lintel level to protect the wall at openings from exposure to water.

Absence of horizontal bands: Generally, load bearing earth wall houses do not have horizontal bands at the plinth, sill or lintel levels [fig 4]. They also lack a continuous band at the roof level. In case of an earthquake or any other horizontal thrust, lack of these bands could result in severe damage to the structure.

**Poor Maintenance:** Traditional earthen constructions require regular periodical maintenance and repairs of floor and wall surfaces. In load bearing construction of adobe or cob walls, occasional refilling of the cracks in the wall or other damaged parts of the structural walls is also necessary. Every few years, the kol needs to be redone. In the frame structure as well, regular lipan work and redoing the daubing is also equally important [fig 5].

In the wooden frames, frequent replacement of the rotten and damaged parts is required which occurs due to the weak foundation and joinery at the base of the walls. Problem of rotting and replacement of wooden members of the roof under structure is also common for all earthen constructions. Similarly, roof tiles also require regular cleaning and replacement.

All the above works require physical labour as well as time. Repair and maintenance, therefore, usually gets neglected.

**Perception and Acceptance:** All the materials and technologies have their unique strengths and limitations. It is necessary to design and construct buildings that use the strength and find solutions to limitations by effectively overcoming the challenges posed by it. Perception has taken roots in minds of people that earth as building material poses insurmountable challenges and therefore, earthen buildings can not be seen as permanent structures or a valid construction system. This
non-acceptance is detrimental to the growth of earth construction as little or miniscule investments are made in developing better construction practices and innovations using earth. The lack of growth and innovation in earth construction practices results in inferior buildings and this compounds the non-acceptance further.

The Way Forward

It is not merely to preserve the traditional knowledge, wisdom and skills for love of antiquity but to further innovate and take earth building practices, the challenge in socio-cultural domains too must be overcome and wider acceptance need to be promoted for earth building practices that are far more environmentally sound than any other building practice. The above-mentioned issues with earthen construction should not be viewed as limitations and instead seen as challenges. There is a need to learn from the best practices, innovate using modern scientific advances in understanding behaviour and performance of materials and buildings and demonstrate improvisations for it to be acceptable to contemporary lifestyle and standards of living. The limitations and challenges associated with earthen construction are not impossible to resolve. A new approach with synergizing learning from past and innovative solutions from modern scientific knowledge is required to take the practice of earth construction forward. There is also a need for formal acceptance of these construction practices in its modified or improvised form. There is an urgent need to develop guidelines for earth based construction, critically looking at the current practises and for validation by scientific community. Development of such technical guidelines will define, improve and promote safe and better quality housing using one of the most available and environment friendly materials.
<table>
<thead>
<tr>
<th>Word</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>Adhau</td>
<td>Tamarindus Indica</td>
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<tr>
<td>Akdo</td>
<td>Pennisetum Glaucum</td>
</tr>
<tr>
<td>Amli</td>
<td>Tamarindus Indica</td>
</tr>
<tr>
<td>Bajra</td>
<td>Pennisetum Glaucum</td>
</tr>
<tr>
<td>Baval</td>
<td>Zizyphus Jujuba</td>
</tr>
<tr>
<td>Ber</td>
<td>House with circular plan commonly found in Banni and Pachchham regions of Kutch</td>
</tr>
<tr>
<td>Bhunga</td>
<td>Kutchi word for wooden element at lintel level in Bhunga, which helps anchor the roof to the wall and transfer the load of the roof to the walls</td>
</tr>
<tr>
<td>Biladu</td>
<td>Literally meaning painting. In this context, the relief work done by hands on earth walls using mirrors</td>
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<tr>
<td>Chhaj</td>
<td>Wooden plank used as lintel member</td>
</tr>
<tr>
<td>Darbh</td>
<td>Acacia Nilotica</td>
</tr>
<tr>
<td>Desi Bawal</td>
<td>Prosopis Juliflora</td>
</tr>
<tr>
<td>Gadar</td>
<td>Gando Bawal: Prosopis Juliflora</td>
</tr>
<tr>
<td>Gha</td>
<td>Gha Bajariyu</td>
</tr>
<tr>
<td>Gokbru</td>
<td>Literally meaning hand. It is used as unit of length, with one haath being approximately 1.5 feet</td>
</tr>
<tr>
<td>Haldarvo</td>
<td>Adina Cordifolia</td>
</tr>
<tr>
<td>Ikdo</td>
<td>Wattle and daub construction using wooden structure with lime plaster over bamboo mat, commonly found in Sikkim and Bhutan</td>
</tr>
<tr>
<td>Ikra</td>
<td>Houses with circular plan commonly found in north Gujarat and Rajasthan</td>
</tr>
<tr>
<td>Jowar</td>
<td>Sorghum Bicolor</td>
</tr>
<tr>
<td>Kamli ni Diwal</td>
<td>Term used in south Gujarat for wattle and daub walls</td>
</tr>
<tr>
<td>Kanj</td>
<td>Saccharum Spontaneum</td>
</tr>
<tr>
<td>Kip</td>
<td>Prosopis Cineraria</td>
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<tr>
<td>Kol</td>
<td>Mud based plaster done in two or more layers</td>
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<tr>
<td>Kotbar</td>
<td>Granary</td>
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<tr>
<td>Term</td>
<td>Description</td>
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<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>Kutcha</td>
<td>Literally means raw, it is also used to denote temporary, used for a house made with mud or other non-engineered materials</td>
</tr>
<tr>
<td>Kuval</td>
<td>Wheat husk</td>
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<tr>
<td>Lai</td>
<td>Tamarix</td>
</tr>
<tr>
<td>Lipan</td>
<td>Mud based surface, rendering done periodically with hand</td>
</tr>
<tr>
<td>Mahuda</td>
<td>Madhuca Longifolia</td>
</tr>
<tr>
<td>Mann</td>
<td>Central wooden piece of Bhunga roof</td>
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<tr>
<td>Marjadvel</td>
<td></td>
</tr>
<tr>
<td>Mobb</td>
<td>Wooden ridge beam in gable roof</td>
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<tr>
<td>Mujari</td>
<td></td>
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<tr>
<td>Neen</td>
<td>Melia Azadirachta</td>
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<tr>
<td>Otla</td>
<td>A plinth built in front, back or sides of the house. It provides open space with a firm surface to carry on many activities.</td>
</tr>
<tr>
<td>Pakbal</td>
<td>Sack made of leather used to carry and pour water</td>
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<td>Patdi</td>
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<td>Phulio</td>
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<tr>
<td>Pila</td>
<td>Salvador</td>
</tr>
<tr>
<td>Puja</td>
<td>Prayer</td>
</tr>
<tr>
<td>Pakka</td>
<td>Literally means strong, it also used to denote engineered house and categorised to be safe for living in legal terms</td>
</tr>
<tr>
<td>Randhaniu</td>
<td>Kitchen</td>
</tr>
<tr>
<td>Robda</td>
<td></td>
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<tr>
<td>Sadavavu</td>
<td>Rotting</td>
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<tr>
<td>Sajal</td>
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<tr>
<td>Salt Grass</td>
<td>Distichlis Stricta</td>
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<td>Shaniyo</td>
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<tr>
<td>Shegatra</td>
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<tr>
<td>Sukbali</td>
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</tr>
<tr>
<td>Teer</td>
<td>Literally meaning arrow. Here it means bracing member in wooden roof structure of wattle and daub houses in east and south Gujarat</td>
</tr>
<tr>
<td>Thamblli</td>
<td>Column (usually small)</td>
</tr>
<tr>
<td>Tiur</td>
<td>Cajanus Cajan</td>
</tr>
<tr>
<td>Vaas</td>
<td>Family hamlet</td>
</tr>
<tr>
<td>Valo</td>
<td></td>
</tr>
<tr>
<td>Vanths</td>
<td>Settlement</td>
</tr>
<tr>
<td>Vans</td>
<td>Bambusa Arundinacea</td>
</tr>
<tr>
<td>Verandah</td>
<td>A usually roofed open gallery or portico attached to the exterior of a building</td>
</tr>
<tr>
<td>Wad</td>
<td>Boundary wall</td>
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</tbody>
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## II. Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>CCA</td>
<td>Corrugated Cement Asbestos</td>
</tr>
<tr>
<td>CEPT</td>
<td>Centre for Environmental Planning and Technology</td>
</tr>
<tr>
<td>CGI</td>
<td>Corrugated Galvanised Iron</td>
</tr>
<tr>
<td>GSDMA</td>
<td>Gujarat State Disaster Management Authority</td>
</tr>
<tr>
<td>IAY</td>
<td>Indira Awaas Yojana</td>
</tr>
<tr>
<td>IISc</td>
<td>Indian Institute of Science</td>
</tr>
<tr>
<td>IIT</td>
<td>Indian Institute of Technology</td>
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<tr>
<td>IITB</td>
<td>Indian Institute of Technology, Bombay</td>
</tr>
<tr>
<td>IPSA</td>
<td>Indian Political Science Association</td>
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<tr>
<td>MSL</td>
<td>Mean Sea Level</td>
</tr>
<tr>
<td>NCPDP</td>
<td>National Centre for People’s Action in Disaster Preparedness</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-Government Organisation</td>
</tr>
<tr>
<td>PCC</td>
<td>Plain Cement Concrete</td>
</tr>
<tr>
<td>PGA</td>
<td>Peak ground acceleration - a measure of earthquake acceleration on the ground and an important input parameter for earthquake engineering</td>
</tr>
<tr>
<td>RCC slab</td>
<td>Reinforced Cement Concrete</td>
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### Bibliography

<table>
<thead>
<tr>
<th>Author(s)</th>
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<td>Ahmedabad Study Action Group (ASAG)</td>
<td><em>Earth as a Building Material for Housing: Experiences in Housing Assistance for Antyodaya Families</em>, Valod, Ahmedabad</td>
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<td>Desai R. and Desai R.</td>
<td><em>How the Poor Build Houses In Rapal Gujarat</em>, Ahmedabad Study Action Group, Ahmedabad</td>
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<td>Jain Kulbhushan B. and Jain Minakshi</td>
<td><em>Mud architecture of the Indian desert</em>, AADI Centre, Ahmedabad</td>
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<td>Jain Minakshi K. and others</td>
<td><em>Typology and mapping of housing zones: coastal region of Gujarat</em>, School of Architecture, CEPT University, Ahmedabad</td>
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<td>New Zealand Standards Council</td>
<td><em>MEarth Buildings Not Requiring Specific Design</em>, Standards Council, New Zealand</td>
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