Disaster as an opportunity for transformative change in developing countries: Post-earthquake transitional settlements in southeastern Iran, based on the 2003 Bam earthquake reassessment

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Thank you to Blaine Brownell who was always willing to guide me with the research process and directions. And thanks to Arturo Schultz for his support and the advice.

Dedication:

This thesis is dedicated to the people of Kerman and Zahedan in Iran, people who lived economically deficient but with abundance of hope and kindness they dream about a bright future for their children. I felt inspired to make this thesis with the hope that this thesis research will help them to improve their quality of life and prevent future the natural hazards to become disasters.

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Chapter 1: Introduction

"Economic development and cultural modernization do not mean bliss: (a) they end forever the physical misery of famine, epidemic disease and early death; (b) they change the quality of material, social, political and spiritual life ... (c) but the material and cultural advances bring with them new problems at all levels, private and public: urchapte slums and unemployment, political factions and pollution."

- G. Dalton, Economic Systems and Society, 1974

According to United Nations Development Program, in the last 20 years 4.4 billion people were affected and 1.3 million people were killed by natural disasters resulting US$2 trillion income losses. These numbers could be drastically lower if the community's vulnerability had been decreased by prevention, mitigation and preparedness plans and actions before the hazard stroke disaster-prone areas. The impacts of devastating disasters in the last 10 years have been some of the largest on record: Pakistan, Haiti, East Africa and Iran.

While natural hazards strike developed and developing countries alike, developing countries are more vulnerable, with risks exacerbated by population growth, rapid urbanization, environmental degradation, and climate change. The human toll is also severe, disproportionately hurting the poor who are often without the benefit of safety nets. According to The World Bank, damages in developing countries can add up to more than 100% of GDP in small, fragile countries, straining public finances and wiping out years of development progress.

Emergency responses after natural hazards turn into disasters where prevention was not properly planned and disaster risk was not reduced by strengthening the resiliency before the hazard. The disaster management after natural hazards becomes complicated and critical when the death toll is high and a high percentage of buildings and infrastructure is damaged or destroyed in only few seconds. In the case of Bam earthquake in 2003 in Iran, late and chaotic emergency response was responsible for the many dead and wounded.

Can disasters be made into opportunities for reconstructions? Looking back in history**,** some great natural disasters could be a catalyst for huge, positive change: The great fire of London in 1666 that led to a massive rebuilding effort, better building regulations and a safer, cleaner city; the 2004 tsunami in Indonesia with successful Multi-Donor Fund strategy that led to a strong partnership with the communities and transition from pure reconstruction effort to a long-term sustainable and viable development strategy; and the earthquake of 2010 in Haiti that promoted Urban Disaster Risk Reduction (DRR) and technical solutions such as transitional shelters.

The concept of 'Building Back Better' was promoted by UN Special Envoy during the 2004 Indian Ocean tsunami response. However, the concept has often been used by various actors taking advantage of build back better to advance a particular agenda, approach or project. Also, according to The Overseas Development Institute (ODI), the concept revealed systemic issues and problematic assumptions present in the humanitarian system since many reconstruction and recovery programs lacked a strong understanding of the local context, history and culture.

While the initial paradigm of building ‘better’ for people in need, after the community’s structure is destroyed, is remarkably valuable, the definition of ‘better’ remains arguable based on specific features and exclusivity of each country and each community.

For instance, one of the primary objectives in reconstruction process after disasters is safety and structural quality. In the case of earthquake affected areas, building ‘better’ structures according to seismic safety regulations is expected to be executed in new buildings. However, examples show that in reality, a rush to relief caused by a deluge of money and aid organizations entering the affected areas, are responsible for the poor quality that is overlooked by reconstruction.

Post-disaster reconstructions are potential opportunities to prevent the effects of disaster and poverty and make resilient communities. But, they are also capable of becoming a potential context for disinvestments, cultural and regional negligence, unrealistic expectations and failed experiences.

Although well-intentioned, the 'build back better' paradigm needs to be tailored to local needs and resources, and balance community involvement with well-managed expectations and results leading to real crisis in long term.

The importance of the local context is something that many aid actors are aware of at most humanitarian policy groups; but the problem arises because the international humanitarian architecture privileges rapid response through the delivery of ready-made solutions regardless of the context. Therefore, the rapid responses formalize the exclusion of local actors, preventing aid agencies from conducting sound analysis of the contexts they work in and engaging with the people who would be best placed to identify best opportunities and sustain deeper structural change in new constructions.

Today, many Middle Eastern countries have become an architecture playground for insanely expensive and fanciful projects. In recent years in Iran, the construction industry has been thriving due to an increase in national and international investment to the extent that it is now the largest in the Middle East region. But before the oil made the deserts bloom in the Middle East, there was another face of architecture over there: one that expressed itself with culturally, environmentally and economically sustainable principles, based on the philosophy and history of thousands of years rather than on steel and glass relying on air conditioning. Therefore, the interpretation of 'build back better' in these regions remains in limbo.

After the Islamic revolution in 1979, Iran has been experiencing periods of relative isolation from international relations. This isolation had not only affected the economic and political structure of the country, but also in educational level where scientific exchanges and international projects can be placed. As a result, unlike some other Middle Eastern countries, without sudden innovations, and despite the repeated trauma of invasions and cultural shocks, Iranian architecture has achieved an individual distinct from that of other Middle Eastern countries.

Iranian architecture has a continuous history from at least 5000 BCE to the present. Residential architecture of hot and arid regions in Iran is an expressive sample of ecological architecture. Traditional architecture in hot and dry region is in accordance with environmental factors such as desired and undesired winds, humidity, sun, etc. Courtyards, Persian gardens, wind catchers, Sabats (shaded areas in narrow streets) Sardaab (cellar) and structural inventiveness, especially in vault and dome construction, are only a few to name.

However, industrial construction is now applied to almost any rural and urban textures in Iran and the new developments are no exception. With the high population growth in rapidly growing cities, construction industries bring about the possibility of rapid developments in developing countries such as Iran. Concerns about the seismic behavior of vernacular architecture and earthen buildings on one hand, and relative ease and quickness of constructions with concrete, steel and glass on the other hand, leave no doubt in many development agendas.

Although making decisions for new urban developments in modern and developed countries demands concerns for GHG emissions, carbon footprint and environmental pollution, the work becomes more complex in post-disaster reconstructions for developing countries where poverty, deep socio-cultural background, and lack of knowledge about building construction techniques combines with thousands of years of building with traditional materials.

Iran is one of the most seismically active countries in the world, being crossed by several major fault lines that cover at least 90% of the country. As a result, earthquakes in Iran occur often and are destructive. In the 20^{th} century, at least 126,000 fatalities have resulted from earthquakes in Iran (Encyclopedia Iranica). The latest most deadly and destructive earthquake in

Iran occurred in 2003 in Bam killed more than 25514 people, affected over 305,000 people, left more than 75,000 people homeless and destroyed the approximate of 93% of buildings (Fayazi and Lizaralde, 2013).

Despite the fact that the probability of another same or higher magnitude quake is very high in Iran and Bam's earthquake happened only 13 years after the earthquake of Manjil-Roudbar (with 35,000 fatalities), no earthquake mitigation or disaster prevention plans were implemented before the earthquake in Bam to reduce the threat of the hazard.

In addition, evidence shows that not only many buildings after the earthquake of 2003 in Bam are not seismically resistant for future quakes, but also the new city is forgetting traditional architectural solutions and old sustainable techniques in respond to the climatic conditions of the central desert of Iran which were developed over thousands of years. As a result, post-earthquake construction reassessment and overview of lessons learned from Bam earthquake is inevitable and essential for future probable events.

Although after the earthquake of Bam many scholars and professionals, inside and outside of the country, have published papers covering many aspects of post-earthquake plans and management in Iran, many research areas are still remaining intact, including the study of potential unimproved local resources.

This thesis examines the design of post-earthquake temporary settlements in the hot and arid climate of central and southeast parts of Iran. It is a study of past, analysis of present and an imagination of a possible future for cities similar to the city of Bam. It observes the spacial, material, cultural and economic forces that shape the environment, viewing the complex socio-political forces that pressurize issues of post-disaster construction. The aim of this thesis is to investigate the interpretation of 'better' for building back in relatively isolated communities within the historic and cultural landscapes. It also proposes for ways local governments can energize the cities' potential for building self-sufficient communities and re-envision approaches to establish sustainable cities after disasters for lasting results and will help people help themselves and their environment by providing resources and sharing knowledge among them.

Because of the relative coherence between post-disaster housing resettlement phases and the importance of transformation of the temporal to permanent housing, it takes an analytical approach into the post disaster permanent construction to develop into questions of temporary settlements design: What are the 'best' possible methods of building construction for the above mentioned regions? What are the core sustainable architectural notions that need to be preserved? What are the worldwide multidimensional solutions for similar situations?

This thesis also attempts to explore the locally available and renewable resources in order to find new incubators for economic development through the architectural viewpoint. Architects can use the case study of post-disaster housing to explore the means by which design solutions should reconsider reuse of consumer products and re-think the way we use building materials.

The development of this thesis follows two methods of data collection:

- Quantitative : secondary analysis and official statistics
- Qualitative: observation, case study, documentary analysis and speculations

According to Charles Correa, "The architect is the generalist who speculates on how the pieces could fit together in more advantageous ways. One who is concerned with what well might be. Architect is not just the reinforcement of existing values –social, political, economic. On the contrary, the architects open new doors to new aspirations." Therefore, the goal of this thesis aspires to such vision by following the process of observation, experience, investigation, research, documentation, proposition and submission.

As designers, we have the opportunity to make our work rich from a deeper and wider observation and understanding the vernacular of the culture which reveals the basic truth of human condition. The transcendence of the vernacular work can be an asset for the architect to be used in order to open up new ways in which we can live and think about the future of our societies.

Chapter 2: Background information

"The more governments, UN agencies, organizations, businesses and civil society understand risk and vulnerability, the better equipped they will be to mitigate disasters when they strike and save more lives"

- Ban Ki-moon, United Nations Secretary-General

My desire for developing this thesis was sparked in the spring of 2009 during a visit to the cities of Kerman and Bam. This was the first time I experienced the contradictions on what we see on the media with the real situation years after an earthquake stroke historic cities and poor communities. The main streets near Bam ring expressway were well organized featuring governmental buildings all covered by natural granite claddings. No further than one block away from the main streets, the tragedy could be found: some people were still living in the UN or Red Cross white tents after six years, dirt roads filled with rubble and unfinished exposed steel or concrete building structures could be found on every street.

This situation made me question much of what we assume as post-disaster development. I wondered with such a huge deluge of national and international aid, both professional and financial, how the new city could not preserve its culture and history. A huge gap between the old and the new city could be easily felt. The beautiful, well designed city of Bam that is a part of the world heritage is now very similar to any other new urban developments in Iran.

After talking to local people, it appeared to be a hopeless situation, for people living in the city and even for those who may want to help find a solution to eradicate prefabricated steel units and tents from the new urban landscape. I wondered somebody must be doing something to help.

This experience left an impression that opened my eyes to become conscious of a situation that needs attention from all of us. It is a situation that is being repeated over and over again in the past years from the cold climatic regions in northwest of Iran to the hot and arid zones in southeast of the country. Poor communities being affected by natural disasters are the victims of poor post-disaster management and regional planning in Iran and we are obviously not learning enough from the past experiences.

What was the reason of the relative failure in the reconstruction of a world heritage landscape? Are these the 'best' possible options for rebuilding the old cities in Iran? Which decisions changed the proudness of the people of the city of Bam to the present alienation and hopelessness about the future of their city? Could this scenario end up differently? These questions remained bold in my mind during my master's studies while thinking about the implementation of sustainable strategies and technologies in developing countries and exclusively in Iran.

In preparation of this thesis I interviewed with many people inside and outside of Iran; scholars, residents of Bam, professionals in affordable housing industry and sustainable design researchers since my last visit to Iran in January of 2013.

Perhaps the most impressive characteristic of the city is the integration of natural and built environments. This is one of the unique features of Iranian Architecture. Some of the most charming Persian gardens are located in central parts of Iran on the edges of the central desert in Esfahan, Fars, Kerman and Khorasan provinces.

2.1. Introduction to Iran:

Iran is the eighteenth largest country in the world and the 2nd largest one in the Middle East with an area of 1,648,195 km^2 (636,372 sq mi) and lies between latitudes 24° and 40° N, and longitudes 44° and 64° E. It is located on the Iranian Plateau and as one of the most mountainous countries in the world. Iran is covered by rugged mountain ranges and deserts.

2.1.1 Geography of Iran

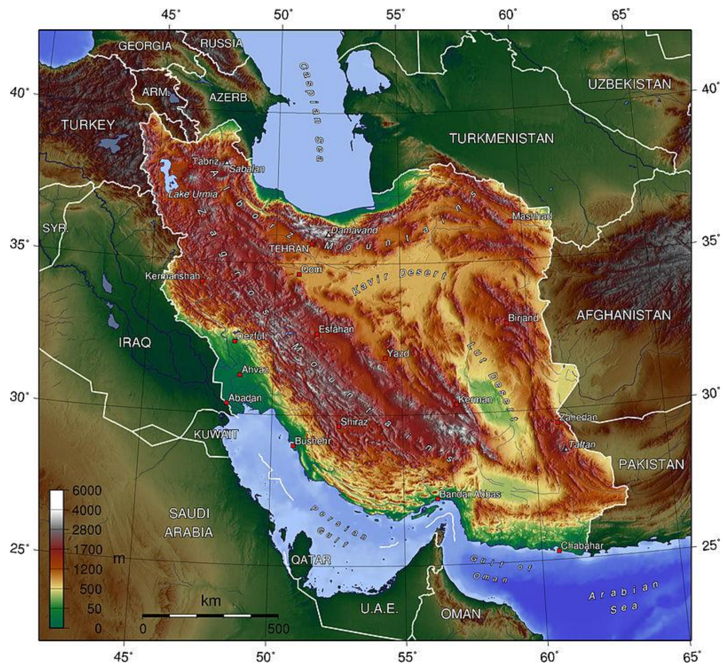

Figure 2.1. Topography of Iran,

World Köppen map, Köppen climate classification

By having dense rain forests in the north, warm sunny beaches in the south, snowy mountains in the west and hot deserts in the east, Iran is one of the few countries that gives the joy of experiencing four different seasons at the same time.

While Zagros and Alborz mountain ranges cover the western and northern parts of Iran, the golden deserts of Dasht-e Kavir (The Great Salt Desert) and Dasht-e Lut (The Emptiness Desert) are located on central and eastern sections.

2.1.1.1. Central plateau regions in Iran – Hot and dry climate:

The center of Iran consists of several closed basins that collectively are referred to as the Central Plateau. The average elevation of this plateau is about 900 meters (2,953 ft), but several mountains of this plateau exceed 3,000 meters (9,843 ft) (Encyclopedia Iranica, 2014). Except for some scattered oases, these deserts are uninhabited.

2.1.1.2. Dasht-E-Lout: Dasht-e Lut (Emptiness desert) is one of the largest of the desert basins in Iranian plateau. The surface of the sand there has been measured at temperatures as high as 70.7°C (159°F) and it is one of the world's driest places (Mildrexler, 2011). This region is called Gandom Beriyan (the toasted wheat). Its surface is wholly matted with black volcano lava. Dasht-e Lut has an area of about 51,800 square kilometers (20,000 mi^2).

2.1.2. Architecture in Iran: Iranian culture is inseparable from the geographical space within which it was formed and crystallized. Later it was caught in the powerful grip of invasions by Arabs and Turks. Yet Iranian culture was able to preserve its identity, even finding in modern times, in its contemporary Persian form.

2.1.2.1. Gardens in Iranian architecture (Persian Garden): Building gardens are ancient art in Iran which includes its very own traditions as a material and spiritual representation. Persian gardens may originate as early as 4000 BCE (Encyclopedia Iranica, 2014). These gardens were earthly symbols of the paradise above and also a figurative forecast of the other world, where the souls of the dead would eventually reside. Nature has run its very roots into the depth of Iranian living. It is therefore no wonder if artists of Persian architecture took elements of nature into consideration to a great extent.

The design of the Persian Garden is based on the right angle and geometrical proportions. The creation of the Persian Garden was made possible due to intelligent and innovative engineering solutions and a sophisticated water-management system, as well as the appropriate choice of flora. Semi open spaces like granges and pavilions are platforms where space and nature reconcile both aesthetically and purposefully.

Figure 2.2. Bagh-e Fin in Kashan, Esfahan

Source: Ali reza_parsi, Flickr

The Persian style often attempts to integrate indoors with outdoors through the connection of a surrounding garden with an inner courtyard.

Designers often place architectural elements such as vaulted arches between the outer and interior areas to open up the divide between them. The two main natural elements of the Persian garden were water and sunlight. A collection of nine Persian gardens which represent the diverse forms of designed gardens in different climatic conditions are on the World Heritage list.

2.1.2.2. Sun in Iranian architecture: Iran's dry heat makes shade important in gardens, which would be nearly unusable without it. Trees and trellises largely feature as biotic shade; pavilions and walls are also structurally prominent in blocking the sun.

2.1.2.3. Water in Iranian architecture: The heat also makes water important, both in the design and maintenance of the garden. Water was stored and also flowed across the garden in many forms. Qanats (a form of underground tunnel below the water table) and connecting wells were used to draw water for irrigation.

Figure 2.3. Shazdeh Garden is one of the largest gardens of Kerman province.

Source: wikimapia.org

2.1.2.4. Wind in Iranian architecture:

The heat is blistering in the south, on the edge of the Great Desert. High chimneys acting as air-vents (Baadgir or Wind Catcher) bring some comfort to these dwellings. This traditional air-conditioning system of local houses around the desert in Iran is the essential elements at the residential structures.

Figure 2.4. Dowlatabad Garden in Yazd, the world's tallest wind tower, is said to be 250 years old and about 33 meters high

Source: www.iranreview.org

Wind catchers are traditional Persian architectural element to create natural ventilation in buildings. Wind catchers come in various designs: uni-directional, bi-directional, and multi-directional. Wind catchers remain present in many countries and can be found in traditional Persian-influenced architecture throughout the Middle East, including in the small Arab states of the Persian Gulf, Pakistan and Afghanistan. In Bam uni-directional winds face towards the northern to north-western direction. Therefore, because the favorable wind tends to blow from only one side, it is built with only one downwind opening. The wind catcher can function in three ways: directing airflow downward using direct wind entry, directing airflow upwards using a wind-assisted temperature gradient, or directing airflow upwards using a solar-assisted temperature gradient. Wind catchers are also used in combination with a qanat, or underground canal. In this method, the open side of the tower faces away from the direction of the prevailing wind. The pressure differential on one side of the building causes air to be drawn down into the passage on the other side. The hot air is brought down into the qanat tunnel and is cooled by coming into contact with the cool earth and cold water running through the qanat. The cooled air is drawn up through the wind catcher.

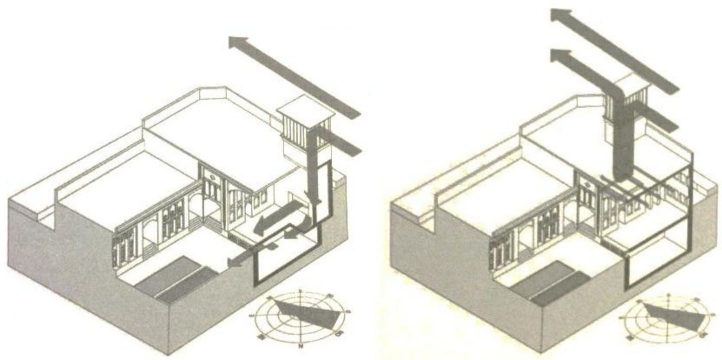

Figure 2.5. Wind catcher functional diagram

Source: Mahmoodi, 2009

2.1.2.5. Material in Iranian architecture:

Available building materials dictate major forms in traditional Iranian architecture. Heavy clays, readily available at various places throughout the plateau, have encouraged the development of the most primitive of all building techniques, molded mud, compressed as solidly as possible, and allowed to dry. This technique, used in Iran from ancient times, has never been completely abandoned. The abundance of heavy plastic earth, in conjunction with a tenacious lime mortar, also facilitated the development and use of brick (Pope, 1965).

Cut-stone and wood (especially poplar) are also used as construction material for roof and ceiling support.

Figure 2.6. Shah mosque in Esfahan

Source: lamicspots.blogspot.com

2.1.3. Climatic responsive design strategies in hot and dry area of Iran:

The major climate in Iran's plateau is the hot climate and most historic cities having spatial values are located in the hot and dry climate. By studying the architectural composition and urban texture of the hot and dry cities and villages we find out that the climate factor plays a major role in shaping the texture of cities and architectural composition.

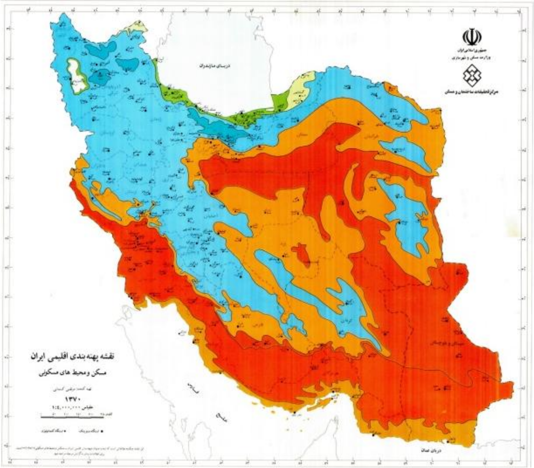

Figure 2.7. Climatic zoning of Iran, Hot and dry climates are shown in red and yellow colors

Source: The Ministry of Housing and Urban Development

Burning sun and excessive temperature, high temperature during days and low temperature at nights (daily temperature undulation specially at summer), very hot summers and very cold winters, dry climate due to lack of rainfall and drought, and dusty storms are the major problems that people living in hot and dry areas are facing. In addition, the scarcity of suitable trees in this area delimits the use of wood for building construction.

Figure 2.8. Compact texture of the city of Yazd in hot and dry climate of Iran

Source: http://historyyazd.blogfa.com/

Different strategies have been taken for reducing the heat by creating a shadow over the buildings. The whole city or villages in this climate look as a compact complex. Urban spaces are surrounded. Streets and alleys are narrow and irregular (with relative tall walls, some covered with vaults to provide enough protection from sun and desert winds. Buildings are attached to each other and trees make natural barriers for dusty and hot winds. Streets are oriented towards the favorable wind direction.

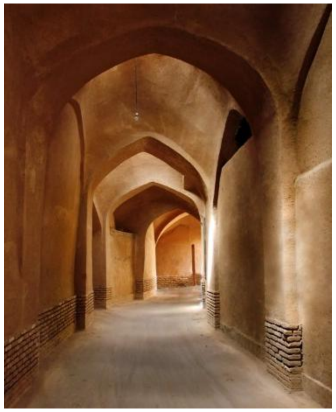

Figure 2.9. Fahadan neighborhood in Yazd, example of covered and narrow alleys in hot and dry climate

Source: http://www.panoramio.com/photo/52917951

2.1.3.1. Building design elements and layout:

- The least surface is designed to be facing the sun and the openings are small and sometimes covered by net-like wooden or brick covers (Fakhr-o-Madin).

- All the traditional buildings are surrounded by other buildings and designed in Iranian introvert type.
- Traditional buildings have at least one courtyard and include basement, wind catcher and porch.
- Buildings and yards are built below the street level (between almost 50 cm to 3 meters) to reduce the temperature fluctuations and heat transfer between inside and outside of the building.
- The height of the rooms is relatively high and the rooms are covered with arched roofs or domes.
- Walls are thick (more than 80 cm) to provide enough thermal mass and also because of the load-bearing structure of them to support domes and arched roofs.
- Except the main entrances, the buildings only have openings that open to the central courtyard. In addition to the climatic considerations, the courtyard is designed to provide enough privacy for residents. Only the favorable direction of the wind could enter the building through the wind towers (wind-catchers) located on the southern side of the houses.
- The best building shapes in are compact forms with the minimum heat transfer between inside and outside.

Figure 2.10. Agha bozorg mosque in Kashan, Esfahan, example of courtyard design in hot and dry climate

Source: Mehr News Agency

2.1.3.2. Four seasons or introvert type residential design in hot and dry climate: In this type of houses, rooms around the courtyard are used in different seasons. On the north side of the courtyard, the rooms will receive the oblique sunbeams during the winter time (Zemestan-neshin). During the summer, rooms located on the southern side of the courtyard are occupied by residents (Tabestan-neshin). Sardaab (cellars connected to qanats and wind-catchers) are located underneath these rooms with almost 10°C cooler temperature than the outside. Rooms on the southern parts have taller walls and the wind-catcher is located on this side of the house (Qobadian, 1998).

In the afternoons, family members gather in the courtyard, sitting on wooden beds around a shallow pool. Over the night, they either sleep on those beds or on the roofs. Based on the economic situation and social level of the household, building sizes varied from one to even up to six courtyards.

During the winter time (50 to 70 days a year) they covered a small decorative courtyard called Narenjestan with thick cotton fabrics to protect the evergreen plants and use the courtyard.

Figure 2.11. Boroujerdi House in Kashan, Esfahan, example of four seasons houses in hot and dry climate

Source: www.makanbin.com

In the new urban layouts, because of the increased population after the modernization in Iran, four season building designs no longer can be mached with the new life styles and new urban patterns. Since 1920 most of the cities in Iran are layed out in NS and WE urban grids. However, even in the modern cities, buildings can only occupy 40% of the land. Residential builduings that are located on the southern sides of the streets have backyards and buildings on the northern sides of the streets have front yards with the larger sides and windows facing south to use the maximum daylight.

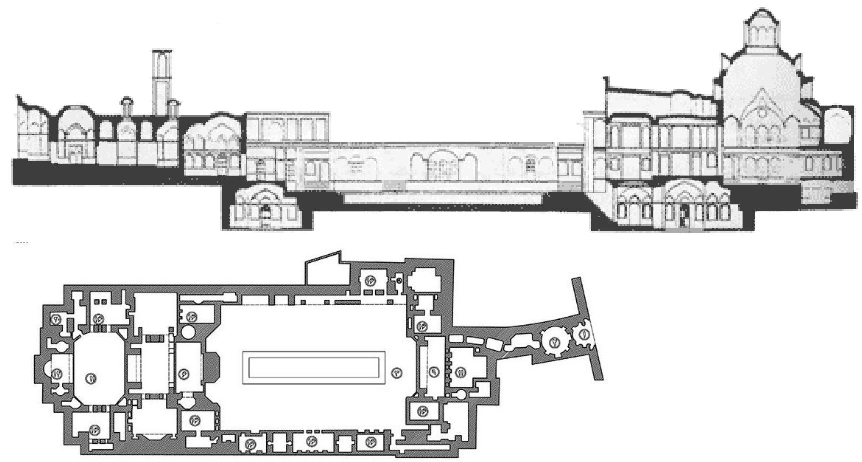

Figure 2.12. North-South section and plan of of Boroujerdi House in Kashan, Esfahan, example of four seasons houses in hot and dry climate

Source: Vahid Qobadian

2.1.3.3. Building materials: There are four types of vaults and four types of domes in Iranian architecture. In hot and dry climate of Iran, these types of ceiling covers provide natural air circulation and therefore the height of the domes and vaults are higher than the ones in the cold climate. In some specific buildings such as mosques, domes are designed in two layers. The inner layer is load-bearing and the outer one is decorative which makes further thermal insulation.

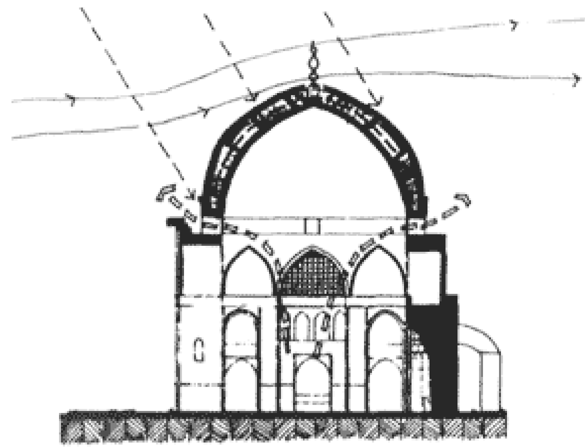

Figure 2.13. Boroujerdi House in Kashan, Esfahan, example of four seasons houses in hot and dry climate

Source: www.makanbin.com

Adobe and brick are widely used as building materials in this climate. Wood is only used for doors, windows and in some cases for porch columns or beams. Stone is also used in foundation or base course.

The wood and paper industries are facing serious challenges in Iran. Annually there is a wood shortage of about 3 million cubic meters in Iran and about one million cubic meters of wood are imported. Moreover, due to the forest preservative policies, wood harvesting has been decreasing continually. On the other hand, because of the rapidly growing population in Iran, the demand for wood and wooden products has increased to intensify the pressure on limited wood resources. These circumstances require an alternative for wood industry in possible areas such as building construction.

Table 1 shows the percentages of building materials in Iran and Kerman province for 3,898,719 houses in Iran and 146,641 houses in Kerman.

2.1.3.3.1. Mud buildings: The oldest mud building in Iran can be tracked back to mid-8000 BC (Ghobadian, 1998). For mud buildings, first they excavate the area under the walls. Then the mixture of clayey soil, sand and straw is pore into small ponds of water being kneaded by feet. The lower parts of the wall have the thickness of 70 cm and the upper parts reach to 40 to 50 cm. Roofs are made of timber, plant stems and mud. Floor is made of rammed earth covered by natural mat (Hasir). Poor seismic behavior, poor moisture resistance and poor resistance to mice, scorpions and beetles are their weaknesses.

	Concrete	Stone and steel	Stone and wood	Brick and steel	Brick and wood	Wood	Adobe and wood	Mud and adobe	Woven mat	Other
Iran	0.27	0.63	7.43	10.80	8.85	1.42	33.09	28.84	2.36	6.27
Urban- Iran	0.63	1.47	2.29	30.87	23.40	4.40	20.89	18.28	0.34	1.39
Rural- Iran	0.09	0.21	10	0.75	1.57	1.92	39.21	34.13	3.36	8.7
Kerman Province	0.01	0.06	8.7	1.02	1.13	2.35	10.35	55.8	15	5.54
Urban- Kerman	0	0.05	0.02	3.4	3.81	0.17	5.13	81.81	0.38	5.17
Rural- Kerman	0.01	0.07	11.11	0.35	0.39	2.96	11.81	48.56	19.06	5.63

Table 2.1. Residential building materials in Iran and Kerman province

Source : Iran Census 1976

According to census 1976, 17.61% of buildings in Iran were adobe or mud. The most recent census on building materials

2.1.3.3.2. Adobe buildings: The oldest adobe building in Iran can be tracked back to 5800 to 6000 BC (Ghobadian, 1998).

that was published in 1966 shows that in Iran 28.84% of rural and urban residential buildings are made from mud and adobe (18.3% of urban buildings and 34% of rural buildings).

In Kerman province 55.8% of all residential buildings (146641buildings in total) were built with mud or adobe from which, 89% were located in rural areas and the rest of them in urban areas. This is the higher percentage after Esfahan province. These statistics become even more critical for Kerman when considering the proportion of these materials to the rest of the building materials: 81.81% of residential buildings and 48.56% of rural buildings were built with mud or adobe.

According to the managing director of the reconstruction and retrofit department of the municipality of Kerman, in 2013 in the city of Kerman there was 1590 hectare of urban distressed areas (Mehr News Agency, 2013). Mud and adobe buildings are self-built and no official building permit or license will be issued for these types of constructions. Therefore, prediction of the exact total number of existing buildings in 2014 is impractical. However, without any comprehensive retrofit programs in the country for these types of buildings, mud and adobe buildings are still one of the fundamental and primary sectors.

Adobe buildings are the advanced types of mud buildings. The only difference is that for adobe buildings, after molding, mud units are sun-dried for 3 to 15 days. In Iran, adobe is the mixture of clay soil with 20-30% sand. The mixture is then pour into shallow ponds for two days to absorb water. After two days, they stir the mixture and add lime to increase the resistance of adobe.

Figure 2.14. Sun-dried adobe blocks with wooden mold

Source: www.yazdprisons.ir

Figure 2.15. Adobe buildings in Kashan, esfahan

Source: shahrmajazi.com

Straw is sometimes used to work as an armature between sand and clay. It also reduces the cracking. In more humid areas Sodium Chloride is added to increase the wall resistance to moisture and freezing. Adobe excreted less water in the latter mixture. In low temperatures, wet adobe could be frozen and cracked. Adobe blocks are made with wooden 20*20 cm square molds with 5 cm thickness.

2.1.3.3.3. Brick buildings: Historical remains of the oldest brick kiln in Shoosh, Iran can be tracked back to 4000 BC (Ghobadian, 1998). Historically, brick was only used for building palaces, mosques and stairs. However, in the last 80 years, brick has become the most common building material in Iran. Bricks are made of clay with 10-15% sand. Brick production is traditional method is the same as adobe but instead of drying the bricks outdoors, they dry the bricks in kilns (Hole kiln, Hoffman and tunnel) in 100°C. According to census 1976, 19.65% of buildings in Iran were made of bricks (in wood or steel structures). In Kerman province 2% of buildings were made of brick.

There are two methods of manufacturing bricks in Iran: hand pressed brick (solid brick) and machine pressed (perforated) brick. The former comes in two sizes: 20*10*5 cm^3 and 22*11*5.5 cm^3 and the latter one is only available in 22*11*5.5 cm size.

2.1.3.4: Building structures: The most recent census in Iran for building structures was published in 2011. With the total number of 19,954,708 residential buildings in Iran, 74.1% of total buildings were located in urban area. Comparing these numbers to the 1976 census, total number of buildings has been increased by 306.8%. However, in 2011 only 25.7% of these buildings had steel structures and 12% had concrete structures.

2.1.3.5: Neighborhood centers: The most important social, cultural and economic events in each neighborhood happened in neighborhood centers. The neighborhood center had a plaza with one or more mosques around tit, a Hussainia (hall of Shia commemoration ceremonies), one or more small stores near the plaza, a public bath and sometimes in large neighborhoods they had a caravansary, an Abanbar (traditional reservoir), Bazaar (Persian market) and a school.

Figure 2.16. City center in Yazd

Source: commons.wikimedia.org

Neighborhood centers were connected by Gozar (passage). Based on the location, the width of these passages varied between narrow and wide.

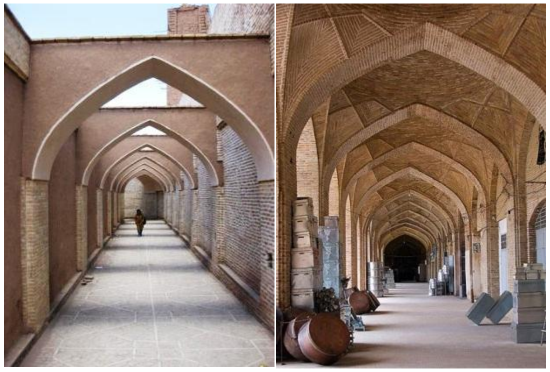

Figure 2.17. and 2.18. Covered and uncovered Gozar in Kerman city

Source: commons.wikimedia.org

2.1.3.6: Urban spaces and structure: After the Islamic conquest of Persia in 633–656, the Sassanid four society classes (priests, warriors, secretaries, and commoners), that shaped the physical structure of the cities, were completely ruined. Instead, the Islamic cities were formed by the religious, ethnic, corporate and ownership bases. Each district performed like a small town inside a larger city with distinct characteristics. Districts had their own gatekeeper and elder (white beard).

2.1.4. Modernization and new urban layouts in Iran: Three general phases in the modern history of Persian cities can be distinguished: the traditional Persian city to about 1920, the beginning of modern urbanization (Europeanization) between 1920 and 1960, which was under the impetus of industrialization with rapidly growing population, and, urban change and restructuring since 1960. In the urban renewal policies and modern renovation models, certain uniformity prevailed in the street layouts and patterns and expanded cities in general. Also, the unprecedented increase in the urban population led to the construction of new residential quarters in adjacent to traditional city centers. At this time, the major east-west and north-south traffic arteries superimposed on the urban cores served as axes for street grids.

Although the ground plans and architectural details were adapted from Western patterns, such basic features as windowless facades and interior arrangements centered on small gardens remained generally unchanged. In the largest cities two- and three-story buildings with rental flats were also common.

The year 1960 opened an era of unprecedented dynamism in urban growth. The new urban quarters that have come into existence since about 1960 are entirely dominated by Western-style architecture and infrastructural features (Marefat, 1988). Department stores, cinemas, and various kinds of public facilities have become typical. Industrialization also accentuated the social and economic contrasts within the cities. Urbanization and urban expansion have continued since the Islamic Revolution in 1979.

Scale	Climate responsive design strategies
Macro	Distance between buildings; Enclosed urban environment; Narrow and irregular streets
Medium	Building form, building envelope, self-efficiency in material; Optical and thermophysical properties of the building envelope
Micro	Module Unite; Eyvan and Revak; Wind catcher (Air trap)

Table 2.2. Summary of climatic responsive design strategies in hot and arid climate of Iran

2.2. Introduction to the City of Bam and its cultural landscape:

About 80 percent of Iran's total area of 164 million hectares has dry and semi-dry conditions. Annually, 600,000 hectares of farmland in Iran are destroyed and 1.65 million hectares of land are added to deserts (Green Party of Iran, 1997).

Kerman is the largest province in Persia, constituting 11 percent of its soil (Encyclopedia Iranica). Bam is a city and the capital of Bam County in Kerman Province. The ancient city of Bam is located on a vast plain in the middle of the desert in the southeast corner of Kerman province, 190 km from Kerman toward the south. The city's plain slopes are from the southwest towards the northeast with a gradient of about 1.2%. Bam covers an area of 19,374 km2 and is situated at 1076 m a.s.l. With the exception of the citadel, which has a height of 60m, there is no natural structure in Bam.

Winds often blow from the northwest to the southeast. From January to October the city has the maximum wind from the west direction. Northern winds are generally four season breezes but south-eastern wind is the destructive and strong winds which blow from the end of spring until fall season. The minimum of average monthly wind speed is 8 mph on January and the maximum is 13.6 mph on June with southeast direction. Finally, the resultant wind has the maximum speed of 10.5 mph on June and the minimum of 4.2 mph on February.

The average annual temperature is 23°C (maximum: 44°C, minimum: -28°C). The city experiences an average of 298 days of dry weather and eight days of rainy weather annually (minimum: 3 days); the average annual rainfall is 62.5 mm.

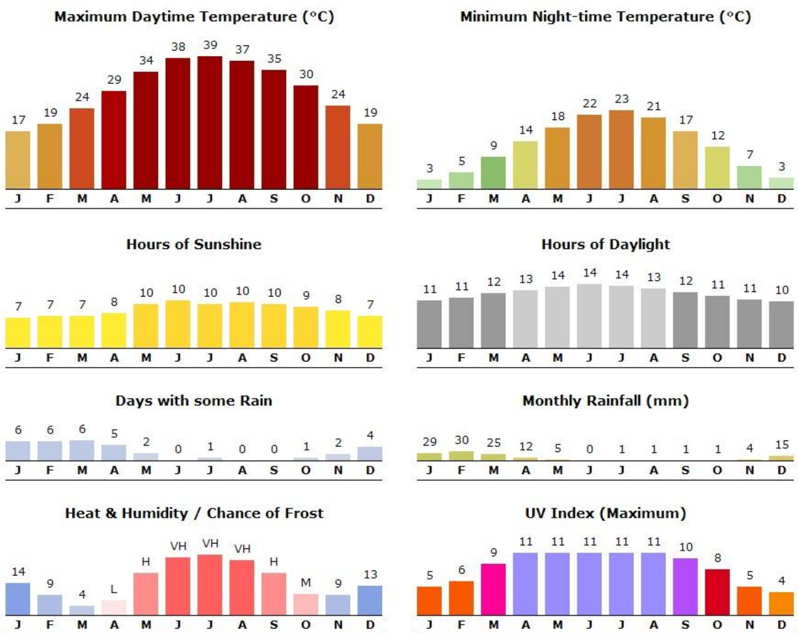

Figure 2.19. Bam Climate Summary

Source: World Climate Guide. Web. 09 Mar. 2014.

The southern part of Bam has rich underground waterbeds of which 51.5% is used in the city's aqueducts. Bam had a sophisticated water irrigation system and a long history of successful agriculture (Eshghi and Zare 2004, Ministry of Husing and Rural Development 2004, Ghafory-Ashtiany 2004).

According to UNESCO, the origins of Bam can be traced back to the Achaemenid period (6th to 4th centuries BC). The cultural landscape of Bam is an important representation of the interaction between man and nature. For centuries, Bam had a strategic location on the Silk Road connecting it to Central Asia in the east, the Persian Gulf in the south, as well as Egypt in the west and it is an example of the interaction of the various influences.

The modern Iranian city of Bam surrounds the Bam citadel, the initial core of the city. Economically and commercially, Bam occupied a very important place in the region and was famed for its textiles and clothes. The modern city of Bam was established later than the old citadel during the Safavid dynasty.

The city has gradually developed as an agricultural and industrial center, and until the 2003 earthquake was experiencing rapid growth. The city benefited from tourism and agricultural industry.

Farming and gardening formed the primary sources of income, and the city has large orchards of citrus fruits and palm groves. Bam's date is well known worldwide, with 100,000 tons of the finest quality dates being exported per year (Ghafory-Ashtiany and Hosseini, 2008). A new major industrial complex was built during the last decade which houses various factories, including a major automobile assembly factory.

According to the most recent statistics, in 1996 Bam had a population of 142,376, of which 52% lived in the urban area of Bam. The dominant culture of Bam is a tribal one, consisting of large family units. There is a very strong attachment to the land, with 81.2% of families owning their homes and only 18.8% living in rental housing.

There were 62,364 buildings in Bam prior to the December 2003 earthquake, of which 34,531 were residential. Few homes were steel-framed or constructed of reinforced concrete (20 steel-framed, 11 reinforced concrete); most were constructed of brick and steel (40.6%), brick and wood (1.9%), brick only (3.5%) or adobe (sun-dried brick and clay, 53.2%). About 84% of the buildings (including 93.1% of adobe buildings) were built prior to the implementation of seismic codes in Iran (1991). Many of the older buildings as well as some of the newer buildings built after the implementation of the code collapsed during the 2003 earthquake due to the lack of effective seismic code enforcement (Iran Statistics Center-ISC 2004).

Prior to the 2003 earthquake residential utility coverage in Bam was 93% for electricity, 86% for clean water. About 51% of homes had coolers. Liquefied natural gas is used by 88.7% of families for cooking and kerosene by 93.4% for heating. The source of drinking water for 14% of the families is from fountains and Qanats (Iran Statistics Center-ISC 2004).

2.2.1. Arg-e-Bam: The ancient citadel of Arg-e Bam has a history dating back around 2,000 years ago, to the Parthian Empire (248 BC–224 AD), being at the crossroads of important trade routes and known for the production of silk and cotton garments. It is the largest adobe building in the world. On December 26, 2003, the Citadel was almost completely destroyed by the earthquake.

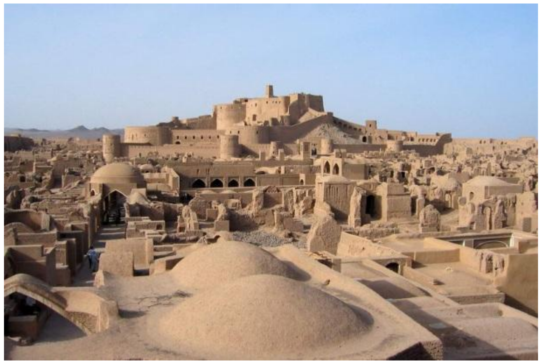

Figure 2.20. Bam citadel before the earthquake of 2003

Source: Roozbeh Shivayi

Arg-e Bam is the most representative example of a fortified medieval town built in vernacular technique using mud layers (Chineh), sun-dried mud bricks (khesht), and vaulted and domed structures. Outside the core area of Arg-e Bam, there are other protected historic structures which include Qal'eh Dokhtar and some shrine-tombs of the descendants of Imams from 12th century.

2.2.2. Natural geography of Bam: Bam lies 1,060 metres above sea level in the center of the valley dominated to the north by the Kafut Mountains and to the south by the Jebal-e Barez Mountains. Bam, one of the oldest centers of urban life in Iran, is located in southeast of Kerman province and is 193 km from the city of Kerman, the capital of the province. Kerman province has 12 regions, 35 districts, 50 cities, and 191 rural districts. Regions on the edge of the deserts and on the foothills (such as Bam city) have moderate weather and more precipitation. However, despite its variety of climates, its water resources and precipitation rank medium to low compared to other parts of the country. Bam is located in semi-desert climate in Iran in the climatic zone 6.

Figure 2.21. Location of the city of Bam and Kerman province in Iran

2.2.2.1. Weather condition in Bam: In zone 6 climate high temperature with hot and dusty winds in the summer, low temperature with cold winds in the winter and the dryness of the weather must be considered in building design. The annual average temperature ranges between 19-23 °C and annual temperature fluctuation is between 35-42 °C. Table 2.3 shows climatic information of zone 6, desert climate in Iran.

	Weather condition	Climatic zone 6
Annual	Freezing	Less than 2 months (December to February)
	Rainfall	40-650 days
Percentage of sunny days	Winter	60%
	Summer	88%
Relative humidity	Maximum winter	55%-85%
	Minimum summer	10%-25%
Annual temperature	Fluctuation	35-42 °C
	Average	19-23 °C
Winter temperature	Minimum night	0-4 °C
	Maximum day	12-20 °C
Summer temperature	Minimum night	35-42 °C
	Maximum day	19-23 °C

Table 2.3 shows climatic information of zone 6, desert climate in Iran, Source: Tahbaz and Jalilian, 2011

According to Tahbaz, during 9-10 months in the year enough shade must be provided for design. Also, during 6-7 months, shading is not enough and appropriate building materials and water evaporative cooling will provide comfort condition in this climate. Between 2-3 months, temperature will reach to 38°C. At this time, evaporative cooling systems must be embedded. During 1 to 5 months of the year, night temperature is suitable to use outdoor spaces for sleeping. During 4-6 months at nights, heating systems must be used for indoor spaces. Between 3 to 4 months a year, night temperature reaches to -5°C (Tahbaz and Jalilian, 2011).

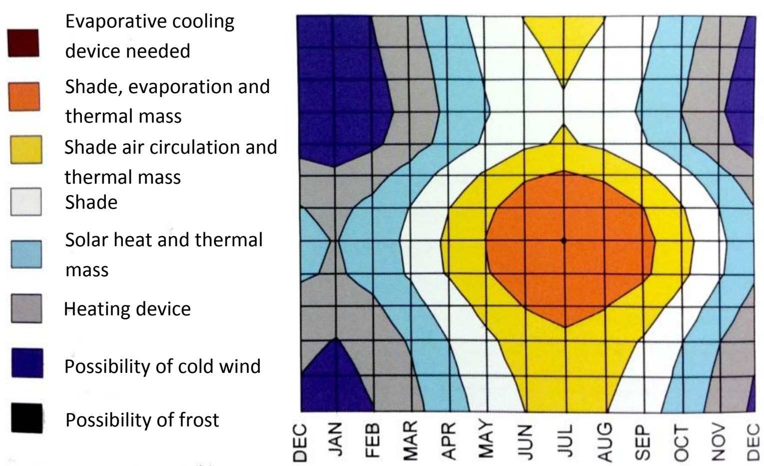

Figure 2.22. Climatic requirements for design in semi-hot and arid climate in Iran

Source: Tahbaz and Jalilian, 2011

2.2.2.2. Humidity in Bam: During the hot seasons in climate 6, we can use water or plants evaporative cooling. With the relative humidity rate in this climate (35-50%) added to the temperature (25-35°C) wood decay does not happen. Also, during 2-3 months each year there is the possibility of condensation (Tahbaz and Jalilian, 2011).

2.2.2.3. Wind in Bam: The wind is mostly with dust on the edges of the deserts. These winds come from the desert during the summer (from North to south east of Bam).

Bam encompasses about 1.3 million hectares of desert. Bam is one of the counties of the Kerman province at risk of wind erosion, with 166,000 hectares considered to be high risk and 39,000 hectares considered to be medium risk (Ghafory-

Ashtiany and Mousavi, 2003). The favorable wind direction is the south direction in the city of Bam

2.2.2.4. Precipitation in Bam: In this climate monthly precipitation never reaches to higher than 200 mml (7.8 inches). However in a short period of time each year they experience heavy but short thunderstorms and the water flow reach up to 10 to 20 cm quickly.

2.2.2.5. Population: Table 2.4 and 2.5 show the male and female population of Bam, Baravat and rural areas before and after the earthquake of 2003.

Location	Family	Male	Female	Total
Bam city	19,0871	45,482	43,663	89,145
Baravat city	3,363	7,854	7,470	15,324
Rural areas	7,973	19,292	18,615	37,907

Table 2.4. Population of Bam before the earthquake of 2003 Source: SCI (Static center of Iran), 2004

Location	Household	Female	Male	Population
Bam region	57416	96939	98664	195603
Urban	35098	62811	62953	125764
Rural	22097	33731	35307	69038
None	221	397	404	801

Table 2.5. Population of Bam after the earthquake of 2003
Source: SCI (Static center of Iran), 2006

Table 2.6 shows the number of households and the average household size in Bam and Baravat cities.

Location	Population	Households	Average household size
Bam	128823	29572	4.4
Baravat	15388	3950	3.9

Table 2.6. Population and household size in Bam and Baravat in 2013 Source: Statistical center of Iran amar.org.ir

Before 2003 the population of the city of Bam was about 400,000 people. Because of the earthquake roughly 32,000 people died and today in 2013, exactly 10 years after the earthquake of 2003, the population of Bam is 107,000 people.

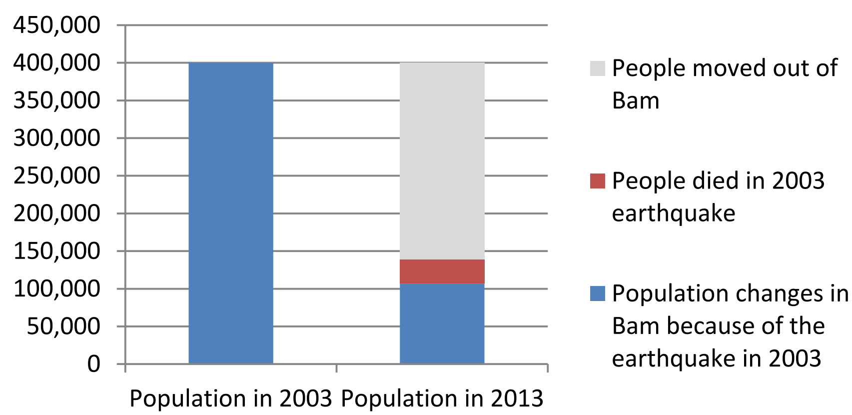

Figure 2.23. Population change in Bam because of the earthquake of 2003 Source: SCI (Static center of Iran), 2004

2.2. 3. Natural sources in Bam:

2.2. 3.1. Water sources in Bam: Water from the Jebal-e Barez Mountains supplies the seasonal Posht-e Rud River that skirts Bam City between Arg-e Bam and Qal'eh Doktar. The Chelekhoneh River and its tributaries gather water from the central parts of the Jebal-e Barez Mountain range. It now runs northeast, although it formerly flowed through the Bam City until it was diverted by a dam into a new course that met with the Posht-e Rud northwest of Bam City. Water from the Kafut Mountains also supplies the catchment area.

The existence of life in the oasis was based on the underground irrigation canals, the qanāts, of which Bam has preserved some of the earliest evidence in Iran and which continue to function till the present time (according to UNESCO it's been over more than two millennia). The number of wells and qanats in the Bam plain is high (723 deep wells with 408 mcm capacity, 222 semi-deep wells with 12.5 mcmcapacity and 348 qanats with 414 mcm capacity). The portion of water used for agriculture is 95.69%, industry 0.15%, and sanitary and drinking water 4.16%. In the Bam-Narmashir plain, 66% of the wells are operated by diesel generator and 34% by electric power (Ghafory-Ashtiany and Mousavi, 2003).

2.2.3.3. Vegetation in Bam: According to Ghafory-Ashtiany the Bam region includes 10,000 hectares of heavy forest, 50,000 hectares of low dense forest, and 100,000 hectares of what used to be forest. In particular, the city is known for its dates and citrus fruit, irrigated by a substantial network of qanats.

2.3. Earthquake of December 2003 in Bam:

The 2003 Bam earthquake was a major earthquake that struck Bam and the surrounding Kerman province of southeastern Iran on December 26, 2003 with the magnitude of 6.5 on the Richter scale. The effects of the earthquake and damage was exacerbated by the fact that the city chiefly consisted of mud brick buildings, many of which did not comply with earthquake regulations set in Iran in 1989, and that most of the city's people were indoors and asleep. Up to 31,000 people died, 300,000 people injured, 75,600 became homeless and 85% of the city was flattened by this quake (USGS, 2003).

The earthquake of 2003 caused 80% of all buildings to be completely destroyed, 17% of all buildings were so badly damaged that they could no longer be used, about 2.8% of the buildings remained undamaged and 0.2% experienced minor damage. The earthquake caused 31,383 deaths and left about 20,000 persons injured and 65,000 homeless.

Figure 2.24 shows a general view of the damage inflicted by the December 2003 earthquake on Bam and its distribution. A total of 27,734 buildings in Bam and 25,022 in the rural area were destroyed and 9,005 were damaged. In addition, most of the public and state buildings, urban facilities, including water, sewage, power, and telecommunication systems, as well as irrigation and agricultural systems, gardens, streets and roads were badly damaged. The Bam historical citadel was totally destroyed.

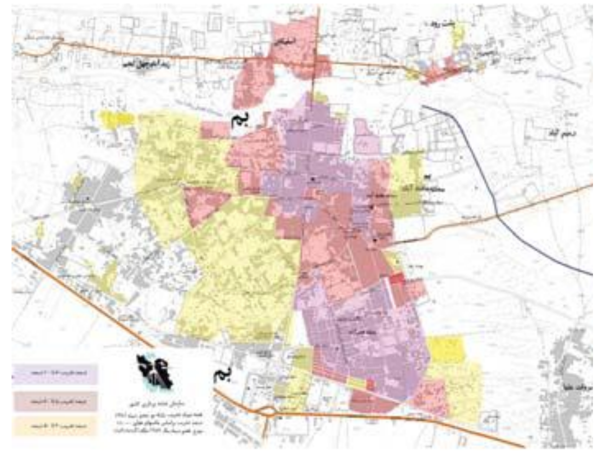

Figure 2.24. Map of the distribution of damage to buildings after the earthquake of 2003 in Bam, Source: Ghafory-Ashtiany and Hosseini, 2008

The earthquake of Bam occurred as a result of stresses generated by the Arabian plate moving northward against the Eurasian plate at approximately 3 centimeters (1 inch) per year. The Earth's crust deforms in response to the plate motion in a broad zone that spans the width of Iran and extends into Turkmenistan.

In Bam, many of those who died were victims of poor building methods. Traditional mud-brick wall construction is often topped with modern steel girders. When once there were only single story dwellings, many people had recently built upwards due to shortage of space (Interactive. Earthquake in Iran, 2011).

The first set of shockwaves travelling at about the speed of sound would make the ground undulate like a shaken blanket (See Fig. 5.4). The buildings would have been jolted up and down- bricks separating from each other and steel roofing girders flung up above the walls on which they were seated (Interactive. Earthquake in Iran, 2011).

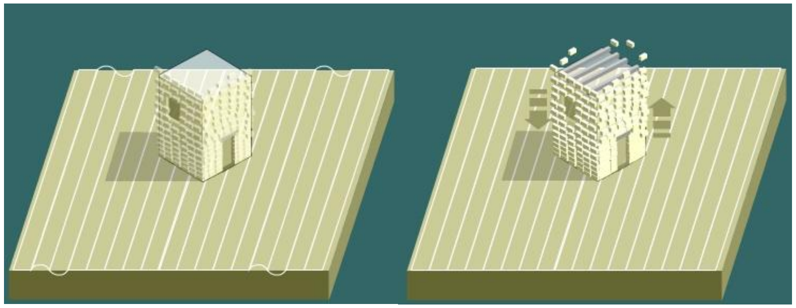

Figure 2.25. First shockwaves in the 2003 Bam earthquake
Source: Guardian.co.uk, Guardian News and Media, 2011.

Immediately after the initial tremor the second set of waves would have shaken the ground from side to side, much like flicking the rope across the ground. The buildings, now largely been disassembled, would have been violently twisted before collapsing on the occupants (See Fig. 5.5) (Interactive. Earthquake in Iran, 2011).

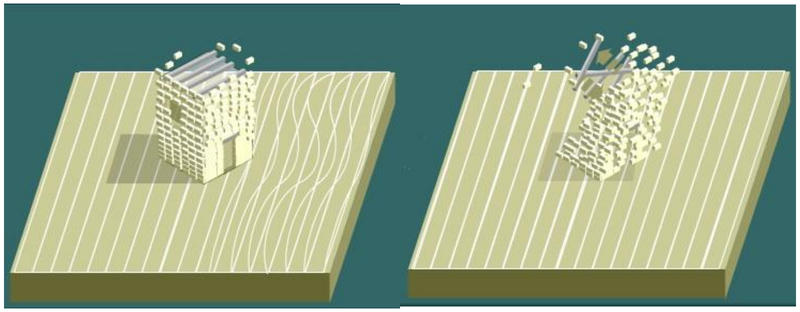

Figure 2.26. Second shockwaves in the 2003 Bam earthquake
Source: Guardian.co.uk, Guardian News and Media, 2011.

2.4. Building damage classification:

Classification of building damage was done using aerial photography. By using a pre-earthquake image, the location of individual buildings was registered on a GIS and city blocks surrounded by major roads were marked. This was then compared with a post-earthquake image. Then visual inspection of building damage was conducted. By this method, buildings were classified from Grade 1–5. A total 12 063 buildings were classified:

• 1,597 Grade 1 and 2;

• 3,815 Grade 3 – buildings surrounded by debris;

• 1,700 Grade 4 – partially collapsed buildings,

• 4,951 Grade 5 – totally collapsed buildings

The thesis focuses on multiple scales and physical frames upon which to conduct a discussion of inquiry and exploration.

- First, it looks at the province of Kerman as a way to understand the notion of 'local' in search for different available sources for the city of Bam. Looking at a wide perspective for implementation of the proposed strategies in other possible location with some similar characteristics as the city of Bam is another target at this level.
- Second, it examines the Bam County with two cities: Bam and Baravat. The evolution of the city of Bam is studied at this level and because of the proximity between the two cities (8 km). The history of the city of Bam and the urban morphology and form of the city are studied at this level.
- The third frame of inquiry focuses on the regions that form the city of Bam and then concentrates on one of the regions specifically to analyze the organization of a sample region inside the city of Bam.
- Forth frame of investigation focuses on a small block inside the above mentioned region to focus on the streets, pathways and potential places for post-disaster settlements and public amenities.
- The fifth frame focuses on the design layout of a single temporary settlement and explores the realm of the

individual dwelling's components looking at specific architectural ideas and systems that define the role of the shelter. The space created by the dwellings allows the inhabitant to act and function in specific way. Certain limitations are imposed and other opportunities are proposed to meet the required flexibility for similar locations and situations.

Finally it must be mentioned that in these scales, two time frames have been considered: before and after the earthquake of 2003.

Chapter 3: Problem statement

"In my experience, poor people are the world's greatest entrepreneurs. Every day, they must innovate in order to survive. They remain poor because they do not have the opportunities to turn their creativity into sustainable income."

- Muhammad Yunus

In the aftermath of global wars and natural disasters, the world has witnessed the displacement of millions of people across continents. Refugees seeking shelter from disasters, resettle in unknown lands, often starting with nothing but a tent or if lucky enough a prefabricated unit to call home.

The process that people and households go through after a disaster to stabilize their housing situation can be quite lengthy, convoluted, and complex. People affected by the same disaster will be affected differently and will respond differently. Some will begin reconstruction of their partially damaged housing in the first days after the disaster, while others will be displaced for a period of time, even finding their situation changing from week to week for many months or even years.

Therefore, it is important to understand the range of options people face and not to impose artificial 'phases' on diverse situations and locations. In some past cases in Iran, support for reconstruction began only months after a disaster, after the affected populations themselves began rebuilding.

The large-scale destruction caused by the 2003 earthquake in Bam, made it unlikely that affected communities would soon have permanent housing. The earthquake left 75,000 people homeless (Walter 2004). According to the Global Facility for Disaster Reduction and Recovery, authorities estimated that at least two years of temporary housing was needed before permanent housing would be available, at least in urban areas. However, in reality, evidences show that this time extended to over 10 years in Bam (HamshahriOnline, 2013). National relief agencies pushed to establish camps, despite the strong desire of the people to erect shelters on or close to their own land.

The justification of the agencies was that camps would simplify the delivery of services and lower their costs. Yet worldwide, as the studies done by the World Bank shows, experiences prove that establishing camps for displaced people following disasters has negative socioeconomic impacts on reconstruction and long-term development, and only makes sense when concerns such as security make other alternatives impossible.

The strategy for housing reconstruction was entailed by the World Bank in the two following categories:

1. In urban areas, providing interim or transitional shelters, including prefabricated units on vacant urban lots or the

family’s land, that would address housing needs for a 2-year period for the entire affected population, and

2. In rural areas, building permanent housing on original housing plots as soon as practicable.

However, in the hot and arid climate of Iran, where the whole city or village looks like a compact complex, urban spaces are surrounded and, streets and alleys are narrow and irregular, building permanent houses on original plots is impossible in many cases and the options must provide more flexibility in size and location. On the other hand in many historic areas and also in most of the villages, new constructions have taken place in the previous locations of the old houses and therefore old streets and alleys are now occupied by denser population the in modern cities.

Figure 3.1. Typical compact city layout in Birjand in hot and dry climate of Iran. The image shows that houses are attached in sides and the streets are very narrow in this climate. New constructions are mostly in previous plots as shown in the left side of the photo. Source: Elham Alimardani

The primary question about the high death toll in the earthquake of 2003 in Bam was about the importance of traditional building techniques in building damages. It was widely accepted between the folk in Iran that the main reason for this deadly earthquake was the traditional construction methods of adobe techniques in this city. However, closer examinations show that this was not the main reason (Gharaati, 2008).

3.1. Main reasons for high death toll in Bam earthquake of 2003:

In addition to the geophysical factors whose unfortunate combination led to the strong ground shaking, coupled with the poor quality of the physical infrastructure and a lack of adequate risk management by the Iranian government, it was the widespread failure of poor quality buildings that contributed to the high death toll.

3.1. 1. Lack of disaster planning and management:

Due to the lack of disaster planning and management, a belated reaction in emergency search-and- rescue operation at the local, provincial, and national level of emergency response was compounded further by the lack of coordination and communication in the first few vital days after the event between those on the scene and governmental officials operating elsewhere.

As a result of such bureaucratic delays, victims faced serious asphyxiation, suffocation, and hypothermia, leading to a dramatically increased death toll. The destroyed emergency medical system and hospitals in Bam and lack of a comprehensive disaster management plan were the reasons that during the early stages following the earthquake, 85.9% of patients did not receive any basic medical care (Mirhashemi et al. 2007).

3.1.2. Poor quality of buildings:

In Iran, the owner generally commissions an architect or engineer to do the design work on a typical one to two-story houses. A structural engineer is then expected to inspect it during construction to ensure that it meets earthquake design codes. However, there is a lack of control of engineers and authorities who tend to ignore it.

> Almost all who died during the earthquake were killed in buildings less than 30 years old. Nearly 90% of the buildings in Bam suffered 60-100% destruction, and the remaining 10% suffered 40-60% damage. The extent of destruction in some quarters of the city reached 100%. Almost 95% of the buildings in the city of Bam (approximately 25,000 buildings), the town of Baravāt (4000 buildings), and in a large percentage of the villages (24,000 buildings) within 10 km of the city were devastated or severely damaged (Maheri et al., 2005).

3.1.3. Mismanagement in post-earthquake rescue and recovery: After the earthquake of 26 December 2003, rescue, evacuation, and transportation of the casualties started. During the first days after the earthquake, the Iranian Government evacuated 10,000 injured to hospitals in other parts of the country (mostly Kerman city). The Iranian Red Crescent Society mobilized 8,500 relief workers and distributed 108,000 tents 380,000 blankets, 65,000 plastic sheets (UN Office for the Coordination of Humanitarian Affairs, 2014).

However, no organized rubble removal effort, and hence no local search-and-rescue team was present during the first twenty-four hours of the earthquake, and thus the local citizens were mainly responsible for clearing the rubble and engaging in rescue work as much as they could with their bare hands.

After the earthquake, preliminary Emergency Appeal was launched on 8 January 2004 from the international Federation of Red Cross and Red Crescent Societies. Five days after the earthquake approximately 1,600 international staff members from 44 countries were operating in the affected areas. A total of 200 international flights with emergency response teams and relief supplies arrived in Kerman and Bam airports sheets (UN Office for the Coordination of Humanitarian Affairs, 2014).

The city of Bam was swiftly under the attack of national and international media. Consequently, the unorganized loads of organizational and personal aids from all around the country caused traffic jam to the main highways and roads to Bam. Those that owned motorized vehicles were met with jammed traffic going both ways through Bam and were unable to reach to the city. Unnecessary and inappropriate commodity and food, not only couldn't help the affected population, but also became one of the main reasons for a chaotic situation that the governmental organizations were unable to control it.

3.1.4. Environmental conditions: On the other hand, during the nights following the earthquake, the temperatures dropped to bitterly cold extremes, effectively killing some survivors. These people were living in unheated tents among the rubble. For these reasons, thousands of families were moved to heated camps on the outskirts of Bam. This was not met without resistance because many residents wished to stay in place to make sure that they would not lose their lands. The Iranian government was, conversely, criticized for not doing enough supplying of tents. Occasionally heavy sandstorms swept across the area and hampering the relief operation and periodically closing the two airports in the region.

According to the Iranian Red Crescent Relief Assistant, organizing and providing food for more than 40,000 international and national rescuers in Bam in the airport of Bam, was the reason for returning the new rescuers after the fourth day from the earthquake (ISNA, 2013).

3.2. Temporary housing and temporary camps:

Prefab houses measuring 18 square meters were provided to all urban households who could prove (the testimony of other residents) that they lived in the area prior to the disaster in Bam. For households with more than four people, two prefab houses were provided. An additional unit was also available for purchase. The cost for a prefab house was around US$2,000 including transport in 2004. Each was installed on the land designated by the household.

3.3. Problems and issues about temporary housing and temporary camps in Bam:

It was estimated that at least 10,000 prefabricated homes were needed in Bam to house the typical five to six person family unit in Bam. However, many people from surrounding villages had moved into the city since the disaster. These people often lived in poorer conditions than those in Bam and believed that by moving to the city they might ultimately obtain better housing when the reconstruction program got going. They were therefore prepared to live in tents in Bam for a short while, even though they had homes elsewhere.

In addition to the high cost of the prefabricated steel units, the transportation cost was also added to the resettlement project for the government of Iran. A large portion of prefab steel units was imported to Iran. One example was Turkey which is a neighborhood country on north-west of Iran. 2000 units were imported from Turkey between June to November 2005 from Dorce Inc. with the total building area of 36,000 m^2.

This operation time shows that even from one of the closest sources of international aids, a large portion of the earthquake affected people could receive their temporary houses and move out from tents at least 6 months after the quake in winter and spring time. Many people experienced the harsh summer of Bam in white tents at least for one year. Evidences show that some people were still living in the emergency tents until 2013 (HamshahriOnline, 2013).

Figure 3.2. Earthquake Field Emergency Accommodation Units in Bam, Iran located in Camps and imported from Turkey in 2005. Source: Dorce.com.tr

Moreover, in the hot climate of Bam with high temperature fluctuation between night and day, those prefabricated steel units were not adaptable to the environment. Therefore, with the low thermal comfort level of the prefab units for the occupants, people in Bam (and also in other disaster-affected parts of Iran) had problems in both low temperatures and high temperatures.

Nothing says misery like a hot tent or prefab unit in the desert area for disaster-affected people. That's especially true when a family spends year after year under a triangle of canvas meant to last only six months. Because of the high cost of cooling systems, only a few numbers of units were equipped by evaporative coolers, vapor-compression (gas) coolers, electric heaters, gas heaters, or electric fans.

3.4. Development of the ancient city of Bam:

After the quake of 2003, national and international organizations and firms gathered to discuss about the reconstruction programs in Bam. As a result, the Sustainable Development Manifesto and the Child Friendly City project were selected as the major guidelines for the development and reconstruction of the historic city of Bam.

According to the Bam Sustainable Development Manifesto, the aim of providing permanent shelters for survivors during the reconstruction phase was to make them as independent of government aid as possible. Householders were encouraged to take an active part in the relief process. During the reconstruction period the Housing Foundation and a number of private engineering and architectural firms announced that ‘the responsibility for rebuilding was for the homeless’.

3.5. Post-disaster housing results after 10 years from the earthquake of 2003:

Post-disaster housing programs can improve the living conditions of affected families or make them even more vulnerable. For the historic city of Bam, Plan of Action for Rehabilitation and Reconstruction phase was presented on 29 September 2004, to reflect on-going programming into 2005-2006, under the overall Emergency Appeal budget and totaled to USD 45,231,315. (International Federation of Red Cross and Red Crescent Societies).

Considering the generous international aid for both financial and professional resources during the reconstruction of Bam, we realize that this historic city had a great opportunity to become a successful case and model for post-disaster reconstruction projects in Iran and also for other developing countries. However, in reality and based on my own observations, 5 years after the earthquake many households were still living in UN and Red Cross relief tents and many people in the city of Bam were still living in very poor conditions.

On the other hand, in the first few years after the earthquake of 2003, structural and material engineering inspections for new constructions had been regularly controlled by the Housing Foundation. Nevertheless, in less than 10 years after the earthquake, poor material and construction qualities could be easily found between the post-earthquake buildings.

In a larger scale, the new urban spaces not only could not reflect the cultural heritage of the city, but also in reality the primary ideas of rebuilding Bam as a child friendly city according to the sustainable development manifesto, had been limited to a few parks and urban spaces very similar to other new development areas in Iran with low sense of belonging and connection between people and the city, no harmony or consistency between urban spaces and new buildings and no climatic adaptive design strategies required for this climate. All these deficiencies are in contrast to the climatic responsive Iranian architectural strategies and design.

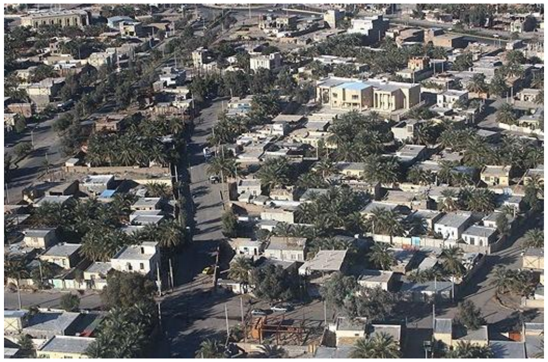

Figure 3.3. City of Bam 10 years after the earthquake. Exposed steel and concrete structures and lack of harmony in urban spaces and new buildings Source: Mohsen Rajabpor, Fars New Agency

Despite the numerous academic researches about the effects of the earthquake of 2003 on the city of Bam and the increased interest in the study and analysis of post-earthquake conditions a few years following the quake, no researcher has yet studied the social and cultural effects of reconstructions and only a few researchers have studied the remarkable transitional period between emergency to permanent settlements or the problems and issues relating to the post-disaster temporary housing.

There are many different factors contributing that caused the long gap between the emergency shelters, temporary settlements and permanent housing phases in disaster relief projects in Iran. However, certain patterns, such as the long importing process and transportation time to make the permanent housings ready, lack of climatic adaptability of emergency shelters to almost any climate in Iran, and the high cost of pre-fabricated units, could be found in all recent disaster management projects in Iran.

Considering the high price of steel and cement in Iran, there is no wonder that without enough governmental loans many households still do not have the economic power to afford building materials for finishing the construction of their new houses.

Another reason for the long gap between temporary and permanent settlements in Bam was that permanent shelter in urban areas could not be built until the city master plan was updated and reconstruction guidelines were approved. In the case of Bam the master plan of the city had been prepared almost completely before 2003 by Armanshahr Consulting. However, the revision of the master plan took almost one year.

3.6. Summary of research question: This project is supposed to give form to a gap in people's needs while consider the long term impacts of temporary settlements design and policy and planning approach on social, economic and environmental qualities of the disaster affected communities. In contrast to the limited, cost effective and time effective options for temporary and permanent housing construction that the national and international humanitarian agencies and housing ministry of Iran have to offer after disasters, the aim of this project is to not only find a potential local resource to close the gap between need and desire as people metaphorically weave and build their lives back together, but also to build their environment into a place both new and familiar, private and connected, safe and flexible. They weave and build their shelter into home.

Despite the strong connection between the natural and built environment in the city of Bam, in the new developments local materials or agricultural economic incubators have no place. These indicators simply show that the communities inside the city of Bam were dependent on governmental aids and remote sources for building materials and expertise in post-quake constructions.

In order to reexamine the traditional architectural concept of tent shelters, this thesis examines the possibilities of the utilization of organic fabrics and structures from local and natural resources that provides the flexibility to expand and enclose, the mobility and the comforts of contemporary life such as heating and cooling, water, electricity, storage, etc. In search for the innovative solutions in post-disaster projects for the hot and dry climate of Iran, this thesis aims to find the new alternatives that increase the community resiliency and decrease the vulnerability of disaster-stricken populations for future possible events.

All in all, there were two main questions which formed the basic idea of choosing this topic for my Master's thesis:

First, how much was the post-earthquake reconstruction program successful to build a safe, resilient and independent city in Bam?

Second, how could the traditional concept of temporary housing be altered to benefit the disaster-stricken populations within the principles of economic, environmental and socio-culture sustainability to help the poor to build their own communities resilient and more independent from governmental aids?

Chapter 4: Literature review

“Resilience is all about being able to overcome the unexpected. Sustainability is about survival. The goal of resilience is to thrive.”
-*Jamais Cascio, writer and futurist*

“Any vision of sustainable development fit for the 21st century must recognize that eradicating poverty and achieving social justice is inextricably linked to ensuring ecological stability and renewal.”
- *'A Safe and Just Space for Humanity'*, Oxfam (2012)

The following chapter is divided into two sections to analyze the reconstruction program in Bam:

I. Part one: Bam reconstruction assessment overview
II. Part two: Post-disaster temporary housing in Bam

I. Part one: Bam reconstruction assessment overview

4.1. Rescue and relief operation:

According to the United Nations Disaster Relief Organization, post-disaster housing is defined as housing policies and applications follow a disaster for meeting the urgent, temporary and permanent sheltering needs of the survivors of the disaster.

After the earthquake responsible organizations, such as Iran Red Crescent Society, law enforcement forces, Basij (volunteer mobilization force) and volunteers from both inside and outside of the country rushed to the area and made every effort to rescue the people, transport and treat the injured and help the quake-stricken people. Injured people were transferred to the Kerman and Tehran hospitals by planes and helicopters

Relief workers removed the victims and wounded people from the debris with the help of machinery and people. The dead were buried through traditional religious ceremonies in the newly-established cemetery. However, the chaotic situation caused by the lack of proper disaster planning and management made all of these different actions lengthy and not completely successful in rescue operations.

4.2. Emergency shelters:

The Iranian Red Crescent Society began distributing more than 50,000 tents as emergency shelters among those made homeless by the earthquake as early as the first day of the earthquake. The tents were set up either near the victims' homes, in groups in an open area or in congregate camps throughout Bam.

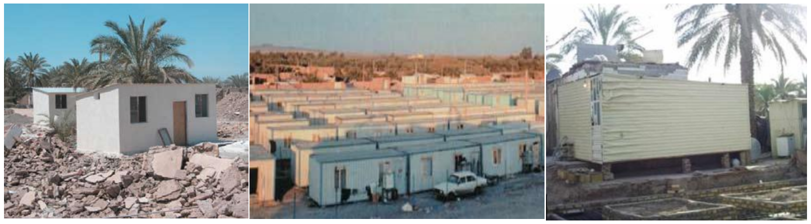

Figure 4.1. Temporary shelters on individually-owned plots of land,(left) and pre-fabricated camp cities (right and middle)
Source: Hosseini and Ghafory-Ashniany, 2008 and Dorce Inc.

4.3. Intermediate shelters or temporary housing:

For intermediate shelter, the Interior Ministry and Kerman Governor Office were ordered to provide the homeless with temporary housing units in the form of prefabricated or in-situ built dwellings each of them about 16 to 20 m^2, equipped with a water heater, air conditioning and sink; sanitary facilities were erected in the area and in the camps housing the survivors.

Figure 4.2. Temporary housing in Bam after the earthquake of 2003

Source: Hosseini and Ghafory-Ashniany, 2008

From the 35,905 units, 9,005 units were set up in camp form (which were not welcomed by most of the people and consequently were used for student housing) and 26,900 were built within the owner's property (Hosseini and Ghafory-Ashniany, 2008).

About 18,000 showers and latrines were installed to support the sanitation need of the victims. Most of the survivors were moved from the tents to the temporary housing by the end of March 2004, and the settlements were finished by June 12, 2004, 2 months behind schedule.

However, a better planning and need assessment is recommended for future disaster scenarios. It was expected that the reconstruction would be finished by mid-2007. Therefore, those made homeless did not have to live longer than 3 years in temporary housing. In reality, this time extended to up to 10 years for many households.

4.3. Overview of reconstruction program in Bam:

The reconstruction of Bam started about one year after the earthquake whereas the rural reconstruction started rapidly. In addition to the lack of pre-provided reconstruction program for a mid-size city like Bam before the disaster, the rather proper condition of the temporary shelters and the poor psychological situation of people were the reasons for this delay (Ahmadzadeh, 2004). According to Ministry of Hosing and Rural Development, a prolonged post-earthquake reconstruction period would not benefit the city, either financially or esthetically, and it has been the case in other post-earthquake reconstructions in Iran such as in Manjil.

The housing foundation of Iran as the reconstruction executor of arranged Bam's reconstruction charter. In this charter the policies have been described as follows (HFIR, 2003):

- Reconstruction management and community participation policies
- Financial policies
- Construction technology policies
- Policies related to construction materials and their production. Materials must be economical and compatible with the environment and have the production capabilities in the country
- Architectural planning and design policies

- Reconstruction organization and administrative policies

The government's roles in assisting the affected people in the charter were as follows (Zafari, 2008):

- Debris management; by March 2006 up to 97% of debris were removed
- Preparing the construction plans (up to 136) for rural communities
- Preparing the necessary structural plans
- Inviting working groups to participate
- Contributing to the establishment of soil mechanics and material laboratories (mainly for Arg-e-Bam restoration)
- Performing the technical control over the constructions by local inspectors
- Supplying and distributing materials like cement, steel, sand and gravel assisting in the construction of new small production plans
- Use of mass construction management were possible
- Establishing technical and engineering centers
- Conduction a census, performing documentations and introducing the applicants to the bank for acquisition of loans. The government's aim was to decrease the governmental investment in the private sector.

Bam Reconstruction Supreme Supervisory and Policymaking Association was established in Bam and the implementation of debris removal, reconstruction, renovation and retrofitting programs for both residential and commercial buildings was assigned to the Housing Foundation of Iran.

4.3.1. Reconstruction of Bam as a world heritage property:

The 2003 Bam Catastrophe caused the Iranian authorities to face two new major challenges in the post-disaster reconstruction: First, contrary to the previous earthquakes which mainly affected rural areas, the bulk of damage in Bam occurred in the center of an urban area; and second, this urban area had considerable historical significance. Bam and its cultural landscape represent an exceptional testimony to the development of a trading settlement in the desert environment of the Central Asian region and citadel in the Central Asian region, based on the use of mud layer technique (Chineh) combined with mud bricks (Khesht).

The UNESCO World Heritage Committee was held six months after the Bam disaster and there Bam was registered as a World Heritage site and also inscribed on the World Heritage in Danger List until 2013 (UNESCO World Heritage Center, 2013) .

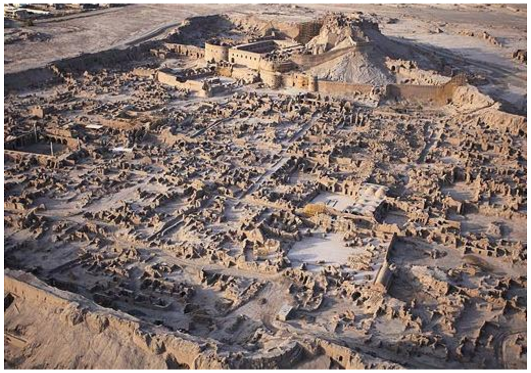

Figure 4.3. Bam citadel, 8 years after the earthquake of 2003

Source: Mehr News Agency

Many ancient areas which hold long established and entrenched histories and inherited traditions are particularly vulnerable in the event of such disasters. Buildings in these areas are not only being deteriorated but urban infrastructures have not been modernized in order to be able to survive further environmental and industrial threats.

Similar to most disasters, the 2003 Bam earthquake presented windows of opportunity for disaster mitigation, risk preparedness, physical planning, and socio-economic and cultural developments. The earthquake damaged a significant part of the historical areas of the city and created an opportunity for developing a resilient community that could be used as a model city for other parts of the country.

The earthquake provided an opportunity for further development and growth of the city's unique and internationally known date production through more publicity, renovation of the old irrigation systems, and expansion of its related industries. It also created new opportunities for the city's exceptional cultural heritage and further developments in tourism. The city could use this disaster to reshape its physical planning and development by introducing new planning ideas and innovations.

4.3.2. Materials, technology and culture in disaster preparedness in Bam:

Studies on pre-earthquake building practices in Bam show that the failures of the buildings in the earthquake were neither the result of a lack of construction technology, nor the consequence of a shortage of building materials but were the result of poor workmanship and lack of construction knowledge (Gharaati, 2006).

A number of earthquake incidences have indicated that different buildings experience varying degrees of damage. For instance, in the case of Bam, dome shaped buildings survived in the majority of cases (Fallahi, 2008). This means that the safety of a building against an earthquake is influenced not only by the materials used but also by the type of construction and methods of disaster prevention.

According to Fallahi evidences provided following the 2003 Bam earthquake indicated that few modern buildings survived while a number of traditional buildings were able to withstand the tremendous force of the natural disaster (Fallahi, 2008).

Technology is a part of the culture. Refined culture with a history of its own has incorporated new techniques and new materials. Therefore it is important that we do not deny the development of new disaster prevention techniques or new materials. The issue here is the way in which new materials, such as concrete and new techniques are introduced and incorporated. The uniqueness of a given culture must not be compromised by introducing these materials and techniques in an inappropriate or incompatible manner.

For instance, based on the field analysis and studies in Bam after the earthquake, none of the walls were reinforced and some of the load-bearing walls were not thick enough to resist the bending and shear strength of the earthquake (Gharaati, 2006).

If we look at disaster preparedness from the point of view of culture, it may be recognized that the more affluent a culture is, the stronger the interest in disaster preparedness. The motivation for disaster preparedness strategies is to protect the life, history and culture. One example could be the traditional four-sided domes which seem to be manifestations of technological technique in order to withstand unpredictable forces. Culture which has been protected and nurtured by disaster preparedness must not be destroyed by disaster reconstruction.

Furthermore, cultural indicators have remarkable results on post-disaster actions and decisions of people. Based on survey results after the earthquake of Bam there are significant differences between the long-term residents of Bam and those who have migrated during the post-earthquake period with regard to their feeling of belonging to Arg and other historic sites (Fallahi, 2008). Also, for younger residents of Bam, there is an urgent need to education training in order to improve cultural awareness and to build a framework of prevention and preparedness because of the lack awareness about Arg-e Bam and other historic monuments.

Field studies in post-earthquake Bam show that owners' participation in housing reconstruction process within setting arrangement has a significant positive impact on their attitude towards newly built homes (Remaz Ossen, 2012).

Lack of sense of belonging to the city not only affects the built environment but in the garden-city of Bam the natural environment was also damaged by relative disconnect between people and nature after the earthquake. Some people have been involved in burning date palm trees and bushes in an attempt to alter the land from agricultural to residential. This has been undertaken in order to financially gain from the difference in price between these two land uses.

By destruction of Qanats in villages, people moved from those areas to the city since they became poor. Outsiders created shortage in house stock and also cultural interest in Bam. Also many native people of Bam have left the city and were not willing to come back. More importantly many outsiders turned the city to become a nest of drug dealers, smugglers and thieves.

In other words, good connections between heritages, palms, qanats and cultural behavior, will in turn conduct development program to help conservation both in physical and social aspects.

4.3.3. Building practice in Bam before the earthquake: The majority of houses in Bam were built out of adobe, and the vast destruction in the city was first thought to be the result of these poor construction materials. A closer look at what remained of the city, however, reveals that this is not the whole story. Gharaati identified two main reasons for the devastation based studies on the fieldwork one year after the earthquake of 2003 and pictures taken from the buildings by other people: poor workmanship and lack of construction know-how. Since in Bam, local masons or even the owners themselves were the builders for the most part, many of whom lacked knowledge about effective construction techniques. Building construction failure in Bam can be divided into two main categories:

4.3.3.1. lack of knowledge about structural components, building design and inadequate building inspections: To name a few indicators, lack of a good and appropriate foundation; lack of any reinforcement in load-bearing walls; heavy roofs;

addition of new stories on top of the existing houses; complex plan layouts; lack of enough thickness for many load bearing walls to resist the shear force; and inappropriate placement of openings were between the common reasons for building destruction. Generally, lack of knowledge about concrete construction is a serious problem in Iran, but specifically in smaller cities, towns and villages it is even much more critical.

4.3.3.2. Lack of decent and affordable building materials: Since the majority of Bam citizens are poor or lower-middle class, it is very hard for them to afford quality material which are imported from other parts of Iran. Poor construction material could be found in a range of different types of buildings from earthen buildings to steel and concrete structures to hybrid buildings. Building construction material reuse was also effective in poor mortar bonding.

HFIR provided materials such as cement and steel during the first 2 years of the reconstruction period by its respective companies including Saman Mohit Co. and Concrete Foundation. In some cases people provided the construction materials themselves (Omidvar et al., 2009). Beyond this time period, material quality in constructions was reduced.

4.3.3.2.1. Earthen and adobe buildings: The survival of earthen building materials in Bam, dating back some 2500 years, is a good indicator of durability and adaptability of this material to environmental qualities of the area. Adobe and mud bricks are one of the oldest and most widely used building materials in the southeast of Iran.

The adobe buildings normally have domed or vaulted roof systems. For these roof systems the final finished level may still be flat. In this structural system thick and stiff walls provide the main load bearing system. From structural standpoint, adobe structures are bulky and heavy. More importantly the roof can be very heavy due to the complex vaulted system, or due to additional weight accumulating by the application of insulating layers normally added every few years.

Figure 4.4. Total collapse of adobe building in Bam

Source: Manafpour, 2008

During the earthquake, a number of earthen buildings remained intact, showing that use of appropriate material and adequate maintenance could help earthen buildings withstand the earthquake. Although the vaulted roofs perform well in transferring gravity loads, due to utilization of mud bricks in compression, they are not well suited to transferring horizontal seismic loads or strong vertical seismic loads. The result is a sudden collapse of the structure with insufficient time for evacuation and a dusty atmosphere afterwards.

Figure 4.5. Non-collapsed adobe building after the earthquake
Source: Tetsuo et al. 2007

4.3.3.2.2. Masonry buildings:

URM dominates the entire Bam city except the old part of the city near the citadel. Burnt bricks are typically used and are bonded by mortar or poorly mixed gypsum and sand paste. The sidewalls support the roof as a structural component without lateral confinement (Tetsuo et al. 2007). In these buildings, roofs are made of wide-flange beams with burnt bricks forming a low-rise arch called a jack-arch.

Figure 4.6. Collapsed jack-arch roof
Source: Tetsuo et al. 2007

Masonry buildings constructed of fired bricks have become one of the most common construction methods in Iran since the early 1960's. Masonry buildings are in most cases partially combined with steel frame. The flooring system either consists of steel joists and brick jack-arches or reinforced concrete joists with hollow bricks. Vaulted roofs were also seen in fired brick masonry buildings, again in some cases with good performance (Manafpour, 2008).

The use of horizontal ties in Iran started in the 1960s and the use of vertical ties began in the 1970s. However this practice took much longer to be implemented in rural regions such as Bam (Manafpour, 2008).

Based on the field studies in Bam, for masonry structures without ties observed main failure types included: a) horizontal displacement of simply supported joists in jack-arch system resulting in collapse of arches between the joist b) horizontal movement and slippage of the whole roof system on the walls resulting in total collapse of the building (Manafpour, 2008). Mortar materials used in older masonry buildings are lime-clay, lime-sand or lime-sand-cement. Although in more recent construction sand-cement is predominant, lime-sand is still used in some private houses which provides a poor bond.

Figure 4.7. A residential masonry building without ties in Baravat. Construction finished about 6 months before the earthquake
Source: Manafpour, 2008

The Iranian building code and standards (BHRC 1999) specifies the use of confining ties and requires these for newly constructed buildings. Unfortunately existing buildings are exempt from the regulations. A typical collapse for these walls is due to the inclination or collapse of side walls. The collapse rate for this type of building is high in the entire city (Tetsuo et al. 2007).

4.3.3.2.3. Steel frame buildings: Simple frame structures that were obviously badly constructed were among the most severely damaged structures. In case of jack arches, where the mortar is soil and chalk, some roofs are composed of steel beams with the same inappropriate bond.

Figure 4.5 shows a typical example of large lateral and torsional displacements which is combined with poor quality of welding contributed to total collapse of the structure.

Figure 4.8. A combined residential-commercial building with braced steel frames in Bam city center. Source: Manafpour, 2008

4.3.3.2.4. Concrete buildings: Considering that concrete is a relatively new construction technique in many parts of Iran such as Bam, high price of materials in addition to shipping and handling prices led to the reduction of the appropriate amount of cement in concrete mix and steel for efficient reinforcement and also use of construction waste and debris as concrete filler.

4.3.3.2.5. Hybrid buildings: Steel columns with flat concrete roofs or loadbearing earth walls with steel girders are the consequence of efforts to reduce the cost of the building construction. Incontinency of building materials in hybrid buildings requires sophisticated methods at joints where the two joints meet which was generally ignored in these buildings.

4.3.3.2.6. Conclusion:

Generally speaking, when new construction materials were introduced to the locals in Bam, builders tried to adapt these new materials to their traditional techniques. The result was incorrectly implementation of various techniques.

In addition, while Bam is famous worldwide for its adobe buildings and earthen structures, the knowledge of bricklaying has been apparently forgotten among local masons over the last few decades.

Despite the history of tragic earthquakes it appears that the issue of seismic risk has not to date been addressed particularly effectively. This failing runs through every level of society and it is reasonable to ask why the obvious lessons of the earthquakes are being ignored. Perhaps the intermittent nature of devastating earthquakes tends to create a culture of acceptance of the status quo and failure to take responsibility in a society which has mainly focused on short term needs.

4.3.4. Building practice in Bam after the earthquake: After the earthquake, the Housing Foundation of Islamic Revolution (HFIR) was assigned to take the control of the reconstruction of Bam. HFIR is a publicly funded, yet non-governmental, organization ruled by a principal designated by the Supreme Leader of Iran. All the activities with regard to the reconstruction of Bam must be accepted by HFIR from the first stages. This situation was one of the reasons that made the process of the reconstruction of Bam very time consuming. The management of the housing reconstruction program took the form of one resident team with one supervisor for each 100 units, and one head supervisor for each ten teams.

4.3.4.1. Reconstruction phases after the earthquake: In order to take part in the reconstruction of the city, a number of construction factories, building contractors and architectural consultants had either moved to Bam or established a representative office; the majority of these offices were housed in a complex building provided by HFIR at the periphery of the city. This building was the main core of the reconstruction engineering and architectural enterprise. Also, HFIR designated an extensive lot for construction companies and architectural firms to build samples of their proposed buildings to demonstrate their proposed construction methods to the locals. Each building offered earthquake-resistant features, according to the promoters, who tried to convince the citizens to use their specific techniques in the reconstruction of their house.

4.3.4.2. Housing design strategies, educational samples and exhibition site by HFIR: A relatively small house of 9x9 m^2 has been designated by HFIR engineers and architects as the standard size of a house for an average-sized family in Bam. All the construction companies and architects were advised to design and build within these fixed dimensions. In addition, HFIR has designed and proposed a prefabricated steel-frame structure that fit the 9x9 m^2 house.

The structure proposed by HFIR consisted of prefabricated steel posts, beams, and bracings that were designed in a way that can easily and quickly be assembled in just a few hours employing only two laborers to fasten bolts and nuts together. This method could remarkably reduce the number of failures caused by inadequate welding.

4.3.4.3. Building construction method and details by HFIR: HFIR has built an educational sample of the proposed structure on the exhibition site, where citizens could visit and learn about essential construction details. The whole structure was placed on a reinforced concrete foundation, to which the frame is connected using bolts and nuts. The roofing system and wall infill technique remained flexible to the constructor's or owner's decision. L-shaped steel bars or chicken wire wrapped columns were proposed to reinforce corner joints or enhance the sand-cement bond.

The roofing system proposed by HFIR consisted of prefabricated I-steel beams as girders, which hold a 7-10 cm concrete slab molded on corrugated galvanized steel sheets as left-in-place molds. Small Z-shaped steel laths are welded to the girders, connecting the concrete slab to the girders every 50 centimeters. This construction method might change, however, when citizens or other builders in the city began to make decisions about their building.

Figure 4.9. Steel structure proposed by HFIR in Bam

Source: Gharaati

4.3.4.4. Building construction method and details by other building practitioners: According to Gharaati, all other construction methods could be parts of the following categories in Bam reconstruction program:

1. HFIR's structure, different components

2. Prefab construction and components such as sandwich panels, prefab trusses, cold-formed joists and studs, drywall panels or precast concrete roofs.

3. Conventional steel-frame structure (welding) and lightweight materials roofs and walls, such as sandwich panels and corrugated steel sheets.

4. Reinforced masonry which was proposed by two foreign institutes; Auroville (India) and Peace-Winds (Japan) with

horizontal reinforcement (concrete ring beams), vertical reinforcement (steel bars) and buttresses alongside the openings. Peace-Winds taught this method to four local masons.

Figure 4.10. Quake-proof model buildings built by trained local workers under the UNDP-backed project were cost-effective and consistent with the cultural identity of the ancient city of Bam. Source: Kianpour, 2009

Citizens towards Overseas Disaster Emergency (CODE) cooperated with an Iranian NGO to have a workshop for disseminating the earthquake-safe construction. They built a model house in the exhibition site of Housing Foundation. The workshop had more than 300 participants from various fields such as local governments, local masons, NGOs, and university students who learn architecture (Citizens towards Overseas Disaster Emergency, 2004).

According to the application of Bam Reconstruction Center and International Blue Crescent Relief and Development Foundation (IBC Turkey), regarding the testing of the compressed stabilized earthen blocks and structural behaviors in earthquake, the results are standard. This system is the same as masonry structures of Iranian earthquake standard (2800) with vertical rods reinforcements. The sample house which was built in the Exhibition site in Bam for reconstruction project was one story building. It is possible to construct the 2 stories buildings with the height of maximum 8 meters from the ground level (Parhizgar, 2004).

Tests	Results
Water absorption	11%
Strength(kg/cm2)	57
Erosion resistance	Resistible
Density (g/cm3)	1.83

Table 4.1. Test results for compressed stabilized earthen blocks, approval from Iran for the Reconstruction of Bam with CSEB

4.3.5. Proposed construction techniques advantages and disadvantages: The proposed techniques were quick and easy in installation and they were earthquake resistant. However, the construction cost remained an obstacle for the earthquake-stricken people in Bam. The prefabricated steel components had to be imported from long distances. In addition, some parts of the structure were over-designed (Gharaati, 2006).

Considering the total constitution of bracings which is about 30% of steel use, the unnecessary thickness of some bracings, or the hollow section bars which could be replaced by brick, could have a considerable impact on reducing the total cost of these buildings.

On the other hand, while the structural system didn't need skilled labors, lack of concrete construction knowledge made the roofing system a potential risk of failure in future earthquakes. Apparently even during the time that HFIR controlled the construction of the buildings very closely, instead of the recommended steel-deck flat concrete slabs for roofs local masons used prefabricated reinforced concrete

joists. While these joists were more affordable, the poor bond between steel makes it vulnerable in strong earthquakes.
These sophisticated techniques made the role of supervision and educated inspectors very critical in construction to be successfully implemented by local masons. In addition, the proposed corrugated steel sheets for roofing were not adaptable with the climatic qualities of Bam.
Among all construction companies and practitioners, Peace-Winds focused on educating local masons and improving local know-how. The top-down reconstruction programs impose new technologies which are too far from traditional building systems and extremely expensive foreign materials to the local builders. This imported technology-based program lacks sensitivity in urban and landscape design and like similar programs was incapable of yielding long-term solution for housing market in Bam (Lizarralde, 2001).
All in all, the case of Bam demonstrates that the technology itself without enough education of construction knowledge could not solve the problem of building earthquake-resistant buildings. The inflexible design of housing units also failed to address the cultural, individual and log-term needs for making changes to the designed houses. The reconstruction program had underestimated the importance of local community participation in materials, labor, expertise and supplies.
When the techniques are not easy to be learnt for the local builders, they adopt them to their knowledge. Also, when the

design cannot predict the future needs of inhabitants, housing extensions will follow the past patterns without engineering considerations for extra loads on the structure. The Bam Reconstruction Program relatively failed to achieve its expected objectives due to the complexity and lack of flexibility in housing designs, the underestimation of local resources, and ignorance of the future needs of the inhabitants.

4.4. Execution of the Bam reconstruction policy:

The Council of Architecture and Urban Development (CAUD) consisted of eight distinguished members, including businessmen, academics, architects, engineers and members of the Housing Foundation. This Council outlined the measures and guidelines for rebuilding houses as well as the urban design of the City of Bam. The CAUD approved the amount of credits and bank loans for each individual household and business unit. They also made decisions regarding the allocation of loans for the fencing of gardens, surrounding walls, and the reconstruction of schools.

Based on the government reconstruction policy, the new Bam master plan, which was completed some months before the earthquake, was modified based on the new micro-zonation map of Bam (Askari et al. 2004). For preparing the land for the reconstruction of the residential and commercial units, 17 provincial affiliates of the IHF and other executive organizations in the region were assigned the tasks of removing the debris of following the confirmation of the units' ownership.

To help the victims, the government of Iran has provided low interest (4% for rural area and 5% for urban housing and commercial units) and 15-year loans as well as a grant through the banking system for the reconstruction and repair of residential and commercial buildings in Bam and Baravat and in the rural areas.

The fund was almost enough to cover the expenses for the 60 m^2 and 85 m^2 residential units in villages and Bam respectively. Banks were also encouraged to provide long-term loans at a regular interest rate to those interested in building larger homes. As the permits were issued, the owners were advised on how to receive the loan from the banks, with the amount being decided on by the IHF based on the progress being made in construction.

There have been many complaints, primarily due to a lack of clear understanding of the procedures and the demand for a more flexible usage of the loan. Also, in practice, many households could not receive enough funding to finish their construction process in the estimated time. This was one of the main complaints of the residents about governmental policies for tong-term reconstruction of Bam.

According to Hosseini and Ghafory-Ashtiany the quality assessment of the reconstruction of hospitals, health centers, schools, sport centers, cultural centers and governmental buildings was very good.

The reconstruction and restoration of Arg-e-Bam and other damaged buildings with a cultural heritage have been started with the cooperation of UNESCO, Italy, Japan, and other countries. The process was slow and there is no expected time for their completion. As of 2014, these projects are not completely finished yet.

The total cost of design (free up to 250 m^2), licensing (free up to 100 m^2), supervision and certifications as well as the quality-control process, which are conducted and financially supported by the IHF were covered by a World Bank loan (for US$ 235.00 million from October 2004 until May 2009) and government resources.

A number of factors had to be taken into consideration in making the reconstruction plans for the rural areas, such as the simpler life style relative to urban housing, economy, need for rapid reconstruction, management of migration and availability of the technical manpower. Consequently, rural reconstructions involved were less flexible in terms of design, with fewer variations of the building types.

4.4.1. Bam sustainable reconstruction manifesto:

One of the policies proposed by the CAUD was the Bam Sustainable Reconstruction Manifesto. A Committee on Sustainable Development consisting of academics and experts in reconstruction was set up to develop the manifesto. Three of the principles in this master plan for sustainable reconstruction and development in Bam were:

a) Preserving the city identity in urban design,

b) Strengthening the new houses against the national building code, and

C) Householder participation in the process of rebuilding.

Community participation was suggested in various aspects of physical, environmental, social and economic issues, as well as, improving living quality in Bam without affecting later generations (The Committee on Sustainable Development, 2004).

4.4.2. Community participation:

Research has shown that the lower the level of participation rates of recipient individuals in the reconstruction process, the lower the level of satisfaction rates of the resultant relocation and shelter (Fallahi 1996). In the case of Bam, householders were given the ability to choose their own plans and layouts and act as the supervisors of their own projects, thus paving the way to establish a line of cooperation between designers and contractors.

One very important factor that facilitated the community participation was the presence of a 'construction market' which was developed in Bam just a few months after the event. The HF constructed a construction Bazaar (an exhibition and market) consisting of consulting offices, sample frame, model home and building materials exhibition to provide supervised seismic design construction based on the Iranian National Building Standards. Therefore, the residents could choose the pre-approved design and construction models. The market also provided needed material approved by 7 material testing laboratories and 17 workshops at an affordable price.

Figure 4.11. Construction Bazaar (from left), consulting offices, sample frame and model home

Source: Fallahi, 2008

Another aspect of the community participation was the presence of several small construction companies in the affected area, drawn from all over Iran. As a result, the surviving community could become active in the reconstruction process.

People could contact the municipality for the plan maps. The Kerman Engineering Organization (under the Ministry of Housing and Urban Development) was responsible for checking and confirming the technical drawings (free of charge as another aspect of the Government participation).

In spite of appropriate community participation it should be noted that at the first few months people were more sensitive to the resistance of their new buildings against future earthquakes, but after a while, due to the administrative problems and lack of sufficient and available technology and skilled workers, they had no choice other than to agree that the reconstruction situation would not get any better. Therefore, they restarted the use of masonry construction once again and used the old welding techniques in their construction. Consequently, quality control became very weak at that point. Furthermore, according to Hamyaran, an Iranian NGO which carried out projects in Baravat through community consultation, housing has been the priority of the reconstruction program with no effort applied to bazaars reconstruction in the area (Hamyaran, 2005). Bazaar is the traditional enclosed marketplace in Iranian cities and a sector that contributed to a large proportion of economic activity. This has resulted in a drastic increase in unemployment rates. Another factor was that the authority did not pay attention to public participation in some important decision regarding their houses (Fallahi, 2008), so people lost trust in local authority and do not show good-will to participate in programs.

4.4.3. New constructions shortcomings and deficiencies:

Despite all of the best efforts for ensuring the proper control of reconstruction in terms of structural control and materials, people sometimes used damaged materials that had been salvaged from their damaged home to save costs. Financial constraints during the construction process were the main reason for using low-quality building materials and not following the construction standards. More serious and rigorous supervision was needed to avoid some of the problems observed in the nonstructural sector of the reconstruction program.

Figure 4.12. Technical shortcoming examples; Connection of steel stairs to brick walls (left); using container as a part of the house (right) Source: Hosseini et. al 2003

4.4.4. International community participation in reconstruction of Bam:

International organizations had a remarkable contribution in reconstruction mainly under the supervision of UN. In general, the UN strategy included three distinct but inter-related elements:

1- In short term, specific and targeted technical support to the start-up phase of the reconstruction and recovery program (Feb. 2004- May 2004),

2- Sustained technical and coordination support to the government for the duration of reconstruction program to help ensure efficient and sustainable recovery and long-term disaster risk reduction (May 2004- Dec. 2005), 3- Capacity building for mainstreaming disaster risk reduction into development processes at local, provincial and national levels (2004-2009) (Kishore et al 2004).

4.4.4.1. UNDP: The United Nations Development Program (UNDP) contributed to the Bam reconstruction program by setting up workshops aimed at preparing the model design in consultation with beneficiaries, as well as to provide technical consultation on urban planning and reconstruction programs. The main objective of the organization was to extend knowledge of, and promote expert views on post-disaster development. UNDP constructed about 130 modular model houses whilst training 400 local builders, as part of its rehabilitation program. The UNDP Program for Bam had the design criteria for the houses as:

- To provide options for users;
- To allow for personal expression;
- To create locally familiar design;
- To have environmentally appropriate design;
- To be cost effective;
- To utilize appropriate technologies;
- To incorporate locally available materials;
- To encourage environmental friendly solutions.

However, according to Dr. Kianpur, the UNDP Program Officer for Bam, as a whole, none of the above criteria have been fulfilled in the Bam reconstruction program. She believes the residents were not genuinely provided with options despite there were exhibition showrooms of houses and in addition all the designs were predetermined according to the simplest and most profit-making option (Mobasser 2006).

4.4.4.2. UNESCO: The UNESCO's World Heritage Committee also selected the following priorities for the reconstruction of Bam and its cultural landscape:

- "Develop a new management plan containing legal, institutional and technical provisions to ensure the protection of the listed site, which is much larger than the Citadel, as it extends to the surrounding landscape with the traditional irrigation system of underground canals, the qanat.
- Use traditional techniques and local manpower to restore the qanats, which have allowed Iranian civilization to prosper over millennia and are still used today for agricultural purposes.
- Revitalize traditional earthen architecture, which has proved resistant to seismic stress. This should provide employment opportunities for the inhabitants of Bam and serve as a model for hundreds of other cities in Iran and the Middle East, where earth was the main building material in the past.
- Develop guidelines for the management of archaeological heritage, including the enormous quantity of unknown archaeological evidence found under the debris of the Citadel and in other locations, enabling the study of these findings." (Fallahi, 2008)

In practice, these priorities were limited to the historic sites, mainly the citadel site, and the whole city as a cultural landscape could not fulfill these missions.

4.5. Economic development opportunities after the earthquake: The economy of Bam is mainly based on its unique and internationally known date production and also tourist attractions before the earthquake. Bam exports more than 100,000 tons of the finest quality dates per year which is about

40% of Iran’s annual date export (Ghafory-Ashtiany and Hosseini, 2007). During the earthquake there was no direct damage to date palm trees, but the traditional irrigation system, Qanats, were heavily damages and this has become a threat to the date palm orchards. There is no actual estimation on the number of date palm trees before and after the earthquake. However, by comparing the satellite images of 2004 and 2014, we can realize that the percentage of trees within the urban texture has been changed and the number of date trees have been reduces remarkably in many parts of the city. Earthquake could create some economic development opportunities for agriculture and tourism sector: First, the city’s most famous product could be known to larger number of people worldwide. Second, during the reconstruction process the traditional irrigation system could be repaired and modernized and this could increase the quality and quantity of agricultural products. Third, earthquake highlighted the economic advantages of the city and the need to further capitalizing on that by the government and the private sector. However, these efforts should have been done to fully utilize these opportunities in the form of a major economic development program in order to generate more jobs and income for the residents of the city. The expansion of palm orchards, active marketing of products and further investment in the relevant and new industries and infrastructure have been relatively neglected by the stakeholders in Bam. Since neither the NGOs nor international agencies had knowledge and experience in that field, more collaboration between stakeholders and the government of Iran could enhance the use of these economic development opportunities.

4.6. Bam reconstruction program conclusion:

Although there were deficiencies in the quality of the construction in the initial stages, contact with the authorities eliminated most of these deficiencies, and the overall assessment was that the reconstruction process has been carried out at an acceptable level of safety and was better than past reconstruction projects carried out following the 2001 Ardebil and Ghaen-Birjand earthquakes (The Collection of Work Progress Report of the Islamic Revolution Housing Foundation 2004–2006).

However, due to lack of a comprehensive urban design guideline, this destruction did not have a positive and harmonized impact upon the traditional architecture and community infrastructure. The lack of pre-disaster hazard mapping resulted in an absence of vulnerability assessments and consequent action could have taken place before the event. Based on past experiences and the success in reducing earthquake risk in the re-construction following the 1990 Manjil earthquake, the government adopted the new long-term 'Iran's Strategy of Earthquake Risk Reduction', which comprises several components, including policy change, increasing know-how, improving management quality, using advanced technology, code enforcement, increasing the safety of public buildings and infrastructures (especially schools), public awareness and increasing public preparedness for the correct response during and after an earthquake.

Achieving the final objective of reducing earthquake risk to an acceptable and affordable level with a good response team will require long-term educational goals and the nurturing of a collective culture of safety in Iran.

The idea of establishing the Construction Bazaar was an innovative approach that ensured the maximum use of local expertise, maximized the contribution of local people and resulted in an enforcement of the quality control system in the reconstruction process.

Generally, the overall concept of Construction Bazaar was good; however, the supervision, quality control and evaluation body of the reconstruction should be organizationally separated from the IHF and the Bam Reconstruction Headquarter in order to ensure a higher level of quality control in the reconstruction and to eliminate some of the problems that occurred due to conflicts of interest.

There have been the inevitable delays in different levels of the reconstruction process of Bam, mainly due to the lack of an in-advance reconstruction plan. Also, city of Bam had to purchase almost 1700 properties to facilitate and speed up the implementation of the new plan's recommendations .

Therefore, it is highly recommended that reconstruction plans for cities, particularly the older cities located in highly seismic zones, should be prepared long in advance.

In addition, more attention should be given to social rehabilitation. Post-disaster expectations and demands need to be responded, including rapid reconstruction, larger loans, simplifying the process of construction permits, rapid economic recovery and the job market.

Finally, the financial and construction material aid from the Housing Foundation on one hand, and the survivors' participation in the process of rebuilding on the other hand, were two important factors contributing to the success of the Bam reconstruction program.

The critical importance of offering training in building safety techniques has been emphasized for both mitigation and reconstruction programs. However, an important factor is the improvement of overall local construction techniques.

The objectives of disaster operations and innovation should be linked through community participation. Active survivor participation in housing not only leads to operational cost and time reduction, but also it can reduce the negative psychological impact of earthquakes.

4.6.1. Key lessons in reconstruction works in Bam:

1) The liberty in choosing the type of materials and the architectural design was better for the beneficiaries and the idea of construction market was successful in Bam.

2) Reconstruction of ‘garden houses’ by people themselves was a successful example of public participation in the reconstruction process.

3) Holding training sessions for people who intended to build their own houses proved to be an effective form of community participation in the reconstruction process.

4) Insufficient building expertise in the city and its neighborhood caused some shortcomings in the quality of the construction. This gap was most serious in rural areas.

4) Shortage of suitable materials (cement, aggregates, and steel profiles) in the city and its surrounding areas caused some delay in reconstruction work.

5) People’s indifference, especially amongst those who have had lost most or all of their family members and close relatives, and whose rebuilding of their houses was one of the main causes of the delay in reconstruction.

6) The engineering offices were far from the city center and most of the residents. Bam residents needed to visit the market at some point, quite regularly in many cases, and since the site was inaccessible without a car and other form of public transport, difficulties were created for the people, particularly in the first months after the earthquake.

7) There were some more recognizable problems in the Bam reconstruction process, mainly due to the lack of pre-planned reconstruction works.

8) Over-hasty decision making by the authorities resulted in illogical and over-optimistic promises being made to the survivors

9) Inability to effectively manage the financial resources which poured into the region shortly after the event.

10) Outpouring of nation's emotion in the immediate aftermath of the disaster and rapidly forgetting it. This fall-off of concern occurred just when people of Bam needed more financial and emotional support.

11) Various companies worked simultaneously in the reconstruction process of Bam and their lack of coordination and overlapping roles and activities at the time of crisis produced an impossible management situation.

II. Part two: Post-disaster temporary housing practices in Bam

Building temporary houses is a key component of the recovery phase; yet, it also can lead to several drawbacks in the development of disaster resilience.

The earthquake of 2003 destroyed nearly 85-93% of urban buildings in Bam. The disaster forced national and local authorities to settle affected families in temporary houses until permanent houses were provided. However, the social and geographical characteristics of Bam complicated the temporary housing efforts. One of these difficulties was to distinguish between real affected families and a large number of post-disaster immigrants. A large number of low-income families arrived in Bam from villages with the hope of obtaining financial aid or houses. This made the assessment of needs very difficult and led to poor management of the limited resources for post-earthquake reconstruction.

Around 37900 temporary housing units were built by adopting four distinctive methods to settle affected families (Fallahi, 2005), 5600 of which made from masonry materials (Fayazi and Lizaralde, 2013). There were four types of strategies of housing provision in Bam: A) Temporary camps developed by the national government, B) Temporary camps built by international donors and agencies, C) Prefabricated units built in dispersed areas, D) Units made of masonry and permanent materials.

Figure 4.13. Different types of temporary houses in Bam, from left: A- Camps of temporary houses assembled in-situ B- Masonry temporary houses in the yards of destroyed houses C- Prefabricated units assembled in yards of destroyed houses D-Complete high quality units in camps

Source: Photos by Mahmood Fayazi

Strategy A: Primarily, in order to facilitate the removal of debris in affected urban areas, national authorities first decided on the construction of temporary shelters in camps. About twenty sites in the city and in the outskirts were selected for building 9,050 prefabricated units. The majority of these units (around 8,100) were assembled by the national government in partnership with the Defense Industrial Organization and a private company called Consulting Engineers of Rashestan Co. They were located in 16 camps which were developed six months after the earthquake. The rest of the units (around 950) were assembled by the regional government of eleven provinces in four sites located in the city (Fayazi and Lizaralde, 2013).

Strategy B: Despite the large number of prefab units built by the government, the majority of native families refused to move to the camps, stayed on their emergency tents, and requested to live near their remaining assets and destroyed houses. In response, authorities proposed, almost three months after the earthquake, the construction of temporary shelters on the yards of destroyed houses. Around 5800 masonry units were then built by the HF during a period of five months. The specific location of these units within existing yards was selected by the landlord with the supervision of a representative of the municipality and HF experts.

Despite their modest design, the units were designed to be used after the temporary housing phase besides the permanent reconstructed houses (Ghafory-Ashtiany & Hosseini, 2008).

Strategy C: In response to the beneficiaries' refusal to settle in the camps, the national government also opted (about six months after the earthquake) to transfer about 2500 units developed in strategy A and that were not occupied by the beneficiaries to the yards of affected houses. Moreover, the government built additional prefab units (identical to the ones built in strategy A) in the yards of new beneficiaries.

Strategy D: Three donor countries donated 1,400 high-tech units imported from Turkey, Japan, and South-Korea. They were built at "Doosty", a camp located in the outskirts of the city and about 2kms away from the Bam city center. These units arrived in Iran about 15 months after the earthquake, when temporary shelters were no longer needed. Inevitably, these units settled permanently the families who did not have had access to any sort of temporary shelters and had stayed on their emergency tents up to that time.

4.7. Community resilience:

The post-disaster temporary housing phase brings an important opportunity for enhancing community resiliency. According to Norris et al., community resilience emerges from four primary sets of adaptive capacities: Economic Development, Social

Capital, Information and Communication and Community Competence (Norris et al., 2008).

The concept of 'resilience' has multiple definitions in the literature. Cutter et al. defines resilience as "measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Cutter et al., 2008). Within the field of global environmental change, resilience is defined as the ability of a social system to respond and recover from disasters; it includes inherent conditions that allow the system to absorb impacts and to cope with an event. It also includes adaptive processes that facilitate the ability of the social system to reorganize, change, and learn in response to a threat (Adger et al., 2005; Klein et al., 2003).

Another remarkable factor in resiliency definition is the ability to find unknown inner strengths and resources in order to cope effectively (Ganor et al., 2003). Cutter et al. state that resilience has two qualities: inherent qualities that function well during non-crisis periods, and adaptive capacities, notably flexibility, in response to disasters (Cutter et al., 2008).

Table 4.7 shows the four key elements in definition of resilience by different authors.

Key elements of the concept of resiliency			
Ability to withstand	Ability to mitigate	Ability to recover	adapt the community's

against hazard	impacts of hazard	after hazards	capacities

Table 4.2. key elements in definition of resilience

Fayazi studied the impacts of the different temporary housing strategies and their outcomes for the adaptive recovery of the affected community through the resiliency framework during the time period of five years after earthquake between 2008 and 2012. The results show that certain strategies had negative consequences in the just distribution of resources and in the development of social capital. For instance, it is estimated that nearly 3100 shelters were never occupied (Fayazi and Lizaralde, 2013).

Moreover, temporary shelters raised the survivors' expectations about the permanent units that they were supposed to receive, postponed the construction of permanent houses, and reduced their participation in the permanent reconstruction phase.

The post-disaster temporary housing phase plays a critical role in the recovery of affected families, particularly by potentially increasing their adaptability capacities. Table 4.6 shows the variables linked to adaptive capacities.

Resources	Adaptive capacities	Variables of temporary housing
Economic development	Equity in the distribution of resources	Duration of the benefits
		Waiting time for receiving temporary houses
	Level and diversity of resources	Level and diversity of temporary houses
	Fairness of risk and vulnerability to hazard	Risk and vulnerability of affected communities
Social capital	Sense of community	Sense of similarly and interdependence
	Place attachment	Emotional, physical and financial connection to place
	Citizen participation	Formal decision making
Information & communication	Reliable information sources	Announcement
		Communication with responsible organizations
		Training information and activities
	Narrative	Communication among affected families
Community competence	Community action	Refusal to occupy the units
		Acceptance and occupation of the units
	Critical reflection and problem solving skills	Expressing preferences
	Flexibility and creativity	Creative local solutions
		Re-use of temporary houses
	Collective efficacy empowerment	Involvement in reconstruction of permanent houses
		Collective knowledge and information

Table 4.3. Categories of analysis of temporary housing adapted frameworks of adaptive capacities network
Source: Norris et al. 2008

4.8.1. Temporary housing and economic development:

According to Dr. Fred Krimgold, an architect worked on hazard research at Massachusetts Institute of Technology, there are three basic approaches to shelter following a disaster: The normal housing survives; the normal housing is interrupted by the disaster. Thus, the gap is filled by provision of temporary housing; the normal housing is interrupted by the disaster, however, the gap is filled by starting the reconstruction very early thus, preventing the need for temporary accommodations (Davis, 1978).

The pre-existing diversity of vulnerabilities in Bam was exacerbated after the earthquake by the post-disaster immigrants to the city. Therefore, the target groups were in fact two: the real native affected families (landowners, and tenants), and the temporary low-income immigrants, which include three distinctive groups: low-income families that immigrated just after the earthquake, immigrant workers and immigrant students (Farhoudian et al., 2006).

This demographic distortion led to fictitious assessments of needs, increased demand and a competitive atmosphere. While native landowner families preferred to settle near their destroyed houses, the native tenants and low-income immigrants did not have any choice but to accept the temporary units in the camps.

Based on the categories for adaptive capacities by Norris et al., the effects of temporary housing in four different types in Bam on economic development was listed in the table 4.6.1 by Fayazi and Lizaralde for A- Camps of temporary houses assembled in-situ B- Masonry temporary houses in the yards of destroyed houses C- Prefabricated units assembled in yards of destroyed houses D-Complete high quality units in camps.

Adaptive capacity	Variables of temporary houses	Criteria of analysis of the variables		Cases			
				A	B	C	D
Equity in the distribution of the resources	Duration of the benefits	Only during temporary housing phase		X		X	
		Remained after temporary housing phase	Use as secondary space		X	X	
			Use as secondary living space		X		
			Use as permanent houses				X
	Waiting time for receiving temporary houses	Less than 2 months		X			
		Between 2 and 6 months		X	X	X	
		Between 6 months and one year			X		
		More than one year					X
Level and diversity Of resources	Level & diversity of temporary houses	Location	Camps outside of city	X			X
			Camps within the city	X			
			The yard of destroyed houses		X	X	
		Material and structure	Complete units installed in situ				X
			Prefabricated units assembled in situ	X		X	
			Masonry materials		X		
Fairness of risk and vulnerability To hazard	Risk and vulnerability of affected communities	Natives	Landowner native residents		X	X	
			Native tenants	X			
			Vulnerable affected families	X			X
		Non-natives	Temporary non-native residents	X			X
			Low-income non-native immigrants	X			X

Table 4.4. Comparison of economic development capacities enhanced by temporary housing strategies
Source: Fayazi and Lizaralde, 2013

Analysis of the results of these categories show that the program led to inequity of resource distribution. In addition, the allocating different types of temporary houses to distinctive groups of vulnerable communities reinforced differences between social groups.

In addition to the type of the housings another reason that the local and governmental authorities primarily decided to establish camps was to facilitate the distribution of food and materials. Decentralization of buildings further exacerbated vulnerability of residents of Bam and because of their unfair access to resources.

4.8.2. Temporary housing and social capital:

Environmental threats can enhance survivors’ sense of similarity and interdependence, leading to increased sense of community (Edelstein, 1988). Temporary housing programs influence social capital by facilitating or reducing the sense of community, place attachment, and citizen participation through community bonds and commitments, emotional connections to one's neighborhood and the engagement of community members in formal organizations (Norris et al. 2008).

The pre-existing sense of community enabled the native affected families (B- Masonry temporary houses in the yards of destroyed houses; and C- Prefabricated units assembled in yards of destroyed houses) to expose their concerns about temporary camps which led to enhanced social capital and fast recovery, whereas immigrant families (mostly in cases A- Camps of temporary houses assembled in-situ; and, D- Complete high quality units in camps) accepted inevitably to live in the camps. Native families allied together to challenge to authorities, reject unsuitable units and present their creative solution to live temporarily besides their destroyed houses. Place attachment and connection to place also helped the native affected families to keep their connection with their previous social organizations and to continue their livelihood activities related to the date palm gardens. In other words, a self-correcting system will be made within these active societies.

Moreover, while the native families who settled beside their destroyed houses had a quick adaptive recovery process, the immigrant families and temporary residents were struggling painfully against security problems including lack of security for themselves and their assets, an epidemic of cholera and major barriers to find jobs.

4.8.3. Temporary housing and information and communication:

Information may be one of the most important primarily resources that enable community members to recover adaptively and to create common meanings and understandings.

In fact, social scientists agree that community recovery depends partly on collectively telling the story of the community's experience and response (Landua et al., 2004) and isolated tenants and immigrant families, suffer strongly from post-traumatic stress disorder and its symptoms (Farhoudian et al., 2006).

In Bam, access to reliable information (national or local media) helped the affected families to be consciously become aware of the new challenges and opportunities. Access to reliable information published by responsible organizations played a critical role on reducing the uncertainties of residents involved in the construction and design process, amount of available financial aid, time tables and information about involved companies and contractors.

Affected families who lived in camps had limited chance to make narrative communication with their unfamiliar neighbors, and to adapt to challenges while native landowners adapted quickly to post-disaster challenges by sharing their understandings of reality and experiences among their neighbors (Fayazi and Lizaralde, 2013).

4.8.4. Temporary housing and community competence:

Community competence is a critical resource that enables the community to learn about their risks and options, and work together flexibly and creatively to solve problems (Norris et al., 2008). The differences in community responses to temporary units provided by different organizations (refuse, acceptance and modification) were linked to community competence.

The 3100 units in camps which were not occupied and ultimately abandoned was the most significant indicator of community action and decision-making abilities in Bam. Moreover, in the case of units built in the yard of destroyed houses, the residents modified their units according to their needs, expanding or arranging the units in small groups of families or neighborhoods.

Figure 4.14. Left: arrangement of temporary units according to the inhabitants' needs; Right: expansion of temporary units using local materials   Source: Mahmood Fayazi

Some people expanded their units by using local materials (date palm leaves) and some of them modified and/or arranged their units and even used them after the temporary housing phase as an addition to their permanent houses.

Settling besides the destroyed houses played critical roles was the reason that native residents were involved in planning, designing, managing, controlling and building their permanent houses. They were responsible for choosing the plan and structure among solutions provided by private companies, managing the allocated financial aids and loans, buying the materials, contracting companies and controlling the construction process. This involvement allowed them to learn about construction and disaster mitigation and thus to promote their capacities.

Table 4.8 compares the community competence capacities of temporary housing methods.

Adaptive capacity	Variables of temporary houses	Criteria of analysis of the variables		Cases			
				A	B	C	D
Community action	Refuse to occupy the units				X		
	Acceptance and occupation of the units	Acceptance		X			X
		Acceptance and modifying units				X	
Critical reflection & problem solving skill	Expressing preferences	Formal	Administrative correspondence		X	X	
			By their parliamentary representative		X	X	
		Informal (Strike)			X	X	
Flexibility & creativity	Creative local solution	Local sheltering skills				X	X
		Modifying provided units			X	X	
		Changing the temporary housing strategy			X	X	
	Re-using of temporary houses	As permanent house					X
		Main life space			X		X
		Secondary life space			X	X	
		Demolishing and recycling				X	
		Demolishing and wasting materials		X			
Collective efficacy empowerment	Involvement In reconstruction of permanent houses	Planning			X	X	
		Managing			X	X	
		Designing			X		
		Implementing activities			X	X	
		Financial planning			X		
	Collective knowledge and information	Mitigation knowledge			X	X	
		Disaster management knowledge			X	X	

Table 4.5. Comparison of community competence capacities of temporary housing methods
Source: Fayazi and Lizaralde, 2013

4.8.5. Temporary housing and the natural environment:

The resilience of a natural environment is influenced by factors such as biodiversity, redundancies, response diversity and spatiality. Indicators such as environmental risk mitigation, reduction of environmental impacts, optimization of resources, and conservation of natural resources and ecosystems represent the relation between natural, built and human environments (Cutter et al. 2008).

In strategy A, the government built two crowded camps (one in Amir-Kabir with 750 residents, and one in Golestan with 248 residents) that negatively impacted vital water sources in Bam (Fayazi, 2012). Sewages polluted the soil and water resources (Kouadio et al. 2012). Also, the disposal of non-recyclable materials of the dismantled prefab units also polluted pieces of land in the outskirts of the city. In strategy B, particularly due to the extraction of sand and gravel from the edge of the Poshtrood River in the north of Bam and the production of clay bricks, masonry buildings had irrecoverable impact on the natural environment (Fayazi and Lizaralde, 2013).

4.8.6. Conclusion:

Decision makers and architects are responsible for examining the long-term consequences of temporary housing strategies. The inequity and diversity of houses led to increased social and economic differences among beneficiaries and generally decreased the capacity of economic development in the city. The strategy of temporary housing that opted for constructing units in the yard of destroyed houses, particularly units conducted by masonry materials, had a positive relationship with community resilience.

On the other hand, the strategies that relied on construction of camps in the outskirts of the city brought negative consequences to the development of social capacities. If resilience is to be achieved in post-disaster action, scholars and advocates still need to refine frameworks and units of assessment of community resilience and to adapt them to the particular context of temporary housing.

4.9. The role of low-cost housing in the path from vulnerability to resilience:

Low-cost housing not only reflects, but also greatly influences the vulnerability of a community. However, there is still a question in post-disaster reconstructions on how different housing strategies enhance community resilience.

Generally, there are two vulnerability theories in disaster management literature: The first one demonstrates that disasters are not 'natural' but created by societies and societies accumulate unsafe conditions (such as poverty, unsafe use of land, unsafe buildings and lack of insurance) that become disastrous when triggered by a natural hazard (Adger, 2006; Cutter et al., 2003). The second theory argues that some communities do not necessarily accumulate unsafe conditions but also develop appropriate mechanisms of adaptation to the environment (Adger, 2000; Coles et al., 2004). Cutter et al. believes that these two theories are in fact complementary (Cutter et al., 2008).

Resilience includes pre- and post-event measures (Bruneau et al., 2003). A system adopts adaptive characteristics through sufficient performances during a continuous Process of Enhancing Resilience (PER). This process might start from a vulnerability state with limited or insufficient access to material or non-material assets (Lizarralde et al., 2009).

The system is often composed by several subsystems including; economy, social, natural environment, built environment, governance, and information and communication in individual, family, community, city and national scales. These dimensions are evolving and the subsystems interact with each other (Fayazi and Lizarralde, 2013).

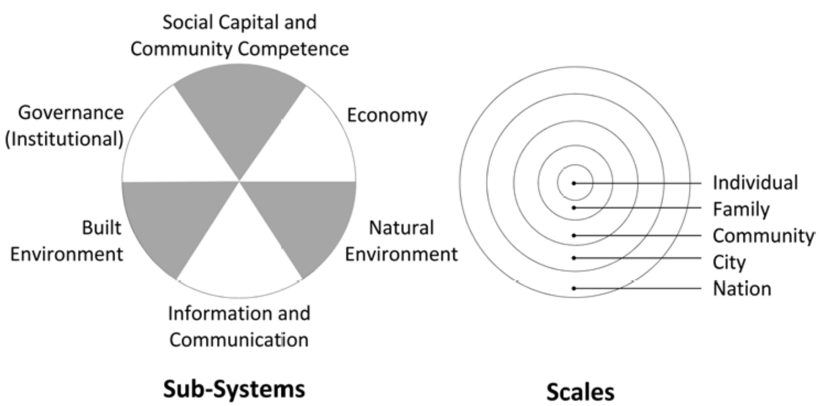

Figure 4.15. The variables of the system: scales and sub-systems
Source: Fayazi and Lizaralde, 2013

Fayazi and Lizaralde illustrated a model for PER which shows that the system ultimately becomes resilient when it adopts the following characteristics in the last step of the PER model: redundancy, robustness, and resourcefulness.

Even though both processes are closely related, it should not be assumed that vulnerability reduction is equivalent to resilience development. In fact, resilience is enhanced by actions that help develop adaptive capacities of the system to withstand, recover from, and reorganize in response to crises, and maintain its function in the event of a disturbance (Howell, 2012). On the other hand, vulnerability reduction occurs when there is increased access to resources that create safe conditions for the system.

Fayazi and Lizaralde examined the effects of different housing strategies used in the reconstruction after the earthquake of 2003 in Bam through interviews and questionnaires given by temporary housing residents between 2008 and 2012.

4.10. Key lessons in temporary shelter action in Bam:

1) Temporary shelters delayed the reconstruction of the permanent housing. The main reason was due to people getting used to the temporary shelters, considering them as their permanent dwellings.

2) Taking shelter in emergency tent camps and in temporary shelter complexes was not welcomed by a majority of the surviving community. They preferred to stay in temporary tents in their own land despite the fact that their homes were totally destroyed.

3) Inadequate, poorly designed yards adjacent to shelters with limited space for parking, limited space for a children's play areas, limited shared space

4) Undesirable impacts on the city as a result of temporary shelters evolving over time into permanent elements due to the lack of sufficient incentives to locate and collect them.

5) The danger of accepting the conditions of the temporary settlements in permanent dwellings, resulting in a decrease in standards thus adversely affecting the quality of life;

6) Delays created in the reconstruction process due to improper initial site selection;

7) Not using masonry in reconstructed buildings for emotional reasons in an attempt to reduce the stress;

8) Converting part of the temporary camps to become an attractive site for Afghan immigrants and providing a settling for those people who did not have dwellings before the disaster as well as establishing new neighborhoods. Therefore making many security problems;

9) A decrease in the observation of building codes, regulations and standards after the earthquake. Buildings built earlier were constructed in a more appropriate manner according to the engineering regulations. This was seen in Lorestan 2006 earthquake as well (Izadkhah and Hosseini 2006).

Chapter 5: Methodology

Follow the sun.
Observe the wind.
Watch the flow of water.
Use simple materials.
Touch the earth lightly.
-- Glenn Murcutt, Hon. FAIA Pritzker laureate, AIA Gold Medal recipient

In the age of 'copy and paste' solutions, what should the post-disaster constructions and temporary housing be? Should we demolish the history of traditional architecture and keep repeating the same pre-fabricated steel structure temporary building typology all around the world in order to construct seismic resistant buildings? And how can a designer change the role of the intermediate housing as an economic burden to become an opportunity to make the disaster-stricken community more resilient and also work as the gate of future sustainable strategies for post-disaster developments?

The approach to discover the ways in which architects can transcend notions of design from pre-fabricated dwellings is three-fold, consisting of **design research** into the neighborhoods and dwellings; environmental, material, energy and economic **analysis;** and design **speculations** on dwelling**s** and temporary settlements materials and construction elements and techniques.

Research covers topics such as the development of the city of Bam and its urban structure and the informal settlements in Southern areas of Kerman province. The thesis examines the efforts others have made to develop strategies to improve the poor cities and environments in which new technologies are suggested by architects where post-disaster settlements reside in developing countries. This phase of research investigates attempts we have made as architects or planners in order to deal with the overarching issues of housing.

The next portion of the thesis, which can be referred to as environmental, material, energy and economic analysis, dissects the physical manifestation of the temporary housing based on documentations and available studies in order to reflect the critical, yet fundamental aspects of temporary housing.

Finally, the thesis advances explorations of design ideas in a process of speculation. It attempts to confront the issues and absorb the ideas attained from both research and documentation ultimately proposing alternative means of creation and utilization of the temporary settlements. It proposes alternative design solutions manifested in the form of architectural elements such as the wall, the structure and the roof. It also investigates for some innovative options in the city for further future researches and explorations.

There are two primary field of criticism based on the method of assessment of the results. First, we must question how the research has been framed and presented. At the opposite end, we must critique the results themselves. The design phase is measured upon the success of integrating the issues. Therefore, the results must be measured based on these questions:

Have I improved conditions of the living environment within realistic frameworks? How successfully have I provided the means to create shelter for individuals with a sense of privacy, safety and pride and also fostered the values of the inhabitants? Have I improved conditions of the living environment within realistic means? Have I provided suggestions that not only can address the temporary settlement issues in the past but also provided flexibility for future needs and desires?

I. Design research

Frame One: Kerman Province

Kerman is the second largest province of Iran with an area of 180,726 km² that encompasses nearly 11 percent of the land area of Iran. The population of the province is about 3 million (Iran National Census 2006). In 1996, 52.9% of Kerman's population lived in urban areas, 46% in the rural vicinities, with the remaining 1.1% accounted as non-residents. The climate in the province varies across regions.

Figure 5.1. Location of Kerman province within Iran

The north, northwest, and central areas experience a dry and moderate climate, whereas in the south and southeast, the weather is warm and relatively humid. Mountain heights of the central and southern areas have cold climate. Near Kerman, the largest city of the province, the climate is semi-moderate and dry, with a maximum and minimum temperature of 39.6°C, and -7°C respectively. Mean annual precipitation of the area varies between 151 mm in Kerman plain.

Scale	Date products	Area	Date palm trees	DPL	DPF
World	5.4 million tones (FAO)	-	100 million (Al-Sulaiman, 2003)	169,500 tons (Al-Sulaiman, 2003)	1,130,000 tons (Al-Sulaiman,2003)
Middle East and North Africa	2,420.5 tones	-	62 million	105,090 tons	700,600 tons (Al-Sulaiman, 2003)
Iran	1,116,610 tons	-	16.8% of world 16.8 million	28,476 tones	189,840 tones (from multiple sources)
Kerman	180,000 tons	45,000 acre	15- 21.1% of Iran (www.aarinena.org)	4,271.4 tones	28,476 tones
Bam	100,000 tons	25,000 acre	8.3% of Iran 1,400,000	2,363.5 tones	15,756.7 tones

Table 5.1 Comparison of date production, date palm leaves and date palm fronds in 5 different scales

Kerman is a special economic zone in Iran and is considered as a passage way for transfer of imported commercial goods from the south and specifically Arg-e-Jadid which is designated as Iran's auto industry. Kerman has the largest pistachio production in the world (Razavi, 2010). Some of the most important agricultural products of Kerman are date, citrus, walnut, cotton and corn.

Kerman's geology and climate are relevant to palm tree cultivation. Kerman has the first rank in high quality date production in Iran (15-21.1% of Iran's total product) with the annual amount of 226,000 tons in 388.84 km² (Safirjonoob.ir, 2014). People in eastern and southern areas of Kerman mostly make living based on the production of date. Table 5.1 compares the annual date production in four scales.

Bam County has 70,000 acres of Mazafati date palm tree from which 12,400 acres are young infertile trees (Hannandate Corporation, www.hannandate.com). This much of the Mazafati date production makes about 1,050,000,000,000 IRR (about 350 million USD).

5.1. Indigenous shelters in southern areas of Kerman (Kapar):

It is critical to provide paradigms of indigenous architecture in order to understand schemes so deeply connected to the land, climate and community from a historical, cultural and ethnographic perspective.

The landscape of Kerman in central parts of Iran is divided naturally into two regions: the volcanic mountain range and the southeastern salt desert area of Dasht-e-Lut and most of the province is largely steppe or sandy desert. Drifting sand dunes, wind, high temperature and exposure to a blistering sun are not conductive to the growth of any kind of vegetation in Dasht-e-Lut.

Figure 5.2. Lut desert Kerman province, Iran

Source: Hadi Karimi

Right on the edges of this extreme heat and dryness of Dasht-e-Lut, where the surface of the sand has been measured at temperatures as high as 70.7°C to become the hottest spot on the earth (159°F) (Mildrexler et. al 2011), the vernacular architecture formed by people over thousands of years demonstrates the profound understanding that indigenous people had of the climate. Orientation of the houses, thickness of the walls (which provides thermal mass) and the layout of the buildings that provide shade are a few to name.

Initially, date palm fronds are used in east-south areas of Iran (southern areas of Kerman province and western areas of Zahedan province) as an indigenous technique for summer resort construction beside mud brick houses. Historically, in southern areas of Kerman where during hot seasons of the year the weather is very hot, people temporarily move to other locations in Northern and cooler areas of Kerman. Therefore, Kapars were used in this nomadic living style of central desert of Iran. Today, there are still nomadic communities living in the southern Kerman.

Farmers and gardeners also use Kapars during the summer. They usually constructed three date palm huts (known as Kapar کپر); one to be used as a cool space to seat, one to be used as a canopy for keeping the water container cool and the other one as a kitchen. In some cases they used Kapar as a storage area for watermelon and onion. Households with low income also used Kapar as their permanent house

(Mohammadyan, 2003). Moreover, nowadays some Kapars are used as primary and/or guidance level schools for children in remote rural areas.

There are different variations for the form of Kapar. Farmers and gardeners usually use four uprooted date palm trunks as the main structure of Kapar. They inserted the trunks into the ground and put the date palm leaves on top of them. Date palm fronds and leaves are then connected with woven ropes made of dried date palm leaves.

The entire shelter or houses is constructed from readily and locally available materials: Earth blocks or daubed combination of soil and sand and straw, palm leaves which were cut annually to allow date palm growth and pollination, palm trunks for structural support and trunk fibers woven into rope to connect building components together.

Leaves were formed into mats known as Hassir, which would have been rolled up for transport and used in single or double layer for the wall. These mats also function as winter insulation.

Figure 5.3.Women weaving Hasir from date palm leaves inside a Kapar shelter in Kerman,

Source: Fars News Agency

Furthermore, these houses also served to enhance social cohesion providing a gathering space dedicated for men only or women and children or a kitchen.

The first and foremost function of these houses was to provide shade in the summer for outdoor and recreation spaces near the orchards. The secondary purpose of construction of these types of houses is the informal housing in southern areas of Kerman province in the name of Kapar houses. Based on the size of the family or the number of working labors in the orchards, the size and the shape of Kapars are different.

Figure 5.4. Kapar shelter in Southern Kerman,

Source: Fars News Agency

5.1.1. Architecture of Kapar:

The story of date palm leaf is not a sequence of historical events but a tribute to human inventiveness. There are many examples of indigenous ways in which date palm has been used testifying to the fact that people can construct buildings without architects. Centuries of knowledge embedded in their societies to enable them to find the most adaptive forms and materials with their environment.

Even the most expert climatologist cannot easily improve upon the simple yet brilliant devices that allow the external envelope of the house to breathe and still permit internal air circulation; the different methods of constructing walls from widely positioned palm fronds with gaps in between to allow the breeze to enter.

In similar examples in the Middle East, the practice of leaving a gap between the top of the walls and the roof permits the wind to penetrate in coastal areas. Also the wind towers, which were inspired by Persian wind towers (wind catchers), can simply form a perfect combination of natural inspiration and human imagination.

Figure 5.5. Example of date palm houses (Khaimah and Arish) in the Middle East (UAE)

Source: Piesik, 2012

Curved geometry as expressed in both roof structures and in the plan formed a distinctive architectural element in hot and arid climate of Iran.

Figure 5.6. Curved geometry and structure of Kapar shelter in Kerman,

Source: Fars News Agency

5.1.2. Kapar prototypes: Table 5.2 summarizes different variations of Kapar in southern areas of Kerman.

Plan	Elliptical	Circular
Roof material	- Layers of Hasir	- Date palm leaves and Hasir - Layers of Hasir - Both
Structure and wall system	- Homogeneous lattice from date fronds - Homogeneous lattice from date fronds with structural elements of date fronds - Homogeneous lattice from date fronds covered with secondary lattice	- Homogeneous lattice from date fronds - Homogeneous lattice from date fronds with structural elements of date fronds - Homogeneous lattice from date fronds covered with secondary lattice
Wall interior coverage	- Hasir - Thatch	- Hasir - Thatch
Wall exterior coveage	- Hasir - Thatch	- Hasir - Tahtch - Fried brick - Mud brick - Thatch

Table 5.2. Different variations of Kapar in southern areas of Kerman province

Figure 5.7. and 5.8. Structure of Kapar with elliptical plan shape, walls are covered by a layer of Hasir Source: Majid Jamshidi, Fars News Agency

Figure 5.9. Curved geometry of Kapar with circular plan shape, walls are covered by a layer of Hasir, cement, thatch and fried brick (from top left to bottom right)

Source: Fars News Agency

5.1.3. Architectural and structural elements of Kapar: There are two general forms of Kapar in southern areas of Kerman:

Elliptical (Mahoori) and domical (ball-shape with circular plan). Structural elements including foundation, columns, wall, roof, bracing and beams are designed intelligently made of leaves of date palm tree.

Date palm fronds (Shaak in local language) are used for columns, beams and bracing structure. Vertical rods are called Jook and horizontal ones (beams) are called Gordaar and diagonal ones (bracing) are Aeeneh-band.

Figure 5.10 and 5.11. Vertical columns, horizontal beams and diagonal bracing in the structure of Kapar (left); Door opening in Kapar (right)

Source: Alireza Mohammad Jafari

For outer envelope (the grid) they use small leaves, called Pish (Pish-Khorma), which grow around the trunk area in the ground. Chilak is the name of the rope which is made of small Pish leaves. Fronds are also connected with Pish leaves together.

Figure 5.12. and 5.13. Envelope of Kapar made from Pish leaves (left); Chilak rope made from pish (right)

Source: Alireza Mohammad Jafari

Hasir is the woven mat from small Pish leaves. People use Hasir as ground cloth, roof cover and wall cover. Net, is the woven net made from Chilak ropes. Kharkareh is the belt all around Kapar to sustain the roof coverage of Kapar which is from palm leaves.

Figure 5.14 and 5.15 Kharkareh belt around the roof (left); Roof coverage from palm leaves and Net in Kapar (right)

Source: Alireza Mohammad Jafari

Door and windows are also made of Shaaks fastened together with ropes. Indoor cooking is very common in Kapars and because of the natural ventilation which is possible through the walls and roof, the smoke does not lock inside the shelter. The other function of these shelters is providing classroom spaces for primary and middle schools in remote areas of these regions.

 

Figure 5.16. and 5.17. Roof coverage from Pish converged in to the center of roof (left); Door coverage from Pish leaves in Kapar (right)

Source: Alireza Mohammad Jafari

5.1.4. Social and cultural aspects of Kapar:

While Kapar has been an inseparable part of the culture in Southeast Iran, nowadays, it brings a negative cultural perception in mind since it's mostly being used by very poor families in southern parts of Kerman province as permanent house.

The head of Imam Khomeini Relief Foundation claimed in 2014 that Kapar in an undefined concept which has cultural and identical roots for people in southern parts of Kerman. Anvari indicated that the structure and the design of Kapar must be refined and preserved to be presented in a new form. "Prefabricated units are not suitable for this region; that is why we had to use local materials to be able to finish the temporary shelters project… These shelters should not be substituted by concrete and stone buildings." (The necessity of Kapar-neshini culture in southern Kerman, 2014)

According to Mehr News Agency, after the earthquake of May 11, 2013 in Bashagard, Hormozgan (the neighbor province of Kerman in south-east of Iran), people built their own Kapars while waiting for their permanent earthquake-resistant buildings to be constructed. More than 3000 dwellings are planned to be built in rural areas (Nooreddini, 2014).

Figure 5.18. Kapar as the self-built post-earthquake temporary houses in Bashagard, Hormozgan

Source: Mehr News Agency

5.2. Earthquake in Kerman:

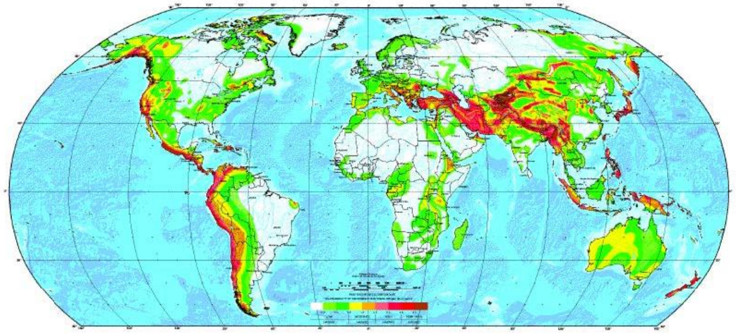

Figure 5.19. The global seismic hazard map
Source: Iranian Studies Group at MIT

Iran suffers from frequent earthquakes, with small tremors happening almost daily (See Fig.5.2) (Iran Earthquake Kills Thousands, 2003). Figure 5.1 shows the historical seismic hazards in Iran. Kerman is located in a high seismic zone in Iran.

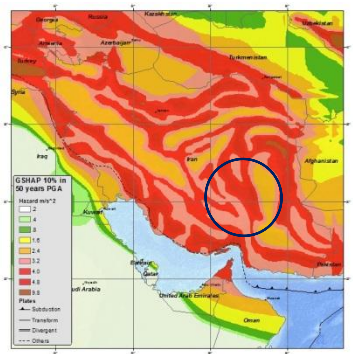

Figure 5.20. Seismic Hazards of Iran
Source: U.S. Geological Survey, National Earthquake Information Center

Figure 5.21. Location of Bam county in Kerman province

Frame two: Bam County

The capital of Bam County is the city of Bam and it has two cities: Bam and Baravat. At the 2006 census, the county's population was 277,835.

5.3.1. History of the physical development of the city of Bam and urban morphology: In historic documents, the Citadel of Bam was constructed between 25 BC to AD 226 during the Arsacid dynasty (Irani and Shirgir, 2007). The history of Bam was originated from the citadel on the north eastern part of the current city of Bam. Before the Islamic era agriculture was the main occupation of the inhabitants. During the Safavid dynasty, from 1501 to 1722, the gardens were developed outside of the citadel towards the southern parts and formed the new city. Thus, the gardens were the main factor which shaped the physical form of the city. During the Pahlavi dynasty in 1956 the city had been developed outside of the Citadel and two perpendicular main streets were built that shaped the structure of the city in the future.

Figure 5.22. In 1956 two perpendicular main streets were built, which shaped the structure of the city Aerial image of the city of Bam in 1956

Source: Irani and Shirgir, 2007

Generally, the first modern road system of the city dates back to 1903 during Reza Shah's Kingdom, which was a north-south oriented street (Irani and Shirgir, 2007). Until 1961 garden pieces on the aerial maps are regular square or rectangular shapes and the connection between natural and built environment was stable.

In 1986, in addition to the new east-west oriented streets, some squares and a ring-way road were built near the city center. Most of the urban developments were near these squares and in north-west and north-east direction. These new streets had a significant influence on the sizes of the gardens as they were divided into smaller pieces of lands and the distances between the pieces were increased. Some gardens in the city center were also completely removed in the new urban structure.

Figure 5.23. In 1986 addition of squares and ring-roads to the city was the reason that some gardens near the central and southern parts of the city were destroyed and the urban and garden grid was broken.

Source: Irani and Shirgir, 2007

As shown in figure 5.23 the fault line is located on the eastern edge of the city where most of Qanats are also located. The main slope of the city has west to east and north to south direction (Irani and Shirgir 2007).

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Figure 5.24. Aerial image of the city of Bam in 1977, The main two streets had influence on the gardens system but the connection between natural and built environment is standing

Source: Irani and Shirgir, 2007

Between 1998 and 2003, the city was developed even more towards southern lands with new streets built in this period. The size and the number of the gardens were reduced by the new road systems and building constructions. The proportion of the natural to built environment was reduced after the construction of new streets and roads. Land use changes were without considering the land capacities and the new road systems were uncoordinated with the garden systems (Irani and Shirgir, 2007).

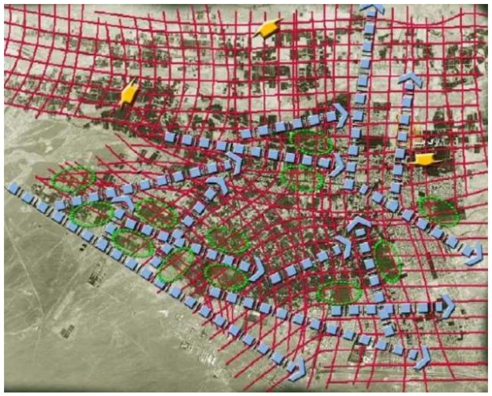


Figure 5.25. Aerial image of the city of Bam in 1998, More streets are built in this period of time and garden lands are divided into smaller pieces because of urban developments

Source: Irani and Shirgir 2007

After the earthquake of 2003 more streets were built and therefore more garden lands and farms were destructed. Urban edges are destroyed and the street network is more chaotic in the central parts of the city. The balance between the natural and built environment is more damaged.

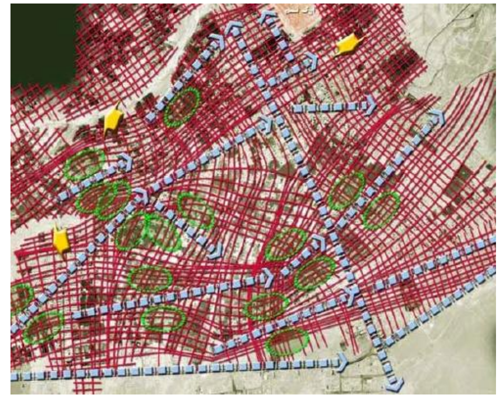


Figure 5.26. Aerial image of the city of Bam in 2003, After the earthquake more streets were built in this period of time and therefore more garden lands and farms were destructed. Urban edges are destroyed and the street network is more chaotic in the central parts of the city.

Source: Irani and Shirgir 2007

Figure 5.27. Summary of the historic developments and urban structure changes for the city of Bam. 1-The citadel 2- Developments towards north west 3- Developments towards south west 4- Developments towards south east

5.3.2. Surface Geology of Bam: The city of Bam covers 5,400 hectares (13,343 Acres) and its altitude is about 1,050 m (3,444.9 ft). In the north part of Bam, Posht-e-Rood river runs from west to east with a seasonal water flow. There was another river about 60 years ago which flew through the middle of the city of Bam from west to east and roughly made a boundary between the old city near Arg-e-Bam and the newly developed area in the southern part of the city

Old riverbeds form the surface soil with altering red to gray silts and silty sands and sandy gravels. The silty sand is hard and brittle when it is dry and has been used for making bricks (Tetsuo et al. 2007).

5.3.3. Ecological classifications of the city of Bam: The following natural and built elements form the physical and cultural shape of the city of Bam:

1. Garden areas
2. Farm lands
3. Garden-farm areas

4. Historic landscape of Bam citadel
5. Fault area and surroundings
6. Qanat systems

According to Irani and Shirdel, after the earthquake of 2003, Qanat systems were significantly damages. But the ministry of agriculture in Kerman and nearby provinces revitalized the water system by dredging all 15 wells which were the main sources for gardens irrigation system.

Figure 5.28 illustrates the characterized zoning map of the city for future developments. Considering a preserved green area near the fault line and distinguishing between three different zones of farms, gardens and garden-houses in the city is an important issue for planning the future developments.

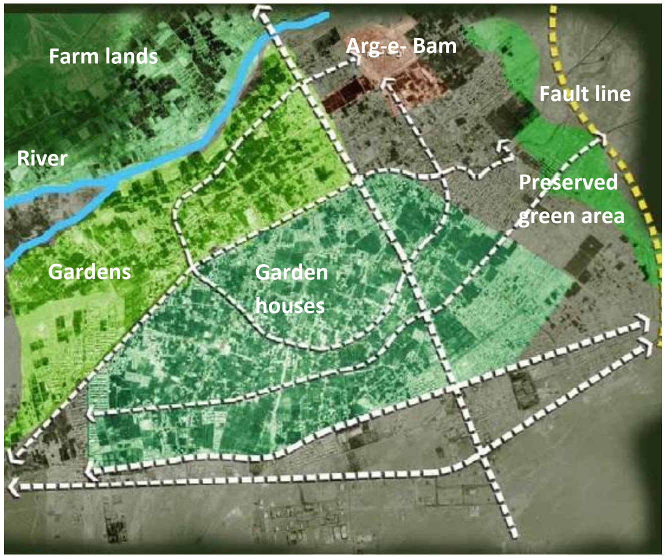


Figure 5.28. Aerial map of the city of Bam in 2003, after the earthquake more streets were built and therefore more gardens and farms were destroyed. Green space edges are damaged and reduced in size and the balance between natural and built environment no longer exists

Source: Irani and Shirgir 2007

5.3.4. Rivers: One of the surface water resources in Bam are the rivers that are originated from western and south-western heights and streamed down to Baravat city on south-east. Water from the Jebal-e Barez Mountains supplies the seasonal Posht-e Rud River that skirts Bam City between Arg-e Bam and Qal'eh Doktar. The Chelekhoneh River and its tributaries gather water from the central parts of the Jebal-e Barez Mountain range. It now runs northeast, although it formerly flowed through the Bam City until it was diverted by a dam into a new course that met with the Posht-e Rud northwest of Bam City. Water from the Kafut Mountains also supplies the catchment area (Bam and its cultural landscape, 2004).

Figure 5.29. Hydrology of the city of Bam

Source: Irani and Shirgir 2007

5.3.5. Geology of Bam and soil quality: The rapid growth of the world's population over the past few decades has led to a concentration of people, buildings, and infrastructure in urban areas. The tendency of urban areas to develop in sedimentary valleys has increased their vulnerability to earthquakes due to the presence of soft soil and sediment. Therefore, local soil and sediment conditions can have a significant influence on earthquake induced round motion and damage pattern.

In order to classify the suitability of the soil and subsurface sediment units for urban planning and compare the mechanical behavior of soil with the non-uniform damage observed in the 2003 earthquake, Khalili et al. performed some geotechnical and geophysical analyses of soil and sediment samples collected from different locations in the city of Bam. (Rezaei et al. 2008)

According to Rezaei et al. the grain size in the shallow depth (<10 m) decreases across the city from south to north and below ~10 m increases with depth across the entire city. There are eight sediment types: clay, cohesive sandy mud, cohesive muddy sand, poorly sorted sand, well-rounded gravel, poorly sorted gravel, muddy or sandy gravel, and clayey sand.

Studies show that at shallow depths (<10 m) the soil structure is fine-grained soils and sediments (clay, clayey sand, cohesive sandy mud, cohesive muddy sand) dominate across the northern quarter of the city. In the central portion of the city, fine-grained sediments interfinger with the coarse-grained sediments (poorly sorted sand, well-rounded gravel, poorly sorted gravel, and muddy or sandy gravel) which dominate the southern quarter of the city. Below 10 to 15m depth, coarse-grained sediments are dominant across the entire city except for the far northeastern edge, near Arg-e-Bam, where volcanic bedrock (ryolite and dacite lava flows) directly underlie the shallow fine-grained sediments and soils. (Rezaei et al. 2008)

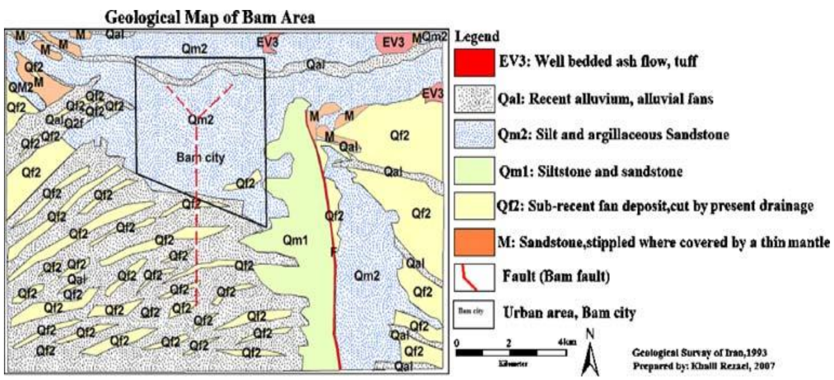


Figure 5.30. Geological map of the Bam area
Source: Geological Surveys Organization of Iran

5.3.6. Soil and sediment composition and the distribution of damage in Bam:

Rezaei et al. show that the portions of the city that were built on coarse and non-cohesive alluvial plain sediments sustained light damage. Their studies showed coarser material in the shallow subsurface beneath the south and west sections of the city, which sustained relatively low damage. The north and northeastern parts of city, which sustained higher damage, are built on fine sediments. (Rezaei et al. 2008)

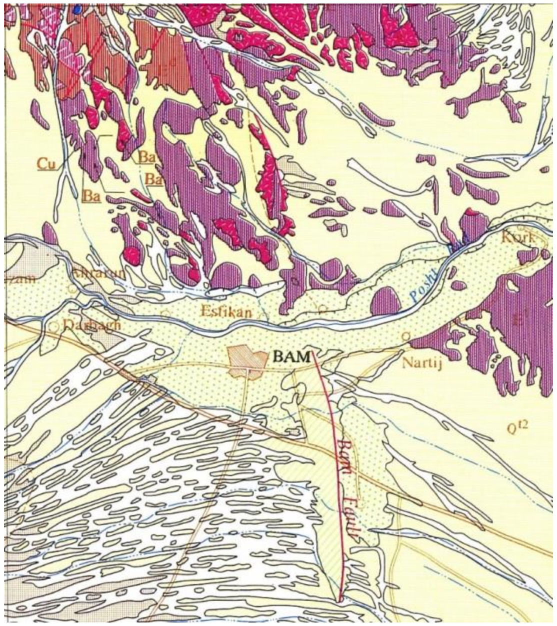


Figure 5.31. Geological quadrangle map of Bam
Source: Geological Surveys Organization of Iran

Ash-flow tuffs, well bedded ;

Subordinate trachyandesitic and basaltic lavas

Younger gravel fans

Silt of argil

Sand dunes and sand sheet

In Bam there is a south to northeast and a west to east increase in the thickness of the near-surface loose and unstable sediment layers across Bam. In the southeast section of the city, the near-surface layer is composed of loose sand with very low shear strength. Further north, the near-surface layer thickens as it transitions to clayey soils (center and northeast of city) with very low permeability, low seismic wave velocity, and a high plasticity and compression index. These loose sandy and clayey soil types are associated with the greatest number of damaged modern structures. The areas underlain by bedrock (north of city) or near-surface coarse-grained soil and sediments (south and southwest of city), exhibiting high permeability, low (or zero) compressibility, and high seismic velocity are associated with lower structural damage. (Rezaei et al. 2008)

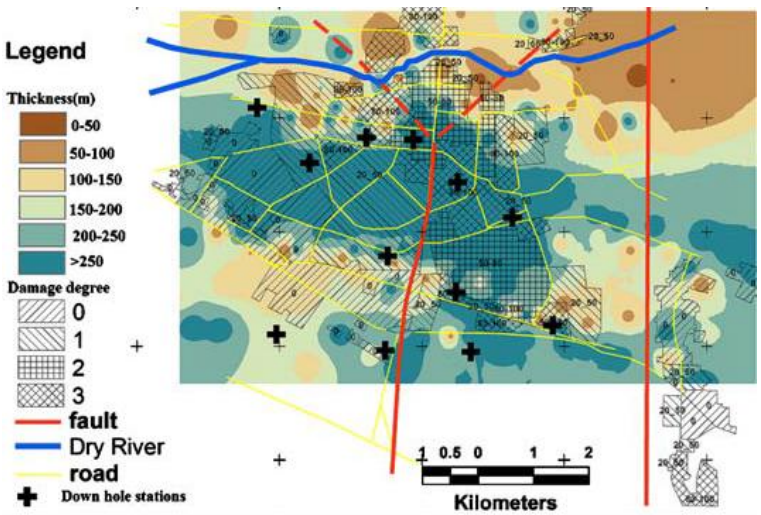


Figure 5.32. The map of thickness of soil and sediments in the city of Bam
Source: Rezaei et al. 2008

There is also a direct relationship between the depth of bedrock and the observed degree of damage. In the southeastern section of the city, where depth to bedrock is greatest, damage is highest. In the northern section of the city, where depth to bedrock is low and where bedrock is exposed at the surface, damage is lower. The sections of the city that were constructed in areas with stable near-surface material and a greater depth to bedrock suffered the least damage, and the sections of the city built on unstable material and a low depth to bedrock suffered moderate to heavy damage. These observations suggest that in Bam, the nature of the near-surface material was more important than depth to bedrock as a controlling factor for the degree of damage sustained in a given area. (Rezaei et al. 2008)

5.3.7. Destruction and distribution of damage in Bam:

The fault which ruptured during the 2003 earthquake is a subsidiary structure to the Bam fault (Talebian et al. 2004) Rezaei et al. showed that there is a relationship between sediment properties and the distribution of structural damage within Bam City. In their studies the structural damage in Bam City was divided into four categories within the range of 0% to 100% destruction. A general west to east increase in damage across the city was identified. (Rezaei et al. 2008)

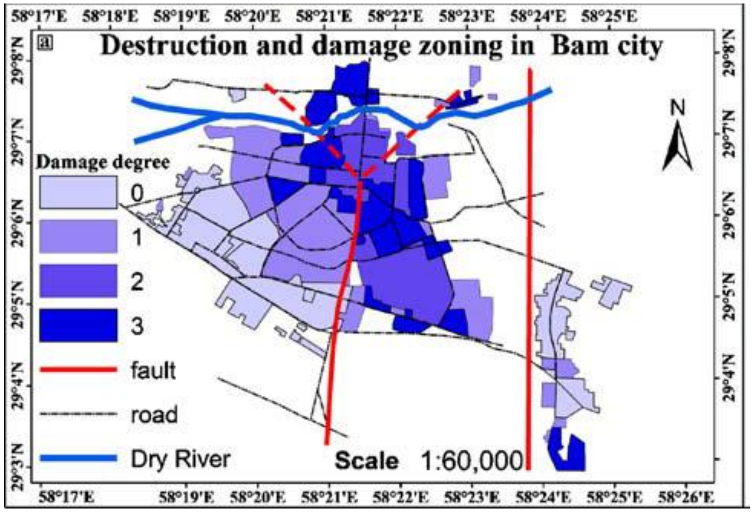


Figure 5.33. Destruction damage zoning in Bam after the earthquake of 2003

Source: Rezaei et al. 2008

The building style (traditional mud brick construction) was more or less uniformly damaged throughout the city. Most of the buildings at the epicenter were old mud brick structures and the majority of them was heavily damaged and, in many cases, partially collapsed.

Few buildings were steel-framed or constructed of reinforced concrete (20 steel-framed, 11 reinforced concrete), most were constructed of adobe (sun-dried brick and clay; 53.2%) or brick and steel (40.6%), the remainder of brick only (3.5%) or brick and wood (1.9%). As expected, the newer buildings of reinforced concrete built according to modern seismic regulations suffered much less damage except where construction regulations and guidelines were not implemented. Foundation depth also appears to be important because buildings in the western portion of the city with deep foundations tended to show less damage; however, in the eastern half of the city, deep foundations did not save many newer buildings from damage, suggesting that the soil mechanical properties of soil and subsurface sediments were also important controls on the damage distribution.

5.4. Qanat: A qanāt is one of a series of well-like vertical shafts, connected by gently sloping tunnels. The existence of life in the oasis in the central arid regions of Iran was based on the underground irrigation canals, the qanats, of which Bam has preserved some of the earliest evidence in Iran and which continue to function till the present time. ("Bam and Its Cultural Landscape, 2004)

Qanats create a reliable supply of water for human settlements and irrigation in hot, arid and semi-arid climates. The qanat technology is believed to have been developed by the Persian people sometime in the early 1st millennium BC and spread from there slowly west- and eastward. (Wilson, 2008)

The value of a qanat is directly related to the quality, volume and regularity of the water flow. Much of the population of Iran and other arid countries in Asia and North Africa historically depended upon the water from qanats; the areas of population corresponded closely to the areas where qanats are possible. Although a qanat was expensive to construct, its long-term value to the community, and thereby to the group that invested in building and maintaining it, was substantial. (Kheirabadi, 1991)

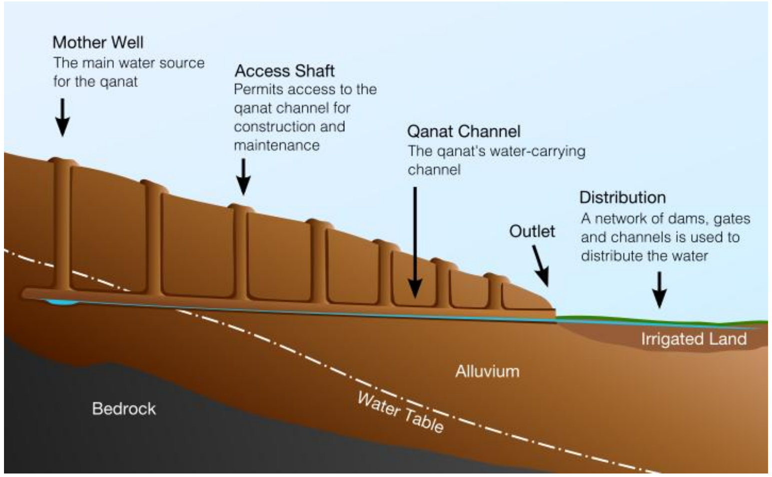


Figure 5.34. Qanats, series of well-like vertical shafts used for irrigation system Source: Wikipedia

Qanats used in conjunction with a wind tower can provide cooling as well as a water supply. A wind tower is a chimney-like structure positioned above the house; of its four openings, the one opposite the wind direction is opened to move air out of the house. Incoming air is pulled from a qanat below the house. The air flow across the vertical shaft opening creates a lower pressure and draws cool air up from the qanat tunnel, mixing with it. The air from the qanat is drawn into the tunnel at some distance away and is cooled both by contact with the cool tunnel walls and water and by the transfer of latent heat of evaporation as water evaporates into the air stream. In dry desert climates this can result in a greater than 15°C reduction in the air temperature coming from the qanat; the mixed air still feels dry, so the basement is cool and only comfortably moist. Wind tower and qanat cooling have been used in desert climates for over 1000 years. (Bahadori, 1978)

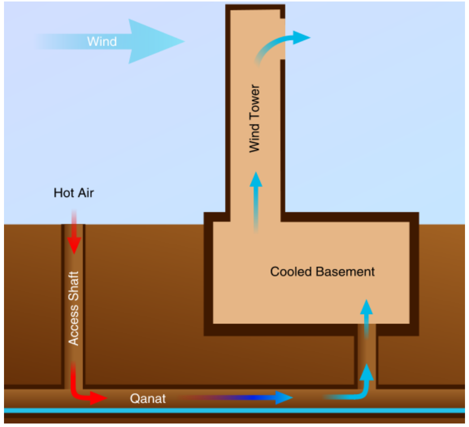


Figure 5.35. Qanats and windtower function in desert climates.

Source: wikipedia

One of the main sources of drinking and agricultural water at Bam area is underground irrigation systems called Qanats. Before the earthquake of 2003 50% of the required water of the area has been supplied with 126 active Qanats. Most of these Qanats can be observed in the aerial photos. Bam Earthquake has considerable effects on a lot of Qanats that excavated in the Bam area and its vicinity. Based on the preliminary evaluations, about 40 percents of these Qanats have been collapsed or experienced severe damages due to the earthquake. In some cases the collapse of the Qanats stopped the water flow completely.

In addition, there are several trends of old Qanats related to the past decades or centuries that their locations are unknown now. Of course most of these old Qanats are now dry and partially collapsed. In some cases the collapse of some of these Qanats caused severe damages to the building and lifelines.

5.5. Baravat: Baravat is a city in the Central District of Bam County, Kerman Province. At the 2006 census, its population was 15,388, with 3,950 families. The Bam fault with a near north-south direction passes from the vicinity of the city of Bam (less that 1km distance to the east of Bam), and between the cities of Bam and Baravat.

Figure 5.36. Bam-Baravat fault line and the location of Baravat on the south east of the city of Bam

Frame three: Municipal districts and areas

The 'Master Plan' of the city had been prepared almost completely before the earthquake by Armanshahr Consulting firm. In this map the city of Bam is divided into three municipal districts. The first district is divided into 9 areas on the eastern side of the city. The second district is consisting of 4 areas on the north-west of city and the third district is the south-west of city with 5 areas.

Figure 5.37. Master plan of the city of Bam. The city is divided into three municipal districts and 18 areas. Red circle shows the center of the city Source: Armanshahr Consulting Co. 2005

Figure 5.37. Master plan of the city of Bam. The city is divided into three municipal districts and 18 areas. Red circle shows the center of the city Source: Armanshahr Consulting Co. 2005

To study the urban characteristics of the city in a deeper level, I chose an area near the city center. In most of the Persian cities, the center of the city is where most of the economic (like Bazaar), religious and cultural centers and activities take place and near the main plaza of the city water storage and governmental buildings are also located. The center of the city of Bam is located where the three districts of the city come together. Within the main body of the city, green spaces are mostly date palm orchards while citrus trees and farmlands are mainly located on the north-west of Bam. Figure 5.38 shows the location of the selected area for the next frame. This area is placed near the center of the city and has relatively the average portion of gardens.

Figure 5.38. The location of the selected area for frame four

As shown in figure 5.38 the distribution of natural environment does not have a homogeneous pattern in the whole city of Bam. Baravat has a larger portion of green spaces (mainly gardens) in comparison to Bam. However to study the urban characteristics of the city, we can focus on one of the 18 areas of the city which has a medium proportion of natural to build environment pattern.

Figure 5.39 focuses on the specific area of the city and categorizes different percentages of damage in buildings by comparing 4 aerial photos of it before the earthquake (2003), one year after the earthquake (2004), seven years after the earthquake (2010) and ten years after the earthquake (2014). In addition to the buildings, it illustrates the green spaces (date palm trees) before and after the post-earthquake construction. As shown in this specific area, almost 30% of the green spaces were destroyed because of the new constructions. These areas are mainly dedicated to new buildings or parking lots.

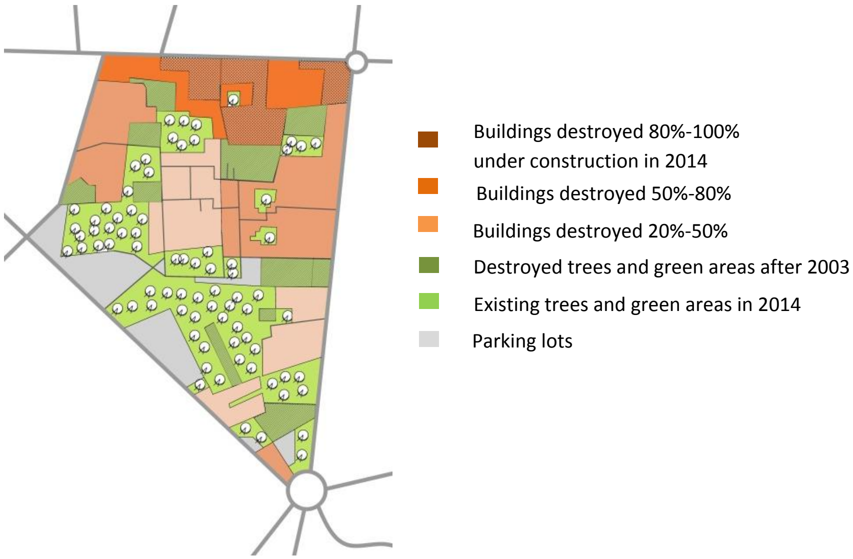


Figure 5.39 Exploration in a specific area of the city as an example of the urban spaces to show different levels of built and natural damage caused by the earthquake and post-earthquake reconstructions respectively.

Frame four: Urban blocks, streets, pathways

In this frame, a specific frame with residential buildings is selected to be studied. Aerial photos from 2003 to 2014 have been compared to understand the difference between pre-earthquake, post-earthquake residential buildings, streets and pathways.

Figure 5.40. The location of the selected area for frame four

The sketches (figures 5.41 and 5.42) show a summary of the studies of a residential block. The comparison of pre-earthquake and post-earthquake streets shows that the new urban planning for the city has modified the irregularities in street patterns and block sizes. Streets have been changed into the similar 15m wide streets in most of the residential blocks of the city. As shown in figure 5.41, while some residential lands had inconsistent forms before the earthquake, the overall layout of buildings was more consistent mainly in 25m by 15m lands shaping the 80m by 50m blocks. Yards were located in the southern sides of the buildings (to use maximum daylight in southern faced private spaces of the houses) consisting 40% of the total area of the land as it was required in building design code in Iran.

A few of older buildings had central courtyards which are mostly placed in the historic and central areas of the city. Blocks are divided into northern-faced and southern-faced single family houses. The majority of buildings were one story and a few of them were two story houses. The width of the residential lands was mostly 15m and a few of the houses had either wider or narrower sizes between 10m to 20m.

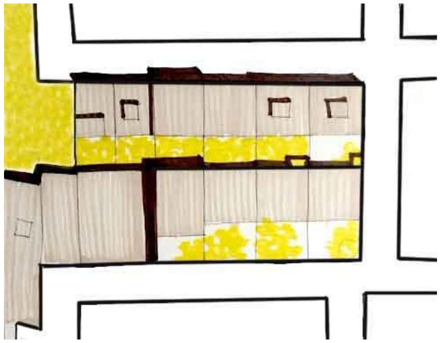


Figure 5.41.1 Illustration of a residential block in the city for pre-earthquake analysis in 2003

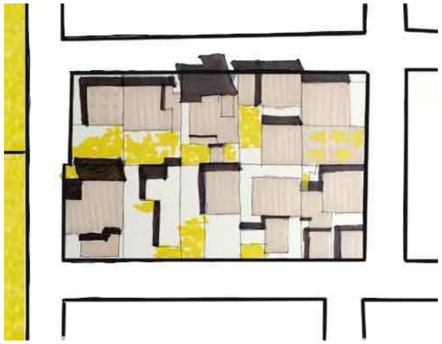


Figure 5.41.2. Illustration of a residential block in the city for post-earthquake analysis in 2014

In the new city plan, most of the residential lands are 16m by 25m with one exception in this block which is 11m wide. The heights of the buildings vary between one to four stories. Building shapes do not follow a specific rule and they are divided into smaller and irregular forms. The new yards are located on eastern, western, southern and even northern sides of the houses with different sizes mostly smaller than the past. The number of trees in most of the houses has been reduced considerably.

Figure 5.42. Views from streets in Bam, 10 years after the earthquake of 2003. The primary and most of the secondary streets are almost cleared from debris and unfinished building construction can be found almost on every street

Source: Mohsen Rajabpour, Fars News

Figure 5.43. Views from streets in Bam, 6 years after the earthquake of 2003. Streets are not completely cleared from debris and unfinished building constructions can be found almost on every street Source: Alireza Saeedi

Figure 5.44. Views of streets in Bam, 6 years after the earthquake of 2003. Temporary buildings have become the inevitable pars of the urban elements (left); new constructions besides the date palm orchards Source: ISNA

Frame five: Dwellings and building configurations

Given the very irregular form of new buildings, defined public and private spaces similar to the traditional definitions in Iranian architecture could not be found in many modern buildings. However, certain patterns can be found in almost all of the urban blocks in Bam. For houses located on the southern sides of the streets, because the parking is located under the building, the yard has more space for date palm trees (Figure 5.44. number 1). If the building has another entrance on the eastern or southern street, then it is possible that the parking is located in the yard (Figure 5.44. number 2). For all dwellings located on the northern side of the street, parking space is part of the yard (Figure 5.44. number 3).

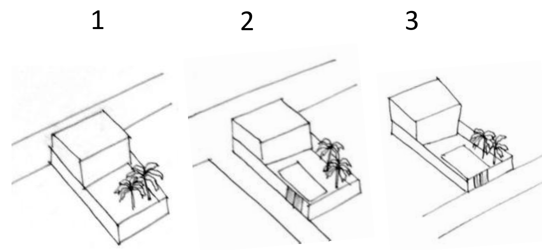


Figure 5.45.1. A dominant residential block pattern in the city of Bam after the earthquake

In the new constructions, there are two more possibilities that we need to consider in building configurations. One is that instead of occupying one side of the land, some buildings have south-north directions and therefore the building is located alongside the eastern or western sides of the land. In these cases the yard is only a small part of the opposite side of the land (Figure 5.45. number 4). For the last scenario, the building occupies all the land area. In these cases, the yard (or the courtyard) is destroyed after the earthquake. Therefore, the only open space is the parking area (Figure 5.45. number 5).

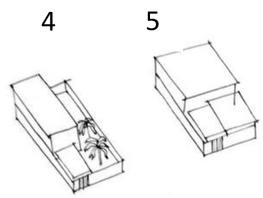


Figure 5.45.2. A dominant residential block pattern in the city of Bam after the earthquake

5.6. Design strategy selection:

Since climatic boundaries have nothing to do with political borders and climatic characteristics present similar problems for people living in such areas, the solutions found by people living in hot and dry areas all over the world are similar, although they might look different.

5.6.1. Passive design strategies for hot and dry climates: The objectives of passive buildings are to improve the comfort levels of the occupants and reduce the energy use for heating, cooling and lighting. Passive building design is of importance in hot climate and specifically in poor and remote communities because of limitations of conventional energy in terms of cost and availability and also the importance of providing thermal comfort for occupants.

Site selection is of importance to maximize the natural shading through vegetation, cooling from prevailing wind while conserving the ecological and cultural resources. Properly oriented buildings take advantage of solar radiation and prevailing wind. A compact form of the buildings reduces the surface-to-volume ratio and heat gain/loss in hot climates. Overheating due to solar radiation is the prominent problem in hot and arid climate in new buildings in Iran. A plan layout which provides good potential for cross-ventilation is more appropriate for developing countries where the vast majority of people cannot afford to buy air conditioners. Rooms that are in use for most times of the day should be located on the northern side and detached from rooms with high internal heat loads.

In addition, good envelope design responds to climate and site conditions to optimize the thermal performance. The building should be designed with protected openings and walls. Generally, materials used in modern buildings obstruct the flow of the air, making the use of mechanical ventilation essential. Nature provides us with some local materials to build with and some of these materials require little processing and are readily available.

5.6.2. Vernacular architecture as a model for contemporary design: Vernacular architecture is by its definition, aim and structure, the most integrated architectural form in communion with the environment. Two important traces of vernacular architecture can be resources for contemporary architecture: the deep respect and perfect communion with the natural environment; and perfect relation and understanding of users' needs. The large scale use of traditional building materials comes at a time when carbon foot printing, along with affordability, are coming a necessary options, especially in those areas of the world where dwindling natural resources are becoming a cause of concern.

5.6.3. Earth architecture as ecological architecture: Presently, 30% of the world's population lives in a home of unbaked earth. Roughly 50% of the population in rural areas of developing countries lives in unreinforced masonry houses. Approximately 50% of population in developing countries, including a majority of the rural population and at least 20% of the urban population, live in earthen dwellings (Houben and Guillaud, 1989).

The extensive use of earth in various parts of the world to create a sustainable architecture is due to some qualities: total recycling possibility of the materials, low carbon emission (earth dried bricks necessitating only 440 KWh/m^3) (Little and Morton, 2001), and the solar gain capabilities. Use of Khesht (unbaked brick), not only adjusts the range of diurnal thermal changes but decreases thermal absorption.

5.6.4. Privacy as the main cultural requirements for design: House design needs to ensure that people such as neighbors and passersby will not be able to see inside the house in comfort. Residents of houses designed using the current approach of the design with locating the building in the northern or southern of the allocated lot, which is different from the traditional layout, are unable to use outdoor spaces because their neighbors can see them and there is not enough shading in the yard. In their attempt to achieve privacy, residents build walls around their houses. This has become a standard requirement to build 3-4 meter concrete or brick walls in Iran. While surrounding walls may help provide privacy from passer-by at ground level, in helps a little in protecting upper floors.

A possible solution is to return to the historically approach central courtyard approach which provides privacy through most spaces looking inward the courtyard. The comforts offered by courtyards -privacy, security and tranquility- are properties nearly universally desired in human housing.

5.6.5. Passive Cooling: The following main technical solutions are determined as passive cooling strategies: Soil cooling, evaporative cooling and induced ventilation.

5.7. Vernacular architecture examples: The paradigm of indigenous architecture offers historically proved alternatives. Vernacular architectures have responded to climate and landscape requirements for thousands of years. They offer the best lessons for passive environmental sustainability within the cultural context.

Studying the lifestyle of people in extraordinary harsh environments with the landscape covered almost entirely with sand, pebble and salt in similar climatic situations demonstrates that while every location and human settlement has its own exclusivity, there are many similarities where the human have found a home.

5.7.1. Doum palm fiber settlements: One example is in El Molo settlement near Lake Tukana in Kenya where lake is located right beside a desert land. In this area people perpetuate an ancient fish-based lifestyle with houses and fishing nets made from doum palm fiber in hot climate.

Figure 5.46. Granary, Tamberma Village, Togo

Sorce: Jarzombek, 2013

5.7.2. Granary: The other example is Granary houses in Dhra in Jordan. The building is roughly circular with a floor elevated from the ground by stones that were notched to fit wooden beams. The elevated floor allowed for air to circulate under the granary to protect it from moisture and rodents. In this area near the desert landscape the buildings are made of mud-brick with a floor of hardened plaster. The structure had either a flat roof or a thatched roof with a lid at the, top. This structure was also common in grain-based (ochre and wheat) villages in Qana and Togo, Africa (Jarzombek, 2013).

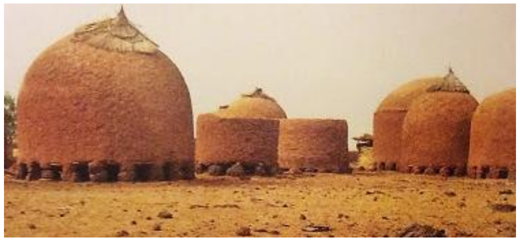


Figure 5.47. El Molo settlements in Kenya made from doum palm fiber

Source: www.wildize.org

5.7.3. Iranian nomads: Non-agricultural herding societies who tended flocks of sheep and goat date back to around 8000 BCE. The rectangular shape of the stone foundation with rectangular shape tents made of black goat hair is remarkable in these societies. The natural oiliness of goat hair sheds rainwater and makes the tents particularly water-proof. The tent is stretched by means of ropes made of wool and hemp and then pitched so that the lower edge does not touch the ground. The tent is for sleeping, receiving and entertaining guests and by women to cook and weave. During the winter the opening is faced towards the south and in the summer the opening faces towards the north. These tents are divided into male and female zones by curtains. Unfortunately these tents are being extinguished in Iran and plastic tarps are being replaced in nomadic societies.

Figure 5.48. Nomadic tents in Iran made from black goat hair Source: Globosapiens.net

5.7.4. Hut: Hut houses are among the most common houses in hot and cold climates as portable houses. The combination of mud houses with mats or thatch in hot climates with either simple vertical and horizontal poles covered with a mat or dome-shaped huts, or entirely made from leaves grass, tree branches, tree trunks or laths. Most huts have the radius of 2 to 4 meters when they are made of bamboo reinforcing arches. Strong laths are planted into the ground about 30 centimeters deep. The support tube-like structure is made into a dome by bending the laths toward the center to support the weight of the thatch (Jarzombek, 2013).

Figure 5.49. A Tuareg tent in Agadezn Niger made from simple poles and mat cover (right); Construction of Bantu grass hut in South Africa made from bamboo arches (left)

Source: Jarzombek, 2013

5.7.5. Yurt: The yurt is very light in weight, and in particular when bamboo for the wall and roof poles is used. The thermal insulation can be felt, or quilted blankets filled with straw, hemp or shredded tree bark, or for low-budget bubble wrap does it as well till -5°C only (4 layers), and keeps the interior of the yurt daylight bright. (www.simplydifferently.org).

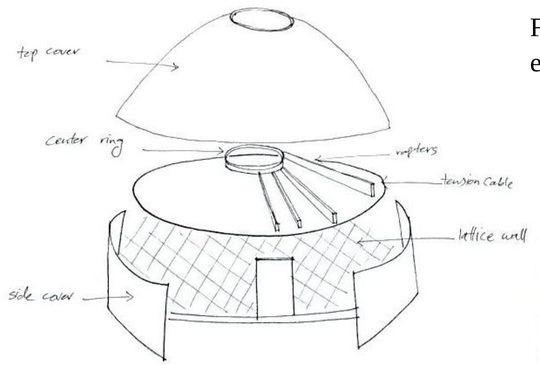


Figure 5.50. Structural elements of a Yurt

5.7.6. Arish, Palm leaf architecture: In these indigenous houses, while the temperature of the sand is measured at 77°C, the temperature inside the houses was 54°C. With double mat wall the inside temperature was measured at 45°C, the sand temperature was 71°C (Piesik, 2012). This means that these houses could provide significant cooling and a relative level of comfort. The distance between the buildings and the placement between the walls of hassir, kept out the tiny sand particles. Palm leaves also offer good reflectivity of sunlight.

Construction of Arish house in Bedu, UAE grew because of the geology of land, the existence of ground water and tribal migrations and possibly the sharing of palm-leaf construction craft with the south of the country. These houses are based on an elliptical plan shape with the usual width of 4 meters and height of 2.1 meter for walls (Piesik, 2012).

Figure 5.51. Construction of Arish house in Bedu, UAE

Source: Piesik, 2012

Traditional Arish houses were influenced by the structures of Khaimah in Abu Dhabi in which people lived during the cold seasons. Khaimah is a pitched-roof Arish building. The frame is constructed of the average of eight timber columns and one beam that support the pitched roof. Walls are made from tightly linked palm-date fronds with leaves intact, joined together by fourteen or fifteen horizontal Arish supports each about 1.8 meters long.

Traditional Khaimahs have the roof frame made from peeled Arish fronds covered with hassir mats and a fabric. Interior walls were lined with hassir mats or with color mats shipped from Egypt or Iran. Sand, earth or hassir mats formed the floor. These traditional buildings had only one door and no other openings (Piesik, 2012).

Similar to Kapars in Iran, the meal was cooked on an open fire in these Arish buildings during the winter months. Waterproofing was done by applying a layer of bitumen. Each Khaimah was home for up to ten people. The Arish was soaked in sea water and put on the sand to dry prior to construction.

In the Dubai, unlike other areas, workers and their families stayed in the city all year round. In this city the wind towers were built to cool houses in extreme heat of summer. This Persian invention can naturally cool the interior spaces by channeling the air throughout the house. Channel timber (hardwood planks about 4 meters long) was used as structural frame, mats for the roof and linen as partition within the tower. Some of the wind towers were composed of rice bags or tea cartons. Next to the pitched roof Khaimah an addition flat roof extension was constructed to house the wind tower in the summer.

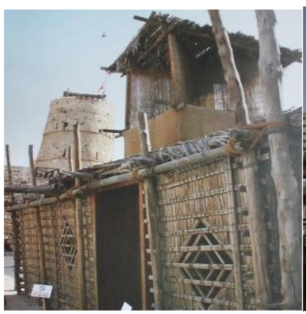



Figure 5.52. and figure 5.53. Construction of Arish house in Bedu, UAE with wind tower Source: Piesik, 2012

5.7.7. Reed buildings: Reed has been used in various rural areas of the world for frameworks, walls and roofs. It insulates well, is light and is easy to work with. But it’s also flammable and makes good insect nesting. Reed does not last long and must be replaced often. However, it’s a material that grows naturally and needs no processing. It’s a 6,000 year old building technique that uses giant reeds 20’ bound into bundles which are then stuck into the ground. When the arches are in place, horizontal ribbing is fastened then mats tied in place (Shelter, 1973)

Figure 5.54 Reed structure (left);
Figure 5.55. Reed buildings in Iraq (right)
Source: Building.co.uk

5.8. Post-disaster temporary housing examples:

More than six decades after the United Nations passed a convention pledging to protect refugees, very little has changed about the way they are sheltered until now.

5.8.1. Disaster-relief projects by Shigeru Ban: Shigeru Ban is well known for finding structural uses for fugitive materials, including paper and cardboard to provide immediate housing for victims. The architect uses shipping containers, paper tubes and canvas to build the immediate shelters.

Figure 5.56. Paper Log House, India (left); Paper Log House, 1995, Kobe, Japan (right) by Shigeru Ban Architects

Source: Architectmagazine.com

5.8.2. IKEA tents: The IKEA solar-powered shelter is flat-packed, requires no tools to assemble, and can be taken apart and rebuilt again elsewhere. Instead of canvas flaps, the shelter is made up of hard panels. The spatial volume in these modular units is more than double that of the UNHCR family tent and they provide higher thermal comfort. The shelters come flat-packed to make the easy transport of the lightweight plastic shelters at once. Assembly of the 188 square foot hut is easy and can be built in just four hours. The roof also helps to deflect solar reflection by 70%, keeping the interior cool during the day and warmer at night. However, the full range of benefits and drawbacks will not be completely known until the prototype goes into field testing in the future in Ethiopia and Somali (IKEA foundation, 2014).

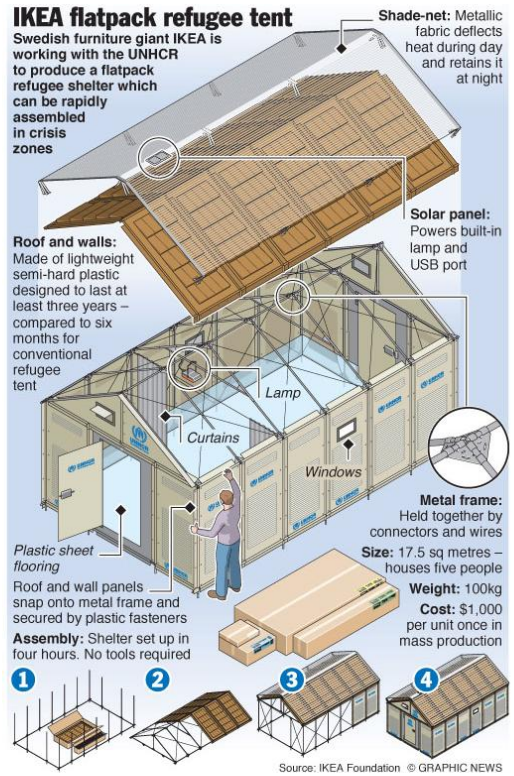


Figure 5.57. IKEA tent for refugees components

Source: IKEA foundation

5.8.3. Weaving a home: ‘Weaving a home’ re-examines the traditional architectural concept of tent shelters by creating a technical, structural fabric that expands to enclose and contracts for mobility while providing heat, running water, electricity, storage, etc. People weave their shelter into home.

Figure 5.58. Weaving a home

Source: abeerseikaly.com

The water storage tank is placed on top of the tent and the water rises through thermo-siphoning. The south side of the tent absorbs the heat from solar radiation and the high efficiency solar absorber material.

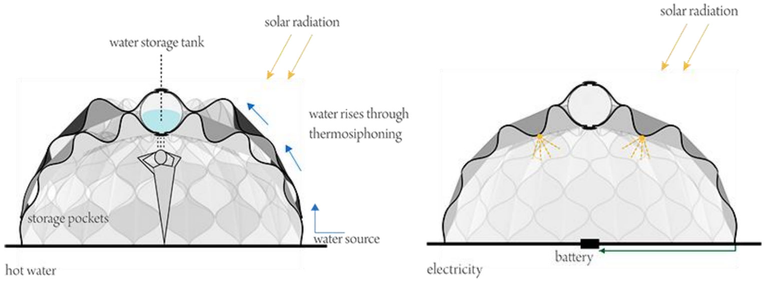


Figure 5.59 Weaving a home, electricity and hot water provision

Source: abeerseikaly.com

5.8.4. Super adobe: Using the super adobe structure, Khalili partnered with the United Nations Development Program and Refugee Agency built emergency shelters in Khuzestan, Iran. The Iraqi refugees themselves constructed fifteen shelters at the cost of $20,000 in 1995 (Rael, 2009). Super adobe is a system for building small stand-alone structure that can be clustered together without the use of extensive skilled labor. A 400 sq. ft. (37 m^2) house can be put up in about four weeks, by one skilled and four unskilled people and it will last for 30 or more years (Khalili, 2007).

Figure 5.60.1 and 5.60.2. Super adobe structures constructed in Khusestan, Iran Source: www.akdn.org

5.8.5. Water for all, solar water heating and rainwater tower in Florianopolis, Brazil: These one-million water tanks are dedicated to low-income dwellings where access to clean drinking water is a serious issue with long periods of drought anticipating and the periods of 17 days without rain. The cost is about 400 USD for a 16,000 liter tank, for a single family 36m^2 house. The combination of solar water heating and rain water tower is the most important concept of these tanks. The integrated structure includes rainwater collection (collected from home's roof for non-potable uses) in the lower 3.6 m^3 tank and potable water in an upper 1000 liters tank. The solar panels can be installed at different angles which provides more flexibility to optimize the effectiveness and they also act as a shading device (Holcim Foundation, 2009)

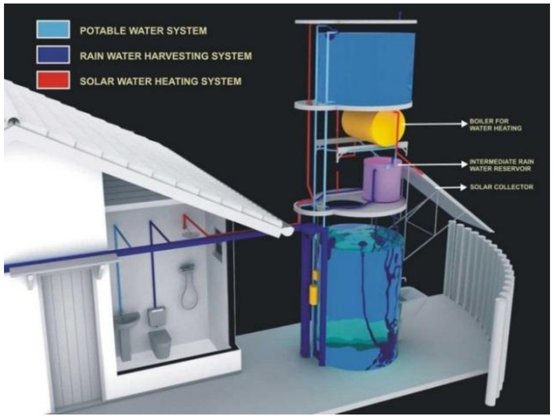


Figure 5.61. Solar water heating and rainwater tower, Components of water tower

Source: Holcim Foundation www.holcimfoundation.org

5.9. Post-disaster temporary shelter design requirements:

After studying the Sphere’s catalog, the Humanitarian Charter and Minimum Standards in Humanitarian Response, the minimum requirements and needs were determined for my project. Some of the shelter design requirements and the quantity of basic needs are summarized in table 5.3.

“Key aspects of the right to housing include the availability of services, facilities, materials and infrastructure; affordability; habitability; accessibility; location; and cultural appropriateness. The right to housing also extends to goods and services, such as sustainable access to natural and common resources; safe drinking water; energy for cooking, heating and lighting; sanitation and washing facilities; means of food storage; refuse disposal; site drainage; and emergency services. People should have adequate space and protection from cold, damp, heat, rain, wind or other threats to health, structural hazards and disease vectors.” (The Sphere Project, 2004)

Description	Quantity
Basic water need	• Average water use for drinking, cooking and personal hygiene in any household is at least 15 L per person per day (2.5-3 L drinking and food, 2-6 L hygiene, 3-6 cooking) • The maximum distance from any household to the nearest water point is 500 meters • Queuing time at a water source is no more than 15 minutes • Maximum numbers of people per water source: 250 people per tap or 500 people per handpump
Basic toilet need	• A maximum of 20 people use each toilet • Toilets are no more than 50 meters from dwellings • Public toilets: 1-2 liters/user/day for hand washing and 2-8 liters/cubicle/day for toilet
	cleaning
Solid waste management	All households have access to a refuse container and/or are no more than 100 meters from a communal refuse pit At least one 100-litre refuse container is available per 10 families, where domestic refuse is not buried on-site.
Drainage	Areas around dwellings and water points are kept free of standing wastewater, and stormwater drains are kept clear
Shelter and settlement	• Affected households return to the site of their original dwellings where possible • Affected households who cannot return to the site of their original dwellings or who cannot settle independently within a host community or with host families are accommodated in mass shelters or in temporary planned or self-settled camps • Area or cluster planning by family, neighborhood or village groups as appropriate supports

	existing social networks, contributes to security and enables self-management by the affected population • Temporary planned or self-settled camps are based on a minimum surface area of $45m^2$ for each person • The initial covered floor area per person is at least $3.5m^2$ • The covered area enables safe separation and privacy between the sexes, between different age groups and between separate families within a given household as required • The design of the shelter and the materials used are familiar where possible and culturally and socially acceptable • Alternative materials required to provide temporary shelter are durable, practical and acceptable to the affected population

Climatic requirements in hot, dry climates:	• Construction should be heavy to ensure high thermal capacity, allowing changes in night and day temperatures to alternately cool and heat the interior, or lightweight with adequate insulation. • If only plastic sheeting or tents are available, a double-skinned roof with ventilation between the layers to reduce radiant heat gain should be provided. • Door and window openings positioned away from the direction of the prevailing wind will help to minimize heating by hot winds and radiation from the surrounding ground. • Shade and protection from hot winds can also be gained from adjacent shelters and surrounding natural land forms or trees. • Flooring contiguous with

	the external walling should be provided to minimize sand penetration. • Locally sourced materials and labor are used without adversely affecting the local economy or environment • Locally derived standards of workmanship and materials are achieved
Environmental impact	• The production and supply of construction material and the building process minimizes the long-term depletion of natural resources • Trees and other vegetation are retained where possible to increase water retention, minimize soil erosion and to provide shade

Table 5.3. Design requirements and basic needs in designing the temporary shelters in humanitarian projects

Source: The Sphere Project, 2004

"Livelihood support should be promoted through the local procurement of building materials, specialist building skills and manual labor. Multiple sources, alternative materials and production processes, or the provision of regionally or internationally sourced materials or proprietary shelter systems are required if the local harvesting and supply of materials is likely to have a significant adverse impact on the local economy or the environment. The re-use of materials salvaged from damaged buildings should be promoted where feasible, either as primary construction materials (bricks or stone masonry, roof timber, roof tiles, etc.)." (The Sphere Project, 2004)

“Shelter and associated settlement responses should support communal coping strategies, incorporating as much self-sufficiency and self-management into the process as possible. Any such responses should also minimize the long-term adverse impact on the environment, whilst maximizing opportunities for the affected communities to maintain or establish livelihood support activities. Consideration must also be given to the rights and needs of those who are secondarily affected by the disaster, such as any host community. Moreover, involving women in shelter and settlement programs can help ensure that they and all members of the population affected by the disaster have equitable and safe access to shelter, clothing, construction materials, food production equipment and other essential supplies.” (The Sphere Project, 2004)

II. Analysis

5.10. Material:

5.10.1. Low-cost reinforcement techniques for masonry structures in Bam: The first trajectory of finding the connections between temporary and permanent housing phases was to study the permanent housing assessment in post-earthquake constructions. Generally speaking, as discussed in previous chapters, inattention to the locally available materials and construction techniques, high cost of some construction materials such as cements and steel, and lack of expertise in modern building construction techniques were among the most significant reasons for the lengthy construction phase, poor materials quality and lack of rigorous engineering design in post-earthquake reconstructions.

Finding the best options to modify the traditional building materials and techniques to make them seismically resistant required an investigation on low-cost masonry reinforcement techniques around the world. Appendix 1 summarizes some of these low-cost techniques for adobe masonry reinforcement in new and existing buildings aiming to find a locally based material and engineering solution which is more adaptable to the traditional mud-brick construction methods. These techniques include additional structural elements, external coating, injection, surface coating and reinforced coats.

Only a few techniques have been tested in full scale so far. Therefore, the reinforcement testing results are not available for all of these techniques. In addition, some of these methods have been only implemented in academic research projects. Therefore, the construction complexity and economic assessment of these techniques specifically in Bam could be another field of research for future studies.

Jäger and Braun studied the improvement of shear resistant of adobe masonry by adding natural fiber reinforcements including date palm tree fibers to the clay brick. Under tension and compression tests, the results showed that the date palm tree fiber reinforced clay bricks could continue to absorb energy even after the failure of the clay (about 16 times more than unreinforced clay bricks and 13.7 times more than industrial bricks) and the ductility was also increased for these blocks. Also, the average tensile strength of fine size (0.15-0.3 mm) could increase the tensile strength of the blocks better than course and middle sizes. The best results were achieved by jute fibers. Therefore, in addition to the low-costs techniques presented in appendix 1, the traditional mud brick techniques can be reinforced by adding natural fibers (Hernández et al, 2010).

In conclusion, considering the above mentioned factors only a few techniques for low-cost masonry reinforcement which are tested by engineers and researchers may be applicable in Bam based on the level of complexity, cost and material availability: external reinforcement with wire mesh, external reinforcement with polypropylene band and confinement.

However, many of the indicators are comparative - such as construction complexity which is categorized in simple, moderate and complex. Thus, finding an absolute decision on the best technique for adobe masonry reinforcement is not realistic unless it is built in full scale in the intended location.

Moreover, some potential techniques such as internal and external date palm frond and reed reinforcements may also be future possible techniques to be tested for earthquake-prone Middle Eastern countries. These technics can be the local translations of the previously tested reinforcements with cane and bamboo materials in Peru, Germany or Canada.

5.10.2. Disaster recovery and temporary housing timeframe:

Disaster recovery has three distinct but interrelated meanings. First, it is a goal that involves the restoration of normal community activities; second, it is a phase and a process in the emergency management cycle that begins with the stabilization of emergency responses and ends when the community has returned to its normal routines (Lindell, 2009).

There are three fundamental patterns of household recovery that are defined by three corresponding sources of assistance: autonomous (own resources), kinship (extended family resources) or institutional (governmental) - although few households rely on only one resource (Bolin and Trainer, 1978).

The line between emergency response and disaster recovery is not always clear because some sectors of the community might be in response mode while others are moving into recovery and therefore some organizations are carrying on both types of activities at the same time.

As indicated before, in post-disaster reconstructions, we must shorten the reconstruction period as little as possible. Temporary housing, therefore, must play the role not as an extra burden, but as an enforcement and supporting part of the larger plans for permanent housing projects. Therefore, helping the vulnerable disaster-affected community to take the first steps towards self-sufficiency and resilience is the main purpose of this thesis.

The main intent of this project is to fill the gaps between the emergency shelters to temporary housing phases by optimizing the transitional timeframe, simplifying the temporary housing project and involving the residents of the city as the executive force in the temporary housing phase as a community based organizational project.

For this purpose, I aimed to focus on autonomous and kinship sources of assistance in recovery phase for building the temporary houses. This will facilitate the transitional process to the recovery level for the community-based organizations and also allows the government to initiate the infrastructure recovery projects and permanent housing phase faster.

The emergency response stars in the first hours after the disaster. The recovery phase is assumed to start after the emergency aids are provided and the debris is removed, 3-7 days after the starting date of emergency response. Aiming to shorten the required time of the temporary housing construction, I focused on searching for the temporary housing options within the timeframe of 7 to 10 days for construction.

5.10.3. Basic human needs and the definition of ‘local’: To address the basic needs of people within the realm of sustainable practices, economic, social and environmental issues must be considered and tackled simultaneously. In order to establish strong connections between needs and resources, first of all we need to make a definition for ‘local’ resources to be able to search for available resources within the defined distance.

The US Green Building Council has used a 500-mile radius to define regional products. In 2012 they added a more flexible approach for coastal or remote regions and now there are two options for ‘local’definition:

Option 1: The old familiar option uses a simple 500-mile radius from the site for both extraction and manufacturing distance.

Option 2: This new option allows you to do a prorated calculation based on the lower relative impact of shipping materials by rail or water. Calculate a 500 mile (800 km) total travel distance to the project site using a weighted average. Distance by rail can be divided by 3; distance by inland waterway by 2, and distance by sea by 15.

Previous experiences in post-earthquake temporary housing projects in Iran such as - Manjil, Lorestan and Bam earthquakes – show that providing building construction materials for temporary settlements preparation took up to 5 years to be prepared. In some cases, UN emergency tents were directly transitioned into permanent houses after 1 to 10 years. In Bam, where the large city of Kerman was located within the 500 mile distance, problems such as traffic jam and mismanagement made the transportation to become impossible between these two cities.

The reason behind this lengthy transition had multiple reasons as discussed in previous chapters. However, it is an indicator that in these chaotic circumstances, there is a great need for minimizing the scope of material resources for post-disaster situations and helping the communities to become self-sufficient becomes vital.

This project is based on the first definition of the local distance. Figure 6.1 shows the distance of 500 mile around the city of Bam. City of Kerman, Baravat, Jiroft, Baft, Mahan and Zahedan are among the biggest cities in this area that will be considered as local to the city of Bam.

Figure 5.62. The distance of 500 mile around the city of Bam

5.10.4. Connecting the locally available resources and long-term needs within a closed loop: In order to find the connections between needs are resources in post-disaster situations for Bam, long-term needs can be categorized in: Food and water, job and economics, shelter and building constructions and waste management. Figures 5.63 to 5.64 illustrate the connections between natural resources in Bam and long-term needs after the disaster for this city through two frameworks:

1) The first one makes connections between agricultural resources (date palm, citrus and wheat as the economic base), waste management (agricultural and building construction waste) and energy requirements (electricity, heating and cooling). The loop could be closed by adding a biodigester into the cycle to collect agricultural and municipal waste and then produce fertilizer for agriculture and methane gas as the energy source for the community.

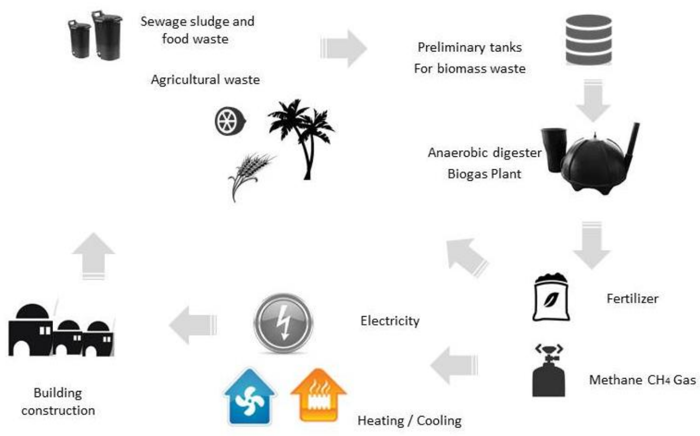


Figure 5.63. Energy, waste and agricultural products cycle

2) The second framework shows the connection between other natural resources - solar energy, sand and water from Qanats – and the required energy for the residential sector. Water storage tanks equipped with solar hot water panels can provide hot water for washing and laundry and also provide enough storage for drinking water. Water and energy resources are then distributed between the dwellings. Small off-grid solar panels can also be used for street lighting in the district.

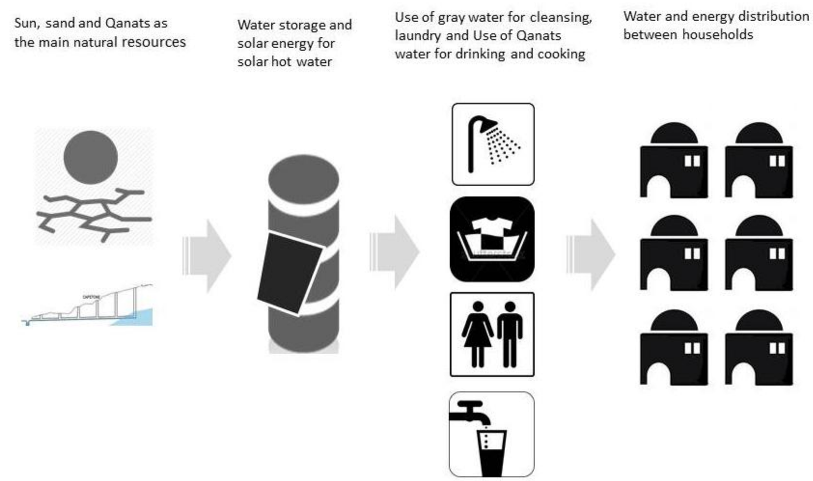


Figure 5.64. Connection between natural resources and dwellings

These two strategies are generally applicable in many cities alongside the central deserts of Iran where the water scarcity is combined with difficult access to energy and material resources, and, gardening and agriculture are the basic economic activities. Figure 5.65 spots some examples of cities with similar urban patterns to Bam in semi-desert areas near Lut desert and central areas of Iran with integrated natural (specifically date palm trees) and built environment. Main city areas include, but are not limited to, Booshehr, Hormozgan, Jiroft, Khoozestan, Bam and Narmashir. These patterns could be also found near Oman Sea or Persian Gulf. However, the climate changes to hot and humid in these regions.

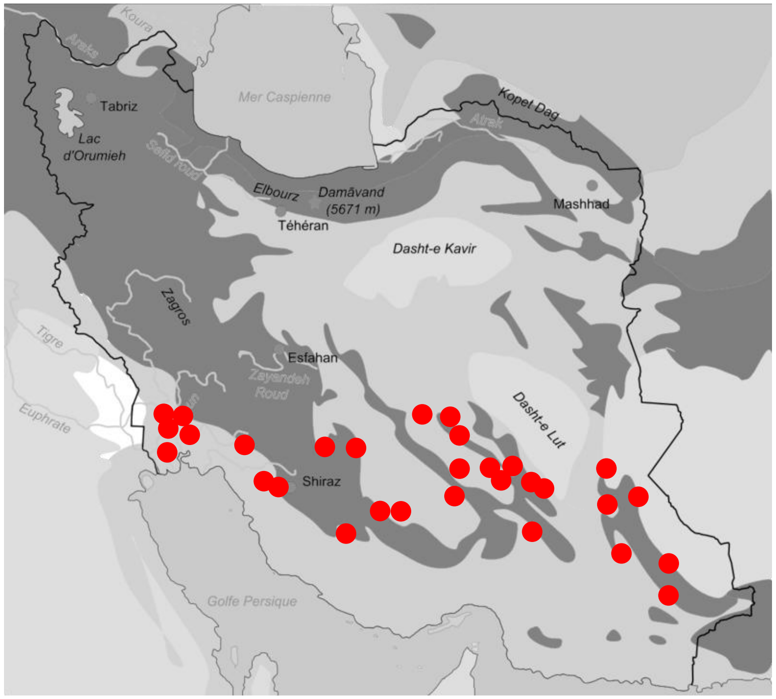


Figure 5.65. Examples of cities with similar urban pattern to Bam with the integrated built and natural environment in southern parts of Iran

5.10.5. Date palm - Phoenix dactylifera: Having more than 1,400,000 Phoenix dactylaferia trees only in the city of Bam, the strong ties between the social structure and the agricultural based economy of the city, and the integrated physical pattern of natural and built environment of the city, makes the agricultural by-products of this tree a unique target for research and studies to understand the influence of this tree on both traditional and innovative design options.

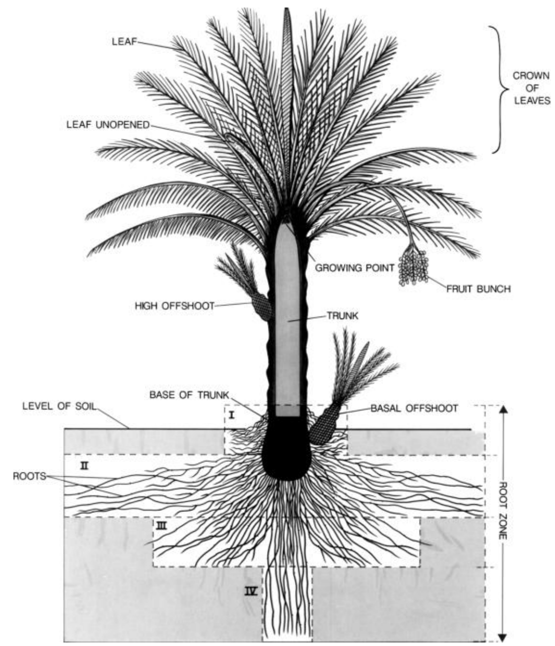


Figure 5.66. Diagrammatic representation of date palm structure, showing attachment of offshoot to mother palm, among other morphological features. (USDA archival diagram)

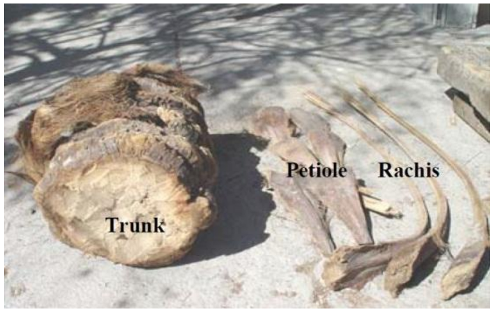
Form: tall palm with feather fronds; fronds held upright in "feather duster"-like arrangement; usually single trunked
Seasonality: evergreen
Size: to 100ft, spread to 30ft; growth rate is slow, may take 15 years to attain 10ft
Trunk diameter: up to 20 inches, what look like branches, are really leaves that grow out of the crown or top of the trunk.

The leaves are barbed, and they keep camels and other animals from eating them. As the date palm grows, the leaves fall off and leave a scar mark around the trunk. The inside of the trunk is filled with soft fiber called pith. This means that, unlike other trees, palms do not add growth rings each year to show their age.
Leaf length: up to 16ft
Leaves: pinnate, feather-like fronds, 15-20ft long, more silver-gray than other Phoenix palms, rough and sharp, toothed petioles, held more erect (not arching); life span of leaf is 3-7 years; frond bases usually persist on trunk if not removed
Flowers: deciduous; off-white clusters, not ornamental
Fruit: edible dates on female plants (if pollinated); cylindrical 1-2in long yellow or red fruit held out amongst fronds in pendulous clusters The first berry-like fruit appears when a date palm is about 8 years old. The tree continues to produce dates for more than 20 years. First, yellow flower spikes appear from between the leaves. Then the fruit forms in clusters of 200 to 1,000 dates each. When the dates are ripe, they are dried to prevent spoiling. A date palm can live for up to 150 years. *Stems/Trunks:* slender trunk, 18inch diameter, leaf base scars form interesting geometric pattern; may produce basal offsets
Range/Origin: Asia, in cultivation worldwide for millennia
Hardiness: damage seen in mid-twenties
Exposure required: full sun to shade, thrives in heat, it also likes humidity
Soil required: somewhat adaptable, best in sandy well-drained
Propagation required: seed from isolated population, or offsets to ensure sex and quality or fruit
Maintenance required: high, fruit on females attracts animals and drops messily, frond removal Date trees take as much water as a willow trees, yet they cannot tolerate rain or humidity. That's why dates have to be grown in the hot desert.
Breeding: Most of the date trees are grown from pups (offshoots from the parent tree) to be identical to the parent. It takes between 6 to 8 years before the pups will be big enough to transplant, and then another six or seven years before they will begin to produce.
Date Palm Harvest: Date palm trees have thorns that are approximately 4 to 5 inches long, and can easily pierce thru a truck tire. So the very first thing we do is to remove the thorns to make it possible to work in the date trees (https://ag.arizona.edu/pima/gardening/aridplants/Phoenix_dactylifera.html) .

Figure 5.67. Date Palms in Bam after the earthquake

Source: www.anobanini.ir

5.10.5.1. Date Palm Fiber: Date Palm Fibers (DPF) is one of the most available natural fibers in the Middle East, especially in Iran and the Persian Gulf region (Mahdavi et al. 2010). There are about 20 million date palm trees in southern regions of Iran, based on Jihad agricultural ministry estimation and there is a huge pruning waste (about 15 to 20 kg per tree) which has good potential as renewable cellulose material. In addition, there are numerous crownless date palm trunks that remained standing after the Iran-Iraq war. According to Mahdavi et al. Petiole fiber has the highest aspect ratio and its lower lignin content leads to better flexural properties for fiber composite than trunk and rachis fibers. But, this lower lignin increased the hydrophilic character of the fibers (Mahdavi et al. 2010).



5.68. Three types of date palm fibers, trunk fibers, petiole fibers and rachis fibers

Source: Mahdavi et al. 2010

It is not advisable to take fibers from the base of old leaves because of their partial rotting after a long period of bacterial and fungal activity.

In the recent years, natural organic reinforcements such as cellulose fibers have entered slowly into the market because of the advantages that they offer over most inorganic fillers. Cellulose fibers are abundantly available, renewable, recyclable, non-hazardous, biodegradable and have lower costs and density. Natural fibers have reduced wear of processing equipment. The residual stems of herbal plants such as kenaf or straw cannot be compacted much beyond 135 kg/m^3 which may limit the feasible supply basin to range of 25-35 kg.

However, the low bulk density of date palm fibers can increase the transportation costs (Sanwell, 1991).

Figure 5.69. Trunk fibers of date palm tree at the leaf bases

Source: wikipedia

Mahdavi et al. showed the packed bulk density of fibers among date palm tree parts in the following chart:

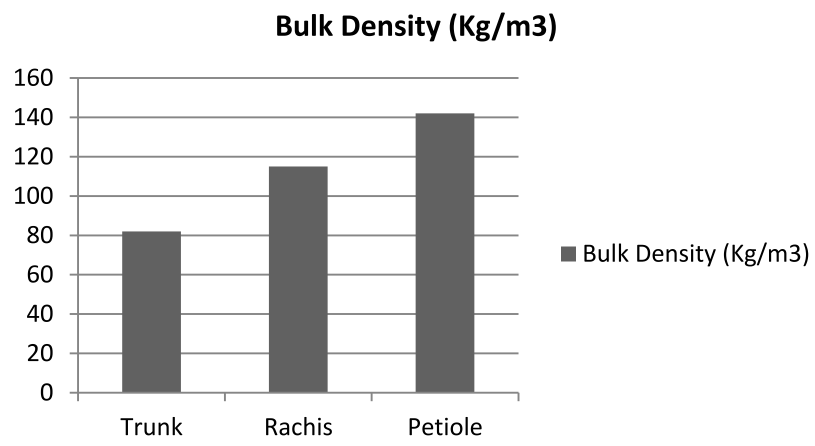


Figure 5.70. Bulk density of date palm fibers among three date palm tree parts Source: Mahdavi et al. 2010

The following chart also shows the fiber diameters for different parts of the date palm tree:

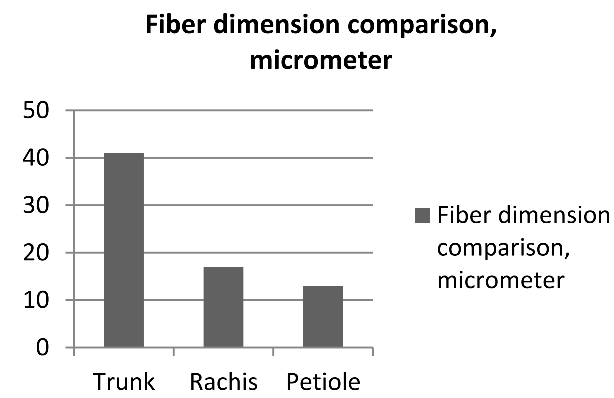


Figure 5.71. Date palm fibers dimension comparison Source: Mahdavi et al. 2010

5.10.5.2. Estimation of the total number of leaves on a date palm: The total number of leaves on a date palm is easy to estimate because of their orderly arrangement. Leaves are usually arranged in nearly vertical but slightly spiraling columns. We should multiply the number of leaves in one column by the number of columns to give an approximate number of leaves. However, estimating the number of leaves can still be tricky, because sometimes it is difficult to count the number of columns of leaves on a palm (Hodel et al. 2007). In average, date palm trees in hot and dry climate of Iran have between 30 to140 and every palm tree produces 10 to35 new leaves annually (Ghasem Khorshidi, gardener from Bam).

5.10.5.3. Current date palm leaves and fiber uses: In Iran and many other countries, after leaf pruning, orchardmen burn most of the dried leaves of date palm trees. Only a very small number of leaves will be used by women for weaving handmade crafts such as baskets, mats, hats and handheld fans.

Figure 5.72. Handcrafts from date palm leaves in Bam Source: Iranian Students News Agency, 2013

Recently, in the spring of 2014, Agricultural and Natural Resources Research Center of Iran made an announcement that for the first time in Iran researchers invented a chemical process to use date palm leaf wastes as livestock feed (IR News Agency, IRNA).

In the case of palm-leaf architecture, the answer may be to find new applications for the abundant materials that are readily available. In the absence of technical data about traditional and vernacular building techniques with this material, the only way to explore all the possibilities is to construct full-scale prototypes and test the behavior of the materials in structure and building material.

5.11. Temporary housing practice after the earthquake of 2003 in Bam:

Figure 5.73. Prefabricated steel structure temporary houses based on HF designs in owner's lands

Source: Fayazi, 2011

After the earthquake HFI divided the city into 13 areas. Each of these areas was designated to one of the provincial HF centers to build their own temporary camps in that area. Thirteen provincial HFs were in charge of the 20 temporary camps, 23,628 temporary units provision and permanent housing constructions under the supervision of HF headquarters. However, in the fourth phase of temporary housing constructions until August 2004, about 2,795 units were built in the yards of the houses and 1,650 units in caps were occupied. More than 5,593 units in cams were vacant. Therefore the HF decided to move some of those units to the houses. Almost until one year after the earthquake, electricity, water and septic tanks were not available in some temporary camps (Fayazi, 2011).

Most of the camps were located on the edges of the city as shown in the following figure (Source: historic aerial photos from google and Mahmood Fayazi, 2011).

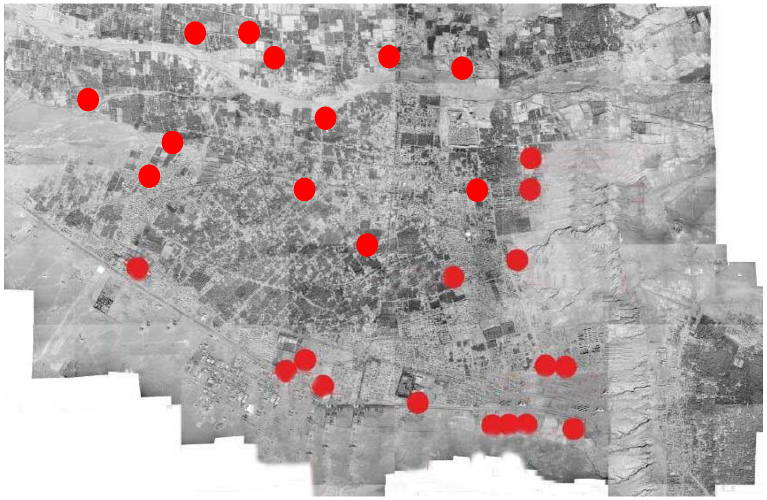


Figure 5.74. The distribution of temporary camps in the city of Bam after the earthquake of 2003

Source: Mahmood Fayazi, 2011

When the initial criteria for temporary housing design – including the minimum square footage of the units to be 18 m^2 (194 sq ft), the structure to be prefabricated steel, unit height 3m from one side and 2.7m from the other side, and spaces to be one living room, one kitchen and one bathroom – were proposed by HF headquarter, each of the centers had their own variations of building design and camp plans.

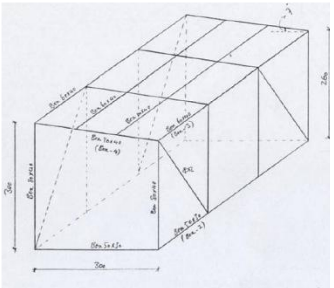


Figure 5.75. Basic esign concept of prefabricated steel structures for temporary houses proposed by HF

Source: Mahmood Fayazi, 2011

Buildings had 18 to 22 m^2 area, some of the camps had kitchen and bathrooms located inside the units and some had separate buildings for kitchen, bathrooms, toilets and laundries. There were also different variations of plans and materials. In addition to these, 10 camps had designated areas for some of the cultural, educational, religious, commercial, healthcare and recreational lands for about 140 m^2 (1506 sq ft) for each activity. The following images show AmirKabir Camp. The central buildings are dedicated to recreational, educational and healthcare services.

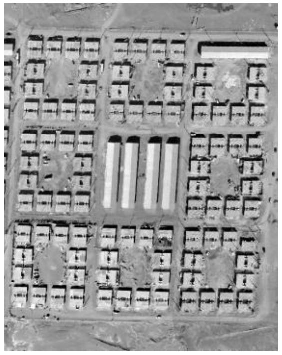


Figure 5.76. Aerial image from AmirKabir camp built by Arak HR

Source: National Cartographic Center

The following images show the structural system proposed by HR and one example of temporary building plans from Sahab camp by Kerman HF. Each unit had two 1*2 m^2 aluminum windows.

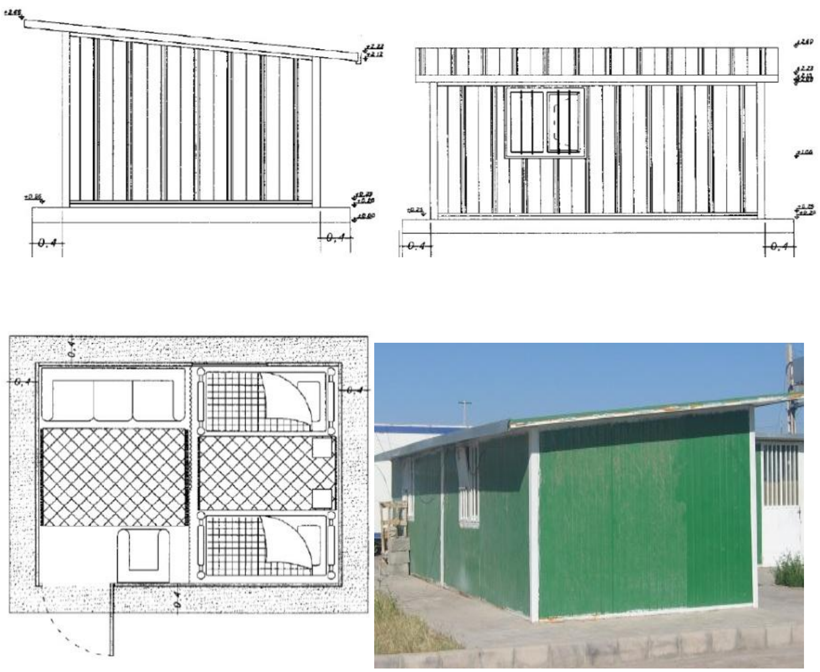


Figure 5.77. Construction documents of an example for temporary prefabricated steel structure units in Bam in Sahab camp

Source : Mahmood Fayazi, 2011

One of the most important features of the temporary houses in Bam was its growth and evolution over time from a simple pre-fabricated steel unit or masonry building into an attachment to the permanent buildings. Even today, throughout the city we are able to witness many forms of existence of temporary settlements. The following diagrams and photos illustrate how these dwelling were attached to the buildings and changed based on the needs of people over time.

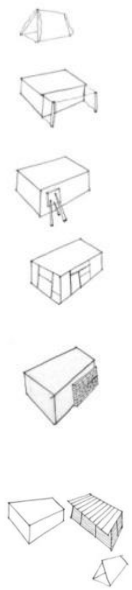


Figure 5.78. The evolution of temporary houses over time in both emergency tent and prefabricated steel structures

The diagram illustrates the modification of different types of temporary settlements in Bam. For emergency tents the only adjustment was the use of plastic sheets to make the tents waterproof. Pre-fabricated steel units had a diverse range of adjustments in temporary settlements. Additional plastic sheets in front of the units made an extra open space for users and their stuff to be covered from rain. In some cases during the cold months of the year, openings had been covered by pieces of wood or plywood. In some examples, the walls were all covered by plywood to provide more thermal insulation. Some people added an extra layer of hollow masonry blocks to the walls.

Figure 5.79. A temporary housing unit with walls covered by low quality plywood sheets

Source: ISNA

Table 5.4 shows wall and roof materials systems used in temporary houses in Bam with cost estimation. The costs do not include labor, transportation, insurance, or workshop equipment costs.

Roof /Wall	Siporex blocks	Concrete blocks	Cantex panels (compact reed sheets connected with galvanized wire)	3D panels
Fabis sandwich panels	930 USD	1,015 USD	1,075 USD	1,295 USD
Corrugated aluminum sheets with polystyrene thermal insulation	884 USD	969 USD	1,029 USD	1,250 USD

Table 5.4 Roof and wall systems and materials in temporary housing in Bam

Source: Mahmood Fayazi, 2011

The comparison of the costs shows that 3D panels were the most expensive options.

5.11.1. Roof systems:

Fabis sandwich panels: The aluminum composite panel is a type of flat panel that consists of two thin aluminum sheets typically 0.3 to 0.5 mm thick bonded to a non-aluminum core. Fabis panels are 5-6 cm thick with 4 cm polyurethane core (40 kg/m^3).

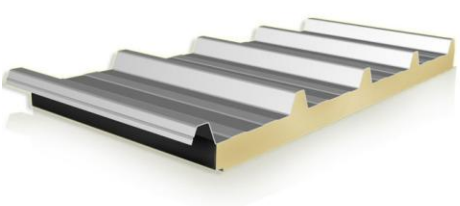


Figure 5.80. Section of sandwich panels roofing

Source: www.mei-uae.com

Corrugated aluminum sheets with polystyrene thermal insulation: These sheets are consisting of 0.5 mm (0.02 inch) and one layer of 4 mm (1.6 inch) polypropylene sheet.

5.11.2. Wall systems:

Siporex blocks: Silica Pore Expansion are lightweight concrete blocks which need 200 kg cement, 350 kg sand, 100 kg lime for every cubic meter. Aluminum powder is used at a rate of 0.05%–0.08% by volume. Atuoclaved Aerated Conceret (AAC) will be then in steam pressure hardening process when the temperature reaches 190° Celsius (374° Fahrenheit) and the pressure reaches 8 to 12 bars (10 atm). It can carry loads of up to 8 MPa (1,160 PSI), approximately 50% of the compressive strength of regular concrete and one fourth the weight of dense of concrete (ACC India, 2014).

Cantex panels: Cantex panels are compact reed sheets joined by galvanized wire together. The application of these panels is in walls, ceilings and also concrete construction frame. The manufacturer is located in the city of Ahvaz in the south-west of Iran. Cane stems are harvested, peeled and dehydrated in the outdoor area of the factory and then conveyed to the texturing machine where they are textured with steel wires to form 2m high, 1m wide and 5 to 3cm thick panels.

Resources and raw materials include: wood waste, cotton fiber, cannabis fiber, cork, date palm leaf, wheat family species with hollow, jointed and soft stems, bamboo and cane. Thermal performance of every 5cm thickness of these panels equals thermal performance of every 2.5 cm thick fiber glass. Bamboo and cane panels can tolerate a maximum pressure of 400kg per square meter. Cantex panels are bendable and can be used in mild curves. The minimum rate of bendability of these panels is about 5/0 to 18/0 Mega Pascal. Various coatings such as plaster, cement, paint, clay, romalin, conitex, etc. perfectly engage with these panels (CantexAhwaz, 2013).

Plant fiber sheets are basically flammable; however, due to the silica coating of bamboo stem, Cantex panels are self-extinguishing. If coated with cement and plaster finishing, these panels become further fire resistant. Cantex panels can host insects, termite in particular. The best way to prevent penetration of insects is coating these panels with proper finishing materials. The main advantages of Cantex panels include easy handling, cutting and installation as well as being light weight. The specific gravity of bamboo panels is about 200kg/ m^2 (CantexAhwaz, 2013).

Figure 8.81. Cantex panels in 1 layer (left) and three or five layers (right) from reeds and bamboo

Source: cantexahwas.com

Cantex company for Bam project could not use date palm materials for the panels simply because the demand exceeded supply in a short time.

3D panels: 3-D wall panels are used in the construction of exterior and interior bearing and non-load bearing walls and floors of building of all types of construction. This system consists of a welded wire space frame integrated with a 60 mm (2.3 inch) polystyrene insulation core. The wall panel is placed in position and wythes of concrete are applied to both sides each 40 mm (1.6 inch).

Figure 5.82 3D wall panels

Source: www.3dpanels.net

5.12. Comparison of materials in temporary houses:

5.12.1. Life Cycle Analysis:

Life Cycle Assessment (LCA) is the compiling and evaluation of the input and outputs and the potential environmental impacts of a product system during its lifetime. The following graph shows the material percentage share of initial embodied energy in construction industry. Steel and concrete, the main two materials for temporary building constructions in Bam contribute to 42.4% and 35.4% of the total energy respectively. However, considering the total life cycle of these materials and more importantly the transportation energy and costs, the real embodied energy for pre-fabricated steel structures in humanitarian projects becomes even more significant.

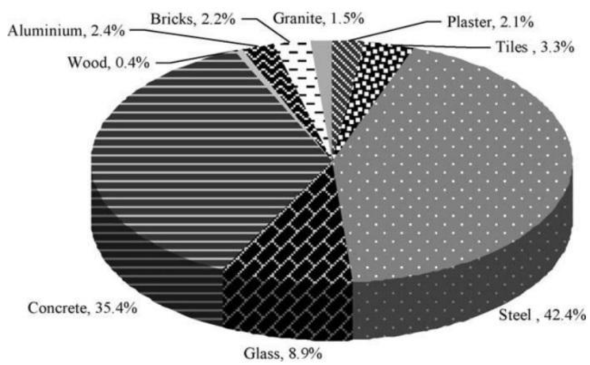


Figure 5.83. Material percentage share of initial embodied energy

Source: Lisbeth Hsu,2010

In order to provide a tangible comparison of the environmental impacts of the materials used in temporary housing phase in Bam, I used Athena Impact Estimator software. Appendix 2 includes the graphs results of the total primary energy, ozone depletion potential, non-renewable energy consumption, global warming potential, fossil fuel consumption, eutrophication potential and acidification potential of each cubic meter of 5 material options in production, construction process, use, operational energy, end of life and beyond building life.

Generally, we can divide these materials into four basic categories: Aluminum based materials, concrete materials, plastic materials and plants.

The graphs are based on calculations for a single family 215 sq ft (20 m^2) house with 581 sq ft wall. Table 5.5 summarizes the building components for these 5 variations which were simpulated by Athena software. To compare the results, we must consider that the wood stands for the Cantex panels. In reality, comparing to the timber processing, the required processing of these materials are negligible enev if the raw materials are reeds instead of date palm fronds. Moreover, These analysis show that metal cladding had less environmental negative impacts than the baked bricks. It should be noticed that steel components were the ones which were mainly transported from Korea and Turkey. Therefore, the total cost and embodied energy of these materials are highr than these amounts in practice.

Wall system	Wall insulation	Wall caldding	Roof	Roof insulation	Foundation
Concrete block	-	Stucco over metal mesh	Metal roof system	Polystyrene	Concrete footing
Metal system	Polystyrene	Cement	Metal roof system	Polystyrene	Concrete footing
Steel stud	-	Metal cladding	Metal roof system	Polystyrene	Concrete footing
Steel stud	-	Brick	Metal roof system	Polystyrene	Concrete footing
Wood stud	-	Stucco over porus surface and brick	Lightweigt wood	-	-

Table 5.5. Building material properties of 5 simulated examples by Athena Impact Estimator for LCA

Athena Impact Estimator's database is not defined for locations beyond the US and Canada. Therefor, to have an estimation of the export influence on LCA, BEES software was used to see the impacts of transportation costs and energy on the total LCA results. As a result, four types of materials have been selected based on the location of the building components for these four materials. Brick and mortar are based on 2o mile distance from the city, stucco is based on 117 mile that comes from Kerman, alluminium sheets were imported from Turkey and Korea the average of 2,925 mile was assumed for this material. Finally wood refers to the local and avaiable plant-based materials within the 3 miles from the center of the city of Bam.

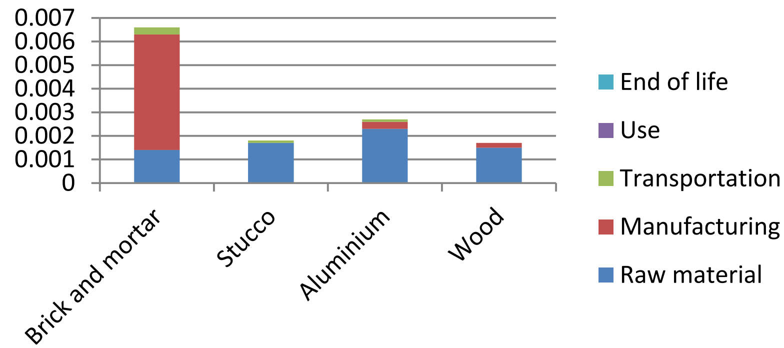


Figure 5.84. Embodied energy comparison of four types of materials based on the location of the resources calculated by BEES

While the source location was significantly different in thse four options, the results also support the Athena Impact Estimator results on the higher amount of embodied energy for brick compared to the aluminium sheets. I think the reseon behind these results is that Athena's database is based on the fact that it's assuming that the firing fuel for bricks is gas.

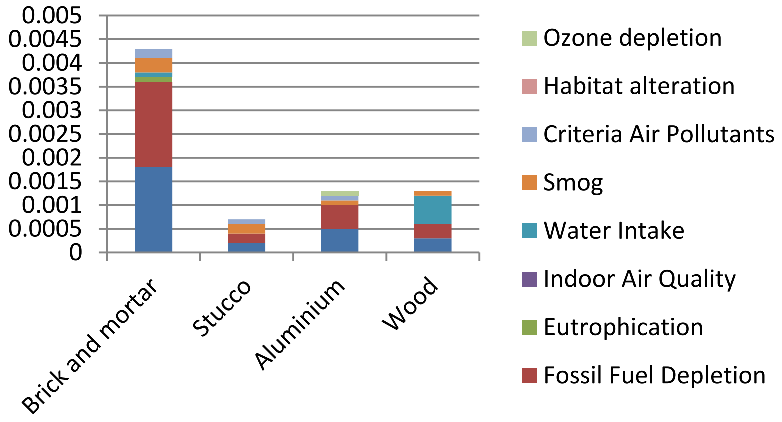


Figure 5.85. Environmental impact comparison of four types of materials based on the location of the resources calculated by BEES

For clay bricks manufacturing in post-earthquake reconstructions in Bam, natural gas was used as the fuel source. However, there are still a traditional brick-baking factories (or manually or pressure bricks) all over Iran including near Bam. In the traditional brickworks, clay is taken from the quarry, and then carried by workers to the yard After the forming or cutting, the bricks must be dried, in the open air, in drying sheds, When the bricks have been dried, they must then be fired or 'burnt' in a kiln, to give them their final hardness and appearance. The fuels in these factories are coal, wood and oil. Therefore the environmental impacts of these types of bricks can be lower than the presented results.

5.12.2. R-value comparison of temporary building material options: The following chart compares the R-Value estimations of the four different material options:

Material	R-Value per inch	Thickness	Total R-Value
Polyurethane foam insulation	5.5- 5.6	0.92 inch	8.87
Aluminum sheet	0.61	2 layers of 1.6 inch	7.6
Polypropylene insulation	4.4 Arpro.com	2 layers of 1.6 inch	
Lightweight concrete blocks 8”	1.14 - 2.96	8 inch	16
Concrete blocks 8”	1.11- 2.5	8 inch	9.8
Polystyrene expanded insulation	3.6- 5	2.36 inch	7.07
Concrete 90 pounds per cubic foot	0.26 archtoolbox.com	1.6 inch	
Brick 4”	0.44 – 0.8	4 inch	4.62
Reed sheet	3.4 (similar to 2.5 cm of fiberglass) Cantex.com	1 inch	3.4

Table 5.6. R-value of main materials used in temporary buildings

Source: www.coloradoenergy.org

The results show that a two layer Cantex panel can achieve the R-value which is higher than clay brick and almost equal to 3D wall panels and corrugated aluminum sheets as the roof panels.

5.12.3. Comparison of the surface physical properties of materials: To choose the roofing material, I compared the surface absorption and emission properties of 7 materials. Table 5.7 compares these properties (Nielsen, 2002):

Material	Roof aluminum galvanized sheet	Plaster	Clay brick	Concrete block	Plant	Earth
Absorption %	20-30	20-30	65-80	45-65	5-10	30-40
Emission %	20-30	85-95	85-95	85-95	85-95	85-95

Table 5.7. Comparison of surface absorption and emission percentage

Source: Nielsen, 2002

Apparently, these values can demonstrate that the low level of energy absorption and high level of energy emission of plant-based materials make them a compatible building material in hot climates.

5.13. Energy, resources and waste management: the biodigester plant:

The idea of proposing a biodigester plant was first developed when I thought about the integration of waste management system after the disaster, renewable energy resources for residential sector and the economic profitability of agricultural by-products for the residents of the city.

By using food waste as our source of power, we are diverting this material from landfill. When food rots down in landfill sites, it gives off methane. The comparative impact of CH4 on climate change is over 20 times greater than CO2 over a 100-year period (US Environmetal Protection Agency, http://epa.gov/climatechange/ghgemissions/gases/ch4.html). Furthermore, by capturing the methane in our plant and using it for energy, we reduce society's need for burning fossil fuels, saving even more carbon. Finally, by substituting manufactured fertilizers for our digester, farmers using it will have saved still more carbon emissions due to the high levels of carbon emitted when conventional fertilizers are manufactured.

According to Kerman Public Relations Regional Electricity Company News, per capita consumption of crude oil is 1.82 Tonnes. Also 24.6% of residential energy consumption is based on the subsidies (Regional Electricity Company of Kerman, www.afshankrec.ir). Table 5.8 shows the average annual cost of energy for urban and rural households and its share in total household expenses in 2008.

Energy costs	Food expenditures	Non-food expenditures	Total cost	Total cost thousands of Rials
Urban households				
2.5	22.4	75.1	100	81,289
Rural households				
4	37.3	58.7	100	48,846

Table 5.8 .The average annual cost of energy for urban and rural households and its share in total household expenses in 2008

Source: Regional Electricity Company of Kerman

From the total primary energy supply about 67% of the energy is produced from crude oil, 32% from natural gas, and only 0.003% from renewable energy resources. Considering that the agricultural sector is responsible for 3.6% of total energy consumption in Kerman and the residential and commercial sectors consume more than 41% of the total energy, finding an alternative renewable energy resource is a rewarding investment in long-term rural and urban planning (Regional electricity company of Kerman, www.afshankrec.ir).

During the temporary housing phase, every neighborhood has a storage tank for human sewage, food waste and organic waste storage. The agricultural waste from orchards and farms will be collected separately. All of the feedstock will be transported to the main gas generation tank outside the city boundary. The bio-gas will be produced in the anaerobic digester. The liquid Methane gas will be transported to the houses in Bam and Baravat for cooking and heating purposes in canisters.

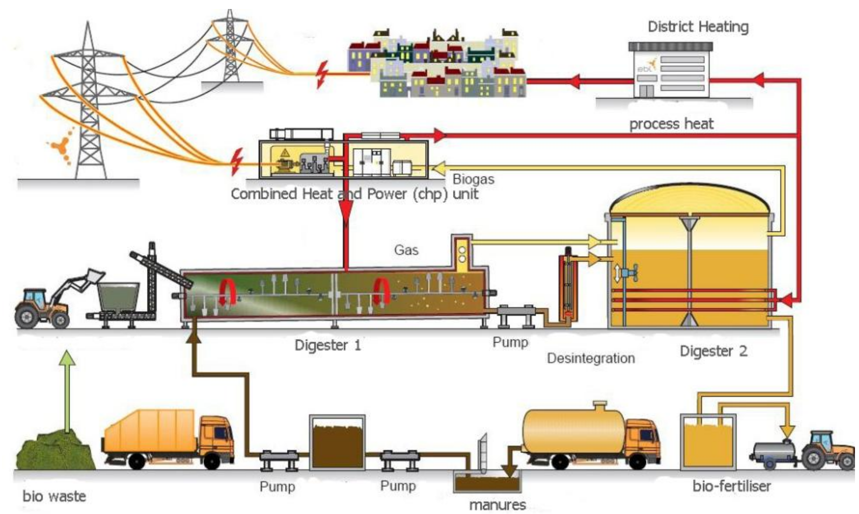


Figure 5.86. Biodigester and biogas plant conceptualdiagram

Source: energisesussexcoast.co.uk

After the temporary housing phase, the Methane produced in the anaerobic digester plant will be transferred to a generator for electricity production.

Figure 5.87. A biogas plant in Switzerland with 10,000 food waste tonnes per year capacity

Source: http://energisesussexcoast.co.uk/our-biogas-plant/

The Sphere charter had no specific minimum requirement for energy and fuel supply in humanitarian projects. I think that it is because of the variety of energy resources in different locations and projects all over the world and the differences between human needs, life styles, heating system and stove types in every country. However, based on the definitions of WHO a person is in 'energy poverty' if they do not have access to at least:

a) the equivalent of 35 kg LPG for cooking per capita per year from liquid and/or gas fuels or from improved supply of solid fuel sources and improved (efficient and clean) cook stoves

b) 120kWh electricity per capita per year for lighting, access to most basic services (Tennakoon, 2008).

Considering the density of Methane, which is 0.67 kg/m^3, about 52.2 m^3 of Methane is needed per capita per year as the minimum amount of cooking fuel. For the population of Bam based on Census 2006, the biogas will be more than 35% of total annual cooking fuel needed for Bam and Baravat.

The Biodigester plant feedstock calculations: Based on estimations for the amount of feedstock around the city of

Bam, different sources of feedstock have been measured to calculate the capacity of a biodigester in the city.The resources are found within the 2.5 miles radius around the city center of Bam for two cities of Bam and Baravat including human sewage, organic waste, plants and parts of plant.

Figure 5.88. 2.5 miles radius distance from the city center of Bam, including Bam and Baravat cities

For this plant, human sewage was calculated for the population of the city of Bam and Baravat. Therefore the adult population is assumed 144,211 (based on the census 2006 for demography of Kerman province). The average human sewage production in Iran is 150 L/day (Water and Waste Water Company of Iran, www.abfa.ir). This amount equals to 238.43 lb/day. On the other hand, adults with a high-fiber diet produce an average of 349 g/day of wet-stool (Hosseini-Asad and Hosseini, 2000). However, only 104.7 grams of viable fuel can be produced by that, because water makes up approximately 70% of the stool weight.

For date fruit production industry, the estimation of the sugar and fiber content has been equalized with available data on apple production industry for energy production in a biadigester system. Bam is the most famous place for high quality Mazafati dates in the world. Bam region has around 28,000 Hectares of the lands under the harvest of mazafati Date from which 5,000 Hectares pertains to young palm trees. 120,000 tons of the Date is being harvested from the land annually (Datefruit.ir). 100 g of Mazafati Date contains around 1.81 grams of protein, 0.15 gram fat, 74.97 grams carbohydrates, 6.7grams dietary fiber and 113 grams sugar. It produces 282 kcal (1178 kJ) of energy. The same amount of apple contains 52 kcal of energy (USDA). Therefore, for biodigester calculations apple fruit was considered to have approximately 18.4% of energy that date fruit produces. The same amount of clementine also produces 47 kcal. Apple was therefore considered to have 16.7% of clementine energy. It was assumed that 70% of this amount of waste, which equals to 11,049 Tons, will be used in the biodigester plant. The rest can be used as livestock feed.

Bam has also about 6,177 Acre of clementine with 18,000 tons of fruit annually (Young Journalists Club, 2013). From this amount 28% to 31% will be solid waste (Iran Citrus Research Institute). In addition, 2,965 Acres of Bam country are wheat farms that produce 4,365 Tons of wheat product (Young Journalists Club, 2013).

Wheat is highly important in agricultural products because it's a strategic and food staple in the Middle East. Also, from harvesting to post-harvesting processes of wheat approximately 36.85% of solid waste will be produced. This high amount shows that wheat waste management is indispensible (Asadi et al, 2010).

There is no mechanized method or harvesting machine available for date in Iran. 30% to 40% of the annual date fruit production turns into waste before reaching to the packing industry and 10% of it is exported to other countries (IRNA, 2013). Besides the new and only industrial alcohol from date waste producer in Bam, this amount of waste will be animal feed. Date palm harvesting solid waste was increased in the past years in Bam because of the droughts and pests.

The figure 5.89 illustrates the physical composition of solid waste in Iran and in Bam. These graphs show that 62% of solid waste in Bam is produced from food waste and putrescible materials. The portion of paperboard (consisting of paperboard and cardboard) is lower in Bam because of the date packaging industry that recycles a portion of the paper and cardboard waste for larger cardboard boxes.

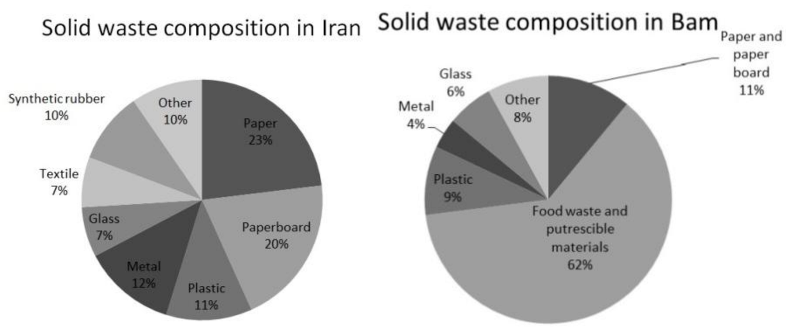


Figure 5.89 Solid waste composition in Iran and in Bam

Source: Mahvi et al, 2005

Organic waste in biodigester feedstock calculations refers to the food waste and also paper and cardboard waste production in Bam. The date industry in Bam produces the average of 7,000 tons of date production annually. The estimation of 16,500,000 packages will be produced annually in Bam in 2.2 lb and 1.1 lb sizes which make the production of 4.4 Tons of cardboard. According to Mahvi et al. 65.6 Tons of putrescible and food waste and 11.6 Tons of paper and cardboard is being produced in Bam (Mahvi et al, 2005). Thus the amount of paper and cardboard which is not recycled in the city is assumed to be 2.4 Tons per year. Also, about 60% of the food waste is considered to be used as feedstock in biodigester.

In addition, as mentioned earlier in this chapter, more than 2,363 Tons of DPF and 15,756 Tons of DPL are produced each year in Bam as the agricultural by-products. The approximate amount of 60% of this organic waste was considered to be used in biodigester. The rest can be used in new and innovative agricultural-based building materials.

The following table shows the feedstock resources for the proposed Bam anaerobic biodigester plant.

Feedstock	Amount	CH4 m^3/yr	kWh
Human sewage	5.51 Tons	542	5,417
Food waste	39.36 Tons	4,107	41,067
Fruit production industry (10% of date production)	12,000 Tons	1,163,460	11,634,597
Fruit (30% of clementine production)	5,400 Tons		
Grain (30% of wheat production)	1,309 Tons	374,912	3,749,117
Biowaste from farms and orchards and paper	10,871 Tons 2.4 Tons	126,183	1,261,829

Table 5.9. The feedstock resources amounts and energy production of the proposed Bam anaerobic biodigester plant

Based on the analysis of the biodigester, the total capacity of the biodigester plant will be 2,629 kW (2,492 BTU/sec) with 2,302,658 m3 Biomethane and 23,026,578 kWh energy production annually. For the population of Bam based on Census 2006, the biogas will be more than 35% of total annual cooking fuel needed for Bam and Baravat. (http://www.biowattsonline.com/biogas_calculator).

Totals yearly	34,161 Tones fresh matter	2,302,658 m3 Biomethane	23,026,578 Energy kWh

Table 5.10. Energy and Methane production capacity of the proposed Bam anaerobic biodigester plant

5.14. Structural tests on date palm frond structures:

Piesik and her team built a full scale structural model of arched roof Arish house in Al Ain. In order to assemble the arch, palm fronds were peeled from leaves and soaked for a night in non-saline water. Wet fronds were then connected with rope made traditionally from palm tree fibers to form an arch. However, for actual building construction it is recommended to use adjustable steel brackets.

To build a 13 meter span with 4 meters height, the arches were propped up by palm tree columns in three spaces to make a strong support for roof covering. The largest distance between the arches could be 3.5 meter and each column was consisting of about 40 tall and thick fronds (Piesik, 2012).

The weight of each arch was about 500 kilograms and three arches could comfortably support the load of 2 tons of palm leaves. With the wind speen of 35 kmph in Al Ain, the the structure was left untouched (Piesik, 2012).

Based on the test results on mechanical and physical properties of dare palm fronds by Piesik, I used SAP software to analyze the impact of lateral and gravitational forces on one variation of Kapar structure with date palm fronds prototypes. In addition to the weight of the roof – consisting of roof cover, snow and designed wind-catcher- lateral loads of wind and seismic forces in the city of Bam have been considered for these analyses. The simulation was based on the following material properties of date palm fronds:

- Bundles could carry tension between 45-50 N
- Average tension is 1600 N/mm2
- Modulus of elasticity for each stalk is 20,000 N/mm2
- Ultimate tensile strength of the peripheral portion of the stalks is 175 N/mm2
- Ultimate tensile strength of the core zone is 80 N/mm2
- Arches can support the load of 2/3 tons of leaves when the height is 4 meter and the span is 13m (Piesik, 2012)

For simulations, I assumed 20 kg/m^2 of dead load for roof weight and 100 kg/m^2 of live load for snow. In the Iranian earthquake building design code (Standard 2800) it is indicated that it is not necessary to consider both wind and earthquake forces simultaneously for the lateral load. Therefore, the higher amount will be considered as the lateral load. For this simulation the specific location of Bam the maximum wind load was higher than the seismic load (about 10 km/h).

Since it was not possible to simulate the rods with wood material in SAP, I simulated my model with metal given the specific properties of date palm frond materials. In addition, because in the Iranian earthquake building design codes (Standard 2800) there is no specific part for wood structures, I had to use the US building codes in SAP.

Appendix 3 shows the analysis results of the SAP simulations. Based on the defined live and dead loads, the minimum diameter of 12cm for each of the rods is required. The whole structure can withstand the lateral load of the wind and weight load of the roof with minor bending.

Figure 5.90. Rod samples made from date palm fronds

Source: Piesik, 2012

Between the different variations of Kapar structures, I looked for the ones to can withstand the roof load better. Having an extra load of a wind-catcher on the roof during the design process, led me to the selection of the structure with rods connecting together at the highest point of the arches as shown in figure 5.91. An external grid of fastened date palm fronds will be covering the rods. This lattice is fastened to the rods in multiple locations.

Figure 5.91. The original example of the selected type of Kapar structure

Source: IRNA

III. Speculations

5.15. Material and form speculation:

1. The first trajectory of speculation began with an investigation on available local materials for building elements. The following diagram shows the low-cost locally available materials and energy resources in not only the city of Bam, but in many other cities in semi-arid climatic

regions after a hypothetical earthquake in Iran. Solar energy, wind energy, date palm trees, earth, paper and cardboard, debris, plastic bags, rice sacks and water bottles are among the materials which could be easily found in these areas.

Figure 5.92. Available low cost materials in post-disaster situations in Bam and similar cities

2. The next level was finding local shelter techniques associated with some of these materials. At this level, the first common shelter technique in the above mentioned areas was found to be Kapar in different types and variations.
3. Being a threshold to the permanent housing constructions, temporary houses can directly or indirectly make ties to the next phases of post-disaster recovery to facilitate the transitional phases. As previously mentioned in low-cost reinforcement assessment part of the thesis, confinement was chosen to be one of the most adaptable engineering techniques to the traditional building techniques of masonry in these areas. However, internal and external date palm fronds reinforcements of masonry are also among the potential techniques for future researches and tests to be considered as a low-cost and simple construction techniques

for these regions in the forms of internal mesh or external rope and mesh reinforcement. Therefore, earthen materials, plant-based reinforcement techniques and organic materials were can potentially make strong connections between temporary and permanent housing phases.

Appendix 4 proposes an advance list of material alternatives for temporary and permanent housing construction in the city of Bam and similar locations in Iran based on the above mentioned considerations.

4. Considering that because of the poverty many people live permanently in Kapars and many children study in these types of shelters in remote and poor areas of southern Kerman, another aim of the design part of this project was to find solution for the current social and technical problems of the informal settlements of these areas.

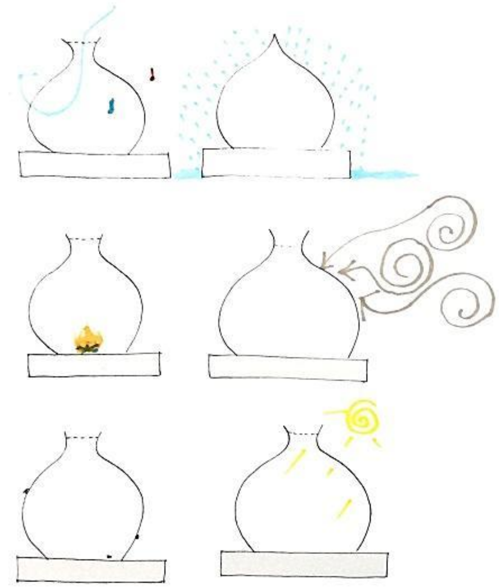


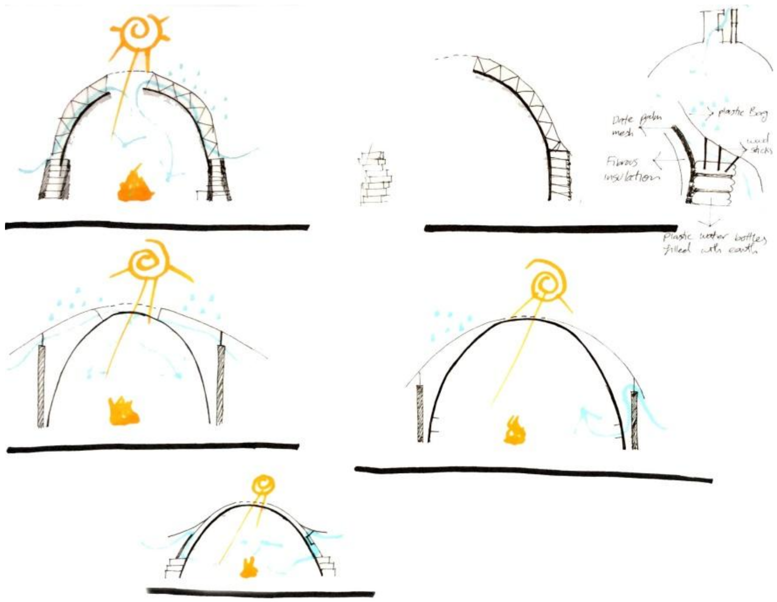
Figure 5.93. Illustration of traditional Kapar issues in remote areas of Kerman being used as temporary houses or schools

The following table summarizes advantages and disadvantages of Kapars as the dominant informal settlement of the hot and arid climate of Iran.

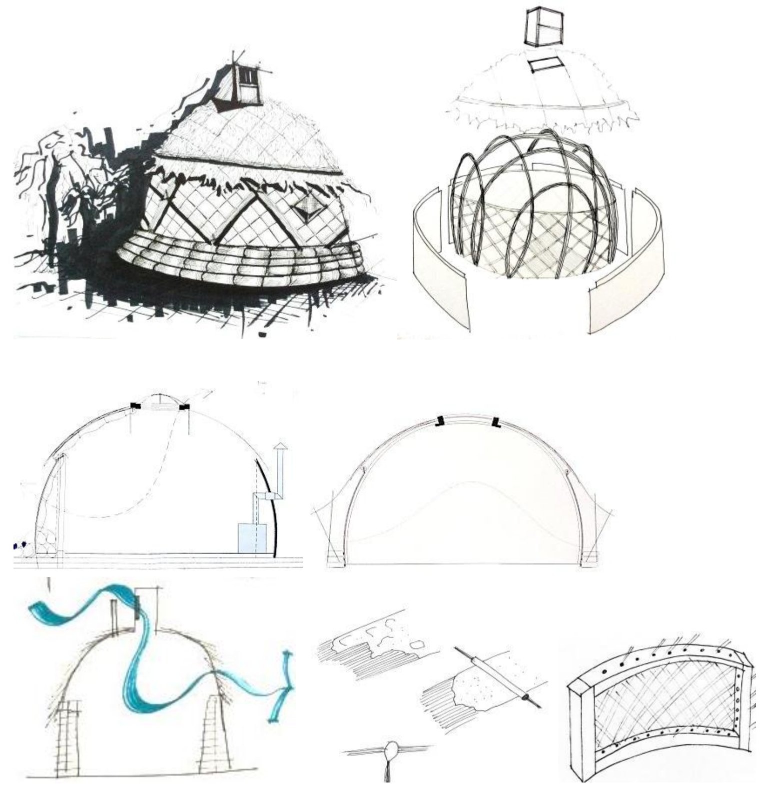
Advantage	Disadvantage	Solution
15-20 degrees Celsius difference between inside and outside	Becomes hot in the extremely hot summer days and cold in the winter time	Need insulation on the wall
Roof is almost waterproof with very small issues in the summertime heavy storms	Walls are not waterproof and rainwater on the ground level can easily enter the shelter	Needs wall coverage specifically and also more roof coverage to protect the interior space from rain water
People easily cook inside the shelters	Evidences of fire events mostly from leaf covers from exterior parts	Plant-based materials must become fire retardant
-	Scorpions can enter the shelter when people pull the mat coverage of walls up	-
Natural ventilation through the small openings of woven mats	Sand can enter the shelter during the sand storm season in the summer	Extra layer of coverage is needed that does not block the natural ventilation
Sunlight enters the shelters through the open spaces between the woven mats	The interior space becomes very dark when the mats are down	Artificial lighting and also openings are needed
Structurally stable if constructed properly	Poor material use and inappropriate construction and design in many areas	Need for standardized quantities and prepared construction directions

Table 5.11. Kapar design diagnosis

5. At the next level, the exercise of speculating different form possibilities for making new variations in Kapar which can address the needs and solve some of the problems were studies. The following sketches illustrate some parts of these exercises.



Date palm mesh
plastic Bag
wood sticks
Fibrous insulation
Plastic water bottles filled with earth



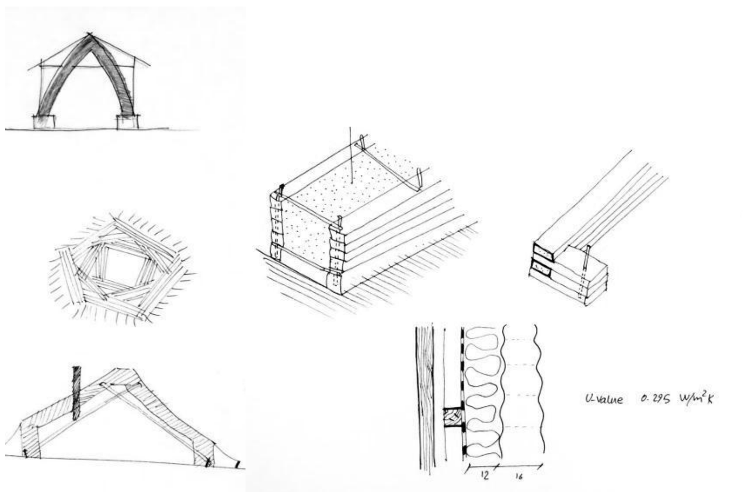


Figure 5.94. Sketch examples on form and construction details for Kapar

The form of hemisphere was chosen because this form has the least Surface-to-Volume ratio comparing to the other geometrical forms. This compact form of the hemisphere reduces the heat transfer between inside and outside of the dwelling.

6. One of the main concerns at the material investigation level was the waste production and post-disaster usage of the units and easy disassembly of shelters. Making connections between several issues related to the post disaster management in Iran - such as waste management, water shortage, building material shortage, environmental impacts and transportation issues- led to the direction of searching for as many locally available organic and natural materials as possible. Therefore, not only the selected organic materials are not environmental threats for the city, but also they will be an energy resource as parts of the Biodigester feedstock after the temporary housing phase

finishes. At this level, studying the low-tech possibilities based on the available materials and resources was the aim to make a list of alternatives for the plant-based Kapar material. The rest of the options were either materials that could be easily returned to the nature –such as loam- or the ones that can be used in permanent housing constructions –such as canvas or goat hair fabric.

7. The process of using such resources is remarkable; the evolution that can occur over time is equally important. The other concern at this level was the flexibility of materials in form and sizes. Due to the past unsuccessful temporary camp projects, the proposed units are designed to be used in the previous lands of house owners. Where possible, these settlements will be located in the yards. While most of the houses have enough spaces in the yards for the survived population, some people have to live in the shelters located on their neighbors' lands.

8. Finally, timing consideration for material selection was the other factor that influenced the decisions. Durability of the materials within the estimated time of 2-3 years on one hand, and short construction period on the other hand, were two main factors. Within the time frame of a week, a kit of all required materials for the construction of the shelter can be available. In order to alleviate the unfinished buildings, the basic model is made from simple techniques and cheap materials. However, in order to make the projects feasible after the disaster, the

local governments need to depot the raw materials in every county. In Kerman province the number of 21 counties shows that at least 21 emergency storage locations are needed to provide construction materials for probable future earthquake events.

5.16. Other potential low-tech building materials:

In addition to the material research, I operated a material test at the University of Minnesota, Department of Chemistry. In an attempt to make a local binderless and self-adhesive wood-based construction panel or insulation layer for areas rich in date palm trees, I examined six different samples in a heat press machine. The following chart shows the different pressure, time and temperatures that the samples were tested. Each of the samples was made of 8 layers of trunk fibers from original trees shipped from the city of Bam. The aim was to find an estimate amount of time, pressure and temperature for a self-adhesive ¼” dense layer made of date palm truck fiber. The best result was achieved at 140° C in 2 minutes under the load of 5000 lb.

Figure 5.95. Testing a sample of 8 layers binderless date palm trunk fiber sheet with heat-press machine at the University of Minnesota

Load lbs	Temperature	Time	Result
7000	50 ° C	1 min	Layers are not bonded
7000	70 ° C	1 min	Layers not bonded very well
7000	85 ° C	2 min	Bonded, ¼”
1000	100 ° C	2 min	Layers not bonded ½”
3500	120 ° C	2.5 min	Inner layers not bonded, outer layers bonded and some parts are melted, ¼”
5000	140 ° C	2 min	Bonded, ¼”

Table 5.12 Test results on a binderless heat-press layer of fine date palm trunk fibers

Figure 5.96. The sample before using the heat-press machine and after the experiment

There are a limited number of researches on the thermal qualities of palm fiber panels. Manohar tested the thermal conductivity of a 51mm thick, 254mm^2 specimens of oil palm fibers in accordance with ASTM C518. The results show that the minimum thermal conductivity for the materials ranged between 0.042 W/m.K to 0.058 W/m.K over the mean temperature ranged 15.6°C to 32°C. These values are within the range of 0.02 W/m.K to 0.06W/m.K which is normally used for thermal building insulation (Manohar, 2012).

5.17. Loam as a building material:

In nearly all hot-dry and moderate climates of the world, earth has been the predominant building material. Even today, one-third of mankind lives in earth houses; in developing countries this figure is more than one-half (Mink, 2000). It has not been possible to fulfill the immense shelter requirements of developing countries with industrial building materials, such as brick, concrete or steel, nor with industrialized production techniques. According to Minke, nowhere in the world the production capacity or the financial resources exist to satisfy shelter demand in developing countries and this requirement can only be met through the use of local building material and through self-help construction techniques (Mink, 2000).

Moreover, earth is the most important natural building material and is available almost in all regions of the world. It is frequently obtained from the building site when excavating for foundations or basements.

Earth construction techniques have been known for more than nine thousand years. In dry climatic zones where wood is scarce, construction techniques where developed in which buildings where covered with mud brick vaults or domes without formwork or support during construction.

Earth used as a building material is often given different names. Scientifically referred to as loam, it is a mixture of clay, silt, sand and sometimes larger aggregates like gravel or stones.

Loam disadvantages in comparison to industrialized materials:

1. Loam is not a standardized building material and it is necessary to know the specific composition of loam
2. Loam mixtures shrink when drying out
3. Loam is not water resistant and earth walls may be protected by roof overhangs, damp proof courses, appropriate surface coatings etc.

Loam advantages in comparison to industrialized materials:

1. Loam balances the air humidity faster and to a higher extent than all building materials. Experiments at the University of Kassel in Germany demonstrated that when the relative humidity in a room was suddenly raised from 50% to 80%, unburnt bricks were able to absorb 30 times more humidity than burnt bricks in a period of 2 days (Mink, 2000).
2. Loam stores heat which is a significant feature in climatic zones where the diurnal temperature differences and high.
3. Loam saves energy and reduces environmental pollution. According to Mink, to prepare, transport and

handle loam on site, only 1% of the energy needed for production, transportation and handling of burnt brick or reinforced concrete is needed.

4. Loam is always reusable. Unburnt loam can be recycled any number of times and forever after soaking in water.
5. Loam saves material and transportation costs.
6. Loam is ideal for self-help construction. Earth constructions can be executed by only one experienced person controlling the construction process. The techniques are not labor intensive and need inexpensive tools and machines.
7. Loam preserves timber and other organic materials which are in contact with it because of its low equilibrium moisture content of 0.4% to 6% by weight and its high capillarity. No fungus or insects will destroy such wood (Mink, 2000).
8. Loam absorbs pollutants in water such as phosphates.

Lightweight loam infill:

The thermal insulation of loam can be increased by adding straw, reeds, husk of grains and other light plant matter. Loam with lightweight aggregates in called lightweight loam if its density is less than 1200 kg/m^3 (Minke, 2000). To produce lightweight straw or date palm fiber loams, rich clayey slurry must be used. In order to increase the thermal insulation, straw with rigid shoots are preferred. If 10 parts of cut straw are mixed with a thick loam slurry made of 2 parts of dry claye loam and 1 part of water, this will give a mixture with dry density of about 1300 kg/m^3 and a u-value of about 2.1 W/m^2K. This amount is based on a 14cm thick wall. To achieve the u-value of 0.5 W/m^2K the thick ness of the wall needs to be 0.95cm (Minke, 2000).

Wattle and Daub building technique:

This is an old technique, which has often been used in medieval Europe. Wattle and daub starts with a lattice of vertical studs and horizontal wattles. Traditional wattle and daub consists of a structure made from cylindrical wood or bamboo filled with earth and straw inside a double structure made from bamboo strips or thin canes. A mix of earth and straw (in my project it can also be with date palm fine fibers) is then daubed onto this latticework, forced into the gaps and smoothed over to fill any cracks. The surface can be left as a rustic finish or rendered for a smoother finish. Wattle and daub walls are non-load bearing and are built into a wooden framework. In my project the framework can be made of reed panels or date palm frond panels. The wall can range from 15 to 20cm in thickness.

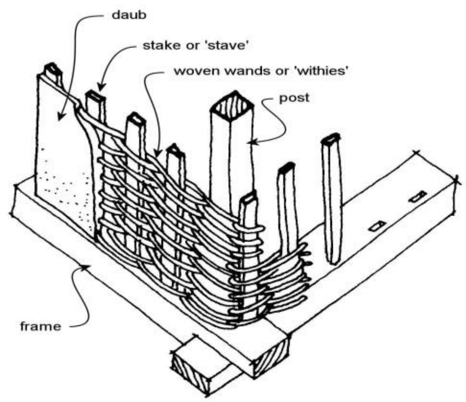


Figure 5.97. Wattle and daub construction elements diagram

Source: www.tonygraham.co.uk

5.18. Design elements and construction stages of the modified Kapar shelters as temporary houses:

Step 1: Decide where to build the dwelling structure. In this case, for every dwelling a 49 m^2 of open area is needed to build a single shelter. If the household is hosting other households' dwellings on their land, the minimum distance of 1m between the shelters must be considered to provide privacy.

Step 2: Before date palm leaf fronds can be used, peeled and dry date palm leaves must be soaked in a pond of water for 3-4 days to become flexible enough for bending.

Step 3: Before date palm leaf fronds can be used, they must be chemically treated. The all the plant-based materials must be soaked. It increases the longevity, preserves the plant parts not to decay easily and also makes the dried date palm leaves fire-retardant. They can build a tank made of bricks, or at cheaper cost, lining an excavation in the ground with polythene sheet. A typical preservative can be prepared to be mixed in the tank in the following proportions: Copper Sulphate 4%, Sodium

Dichromate 4%, Boric Acid 2%, water 90% (Asian Disaster Preparedness Center, 2005). They are then to be immersed completely in the chemical preservative solution for 24 hours. After soaking, the materials are to be raised above the tank and supported on timber battens so that excess chemicals can drip back into the tank and can be re-used.

Then they are to be dried in an open shaded space for 1-2 days and then in sunshine for 3-4 days (Asian Disaster Preparedness Center, 2005). Gloves or polythene bag covers to be worn to protect hands from chemicals during the treatment process.

Step 4: Similar to the treatment of date palm fronds and mats, fibrous thatching materials such as wheat straw need to be soaked in preservation solution for about 24 hours.

Step 5: Soil should be crushed and sieved through a screen. Debris and organic matter should be removed. After mixing 4-5% of stabilizing agent (lime) and mixing it thoroughly, water should be added to make a paste-like mixture.

Step 6: Prepare site. This phase consists of leveling the site and removing unwanted debris.

Step 7: The most determinative elements for the construction of the shelters is assembling the rods that shape the whole structure. Based on the structural analysis of a circular shelter with 6m diameter, the number of 8 arches or 16 rods needs to be prepared to withstand the external loads with 1.5 meter distance between them on the ground level. The summary of simulation analysis done by SAP software is presented in appendix 3. For each of the columns, the best result by SAP was achieved by columns with 12cm of diameter.

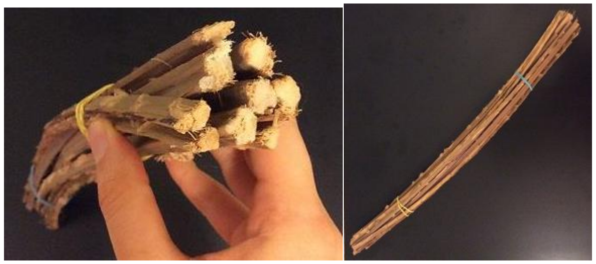


Figure 5.98 and figure 5.99. Medium size leaf samples from Bam and the woven date palm leaf mat sample

The physical properties of date palm fronds and leaves are based on three 2m long leaf medium size samples shipped from Bam.

Figure 5.100. and figure 5.101. Medium size leaf samples from Bam and the woven date palm leaf mat sample

I have also used the similar Phoenix Dactylaferia leaves shipped in small size (1 meter long) from California to make a small scale sample of roof assembly.

Figure 5.102. Small size leaf samples from California

A 12cm rod needs the number of approximately 18-27 date palm fronds in the section of the columns depending on the size of the leaves. Considering that each medium size leaf is about 2 meters long and the large ones are approximately 5 meters long, the total approximate number of 2,300 dried DPL is required to prepare the structural rods for one each shelter. As mentioned in previous chapters the total amount of 15,756.7 metric tons of DPF is produces annually from dried leaves in Bam. Considering the approximate weight of a dried medium size leaf frond as 0.6 lb, approximately 11,400 DPF structures similar to the proposed one can be made with the dried leaves in Bam.

Instead of the traditional natural ropes made from date palm leaves that fasten the arches together, galvanized wire mesh is proposed for the shelters for more durability. The wire mesh must be used in almost every 50cm of the rods to ensure the tightness of fronds.

Step 8: Setting the position of the columns on the ground and digging 12 holes each 1m deep on with 12cm diameter is the next step.

Step 9: After the structure is finished, floor slab must be built. The wall base should be approximately 20cm above the level of the ground on the outside in order to avoid absorbing humidity when it rains. (Aedo and Olmos, 2014).

Traditionally, all the rods are dug into the ground for only 50cm. To ensure that the rods are stable in the ground, I suggest that each columns be dug into the soil (<10-m depth which is fine-grained soil with clay, clayey sand, cohesive sandy mud, cohesive muddy sand sediments).The soil needs to be compacted with a hand rammer to build an earthen 10cm plinth. On top of the compacted earthen plinth, a 5-7cm stabilized earth capping and 15-18cm thick on the sides covers the earthen plinth. For soil with more than 40% sandy-silty particles, about 5% stabilizer (lime) additive is adequate. Stabilization works best together with compaction. Can be cast and compacted by hand and finished with a trowel. For further compaction, a simple hand rammer or wooden battens can be used. At least 3 weeks curing by water should be done. The rice sacks that cover the plinth, will keep moist and water poured at regular intervals to avoid drying (Asian Disaster Preparedness Center, 2005).

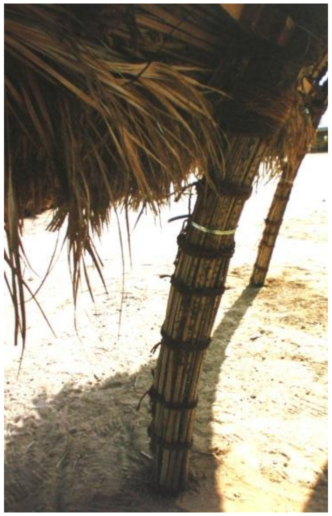


Figure 5.103. Date palm rods inserted into the ground

Source: Piesik, 2012

Step 10: Cheap methods for protecting the lower end of rods embedded into the ground from dampness could be molten bitumen or sump oil. Because there is no local method for damp-proofing the rods, these materials require examination and promotion.

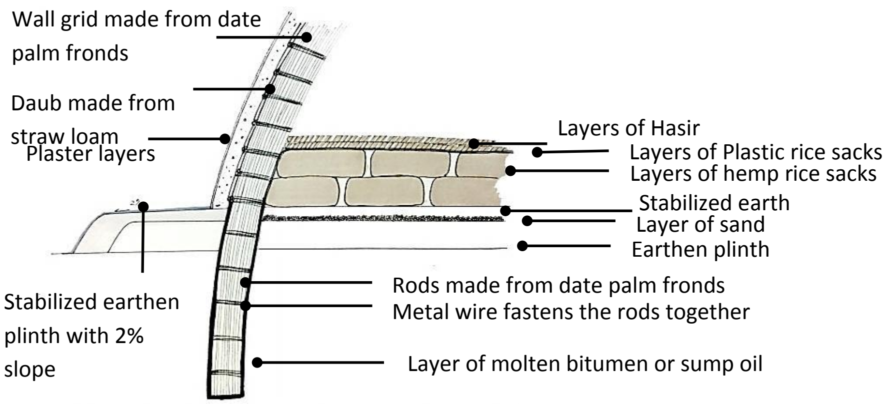


Figure 5.104. Detail from wall and floor section

Step 11: Fastening the peak points of arches together with galvanized wire.

Step 12: The structure should be correctly joined and anchored at the ground level. Three tension cables will be placed to connect the rods horizontally to reduce the effects of suction and uplift in every one meter from the ground level. There are two different options for material selection of these cables. The first one is similar to the rods. The second one is galvanized metal tension cable. In SAP simulations I used the properties of natural date palm frond materials. However, it is preferred to have metal cables for temporary houses. The tension cable is fastened to the rods on the ground level with galvanized wire.

Step 13: Since rice is one of the main parts of the Middle Eastern diet, in emergency food management plans, the local governments send sacks of rice in large numbers. These rice bags are abundantly available in every city or rural area in Iran. On the other hand, there is no major reuse plan for these bags in Iran. My investigations on the types of these bags show that the type of the rice that the government sends after natural disasters for people is low-price Iranian rice. These hemp bags pack 10kg of rice and four hemp bags together are packed with transparent or white color polypropylene bags which are relatively thick and durable.

Figure 5.105. and figure 5.106. A 10kg filled rice bag and a Polypropylene rice bags from Iran

I filled a 10kg rice bag in 30cm by 40cm dimensions with earth and the filled bag weighted almost 13-14 kg. The door must be sewed. A grid of 19 by 19 bags must be placed on the ground enveloping the columns.

For air movement between the bags, from smaller side of the bags (30cm) must be placed 10cm away from each other. To have a 30cm slab, we need three layers of rice sacks. To ensure the stability of bags, the 10cm space between begs can be shifted 15cm on the upper layers. Totally 867 rice bags are needed for each shelter.

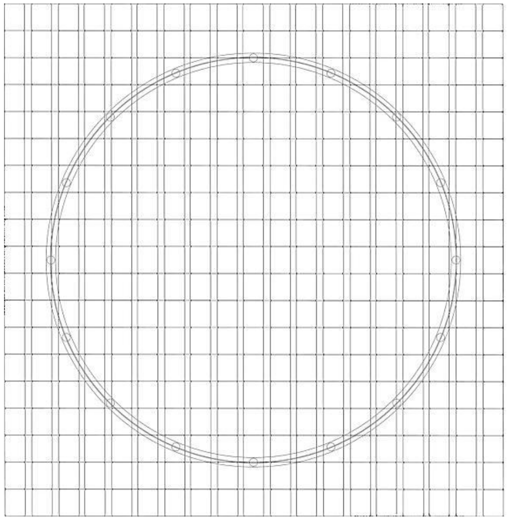


Figure 5.107.

Arrangement of rice bags for floor slab

Finally, a layer of sewed polypropylene rice bags will cover the top layer of hemp bags to provide water proofing for the base. Then two layers of Hasir is the finish layer of the flooring.

Figure 5.108.

Date palm woven mate (Hasir) sample from Bam

Step 14: Interwoven date palm fronds are inserted in such a way that they are self-anchoring. From the structural point of view, this lattice works similar to bracing systems. The whole structure will be covered by this grid. The grid is made from fastened diagonal ties with 2 frond thickness elements fastened by woolen ropes. Traditionally, the fronds are fastened by date palm leave ropes which are not very durable. The goat hair woolen ropes are cheap and they can be used for more than 20 years.

Figure 5.109.

Goat hair woolen rope samples

The lattice (works as the wattle) is shaped by two networks of perpendicular elements placed fastened together in every 10cm. For the 1.5m tall wall, it is estimate that of 1,100 leaves are needed.

Figure 5.110.

Interwoven grid of date palm fronds covering wall and roof, fastened by date palm fiber rope

Source: Piesik, 2012

Step 15: Drag the lattice wall into place and fasten it to the rods with galvanized wire. The door opening is 90cm wide.

Step 16: High crack resistance and impermeability to water can be provided with layers of mortar evenly distributed on a thin chicken wire mesh. Hexagonal (chicken mesh) is commonly used in Iran and it should be galvanized.

I speculated that instead of chicken wire, hemp or jute bags or sheets of treated fine trunk fibers fastened to the wall can be also used. I prepared a model of this speculation by with a layer of clay-sand plaster on a natural sheet of fibers.

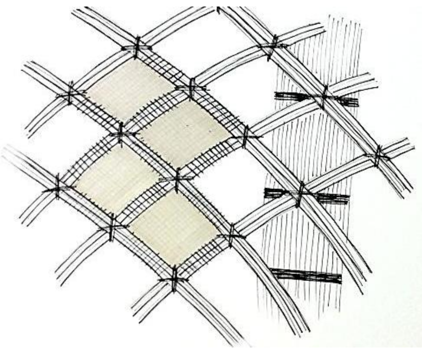


Figure 5.111. Hemp or jute bags fastened to the wall grid can be used instead of chicken wire mesh. The wall grid is fastened to the rods with metal wire

Emami et al. investigated the masonry reinforcement using natural fibers. They have developed a simple and cost effective method to reinforce existing walls by covering them with jute fiber mats with filler compound of an epoxy resin base or epoxy resin enriched fine filler on a cement base can. They tested two fiber orientations, horizontal/vertical orientation [0°/90°] and a diagonal fiber orientation [+45°/-45°] against the main stress axis. Their results showed that for the horizontal/vertical reinforcement [0°/90°] a more ductile behavior could be observed compared to the diagonal reinforcement (Emami et al, 2012). Therefore, the horizontal/vertical orientation of the sheets is preferred.

Figure 5.112 and figure 5.113. Natural fiber reinforced masonry for existing buildings with jute fiber mats tested in Bam

Source: Emami et al, 2012

Step 18: Two layers of lightweight straw loam will cover both sides of the wall lattice to make a14-15cm thick wall as described previously.

Step 19: Adding the lightweight straw loam infill on the grid to achieve a 14cm thick wall.

Step 20: After being assembled, the wall and roof grids will be plastered with earth and straw mortar with one initial layer and then a thin finishing layer and sealing. Plastering could be done with a simple wooden float.

The underlay: The thickness of this layer will be between 8mm and 20mm. The mortar must have the following proportions:

1 part of earth and 2 parts of sand (go through the 5 mm mesh)

1/3 of straw cut into 3cms strips (Aedo and Olmos, 2014).

Incisions: Before the first layer dries, ‘incisions’ are made using a metal brush or nails. This improves the adhesion of the second layer onto the first.

The finish layer: An aesthetic thin seal or protective layer, added once the first layer is completely dry. The thickness is between 1 and 2mm.The mortar will approximately be:

1 part of earth (which goes through the 2mm mesh), 3 or 4 part of fine sand (Aedo and Olmos, 2014).

Sealing: Use a sponge making circular movements then wait for between 15 and 20 minutes before using a dry paint brush in straight movement; the aim is to seal the surface. There are other alternatives and combinations:

Lime and sand; lime, sand, earth; chalk and sand; chalk, lime and sand.

Therefore, the mix is going to be 30-40% clay, 3-4% lime as stabilizing agent, 3% fine date palm fiber with the remaining soil divided between coarse and fine sand.

Step 21: Assembling the door and two window frames with fronds fastened by metal wire. They will be covered by two layers of date palm leaf woven mats sewed to a layer with a layer of canvas lining. These layers are can be pulled up for more ventilation in hot hours of the day.

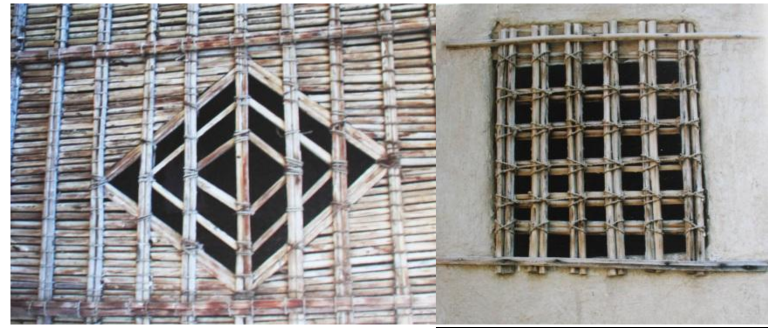


Figure 5.114. and figure 5.115. Window frames made of date palm fronds

Source: Piesik 2012

Step 22: To protect the walls against rainwater splashing, detachable lower panels made from reeds, straw or hemp sacks could be used. For extra water resistance, they can be painted by bitumen.

Step 23: One layer of goat hair fabric (known as Chador or black nomadic tent) will be installed on the interior layer of roofs. Cotton and lamb's wool are not greasy and oily therefore the tribes use goat hair in their tents. Since goat hair is greasy, it is waterproof and an ideal material to make tents out of. The goat hair is cheap (10 cents/kg in 2014 in southern areas of Kerman province as I asked from a nomadic people) and is a durable material. The nomadic tribes in Iran have been using this material for thousands of years both in cold western areas of Iran and in hot and arid central areas. The whole tent can be disassembled into 10-14 small pieces for transport. This fabric has 70-80 years of life span and it is fire retardant. The weight of Chador is about 0.4 lb/sq. ft. I tested the fire-retardancy and water proofing of a sample that was woven by a nomad in Hamedan.

Figure 5.116. and figure 5.117.Nomadic women weave a black tent in Hamedan, Iran

There are two more advantages for using these tents as the thermal insulation for shelters. One is that comparing to the artificial waterproof materials such as plastic sheets or tarp, black tents do not trap the air inside the tent. Therefore, in the summer time the air can moves through this material and provides natural ventilation inside the shelters. The other advantage is that with the sufficient amount of goat hair, weaving the tent (Chador) is very easy and does not need specialty or a specific tool.

Figure 5.118.
Sample of Chador
(goat hair tent)

During the winter or overnight, one layer of Chador can be installed in the interior layer of walls as well. The interior layer of the wall is covered by a layer of Hasir.

Step 24: On top of the black tent layers of Hasir will be spread. To achieve the waterproofing quality for these mats, several layers of Hasir mats (up to 5 layers since each layer is 0.3 kg/m^2) can be used. Treated date palm leaves which were impregnated in Boric Acid and dried in the air must be placed on top of the roof. Traditionally 3-4 layers of dried leaves are placed on the roof. Considering the weight of the leaves (almost 1kg/m^2) 5-6 layers of leaves can be placed on the structure.

Step 25: A metal tension cable will be inserted into the Chador's designated space.

Figure 5.119.
Chador's designed
space for tension
cable

Step 26: A woven treated hemp net will be placed on top of the leaves and fastened to the tension cable to fix the leaves in place.

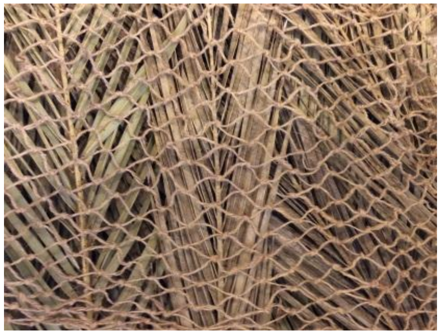


Figure 5.120.
Woven hemp net
on top of dried
date palm samples

Step 27: Lastly, the wind-catcher will be placed on top of the dome. The uni-directional type of wind catcher, which used to be a unique traditional housing design element in hot and dry regions of Iran, will be used in these shelters with some modifications. The wind-catchers in Bam should have northern to north-western direction to direct the favorable northern breeze to the interior spaces.

Instead of the traditional mud brick or baked brick structure of the wind-catchers covered with mud plaster, to reduce the weight of the wind catcher on the structure, we can use Hasir, jute or hemp fabrics to cover the walls of the wind catcher. The whole structure of it can be constructed by date palm fronds to make a 1.5m tall wind-catcher. The wind catcher will be fixed to the ribs by galvanized wire.

Figure 5.121. Samples of wind catchers made from date palm tree fronds and jute fabric

Source: Piesik, 2012

The total construction and preparation time of materials takes almost one week. The process is easy and the materials are very cheap. Because people are familiar with the material and the construction process, no professional training program is needed to build these shelters. Every neighborhood will receive a kit with required materials and the assembly instructions. Larger families can also receive two kits. A few instructors from HF can supervise the constructions in every neighborhood. Table 5.13 presents a list of required materials for the modified shelter.

Material	Description	Quantity estimation
Wood and plant-based	Date palm fronds for rods	2,300 leaves
	Small date palm fronds for wall and roof grid	2,500 leaves
	Date palm leaves for roof coverage	
	Straw or date palm trunk fiber for loam reinforcement	2-3 kg
	Hemp woven net for the roof	28.5 m^2
	Date palm leaf fronds for window and door	50
	Date palm fronds for wind catcher	60 leaves
	Woven Hasir for roof, walls, door and windows	28.5 m^2 in 5 layers 28.2 m^2, 3 m^2
Stone	Stone rubble for base course	2 m^2
	around the plinth	
Plastic	Two layers of hemp rice bags to cover the earthen plinth	30 (80cm by 80cm)
Lime	For loam stabilization and plastering	
Chalk	For sealing the wall	
Chemicals	Copper Sulphate, Sodium Dichromate, Boric Acid	
Textile	Two layers of canvas for windows and door coverage	1.5 m^2
	Two layers of 19 by 19 hem rice bags for the slab	76 bags
	Chador (goat hair fabric)	28.5 m^2
	Goat hair rope	200 m
	Jute or hemp fabric to cover the wind-catcher's walls	6 m^2
Sand	One layer of sand on top of the compacted earth	30 kg
	Plastering the wall	
Earth	Fiber reinforced mud brick for wall cladding	-
	Dirt for filling rice bags	
Metal	Galvanized metal wire	40 m
	Galvanized tension cables	30 m
Water	For loam preparation, frond preparation and solving the chemicals	
Other	Methane canister for cooking	1
	½" electrical conduit	15 m
	electrical wiring	50 m

Table 5.13 List of construction materials required for the modified Kapar shelters as temporary houses

Figure 5.122 to 5.125 presents the design sketches for the proposed shelter.

Figure 5.122. An unfinished temporary shelter showing the wall lattice

Figure 5.123. A sketch showing the finished temporary house house

Chador (goat hair tent)

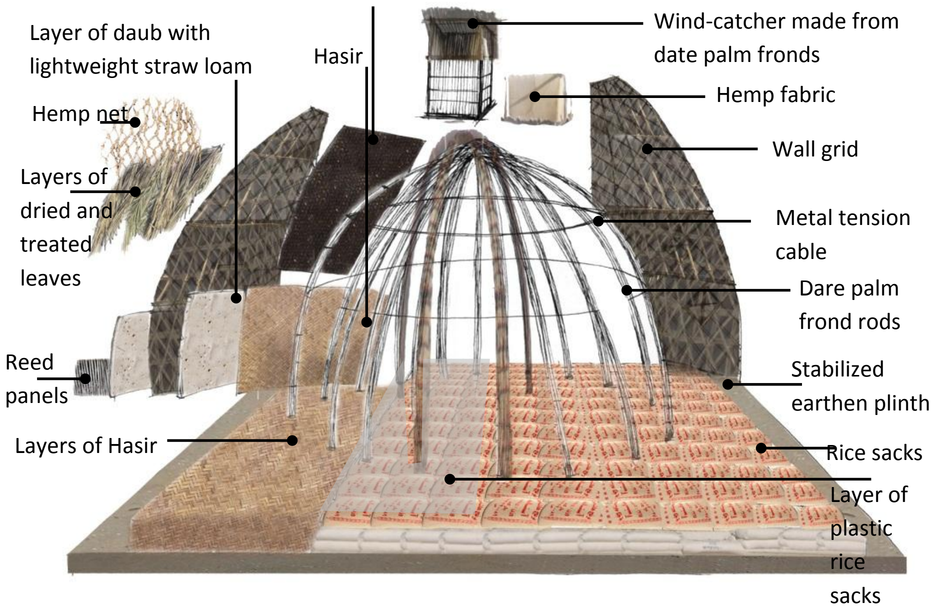


Figure 5.124. The exploded diagram of materials and main construction components for a temporary house

Figure 5.125 A temporary house located in the yard of a permanent house under construction

5.19. Community planning:

Community planning for post-disaster situation is not a separable plan housing design. Since the temporary settlements will be placed in the yards of the houses, no extra infrastructure needs to be provided for camp locations.

There are some key factors that emerge out of the development and reconstruction plans in historic cities of Iran. One major consideration is the Qanat network that plays an important role in the vitality of the city. It is an essential role of the government to repair and renovate the Qanat system for the urban infrastructure of the city. However, considering the growing population of the city on one hand, and the guest population from rural areas after 2003 on the other hand puts extra pressure on the region.

Figure 5.128. Water supply after the earthquake in temporary camps

Source: IRNA

The designer's role becomes substantial on how to integrate different strategies that not only help to facilitate the post-disaster reconstruction process, but also solves some of the past and possible future issues in the urban management. Having this this approach the central and local governments can concentrates more on the long-term and sustainable plans for the cities. The community centers, local commercial centers (Baazaar), orphanage and Children's centers, youth and recreation centers, and agricultural centers as the essential entities for the communities in the new cities are the absolutely essential parts of new master plans according to the needs of the new population. Except for some open space parks, that are not climatic responsive, the new master plan of Bam lacks the above mentioned facilities.

The temporary housing program, aims to reduce the pressure on the disaster affected city by eliminating unnecessary costs and acting as the threshold for designing a sustainable city in the future. For this purpose, the temporary community planning in Bam focuses on small neighborhood centers. These centers are consisting of the following zones:

- Water, food and energy supply zone: Temporary water tanks for potable water supply and water recycling system for non-potable water
- Waste collection and sewage treatment zone: Solid waste management system includes collecting the organic waste and sewage to be used in biodigester and recyclable solid waste.
- According to the president of agricultural ministry of Iran, the agricultural sector consumes about 90% of the drinking water. On the other hand, in Kerman province the average rainfall is half of the average amount in Iran (FarsNews, 2008) (http://www.farsnews.com/printable.php?nn=89032312

85). Considering the water crisis in the past years as an inclusive major issue in most of the rural and urban areas in Iran, droughts, the increasing cost of the potable water in Iran, and the drying Qanats (because of the growing population and also increasing draught periods), finding new ways of recycling waster are reusing the potable water for agricultural use can make a significant impact on the future of the cities, specifically in hot and dry climate.

The small community water tanks not only help the city to pass through the recovery phase more easily, but it will also have positive effects on the poor rural areas in the region when they are transferred to these areas for reuse after the recovery phase.

By providing the water tanks in every neighborhood of the city, these tanks can store enough drinking water for a number of dwellings and also collect the gray water for non-potable uses.

The combination of a solar water heating and two water storages in a portable stainless steel insulated tank provides the desired time for the government to reconstruct the Qanat network in the city. After the constructions finish, these tanks can be transported to the rural areas which have had water issues. The tank can be sprayed with soy-based spray foam insulation.

Based on the Sphere standards mentioned in previous parts, the average water use for drinking, cooking and personal hygiene in a household is at least 15 L per person per day (around 60 L per household in Bam) and the maximum distance from any household to the nearest water point is 500 meters. Therefore, to have enough potable water supply for 10 days, approximately every 16 households need to have a water tank with 10,000 L capacity of potable water. The solar panel on top of the tank provides enough energy for hot water.

As an example, the number of households in one urban region of Bam, discussed in previous chapters, is shown in figure 5.9. The total number of 22 metal tanks for potable water is needed for this area to be filled every 10 days.

Figure 5.129. Number of households in one rural region of Bam for the number of water tank calculations

For rain water harvesting, gray water from bathroom, laundry, and, food preparation area and hand basins will be treated and recycled to flush toilets, and be used in garden irrigation. After the gray water is collected, it is filtered through a progressive filtration technology without using any chemicals or electricity. The filtered water then can be pumped to areas of the gardens. An example of the filtration process is shown in figure 5.130.

Figure 5.130. The gray water filtration system

Source: www.superiorwater.com

Looking at the city plan on a neighborhood scale, there are some ideal locations to place a facility center (water/ food/sanitation) during the recovery phase. Right on the edges of the date palm orchards, at the corners of two perpendicular streets in the residential area, we can find empty areas from vegetation. These corners do not have heavy traffic and they are accessible from the main residential streets. These areas are basically functioning as an entrance zone to the orchards or gardens. In the recovery phase, the proximity of these places to the orchards, make them ideal open spaces to locate a small neighborhood center for water storage, food distribution, cleansing material distribution and water recycling system. The recycled water can be easily directed to the gardens. Gray water from the wash basin and bathrooms are also collected in the water tank at this location. These centers serve the neighborhood as a community center to exchange information and news in order to make strong bonds between the community members.

Based on the Sphere Standards, a maximum of 20 people use each toilet and toilets are no more than 50 meters from dwellings (The Sphere Project, 2004). However, the black water from the toilets- which is stored in septic tanks to be transported to the larger secondary open spaces where the human waste storage tanks and the solid waste storage are located. Building material distribution center and gas distribution center for the neighborhood can be also located in these secondary open spaces.

Figures 5.119to 5.121 spot some of these locations on an illustrated map of the selected neighborhood in Bam.

Figure 5.131. Small neighborhood and facility centers shown by red color including water storage tanks, recycling system, food distribution location, cleansing material distribution location, bathrooms, hand basins and food service sinks.

Larger neighborhood and facility centers shown by blue color are the locations where the construction materials and Methane canisters are distributed between households. Larger waste storage tanks are also located at these places for either recycling or to be used as the feedstock for the biodigester.

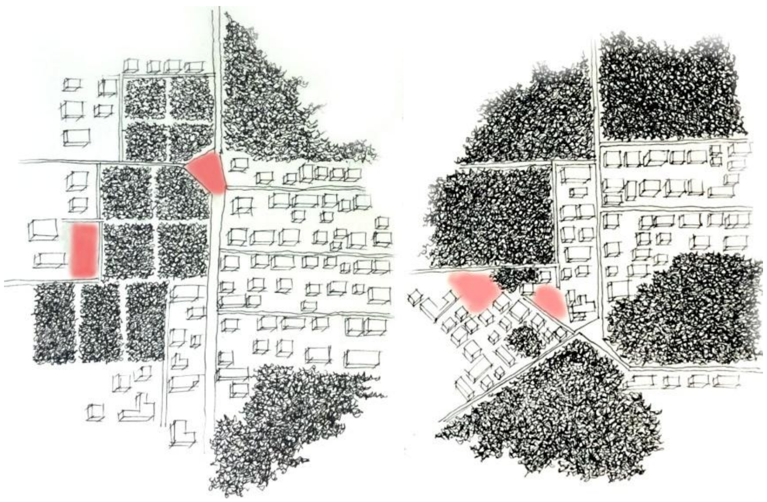


Figure 5.132. and 5.133. Two examples of the locations of small neighborhood and facility centers shown by red color in the selected region in Bam

Figure 5.134 to 5.137 present sketches from the facility and community center.

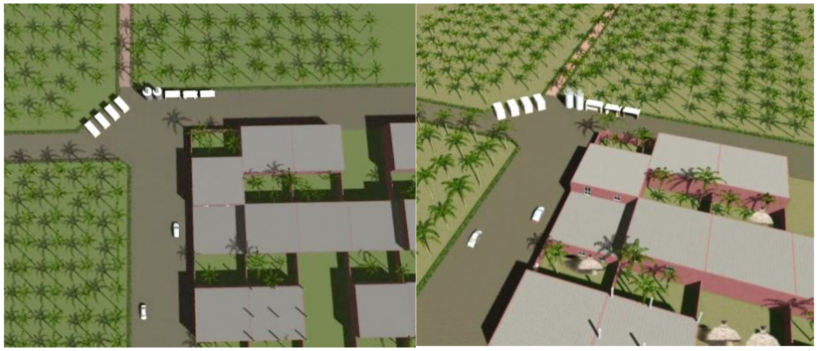


Figure 5.134. and 5.135. The small neighborhood and facility centers shown by red color serve the neighborhood as small community centers to increase the interaction between people and facilitate communications between neighbors.

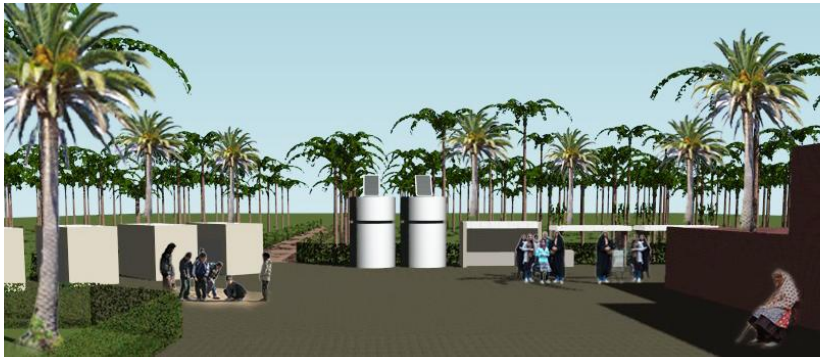


Figure 5.136. Perspective from the small neighborhood and facility centers. Water tanks and water recycling system, hand basins, food service sinks will be located in one side and toilets and bathrooms on the other side of the water recycling system ore privacy.

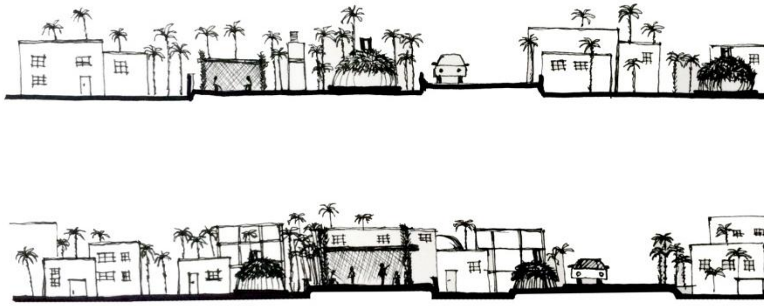


Figure 5.137. Sections from the residential areas in the city of Bam near the central part of the city. Temporary shelters will be located in the yards and community centers are parts of the residential areas.

Chapter 6: Conclusion and discussion of results

"We are living in a phenomenal age. If we can spend the early decades of the 21st century finding approaches that meet the needs of the poor in ways that generate profits and recognition for business, we will have found a sustainable way to reduce poverty in the world."

- Bill Gates

During my master's studies, the idea of providing a regional translation for sustainability practices in poor areas of developing countries with profound tradition of unreinforced unbaked earth constructions have been a question for me. Around one third of the world's population lives in buildings constructed from earth (Houben and Guillaud, 1994). Roughly 50% of the population in rural areas of developing countries lives in unreinforced masonry houses (World Housing Encyclopedia, 2007).

But, what do these mean to us? We are likely go through seven years of design school ignoring the impoverished population of our globe. We are trained to design and committed to designing a world that provides welfare first and foremost. So, why are we ignoring those who perhaps need us most?

We have seen that the prime stage of disasters is not the 'average' man; it is likely to be a poor family living in vulnerable conditions. The reality is disasters are caused by natural phenomena when they strike a vulnerable and dangerous condition.

Bam's problem was not the earthquake itself; earthquakes of the same violence (6.5 or so on the Richter scale) have occurred in more densely populated areas with insignificant loss of life. Bam's problem was poverty. Poverty meant that people flooded into the town, economic migrants in their own country, pursuing any chance of making a living in manufacturing, or picking and packing oranges or dates, or by enduring the manifold humiliations of tourism, and made their homes in the old mud brick compounds. If they had stuck to roofing these with palm trunks and fronds, more of them might have survived, but no one with any kind of cash income would be content with such makeshifts. ‘Improved’ housing, heavier roofing materials resting on the same old friable walls, turned out to be lethal.

Iran has the manpower, the expertise and the emergency supplies; what is missing is money to cover the costs of mobilization, the diversion of labor from other projects to the disaster area in a short period of time, and the maintenance of the culture of earthquake-resistant constructions during and after the reconstruction phase.

Almost every four to five months we hear about a new earthquake and the casualties in Iran. But, what distinguished Bam from other places is the high death toll, not only during the earthquake event, but also in the first days after the quake where the emergency aid could not be provided to the city from other parts of the country.

On the other hand, because of the worldwide historic importance of Arg-e-Bam and its cultural landscape as the largest adobe structure in the world, there was an abundant source of technical and financial assistance both nationally and internationally for reconstructions. The ‘sustainable’ plans and criteria for the new developments in the city were originally appealing. However, only ten years after the earthquake, we can say many new buildings are not even earthquake-resistant, and there is no major difference between the new city of Bam with more than 2,000 years of history and other urban developments all around Iran.

My question was why did this happen in this city and are there ‘better’ options to avoid the Bam’s disaster in the future? What was the role of ‘sustainability’ if it could not provide a holistic perspective to the whole amalgamation of issues and problems such as poverty, mud brick history, earthquake-resistant new constructions, rapid growth of population, waste management, drinking water shortage, climatic responsive needs of building design for the harsh semi-desert climate of Bam, cost of construction materials, cost of energy, need for economic activities and resources, environmental protection and stewardship, agricultural and industry support, community engagement, social vitality, post-disaster emotional recovery, solving social dilemmas such as Kapar issues and planning for a sustainable future?

Under the immediate impact of a disaster, people are ready to change long-standing methods and costumes. Therefore, acting quickly to introduce improved construction methods is a rewarding decision. However, quick action means planned action. It is no good starting making plans after the event. The lengthy process of city's master plan revision and reconstruction process almost made the comprehensive supervisions of building constructions and urban planning impossible by the Housing Foundation of Iran. In addition, the valuable original development strategies were neglected over the time. In this situation there has been an 'out of sight, out of mind' or in other words, 'out of media, out of mind' attitude.

These are the reasons that I decided to overview the whole experience of Bam from 2003 to 2014 to understand the multi-dimensional and multi-layered reconstruction programs and the reasons behind the failure of the programs in different levels. I can name three primary reasons for that:

First, lack of understanding of the profound cultural traditions both in the life style of people and in the building construction was the reasons that people returned to their old construction traditions after a short period of time. Their large single family houses (mostly more than 200 to 300m^2) were turned to 18 to

$20m^2$ temporary houses and $85m^2$ permanent houses. The new temporary steel structure houses were not suitable for the hot and arid climate of Bam with cold nights. They were uncomfortable during night and day, summer and winter. The training programs, the construction market (Bazaar) and the earthquake itself could not provide enough knowledge and awareness of the importance of material quality and properly built seismic-resistant buildings because of the high cost of building materials such as cement and steel. Moreover, the central government of Iran had to execute four different strategies for temporary housing, from prefabricated units in temporary camps to masonry units on peoples' lands because they could not properly anticipate the public reaction to each strategy. The wasted budget on temporary camps infrastructure and abandoned units in those camps was significant.

The first reason was combined with the second factor and that is the dependency on governmental associations and assistance. Lack of enough low-interest loans made it impossible for people to afford the high cost of steel, cement and baked brick for their new houses. Therefore, they had no option but to decrease the number of columns, the amount of cement and to reuse the bricks to finish their apartments.

Last but not least, the high cost and quality of temporary houses became an obstacle in the transitional phase of housing project from temporary to permanent. The high quality of the temporary units invited the guest population to the city of Bam from other urban and rural areas in hope to find a better house in Bam and to receive governmental and international aids. In addition, the high quality of houses made the situation very hard for the government to meet the high expectations of people for their permanent houses. In response, the government of Iran planned for prefab steel structures or concrete structures for permanent houses and could not provide enough low interest loans for people to complete their building constructions within the expected timeline.

I believe that in the case of Bam, and many other projects all around the world, there is a misinterpretation of the word 'sustainable'. Sustainable means achieving economic, social and environmental benefits in long run. If more than 10 years from the beginning of a housing reconstruction project in a city, there are still unfinished exposed structures all around a city and some people are still living in UN emergency tents, if the rate of agricultural exports in a city with the highest quality of products in the world is still lower than pre-earthquake conditions, and if the post-disaster plans not only could not protect the natural environment but they also destroyed a significant portion of the green areas in a garden-city, it obviously means that we did not pursue a sustainable criteria for new developments.

There are multiple factors contributing to the final results of post-earthquake permanent housing and urban design in Bam. I realized that while the temporary housing project is considered to be a short phase, it has profound impacts on the success of future phases of recovery and permanent housing project. If there are strong connections between the two phases of permanent and temporary settlements, the transitional process is more likely to be successful and extra costs are more likely to be reduces. Therefore, I decided to focus on temporary housing as a smaller scale of the whole reconstruction program and also as the initial phase of reconstructions through different lenses of sustainability.

My first intention for this project was to investigate local potentials for temporary houses. This attitude can lead the industry to develop accordingly and open new doors to innovative options in permanent building materials as well. I can summarize some of the advantages of local-based materials and techniques:

- The new building material creates additional uses for local resources, turns the former burden of waste disposal into a supplementary income stream for local farmers, and reduces dependence on expensive imported alternatives. By making economic interest in recycling these materials and encouraging farmers to generate extra income by agricultural waste recycling, the technology can be transferred to local industry. Economic benefits of waste material utilization will promote economic modernization and diversification to make a new added income opportunity for local farmers.

- The reduced demand for expensive building material import is other significant aspects of these building material resources. In addition, the material has the potential to create a new industry, strengthening economic independence and a potential export. Produced locally, with a natural resource and semi-skilled labor, almost without transport, it will be definitely cost effective. Beyond this, the product’s characteristics will provoke unique design responses.
- Environmental quality and resource efficiency by recycling and appreciation of agricultural waste is another advantage. Burning waste crops is one of the main reasons for causing air pollution and substituting steel, plastic and cement with plant-based and organic materials decreases the environmental hazards caused by that burning.
- They are affordable building materials for housing economically disadvantaged communities and help to improve rudimentary living conditions (Kapar).
- Being produced locally it is easily adapted to the various needs: technical, social, cultural habits. Efficient training center will transfer the technology in a week time. It can also create jobs.

Vernacular technologies are often appropriate solutions in terms of cost, environmental impact, climate, cultural and architectural suitability, and should generally be given priority. However, these technologies are not always optimal due to such concerns as their vulnerability to hazards and durability, and often need to be improved through the introduction of modern technology or components.

Therefore, the next level was to search for alternatives and modifications to adjust the materials and techniques to the new situation and function. The high tensile and compression strength, low thermal conductivity, light weight, resistance to corrosion and abundance of Date Palm Fronds (DPF) and Leaves (DPL) were utilized in producing curved roofs, structures and wall coverage. Then I investigated for other low-tech materials and techniques to reduce the thermal conductivity of the shell and roof as much as possible while other needs for a climatic responsive design in a semi-desert area, such as air circulation inside the building during the day, were considered simultaneously.

I wanted to use any profits from the plant to address fuel poverty in the new developments. Moreover, human waste management, water shortage for drinking and irrigation and also energy cost for heating and cooling were the other major issues for the disaster affected population. Therefore, through the integration of urban waste management, energy production and agricultural-based economic growth, an anaerobic biodigester plant and water recycling and storage systems were proposed for the city to address those issues during and after the recovery phase.

In addition to the needs for a comprehensive master plan I suggest that for small and large cities, the government prepare a disaster plan for each city which specifies the best locations for shared resources allocation such as drinking water, hot water and food supplies. These places can also serve the population as the small community centers.

My aim was to investigate between various opportunities to find some potential areas for further sustainable development and growth of the city and its unique related industries. The city of Bam could be an example for similar situations in Iran and other developing countries to use the disaster as an opportunity to reshape the physical planning and development strategies by introducing new planning ideas and innovative options based on the local needs and resources.

Further important points of investigation such as the experiments of construction physics in full scale, thermal conductivity of materials with laboratory tests and the exact cost of constructions have not been taken into account in this study. I have provided a few suggestions for permanent housing low-tech and agricultural-based construction materials and low-cost reinforcement techniques for masonry structures but these two areas also need to be studied in separate research projects. In addition, there are great opportunities for the city's exceptional cultural heritage and further developments in tourism. This area must be addressed in economic studies to find other incentives for the city.

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Appendix 1

Table: Active Degrees of Freedom

Table: Active Degrees of Freedom

UX	UY	UZ	RX	RY	RZ
Yes	Yes	Yes	Yes	Yes	Yes

Table: Analysis Options

Table: Analysis Options

Solver	SolverProc	Force32Bit	StiffCase	GeomMod
Advanced	Auto	No	None	No

Table: Frame Section Properties 01 - General, Part 1 of 6

Table: Frame Section Properties 01 - General, Part 1 of 6

SectionName	Material	Shape	t3	t2	tf	tw
			m	m	m	m
FSEC1	A992Fy50	I/Wide Flange	0.304800	0.127000	0.009652	0.006350
wood10	MAT	SD Section				

Table: Frame Section Properties 01 - General, Part 2 of 6

Table: Frame Section Properties 01 - General, Part 2 of 6

SectionName	t2b	tfb	Area	TorsConst	I33	I22	AS2
	m	m	m2	m4	m4	m4	m2
FSEC1	0.127000	0.009652	0.004265	9.651E-08	0.000066	3.301E-06	0.001935
wood10			0.007804	9.692E-06	4.846E-06	4.846E-06	0.007058

Table: Frame Section Properties 01 - General, Part 3 of 6

Table: Frame Section Properties 01 - General, Part 3 of 6

SectionName	AS3	S33	S22	Z33	Z22	R33	R22
	m2	m3	m3	m3	m3	m	m
FSEC1	0.002043	0.000431	0.000052	0.000491	0.000081	0.124145	0.027823
wood10	0.007058	0.000097	0.000097	0.000165	0.000165	0.024920	0.024920

Table: Frame Section Properties 01 - General, Part 4 of 6

Table: Frame Section Properties 01 - General, Part 4 of 6

SectionName	ConcCol	ConcBeam	Color	TotalWt	TotalMass	FromFile	AMod
				Kgf	Kgf-s2/m		
FSEC1	No	No	Magenta	0.00	0.00	No	1.000000
wood10	No	No	Magenta	586.00	59.75	No	1.000000

Table: Frame Section Properties 01 - General, Part 5 of 6

Table: Frame Section Properties 01 - General, Part 5 of 6

SectionName	A2Mod	A3Mod	JMod	I2Mod	I3Mod	MMod	WMod
FSEC1	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
wood10	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000

Table: Frame Section Properties 01 - General, Part 6 of 6

Table: Frame Section Properties 01 - General, Part 6 of 6

SectionName	GUID	Notes
FSEC1		Added 9/26/2014 8:45:54 PM
wood10		Added 9/29/2014 4:46:20 PM

Table: Load Pattern Definitions

Table: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad	GUID	Notes
DEAD	DEAD	1.000000			
LIVE	LIVE	0.000000			
WIND	WIND	0.000000	USER		

Table: Material Properties 01 - General

Table: Material Properties 01 - General

Material	Type	SymType	TempDepend	Color	GUID	Notes
4000Psi	Concrete	Isotropic	No	Yellow		Normalweight f'c = 4 ksi added 9/26/2014 6:38:23 PM

Table: Material Properties 01 - General

Material	Type	SymType	TempDepend	Color	GUID	Notes
A615Gr60	Rebar	Uniaxial	No	Gray8Dark		ASTM A615 Grade 60 added 9/26/2014 8:49:37 PM
A992Fy50	Steel	Isotropic	No	Magenta		ASTM A992 Fy=50 ksi added 9/26/2014 6:38:23 PM
MAT	Steel	Isotropic	No	Blue		ASTM A36 added 9/26/2014 6:48 PM

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	Kgf/m3	Kgf-s2/m4	Kgf/m2	Kgf/m2		1/C
4000Psi	2.4028E+03	2.4501E+02	2534563564	1056068152	0.200000	9.9000E-06
A615Gr60	7.8490E+03	8.0038E+02	2.039E+10			1.1700E-05
A992Fy50	7.8490E+03	8.0038E+02	2.039E+10	7841930445	0.300000	1.1700E-05
MAT	7.5000E+02	7.6479E+01	2039432384	849763494.	0.200000	1.1700E-05

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

Material	Fy	Fu	EffFy	EffFu	SSCurveOpt	SSHysType	SHard	SMax
	Kgf/m2	Kgf/m2	Kgf/m2	Kgf/m2				
A992Fy50	35153481.31	45699525.70	38668829.44	50269478.27	Simple	Kinematic	0.015000	0.110000
MAT	25310506.54	40778038.32	37965759.81	44855842.15	Simple	Kinematic	0.020000	0.140000

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

Material	SRup	FinalSlope
A992Fy50	0.170000	-0.100000
MAT	0.200000	-0.100000

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Material	Fc	LtWtConc	SSCurveOpt	SSHysType	SFc	SCap	FinalSlope	FAngle
	Kgf/m2							Degrees
4000Psi	2812278.50	No	Mander	Takeda	0.002000	0.005000	-0.100000	0.000

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Material	DAngle
	Degrees
4000Psi	0.000

Table: Material Properties 03e - Rebar Data, Part 1 of 2

Table: Material Properties 03e - Rebar Data, Part 1 of 2

Material	Fy	Fu	EffFy	EffFu	SSCurveOpt	SSHysType	SHard	SCap
	Kgf/m2	Kgf/m2	Kgf/m2	Kgf/m2				
A615Gr60	42184177.57	63276266.35	46402595.33	69603892.99	Simple	Kinematic	0.010000	0.090000

Table: Material Properties 03e - Rebar Data, Part 2 of 2

Table: Material Properties 03e - Rebar Data, Part 2 of 2

Material	FinalSlope	UseCTDef
A615Gr60	-0.100000	No

Table: Material Properties 06 - Damping Parameters

Table: Material Properties 06 - Damping Parameters

Material	ModalRatio	VisMass	VisStiff	HysMass	HysStiff
		1/Sec	Sec	1/Sec2	
4000Psi	0.0000	0.0000	0.0000	0.0000	0.000000
A615Gr60	0.0000	0.0000	0.0000	0.0000	0.000000
A992Fy50	0.0000	0.0000	0.0000	0.0000	0.000000
MAT	0.0000	0.0000	0.0000	0.0000	0.000000

Table: Element Forces - Frames, Part 1 of 2

Table: Element Forces - Frames, Part 1 of 2

Frame	Station	OutputCase	CaseType	P	V2	V3	T	M2
	m			Kgf	Kgf	Kgf	Kgf-m	Kgf-m
1	0.00000	COMB1	Combination	-430.25	-115.28	-1.308E-14	-2.744E-15	-8.229E-15
1	0.77646	COMB1	Combination	-460.83	-1.13	-1.308E-14	-2.744E-15	1.925E-15
1	1.55291	COMB1	Combination	-491.42	113.02	-1.308E-14	-2.744E-15	1.208E-14
1	0.00000	COMB2	Combination	-239.67	-262.57	71.34	14.01	14.29
1	0.77646	COMB2	Combination	-121.68	-117.54	8.58	14.01	-16.74
1	1.55291	COMB2	Combination	-3.69	27.48	-54.17	14.01	0.96
1	0.00000	COMB3	Combination	-557.93	48.85	-71.34	-14.01	-14.29
1	0.77646	COMB3	Combination	-732.63	115.45	-8.58	-14.01	16.74
1	1.55291	COMB3	Combination	-907.32	182.05	54.17	-14.01	-0.96
1	0.00000	COMB4	Combination	98.62	-171.92	71.34	14.01	14.29
1	0.77646	COMB4	Combination	240.67	-116.66	8.58	14.01	-16.74
1	1.55291	COMB4	Combination	382.71	-61.40	-54.17	14.01	0.96
1	0.00000	COMB5	Combination	-219.64	139.50	-71.34	-14.01	-14.29
1	0.77646	COMB5	Combination	-370.28	116.33	-8.58	-14.01	16.74
1	1.55291	COMB5	Combination	-520.93	93.16	54.17	-14.01	-0.96
2	0.00000	COMB1	Combination	-413.10	-72.78	1.054E-13	1.449E-15	9.724E-14
2	0.77646	COMB1	Combination	-475.36	-10.53	1.054E-13	1.449E-15	1.540E-14
2	1.55291	COMB1	Combination	-537.61	51.72	1.054E-13	1.449E-15	-6.645E-14
2	0.00000	COMB2	Combination	56.08	-298.14	-161.41	36.85	-209.16
2	0.77646	COMB2	Combination	105.64	-133.44	-224.17	36.85	-59.47
2	1.55291	COMB2	Combination	155.21	31.25	-286.92	36.85	138.95
2	0.00000	COMB3	Combination	-820.13	163.45	161.41	-36.85	209.16
2	0.77646	COMB3	Combination	-984.82	113.89	224.17	-36.85	59.47
2	1.55291	COMB3	Combination	-1149.52	64.32	286.92	-36.85	-138.95
2	0.00000	COMB4	Combination	376.24	-241.55	-161.41	36.85	-209.16
2	0.77646	COMB4	Combination	474.04	-125.09	-224.17	36.85	-59.47
2	1.55291	COMB4	Combination	571.84	-8.63	-286.92	36.85	138.95
2	0.00000	COMB5	Combination	-499.97	220.04	161.41	-36.85	209.16
2	0.77646	COMB5	Combination	-616.43	122.24	224.17	-36.85	59.47
2	1.55291	COMB5	Combination	-732.89	24.44	286.92	-36.85	-138.95
3	0.00000	COMB1	Combination	-443.11	-14.98	6.172E-14	1.197E-16	9.566E-14
3	0.77646	COMB1	Combination	-477.71	-5.71	6.172E-14	1.197E-16	4.773E-14
3	1.55291	COMB1	Combination	-512.31	3.56	6.172E-14	1.197E-16	-1.914E-16
3	0.00000	COMB2	Combination	717.68	199.79	-261.90	-1.268E-14	-504.17
3	0.77646	COMB2	Combination	725.33	354.59	-324.66	-1.268E-14	-276.45
3	1.55291	COMB2	Combination	732.97	509.39	-387.41	-1.268E-14	-4.692E-13
3	0.00000	COMB3	Combination	-1535.16	-227.20	261.90	1.290E-14	504.17

Table: Element Forces - Frames, Part 1 of 2

Frame	Station	OutputCase	CaseType	P	V2	V3	T	M2
	m			Kgf	Kgf	Kgf	Kgf-m	Kgf-m
3	0.77646	COMB3	Combination	-1605.94	-365.08	324.66	1.290E-14	276.45
3	1.55291	COMB3	Combination	-1676.72	-502.97	387.41	1.290E-14	4.688E-13
3	0.00000	COMB4	Combination	1055.70	210.63	-261.90	-1.278E-14	-504.17
3	0.77646	COMB4	Combination	1087.88	358.85	-324.66	-1.278E-14	-276.45
3	1.55291	COMB4	Combination	1120.06	507.08	-387.41	-1.278E-14	-4.689E-13
3	0.00000	COMB5	Combination	-1197.15	-216.36	261.90	1.280E-14	504.17
3	0.77646	COMB5	Combination	-1243.39	-360.82	324.66	1.280E-14	276.45
3	1.55291	COMB5	Combination	-1289.63	-505.28	387.41	1.280E-14	4.690E-13
4	0.00000	COMB1	Combination	-430.25	-115.28	-1.924E-14	1.127E-14	-1.356E-14
4	0.77646	COMB1	Combination	-460.83	-1.13	-1.924E-14	1.127E-14	1.379E-15
4	1.55291	COMB1	Combination	-491.42	113.02	-1.924E-14	1.127E-14	1.632E-14
4	0.00000	COMB2	Combination	-225.14	-275.92	-0.62	-0.29	-1.08
4	0.77646	COMB2	Combination	-95.09	-127.66	-0.62	-0.29	-0.60
4	1.55291	COMB2	Combination	34.95	20.59	-0.62	-0.29	-0.12
4	0.00000	COMB3	Combination	-572.46	62.20	0.62	0.29	1.08
4	0.77646	COMB3	Combination	-759.21	125.57	0.62	0.29	0.60
4	1.55291	COMB3	Combination	-945.96	188.94	0.62	0.29	0.12
4	0.00000	COMB4	Combination	113.15	-185.27	-0.62	-0.29	-1.08
4	0.77646	COMB4	Combination	267.25	-126.78	-0.62	-0.29	-0.60
4	1.55291	COMB4	Combination	421.35	-68.29	-0.62	-0.29	-0.12
4	0.00000	COMB5	Combination	-234.17	152.85	0.62	0.29	1.08
4	0.77646	COMB5	Combination	-396.87	126.45	0.62	0.29	0.60
4	1.55291	COMB5	Combination	-559.57	100.05	0.62	0.29	0.12
5	0.00000	COMB1	Combination	-413.10	-72.78	1.457E-13	-1.480E-14	1.340E-13
5	0.77646	COMB1	Combination	-475.36	-10.53	1.457E-13	-1.480E-14	2.092E-14
5	1.55291	COMB1	Combination	-537.61	51.72	1.457E-13	-1.480E-14	-9.219E-14
5	0.00000	COMB2	Combination	92.11	-316.64	-7.93	0.15	-8.09
5	0.77646	COMB2	Combination	150.50	-143.11	-7.93	0.15	-1.93
5	1.55291	COMB2	Combination	208.90	30.41	-7.93	0.15	4.23
5	0.00000	COMB3	Combination	-856.16	181.95	7.93	-0.15	8.09
5	0.77646	COMB3	Combination	-1029.68	123.56	7.93	-0.15	1.93
5	1.55291	COMB3	Combination	-1203.21	65.17	7.93	-0.15	-4.23
5	0.00000	COMB4	Combination	412.28	-260.05	-7.93	0.15	-8.09
5	0.77646	COMB4	Combination	518.90	-134.76	-7.93	0.15	-1.93
5	1.55291	COMB4	Combination	625.53	-9.47	-7.93	0.15	4.23
5	0.00000	COMB5	Combination	-536.00	238.54	7.93	-0.15	8.09
5	0.77646	COMB5	Combination	-661.29	131.91	7.93	-0.15	1.93
5	1.55291	COMB5	Combination	-786.58	25.29	7.93	-0.15	-4.23
6	0.00000	COMB1	Combination	-443.11	-14.98	7.625E-14	0.00	1.184E-13
6	0.77646	COMB1	Combination	-477.71	-5.71	7.625E-14	0.00	5.920E-14
6	1.55291	COMB1	Combination	-512.31	3.56	7.625E-14	0.00	0.00
6	0.00000	COMB2	Combination	809.51	217.14	-13.30	-1.066E-15	-20.65

Table: Element Forces - Frames, Part 1 of 2

Frame	Station	OutputCase	CaseType	P	V2	V3	T	M2
	m			Kgf	Kgf	Kgf	Kgf-m	Kgf-m
6	0.77646	COMB2	Combination	820.38	384.00	-13.30	-1.066E-15	-10.33
6	1.55291	COMB2	Combination	831.26	550.86	-13.30	-1.066E-15	1.419E-14
6	0.00000	COMB3	Combination	-1626.99	-244.55	13.30	1.066E-15	20.65
6	0.77646	COMB3	Combination	-1701.00	-394.49	13.30	1.066E-15	10.33
6	1.55291	COMB3	Combination	-1775.01	-544.44	13.30	1.066E-15	-1.419E-14
6	0.00000	COMB4	Combination	1147.52	227.98	-13.30	-1.066E-15	-20.65
6	0.77646	COMB4	Combination	1182.93	388.26	-13.30	-1.066E-15	-10.33
6	1.55291	COMB4	Combination	1218.35	548.55	-13.30	-1.066E-15	1.419E-14
6	0.00000	COMB5	Combination	-1288.97	-233.71	13.30	1.066E-15	20.65
6	0.77646	COMB5	Combination	-1338.45	-390.23	13.30	1.066E-15	10.33
6	1.55291	COMB5	Combination	-1387.92	-546.75	13.30	1.066E-15	-1.419E-14
7	0.00000	COMB1	Combination	-430.25	-115.28	-1.860E-14	1.036E-14	-1.446E-14
7	0.77646	COMB1	Combination	-460.83	-1.13	-1.860E-14	1.036E-14	-1.994E-17
7	1.55291	COMB1	Combination	-491.42	113.02	-1.860E-14	1.036E-14	1.442E-14
7	0.00000	COMB2	Combination	-218.03	-264.56	-72.82	-14.49	-16.60
7	0.77646	COMB2	Combination	-100.04	-119.54	-10.07	-14.49	15.58
7	1.55291	COMB2	Combination	17.95	25.49	52.69	-14.49	-0.97
7	0.00000	COMB3	Combination	-579.57	50.84	72.82	14.49	16.60
7	0.77646	COMB3	Combination	-754.26	117.44	10.07	14.49	-15.58
7	1.55291	COMB3	Combination	-928.96	184.04	-52.69	14.49	0.97
7	0.00000	COMB4	Combination	120.26	-173.92	-72.82	-14.49	-16.60
7	0.77646	COMB4	Combination	262.30	-118.66	-10.07	-14.49	15.58
7	1.55291	COMB4	Combination	404.34	-63.40	52.69	-14.49	-0.97
7	0.00000	COMB5	Combination	-241.28	141.49	72.82	14.49	16.60
7	0.77646	COMB5	Combination	-391.92	118.32	10.07	14.49	-15.58
94	25	COMB2	1.044E-13	78				
94	26	COMB3	-323.06	78				
94	25	COMB3	-1.044E-13	78				
94	26	COMB4	323.06	78				
94	25	COMB4	1.044E-13	78				
94	26	COMB5	-323.06	78				
94	25	COMB5	-1.044E-13	78				
95	28	COMB1	1.735E-14	79				
95	27	COMB1	-1.306E-16	79				
95	28	COMB2	298.02	79				
95	27	COMB2	-6.514E-15	79				
95	28	COMB3	-298.02	79				
95	27	COMB3	6.276E-15	79				
95	28	COMB4	298.02	79				
95	27	COMB4	-6.421E-15	79				
95	28	COMB5	-298.02	79				
95	27	COMB5	6.369E-15	79				

Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 1 of 2

Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 1 of 2

Frame	DesignSect	DesignType	Status	Ratio	RatioType
1	wood10	Brace	No Messages	0.122045	PMM
2	wood10	Brace	No Messages	0.349112	PMM
3	wood10	Brace	No Messages	0.674654	PMM
4	wood10	Brace	No Messages	0.130495	PMM
5	wood10	Brace	No Messages	0.288528	PMM
6	wood10	Brace	No Messages	0.412149	PMM
7	wood10	Brace	No Messages	0.123468	PMM
8	wood10	Brace	No Messages	0.343472	PMM
9	wood10	Brace	No Messages	0.648909	PMM
10	wood10	Brace	No Messages	0.101953	PMM
11	wood10	Brace	No Messages	0.353449	PMM
12	wood10	Brace	No Messages	0.817224	PMM
16	wood10	Brace	No Messages	0.062257	PMM
18	wood10	Brace	No Messages	0.098197	PMM
19	wood10	Brace	No Messages	0.358206	PMM
20	wood10	Brace	No Messages	0.837367	PMM
21	wood10	Brace	No Messages	0.875606	PMM
22	wood10	Brace	No Messages	0.370042	PMM
25	wood10	Beam	No Messages	0.156033	PMM
26	wood10	Beam	No Messages	0.075732	PMM
27	wood10	Beam	No Messages	0.446689	PMM
28	wood10	Beam	No Messages	0.216536	PMM
29	wood10	Beam	No Messages	0.068731	PMM
33	wood10	Beam	No Messages	0.149365	PMM
34	wood10	Beam	No Messages	0.428018	PMM
35	wood10	Beam	No Messages	0.197605	PMM
36	wood10	Brace	No Messages	0.040141	PMM
37	wood10	Brace	No Messages	0.339989	PMM
38	wood10	Brace	No Messages	0.785024	PMM
39	wood10	Beam	No Messages	0.238966	PMM
40	wood10	Beam	No Messages	0.683876	PMM
41	wood10	Beam	No Messages	0.213288	PMM
42	wood10	Beam	No Messages	0.610743	PMM
43	wood10	Brace	No Messages	0.059601	PMM
44	wood10	Brace	No Messages	0.368677	PMM
45	wood10	Brace	No Messages	0.875712	PMM
46	wood10	Beam	No Messages	0.238530	PMM

Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 1 of 2

Frame	DesignSect	DesignType	Status	Ratio	RatioType
47	wood10	Beam	No Messages	0.683610	PMM
48	wood10	Brace	No Messages	0.099075	PMM
49	wood10	Brace	No Messages	0.359918	PMM
50	wood10	Brace	No Messages	0.842412	PMM
51	wood10	Beam	No Messages	0.611989	PMM
52	wood10	Beam	No Messages	0.215577	PMM
55	wood10	Brace	No Messages	0.125359	PMM
56	wood10	Brace	No Messages	0.351089	PMM
57	wood10	Brace	No Messages	0.678589	PMM
58	wood10	Beam	No Messages	0.077065	PMM
59	wood10	Beam	No Messages	0.158411	PMM
60	wood10	Beam	No Messages	0.070529	PMM
61	wood10	Beam	No Messages	0.198327	PMM
62	wood10	Beam	No Messages	0.216837	PMM
63	wood10	Brace	No Messages	0.290461	PMM
64	wood10	Brace	No Messages	0.134375	PMM
65	wood10	Brace	No Messages	0.346118	PMM
66	wood10	Brace	No Messages	0.126252	PMM
67	wood10	Brace	No Messages	0.653107	PMM
68	wood10	Beam	No Messages	0.429361	PMM
69	wood10	Beam	No Messages	0.594012	PMM
70	wood10	Beam	No Messages	0.667029	PMM
71	wood10	Beam	No Messages	0.667132	PMM
72	wood10	Beam	No Messages	0.593832	PMM
73	wood10	Brace	No Messages	0.064467	PMM
74	wood10	Brace	No Messages	0.369210	PMM
75	wood10	Brace	No Messages	0.854841	PMM
79	wood10	Beam	No Messages	0.152265	PMM
80	wood10	Brace	No Messages	0.101028	PMM
82	wood10	Brace	No Messages	0.414852	PMM
84	wood10	Brace	No Messages	0.816483	PMM
85	wood10	Beam	No Messages	0.209849	PMM
86	wood10	Beam	No Messages	0.235745	PMM
87	wood10	Beam	No Messages	0.235524	PMM
88	wood10	Beam	No Messages	0.210233	PMM
89	wood10	Brace	No Messages	0.038485	PMM
90	wood10	Brace	No Messages	0.062555	PMM
91	wood10	Brace	No Messages	0.336330	PMM
92	wood10	Brace	No Messages	0.367855	PMM
93	wood10	Brace	No Messages	0.355142	PMM
94	wood10	Brace	No Messages	0.763507	PMM
95	wood10	Brace	No Messages	0.855269	PMM

Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 1 of 2

Frame	DesignSect	DesignType	Status	Ratio	RatioType
97	wood10	Beam	No Messages	0.447643	PMM

Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 2 of 2

Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 2 of 2

Frame	Combo	Location m	ErrMsg	WarnMsg
1	DSTL19	1.55291	No Messages	No Messages
2	DSTL19	1.55291	No Messages	No Messages
3	DSTL19	0.00000	No Messages	No Messages
4	DSTL19	1.55291	No Messages	No Messages
5	DSTL19	1.55291	No Messages	No Messages
6	DSTL19	0.00000	No Messages	No Messages
7	DSTL19	1.55291	No Messages	No Messages
8	DSTL19	1.55291	No Messages	No Messages
9	DSTL19	0.00000	No Messages	No Messages
10	DSTL19	1.55291	No Messages	No Messages
11	DSTL19	1.55291	No Messages	No Messages
12	DSTL19	0.00000	No Messages	No Messages
16	DSTL19	1.55291	No Messages	No Messages
18	DSTL19	0.00000	No Messages	No Messages
19	DSTL19	1.55291	No Messages	No Messages
20	DSTL19	0.00000	No Messages	No Messages
21	DSTL19	1.55291	No Messages	No Messages
22	DSTL19	1.55291	No Messages	No Messages
25	DSTL15	0.58527	No Messages	No Messages
26	DSTL15	0.58527	No Messages	No Messages
27	DSTL13	1.01372	No Messages	No Messages
28	DSTL13	1.01372	No Messages	No Messages
29	DSTL15	0.00000	No Messages	No Messages
33	DSTL15	0.00000	No Messages	No Messages
34	DSTL13	1.01372	No Messages	No Messages
35	DSTL13	1.01372	No Messages	No Messages
36	DSTL15	0.00000	No Messages	No Messages
37	DSTL19	0.00000	No Messages	No Messages
38	DSTL15	0.00000	No Messages	No Messages
39	DSTL15	0.58527	No Messages	No Messages
40	DSTL19	1.01372	No Messages	No Messages
41	DSTL15	0.58527	No Messages	No Messages
42	DSTL19	1.01372	No Messages	No Messages
43	DSTL15	1.55291	No Messages	No Messages

Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 2 of 2

Frame	Combo	Location	ErrMsg	WarnMsg
		m		
44	DSTL15	0.00000	No Messages	No Messages
45	DSTL15	0.00000	No Messages	No Messages
46	DSTL19	0.00000	No Messages	No Messages
47	DSTL15	0.00000	No Messages	No Messages
48	DSTL15	1.55291	No Messages	No Messages
49	DSTL15	1.55291	No Messages	No Messages
50	DSTL15	0.00000	No Messages	No Messages
51	DSTL15	0.00000	No Messages	No Messages
52	DSTL19	0.00000	No Messages	No Messages
55	DSTL15	1.55291	No Messages	No Messages
56	DSTL15	1.55291	No Messages	No Messages
57	DSTL15	0.00000	No Messages	No Messages
58	DSTL19	0.00000	No Messages	No Messages
59	DSTL19	0.00000	No Messages	No Messages
60	DSTL19	0.00000	No Messages	No Messages
61	DSTL14	1.01372	No Messages	No Messages
62	DSTL14	0.00000	No Messages	No Messages
63	DSTL15	0.00000	No Messages	No Messages
64	DSTL15	0.00000	No Messages	No Messages
65	DSTL15	0.00000	No Messages	No Messages
66	DSTL15	0.00000	No Messages	No Messages
67	DSTL15	0.00000	No Messages	No Messages
68	DSTL14	0.00000	No Messages	No Messages
69	DSTL15	0.00000	No Messages	No Messages
70	DSTL15	0.00000	No Messages	No Messages
71	DSTL19	1.01372	No Messages	No Messages
72	DSTL19	1.01372	No Messages	No Messages
73	DSTL19	1.55291	No Messages	No Messages
74	DSTL19	0.00000	No Messages	No Messages
75	DSTL19	0.00000	No Messages	No Messages
79	DSTL19	0.58527	No Messages	No Messages
80	DSTL15	0.00000	No Messages	No Messages
82	DSTL15	0.00000	No Messages	No Messages
84	DSTL15	0.00000	No Messages	No Messages
85	DSTL15	0.58527	No Messages	No Messages
86	DSTL15	0.00000	No Messages	No Messages
87	DSTL19	0.58527	No Messages	No Messages
88	DSTL19	0.58527	No Messages	No Messages
89	DSTL15	1.55291	No Messages	No Messages
90	DSTL15	0.00000	No Messages	No Messages
91	DSTL19	1.55291	No Messages	No Messages
92	DSTL15	1.55291	No Messages	No Messages

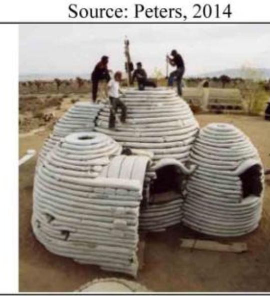
Table: Steel Design 1 - Summary Data - AISC360-05-IBC2006, Part 2 of 2

Frame	Combo	Location	ErrMsg	WarnMsg
		m		
93	DSTL15	1.55291	No Messages	No Messages
94	DSTL15	0.00000	No Messages	No Messages
95	DSTL15	0.00000	No Messages	No Messages
97	DSTL15	0.00000	No Messages	No Messages

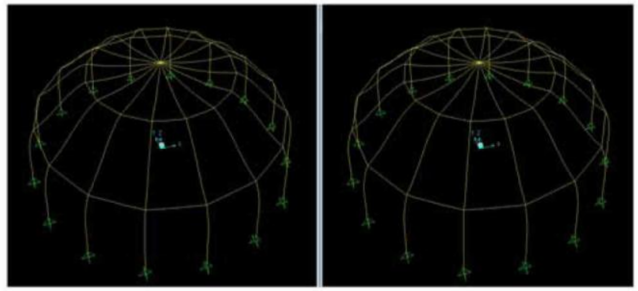
Appendix 2

Material or technology	Required resources or techniques	Brand example	Applications	Images
Lignin-based Bioplastics	Ligning is extracted in a boiling process from wood shavings and fibers, blended with methanol and hydrochloric acid to form a resin-like substance. This can be made directly into a duropolistic.	Alginsulate Foam http://www.vpz.at/index.php/r-d/alginsulate-foam	Could be made from wheat straw, date palm tree fibers and leaves and as the by-product of paper industry to make wall insulations	
Fungus-based materials	Mushroom insulations based on the cellulose found in natural waste products such as husks of rice and wheat, as well as on ligning as a binding matrix. The thread-shape myselium of fungi form a network which solidly binds the various organic waste materials. Needs dark place and drying material in an oven at 43°C	EcoCradle http://www.ecovativedesign.com/	Biodegradable packaging and wall insulation	
Bark cloth materials	Pure Bark Cloth is sealed with textile additives to make elastic, waterproof, tear-proof, and flame resistant textures. Dispersion adhesives and condensation resins are suitable for gluing. Laminates are compressed with phenol or aminoplast papers. (Peters, 2011)	Bark Cloth Texture (Peters, 2011)	Wall and door cladding, light canopies	 Image source: http://www.source4style.com/material/tree-bark-and-sisal-thread-burnt-orange-green-barkcloth-patchwork-3701
Waferboards	Based on laminated strand lumber and compressed wheat straw. The construction material can be entirely composted because of the natural binding agents. Can be installed in 2-4 days	Agriboard http://www.agriboard.com/	Roof construction and partitions, flooring, insulation material	
Recycling paper	Waste paper is a broken down in water then the pulp will be pressed and air dried. Papercrete comprising 50% waste paper, clay, sand and cement. It is pressed into bricks, blocks and panels or can eb applied directly to walls as shotcrete. Wellboard is lightweight and particularly flexible panel comprising 100% cellulose and containing neither adhesive nor binding agents. It is highly stable	Papercrete Wellboard	Cellulose insulation system, wall blocks or panels, and honeycomb cardboard panels	 Papercrete Source: www.semper.xenxnex.com

	in corrugated panels.			 Wellboard Source: ++http://www.well.de/
Natural fiber insulation, Hemp and Flax	Hemp and flax insulating materials. Hemp insulating material comprising 85% hemp and 15% polyester fiber. Impregnation with soda makes sufficient fire prevention. Thermal conductivity 0.026 Btu foot/hour/square foot/°F Fire preventation for Flax is attained through the addition of ammonium sulphate or borate salts. Thermal conductivity of flax boards are between 0.024- .026 Btu foot/hour/square foot/°F (Peters, 2011)	Hock Thermohanf http://www.thermo-hanf.de/	Insulating materials, light construction walls and floors	
Loam	Loam is a good heat accumulator. In addition, loam filters toxic and odorous substances out of the air and has pest-repellent effect with very little primary energy needed for material processing. The material is usually coated with protective plaster layer		Plaster and fiber reinforced loam for cladding	
Binderless wood-based materials	Self-adhesive strength of the lignin found in wood is the base of the development of these processes. The lignin molecules are activated by fungal anzymes. Applied to grind up cellulose fibers, these stick to one another independently without the need for an additional binding agent.		Wall or roof insulation	Examined at the Chemistry department of the University of Minensota with date palm truck fibers 

Straw panels	Construction panels consist of a core made of compressed straw, which is condensed in an extruder press process without the addition of a binding agent. The lignings contained in the straw ensure stalks remain bonded together. Finally, the compressed straw is covered by recycled cardboard to create a stable and simple construction panel with sound-insulation properties. (Peters, 2014)	iStraw	Wall panels	 Source: Ratia Rabemananoro
3D fibrous objects	Manufacturing these objects using molding compounds, plant fibers and organic binding agents. An inflatable inner form is used that can be shaped as desired. The form is then sprayed with mixture of organic materials and a natural binder. Finally, the biocomposite is vacuum compressed hardens. (Peters, 2014)	Organoid	Architectural forms, walls and roofs	 Source: Peters, 2014
Superadobe	The superadobe technique needs polypropylene sandbags 14 to 18 inches in diameter, which can be up to a mile in length. The bags are filled with dirt, sand or clay and optionally mixed with a small amount of locally available stabilizer, such as lime or cement. As the bags are filled they are stacked to form a domed structure. As each course is layered, barbed wire is placed between the bags to give tensile strength to the structure. When the structure is complete it is plastered with local soil and lime to make it water-resistant.	Cal-Earth www.Calearth.org	Whole structure or walls	
	Cantex are compact reed sheets joined by galvanized wire together. Other plant based raw materials such as date palm fronds, bamboo and cane can be also used.	Cantex Co. cantexahwas.com	Wall and roof sytem	
Strawbale	Low cost, available, fire-retardant, high insulation value but susceptible to rot		Wheat straw as structural element and insulation	

Appendix 3



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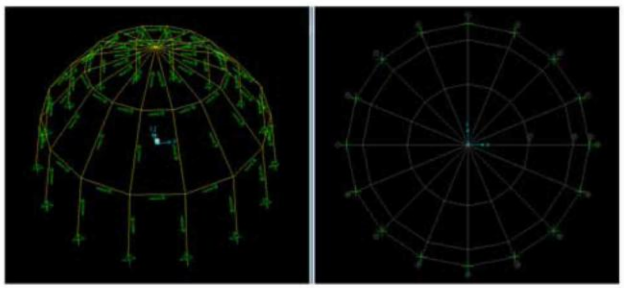

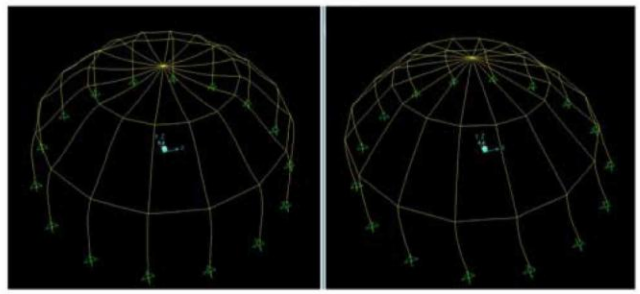

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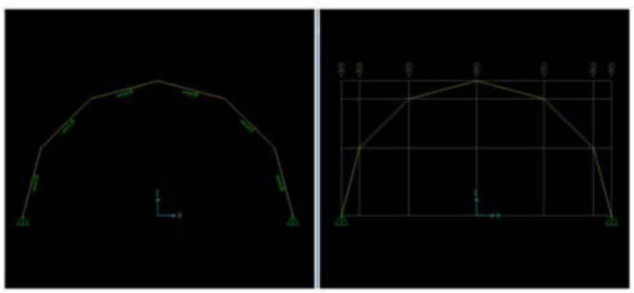

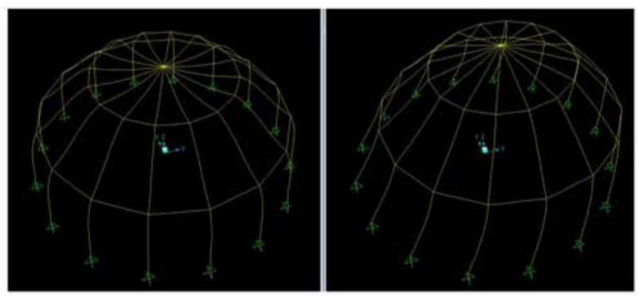

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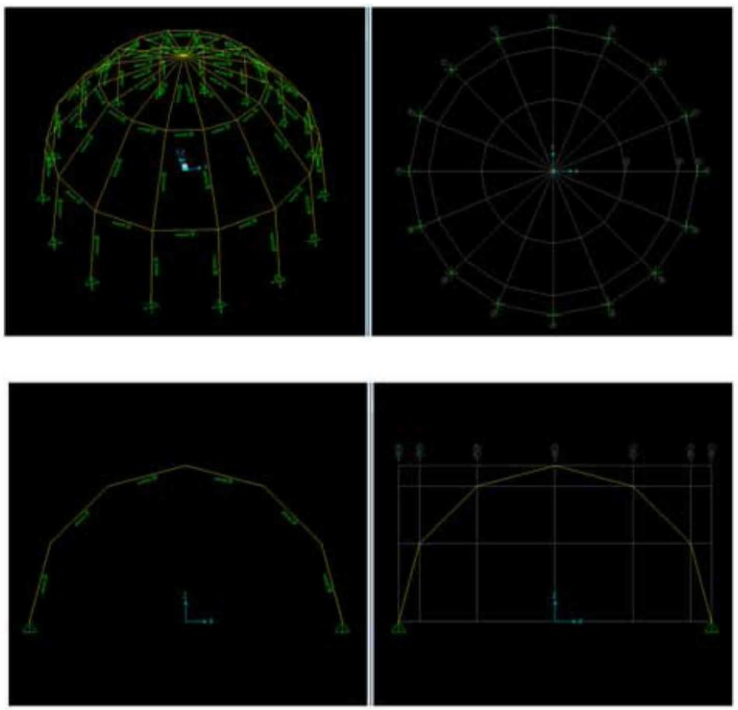
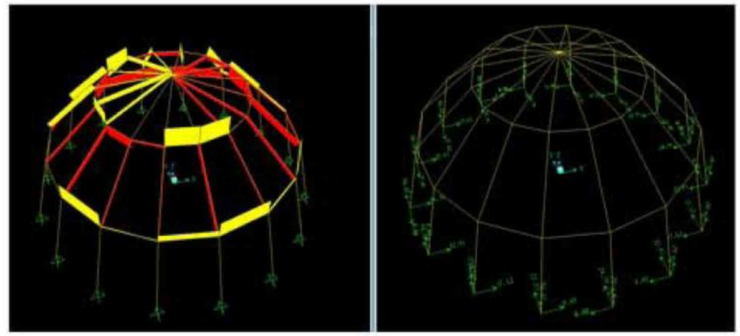
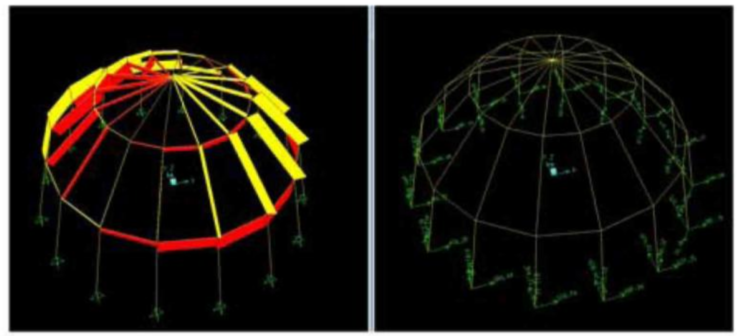




Dead load



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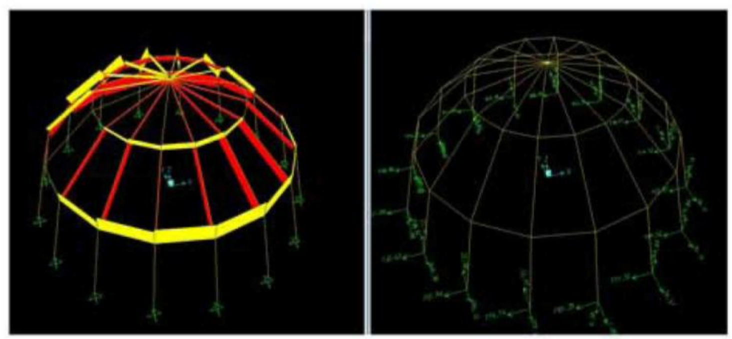
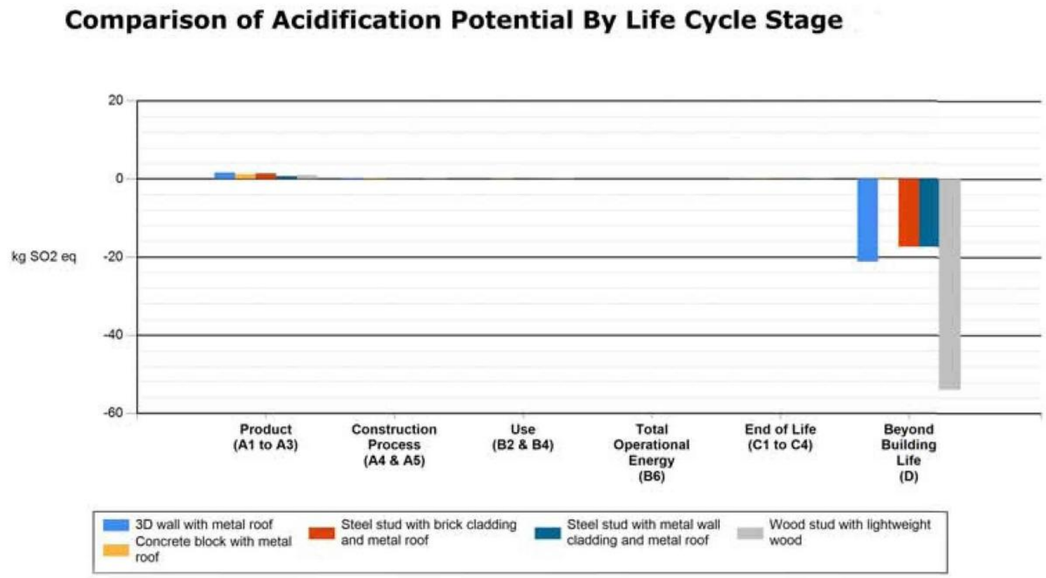


Wind load

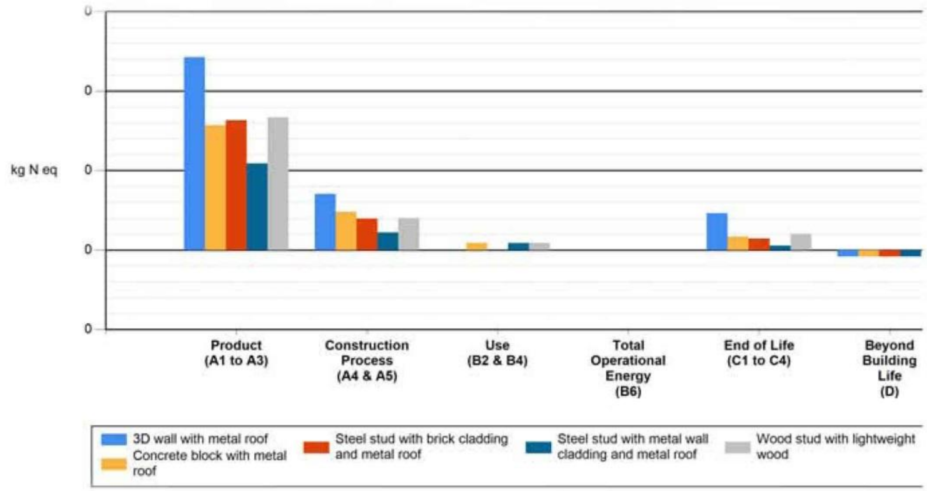
Appendix 4



Comparison of Acidification Potential By Life Cycle Stage

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Project Name	Total
3D wall with metal roof	kg SO2 eq	1.59E+00	2.38E-01	0.00E+00	0.00E+00	1.45E-01	-2.12E+01	3D wall with metal roof	**-1.92E+01**
Concrete block with metal roof	kg SO2 eq	1.22E+00	1.75E-01	1.44E-03	0.00E+00	5.79E-02	-3.21E-02	Concrete block with metal roof	**1.42E+00**
Steel stud with brick cladding and metal roof	kg SO2 eq	1.36E+00	1.57E-01	0.00E+00	0.00E+00	5.04E-02	-1.74E+01	Steel stud with brick cladding and metal roof	**-1.58E+01**
Steel stud with metal wall cladding and metal roof	kg SO2 eq	6.91E-01	7.41E-02	1.44E-03	0.00E+00	2.68E-02	-1.74E+01	Steel stud with metal wall cladding and metal roof	**-1.66E+01**
Wood stud with lightweight wood	kg SO2 eq	9.27E-01	1.62E-01	1.44E-03	0.00E+00	5.99E-02	-5.39E+01	Wood stud with lightweight wood	**-5.28E+01**
Total	**kg SO2 eq**	**5.79E+00**	**8.05E-01**	**4.31E-03**	**0.00E+00**	**3.40E-01**	**-1.10E+02**	**Total**	**-1.03E+02**

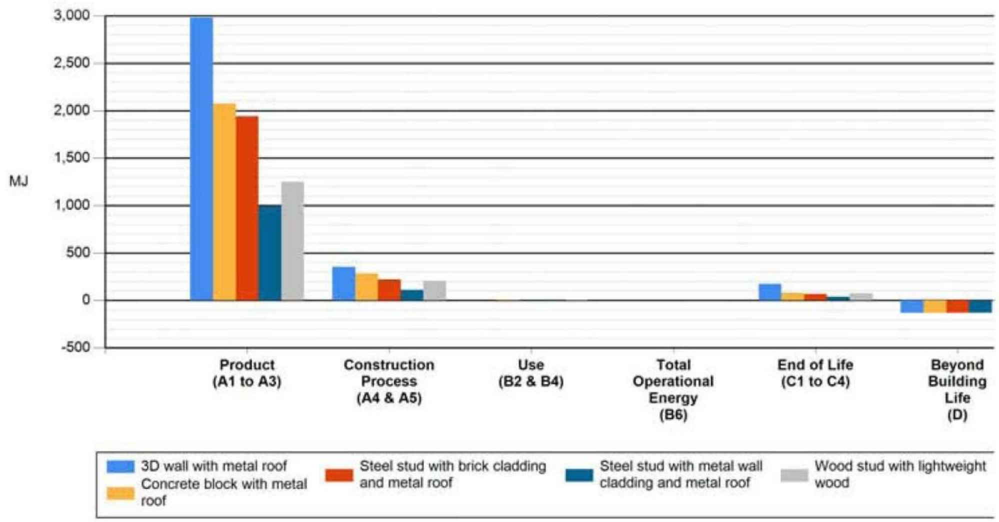
Comparison of Eutrophication Potential By Life Cycle Stage



Comparison of Eutrophication Potential By Life Cycle Stage

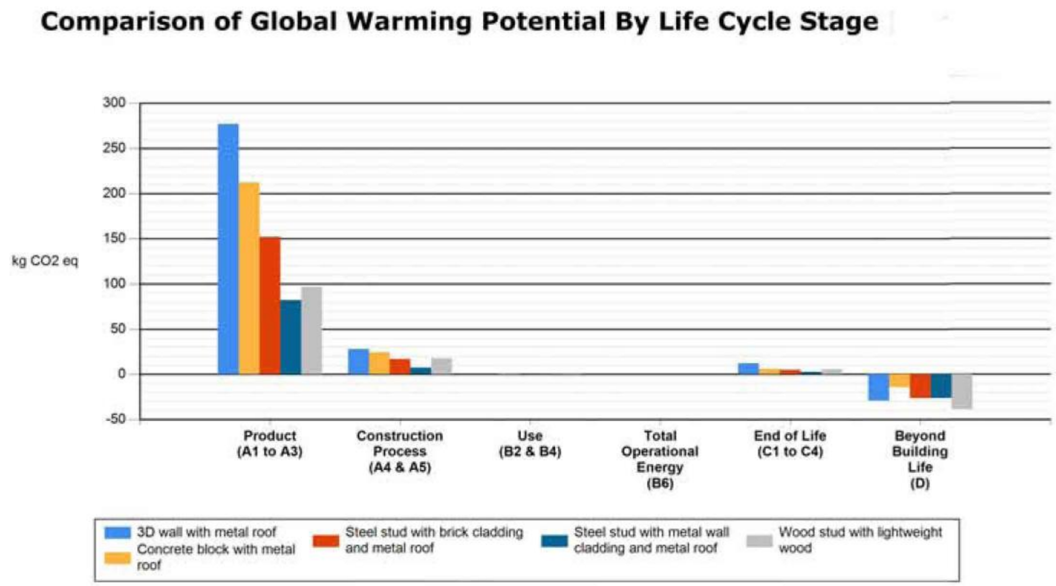
Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)
3D wall with metal roof	kg N eq	4.86E-02	1.41E-02	0.00E+00	0.00E+00	9.29E-03	-1.65E-03
Concrete block with metal roof	kg N eq	3.14E-02	9.62E-03	1.78E-03	0.00E+00	3.33E-03	-1.65E-03
Steel stud with brick cladding and metal roof	kg N eq	3.26E-02	7.92E-03	0.00E+00	0.00E+00	2.86E-03	-1.65E-03
Steel stud with metal wall cladding and metal roof	kg N eq	2.18E-02	4.44E-03	1.78E-03	0.00E+00	1.10E-03	-1.65E-03
Wood stud with lightweight wood	kg N eq	3.33E-02	7.95E-03	1.78E-03	0.00E+00	3.97E-03	-8.69E-05
Total	**kg N eq**	**1.68E-01**	**4.40E-02**	**5.35E-03**	**0.00E+00**	**2.05E-02**	**-6.68E-03**

Comparison of Fossil Fuel Consumption By Life Cycle Stage



Comparison of Fossil Fuel Consumption By Life Cycle Stage

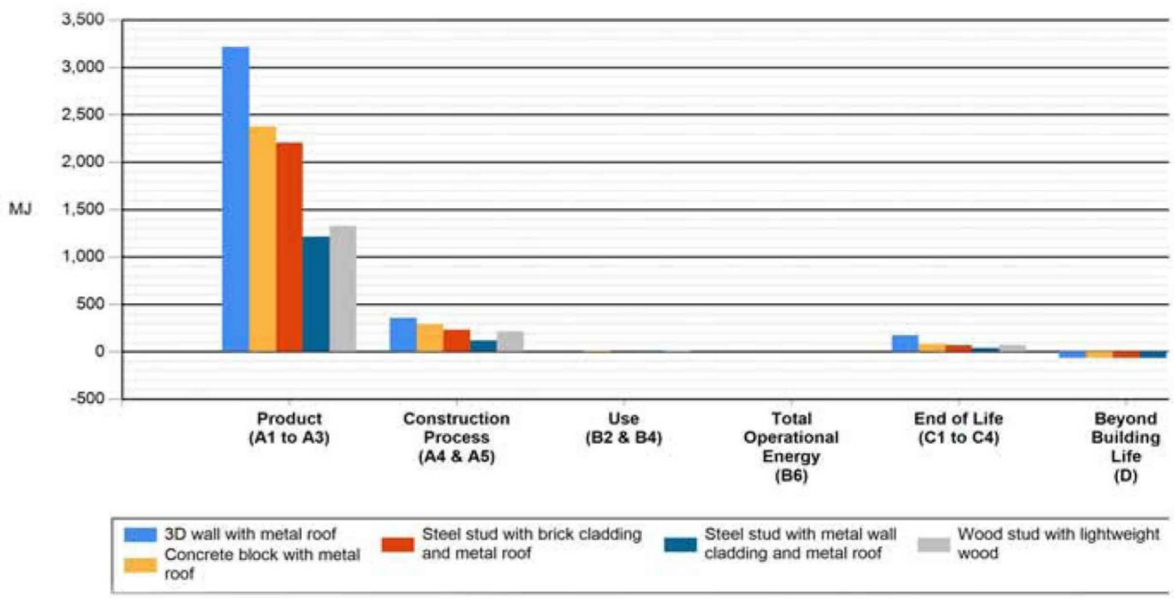
Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Project Name	Total
3D wall with metal roof	MJ	2.98E+03	3.53E+02	0.00E+00	0.00E+00	1.72E+02	-1.29E+02	3D wall with metal roof	**3.38E+03**
Concrete block with metal roof	MJ	2.07E+03	2.81E+02	8.01E+00	0.00E+00	7.72E+01	-1.29E+02	Concrete block with metal roof	**2.31E+03**
Steel stud with brick cladding and metal roof	MJ	1.94E+03	2.21E+02	0.00E+00	0.00E+00	6.61E+01	-1.29E+02	Steel stud with brick cladding and metal roof	**2.10E+03**
Steel stud with metal wall cladding and metal roof	MJ	9.90E+02	1.12E+02	8.01E+00	0.00E+00	3.68E+01	-1.29E+02	Steel stud with metal wall cladding and metal roof	**1.02E+03**
Wood stud with lightweight wood	MJ	1.25E+03	2.05E+02	8.01E+00	0.00E+00	7.43E+01	-6.79E+00	Wood stud with lightweight wood	**1.53E+03**
Total	**MJ**	**9.23E+03**	**1.17E+03**	**2.40E+01**	**0.00E+00**	**4.26E+02**	**-5.22E+02**	**Total**	**1.03E+04**



Comparison of Global Warming Potential By Life Cycle Stage [Per

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Project Name	Total
3D wall with metal roof	kg CO2 eq	2.77E+02	2.79E+01	0.00E+00	0.00E+00	1.23E+01	-2.90E+01	3D wall with metal roof	**2.88E+02**
Concrete block with metal roof	kg CO2 eq	2.12E+02	2.43E+01	2.11E-01	0.00E+00	5.93E+00	-1.41E+01	Concrete block with metal roof	**2.29E+02**
Steel stud with brick cladding and metal roof	kg CO2 eq	1.52E+02	1.71E+01	0.00E+00	0.00E+00	4.97E+00	-2.63E+01	Steel stud with brick cladding and metal roof	**1.48E+02**
Steel stud with metal wall cladding and metal roof	kg CO2 eq	8.22E+01	7.29E+00	2.11E-01	0.00E+00	2.57E+00	-2.63E+01	Steel stud with metal wall cladding and metal roof	**6.59E+01**
Wood stud with lightweight wood	kg CO2 eq	9.69E+01	1.78E+01	2.11E-01	0.00E+00	5.68E+00	-3.87E+01	Wood stud with lightweight wood	**8.19E+01**
Total	**kg CO2 eq**	**8.20E+02**	**9.44E+01**	**6.34E-01**	**0.00E+00**	**3.15E+01**	**-1.34E+02**	**Total**	**8.13E+02**

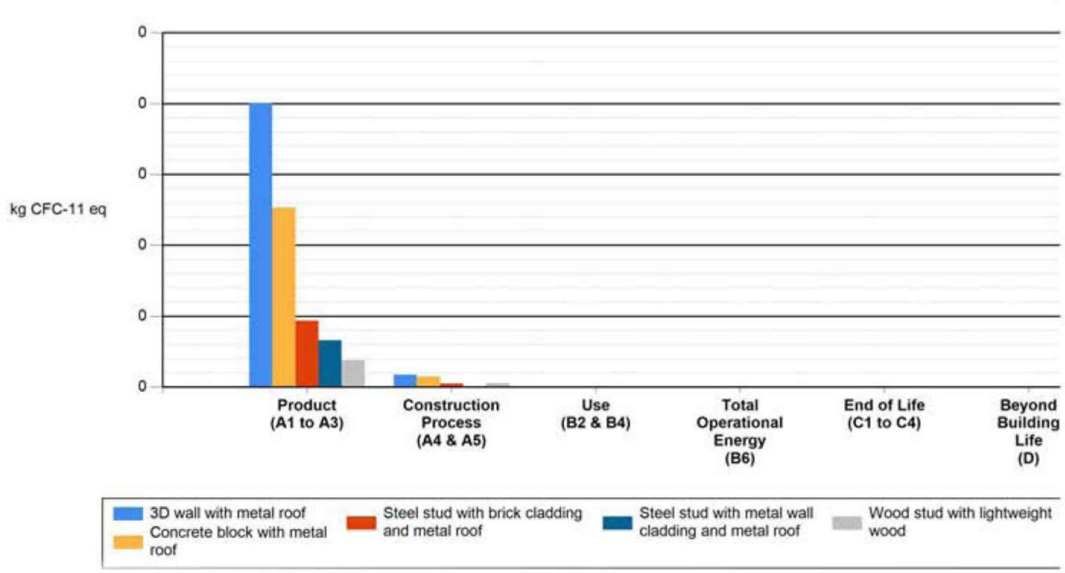
Comparison of Non-Renewable Energy By Life Cycle Stage



Comparison of Non-Renewable Energy By Life Cycle Stage

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Project Name	Total
3D wall with metal roof	MJ	3.22E+03	3.59E+02	0.00E+00	0.00E+00	1.73E+02	-6.42E+01	3D wall with metal roof	**3.68E+03**
Concrete block with metal roof	MJ	2.38E+03	2.88E+02	8.18E+00	0.00E+00	7.98E+01	-6.42E+01	Concrete block with metal roof	**2.69E+03**
Steel stud with brick cladding and metal roof	MJ	2.20E+03	2.30E+02	0.00E+00	0.00E+00	6.85E+01	-6.42E+01	Steel stud with brick cladding and metal roof	**2.44E+03**
Steel stud with metal wall cladding and metal roof	MJ	1.22E+03	1.18E+02	8.18E+00	0.00E+00	3.99E+01	-6.42E+01	Steel stud with metal wall cladding and metal roof	**1.32E+03**
Wood stud with lightweight wood	MJ	1.33E+03	2.15E+02	8.18E+00	0.00E+00	7.46E+01	-3.38E+00	Wood stud with lightweight wood	**1.62E+03**
Total	**MJ**	**1.03E+04**	**1.21E+03**	**2.45E+01**	**0.00E+00**	**4.36E+02**	**-2.60E+02**	**Total**	**1.17E+04**

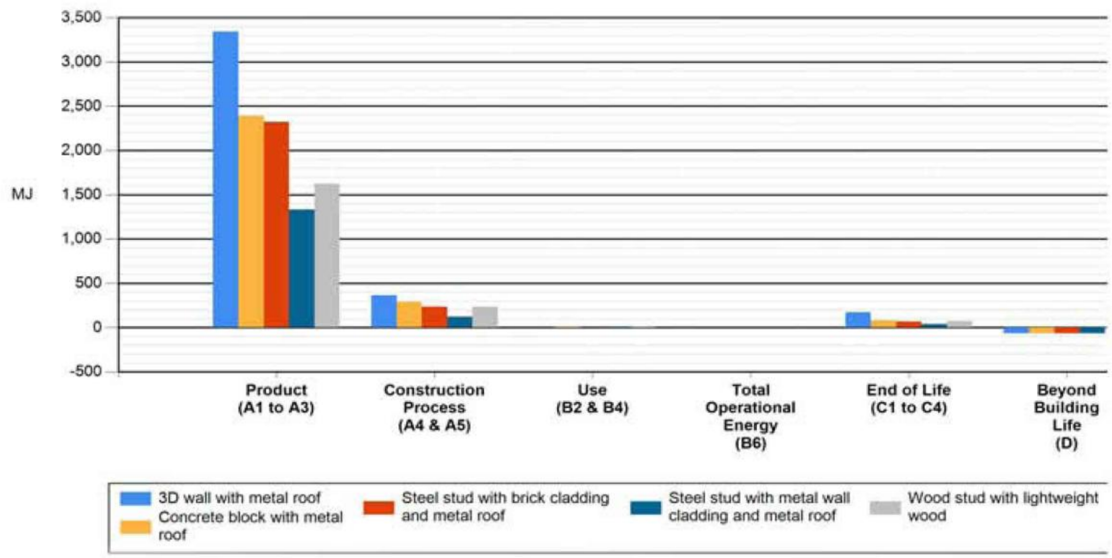
Comparison of Ozone Depletion Potential By Life Cycle Stage



Comparison of Ozone Depletion Potential By Life Cycle Stage

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Project Name	Total
3D wall with metal roof	kg CFC-11 eq	2.00E-06	8.65E-08	0.00E+00	0.00E+00	4.83E-10	0.00E+00	3D wall with metal roof	**2.09E-06**
Concrete block with metal roof	kg CFC-11 eq	1.26E-06	7.27E-08	4.84E-10	0.00E+00	1.95E-10	0.00E+00	Concrete block with metal roof	**1.34E-06**
Steel stud with brick cladding and metal roof	kg CFC-11 eq	4.69E-07	2.38E-08	0.00E+00	0.00E+00	1.64E-10	0.00E+00	Steel stud with brick cladding and metal roof	**4.93E-07**
Steel stud with metal wall cladding and metal roof	kg CFC-11 eq	3.28E-07	2.48E-09	4.84E-10	0.00E+00	6.81E-11	0.00E+00	Steel stud with metal wall cladding and metal roof	**3.31E-07**
Wood stud with lightweight wood	kg CFC-11 eq	1.89E-07	2.53E-08	4.84E-10	0.00E+00	2.16E-10	0.00E+00	Wood stud with lightweight wood	**2.15E-07**
Total	**kg CFC-11 eq**	**4.25E-06**	**2.11E-07**	**1.45E-09**	**0.00E+00**	**1.13E-09**	**0.00E+00**	**Total**	**4.46E-06**

Comparison of Total Primary Energy By Life Cycle Stage



Comparison of Total Primary Energy By Life Cycle Stage

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Project Name	Total
3D wall with metal roof	MJ	3.34E+03	3.65E+02	0.00E+00	0.00E+00	1.74E+02	-6.42E+01	3D wall with metal roof	**3.82E+03**
Concrete block with metal roof	MJ	2.39E+03	2.89E+02	8.20E+00	0.00E+00	8.01E+01	-6.42E+01	Concrete block with metal roof	**2.70E+03**
Steel stud with brick cladding and metal roof	MJ	2.32E+03	2.36E+02	0.00E+00	0.00E+00	6.88E+01	-6.42E+01	Steel stud with brick cladding and metal roof	**2.56E+03**
Steel stud with metal wall cladding and metal roof	MJ	1.33E+03	1.23E+02	8.20E+00	0.00E+00	4.02E+01	-6.42E+01	Steel stud with metal wall cladding and metal roof	**1.44E+03**
Wood stud with lightweight wood	MJ	1.62E+03	2.34E+02	8.20E+00	0.00E+00	7.47E+01	-3.38E+00	Wood stud with lightweight wood	**1.94E+03**
Total	**MJ**	**1.10E+04**	**1.25E+03**	**2.46E+01**	**0.00E+00**	**4.38E+02**	**-2.60E+02**	**Total**	**1.25E+04**