

KNOWLEDGE TRANSFER IN POST-DISASTER RECONSTRUCTION

The Problem of Post-post-disaster Reconstruction

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to my wife;
for all her patience and support

*"Research is heavy jargon; after the first page
we start falling asleep"*
(King 1984).

Abstract

The history of post-disaster reconstruction programs, especially in developing countries, is replete with the failure to provide safe-construction methods that can be sustained and repeated over time, in spite of the usually acclaimed success of these projects by those in charge. One key factor that results in this discrepancy is time; while the success of such projects is typically evaluated by the authorities through its tangible impact (such as physical development) at the end of the reconstruction program, the real impacts of the project can be known only in the long run. In other words, although it may seem to have gained success when it is over, the actual success or failure of a post-disaster program largely depends on intangible aspects such as awareness, preparedness, acceptance or rejection of preventive measures, and sustainability.

The literature on organizing post-disaster reconstruction is abundant, though no clear consensus emerges; similarly, the literature on knowledge transfer and the embedding of tacit knowledge is rich. However, none applies to both domains. Focusing on the transfer of safe-construction knowledge in the case of the reconstruction program after the earthquake of Bam, Iran, three field studies at three periods of time were organized in Bam. The objective of these field studies was to observe the state of the modern and traditional construction knowledge prior to the earthquake, how new knowledge was disseminated during the directed reconstruction phase, and how much of that knowledge was internalized and translated into sustainable, operational tacit knowledge by the local builders.

Based on the theories of knowledge transfer and emphasizing the great distinction between tacit and explicit knowledge, this study demonstrates that in the absence of local builders' understanding of the principles of construction methods introduced to them, very little can be done in terms

of assuring the repeatability of safe-construction practice after the official reconstruction program is terminated. This research shows that it is not sufficient to teach the builders *what to do* for building safely; rather, they must understand *why to do* so, if sustainability of the practice is desired in the reconstruction program for continued application after it ends.

This study further concludes that the chaotic environment and human dynamics that emerge after a disaster conflict with the prerequisites for a successful transfer of knowledge. Therefore, it is suggested that a *process* of safe-construction-knowledge transfer should be added to the usual post-disaster reconstruction *programs*. This process, called a *post-post-disaster* program in this study, should target the network of local builders, incorporating their informal education through an interpersonal and apprenticeship-like training, with accordance to their learning patterns before the disaster. This process would obviously be time-consuming, and therefore calls for deliberately allocating more time than is usually allocated to reconstruction programs.

Keywords: post-disaster, reconstruction, knowledge transfer, earthquake, Bam, Iran.

Résumé

L'historique des programmes de reconstruction *après les catastrophes*, particulièrement dans les pays en développement, est jalonné d'échecs. On semble être incapable d'offrir des méthodes de construction sécuritaires qui peuvent être maintenues et répétées à long terme, malgré les succès annoncés par ceux qui sont en charge de ces projets. Un facteur-clé qui explique cette différence d'opinions est le temps; alors que le succès de tels projets est habituellement évalué par les autorités en termes de son impact tangible (par exemple le développement physique) immédiatement après la fin du programme de développement, les impacts réels du projet ne peuvent être connus que sur le long terme. En d'autres mots, même s'il peut sembler couronné de succès lorsqu'il est terminé, le succès ou l'échec réel d'un programme de reconstruction après une catastrophe dépend largement d'aspects intangibles tels que la sensibilisation de la population, l'état de préparation, d'approbation ou de rejet des mesures préventives, et le respect des mesures d'une façon durable.

Les ouvrages traitant de l'organisation de la reconstruction sont nombreux quoiqu'on n'arrive pas à un consensus; de même, les ouvrages traitant de la transmission des connaissances et de l'ancrage des connaissances tacites sont riches. Cependant, aucun ne s'applique aux deux domaines. En se penchant sur le transfert des connaissances portant sur les méthodes de construction sécuritaire à la suite du programme de reconstruction après le tremblement de terre de Bam en Iran, trois études sur le terrain, s'échelonnant sur trois périodes de temps distinctes, furent réalisées. L'objectif de ces études fut d'observer l'état des connaissances sur la construction moderne et traditionnelle avant le tremblement de terre, comment les nouvelles connaissances ont été diffusées pendant la phase de reconstruction, et quelle fut la quantité de connaissances assimilées qui se

sont traduites par des connaissances réellement mises en œuvre par les constructeurs locaux.

D'après des théories de transfert des connaissances, et en mettant l'accent sur la grande distinction entre les connaissances tacites et explicites, cette étude démontre que si les constructeurs locaux ne comprennent pas les principes des méthodes de construction qui leur sont présentées, très peu de choses peuvent être faites pour assurer une répétition des pratiques de construction sécuritaires, une fois que le programme officiel de reconstruction est terminé. Cette recherche démontre qu'il n'est pas suffisant d'enseigner aux constructeurs *quoi faire* pour construire d'une façon sécuritaire; mais plutôt qu'ils doivent comprendre *pourquoi faire*, si le maintien des pratiques est désiré dans le programme de reconstruction de manière à obtenir une application continue de ces mesures une fois le programme terminé.

Cette étude conclut que l'environnement chaotique et les dynamiques humaines qui émergent suite à un conflit nuisent aux conditions nécessaires pour qu'un transfert de connaissances soit couronné de succès. Par conséquent, il est suggéré que le *processus* du transfert de connaissances portant sur la construction sécuritaire soit ajouté aux *programmes* habituels de reconstruction après les catastrophes. Ce processus, appelé le programme *après-après-catastrophe* dans cette étude, devrait viser le réseau des constructeurs en complétant leur enseignement informel par une formation interpersonnelle d'apprentissage, en accord avec leur modèle d'apprentissage habituel d'avant la catastrophe. Ce processus prendrait bien sûr beaucoup de temps, et donc, demande d'allouer plus de temps que ce qui est fait pour les programmes de reconstruction habituels en tant que tels.

Mots-clés: catastrophes, reconstruction, transfert de connaissance, tremblement de terre, Bam, Iran.

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Glossary and abbreviations

The key terms used in this study are defined as follows:

Community: refers in the context of this research to all the people of the area who have some form of involvement in the building practice, including but not limited to masons, contractors, master builders, and laborers.

Information: data that conveys a message to its receiver, and "is meant to change the way the receiver perceives something" (Davenport and Prusak 1998).

Knowledge: although it has a broader and more complex meaning, in the context of this study it refers to the comprehension of a phenomenon, and is originated from "minds at work" (Davenport and Prusak 1998).

Small cities: are the cities of less than 500,000 residents, as defined by the United Nations Human Settlements Programme, UN-HABITAT (UN-HABITAT 2007). In this research, however, a quality factor is added to the definition as well; the term also refers to remote towns that are away from the more developed and somewhat modernized cities, and therefore, traditional way of life and practice is prevailed among their citizens.

Main abbreviations used in the text are as follows:

HFIR: Housing Foundation of Islamic Revolution (Bonyād-e Maskan-e Enqelāb-e Eslāmi) (Persian: بنیاد مسکن انقلاب اسلامی)

ISEO: Iranian Structural Engineering Organization (Sâzmân-e Nezâm Mohandesi-ye Irân) (Persian: سازمان نظام مهندسی ایران)

MHUD: Ministry of Housing and Urban Development of Iran (Vezârat-e Maskan-o Shahr-sâzi-ye Irân) (Persian: وزارت مسکن و شهرسازی ایران)

PWJ: Peace-Winds Japan (NGO)

SCI: Statistical Centre of Iran (Markaz-e âmâr-e Irân) (Persian: مرکز آمار ایران)

Chapter 1: INTRODUCTION

1.1. Overview

One of the key issues in post-disaster reconstruction is the role of the survivors. Can their participation be mobilized and, if so, what knowledge and skills can they bring to the task? For example, has a new safe-construction technique, introduced to an affected community, been adopted and internalized by the locals? How can one, in such a situation, make sure of the continuity of safe-construction in the long term? The answer to these questions depends, to a large measure, on the organizational strategy deployed for the reconstruction process, which in turn depends on the prevailing administrative structures and on the attitudes of the population regarding them.

The aftermath of the earthquake in Bam, Iran, provided the context for a case study of the concerns of the survivors and their ability to ensure that they were translated into appropriate construction methods. Was the principal preoccupation about reconstructed housing related to the more recognizable features of the design of the houses and the composition of the neighbourhoods, or was it focused on "invisible" features such as structural capability?

To obtain answers to these questions, a three-part longitudinal research¹ was conducted in Bam, (i) in the interval between the earthquake and the start of reconstruction, (ii) during the formal reconstruction phase and (iii) once formal reconstruction was virtually finished. Employing state-of-the-art theories of knowledge transfer, the research examines these questions in the context of post-disaster reconstruction, suggesting that safe-construction knowledge in a stricken

¹ Longitudinal research in general refers to analyzing change through time (Saldaña 2003). For more please see section 1.3.

community² in developing countries can only be transferred successfully in an informal and long-term process, where a close relationship between the informants and the recipients of knowledge can be made. On the basis of the findings, it is proposed that a *process* of construction knowledge transfer should be brought into effect in parallel with and independent of the reconstruction *program* itself, allowing for a long period of informal training (apprenticeship), while taking advantage of the people's natural fear of disaster and their precautionary way of thinking in the immediate aftermath of disasters.

It is important to mention that the focus of this study is based on the structural aspects of post-disaster reconstruction in developing countries. It is acknowledged, nonetheless, that "structural matters" form only part of the so-called "essential requirements" of safe-construction, which are "mechanical resistance and stability, safety in case of fire, hygiene, health and the environment, safety in use, protection against noise, energy economy and heat retention," all of which are crucial in making the built environment safe for proper housing occupancy (EUROPA 2002). However, especially in the case of disasters like earthquakes, it is understandable that the structural performance of buildings becomes the first and foremost concern of almost everybody involved, including the citizens as well as the local and state authorities. Therefore, the structural side of the issue of safe-construction became the focal point of this research and hence, the term "safe-construction" refers here to the structural aspects of safe-construction practice.

Furthermore, it is understood that addressing the specific qualities of vernacular architecture and examining housing units within their urban context are very important aspects of housing studies, the chosen focus of

² The term "community" here refers to all people in the area who have some form of involvement in the building practice.

this study is on the transfer of knowledge, taking as an indicator knowledge about earthquake-resistant construction. In other words, the study is concerned with the earthquake-resistance of housing in Bam. It is not concerned with cost-efficiency, energy-efficiency, or the like. **It is about the transfer of knowledge of construction methods in disaster-affected communities in developing countries, taking as an illustrative example earthquake-resistance.**

1.2. Structure of the research

The research is organized into four chapters. In the first chapter, a general view of the study is introduced. A summary of the findings and the general discussion is briefly presented to give the reader an idea of the orientation of the research as well as what it is about. The first chapter clarifies the scope and the focus of the study, while introducing the overall concepts and the contribution of the research.

As mentioned earlier, three field studies in Bam were conducted: (i) shortly after the earthquake; (ii) before the official termination of the formal reconstruction program; and (iii) after the state authorities discharged their duties and left the city, when the popular (conventional) construction sector had started to take over the remaining reconstruction of the city. Chapter one also illustrates the methods employed in each of these three field studies. The first stage relied on the information gathered from archival photos taken by others in the days immediately following the earthquake. The second fieldwork was based on personal observations and information collected in-situ. The third field-study involved hands-on and real-time experience with the local builders.

The second chapter provides the reader with the antecedents of the study, including the background, review of the literature, and the definition of the problem. The issues surrounding post-disaster

reconstruction programs are reviewed, and the specific context of this research, being the city of Bam, is described. Then, the problem of knowledge transfer in general is discussed through a review of the literature. Finally, the problem being dealt with in this study is demonstrated, namely the transfer of knowledge in post-disaster situations in developing countries.

Chapter three sets forth the results of each of the aforementioned stages of the study, with focus on the transfer of knowledge. In this chapter it is demonstrated that the vast destruction in the earthquake of Bam was not entirely due to the poor quality of traditional construction materials (i.e. adobe and raw earth) as many had thought. Rather, lack of construction knowledge was at fault. A study of the formal reconstruction program follows, describing the approach that the authorities adopted to undertake it. Next, the findings of the third fieldwork are depicted, illustrating the extent of the knowledge of safe-construction that the locals had acquired in the formal reconstruction period. It is shown that know-what³ has been transferred fairly successfully, know-why⁴ has not.

Finally, chapter four draws out the conclusions from this research while opening a discussion for future studies. The argument made is that in a post-disaster framework in a developing country, where reconstruction is rushed towards a physical and visible outcome in a relatively short period of time, it is very unlikely that the knowledge of safe construction will be transferred properly and correctly. Furthermore, as theories of knowledge transfer demonstrate, the transfer of tacit knowledge conflicts with situations in which formality prevails, thus further lowering the likelihood of knowledge transfer through the formal

³ Know-what corresponds to knowing what is involved in generating a phenomena (Garud 1997).

⁴ Know-why corresponds to the "understanding of the principles underlying phenomena" (Ibid).

programs of reconstruction conducted by governments and/or state authorities. What is overlooked in such situations is the fact that only *information*⁵ can be conveyed by formal procedures rather than *knowledge*⁶, yet it is knowledge that is required for the long term preservation of good construction practice.

1.3. Methodology

The research was organized longitudinally. Longitudinal research refers to analyzing change through time. Longitudinal research entails three essential elements, which are "length of the study, time, and change." As Saldaña (2003) describes, "a qualitative study becomes longitudinal when its fieldwork progresses over a lonnnnnnnng time." However, there is no minimum length of time for a qualitative study to be considered longitudinal, and the length of time depends largely on the type of study and thus, varies from one research to another (Saldaña 2003).

According to Saldaña (2003), any longitudinal research requires "at least two reference points" of time, through which the changes are observed and analyzed. This research was based upon three points of time, and each field study employed a different approach as is explained in the following paragraphs.

Three time intervals were chosen to study the reconstruction process in Bam, which corresponded to the best moment for making each of the field studies. The first study took place one year after the earthquake. The second was conducted two years later (three years after the disaster), and

⁵ *Information* represents data that conveys a message to its receiver and "is meant to change the way the receiver perceives something" (Davenport and Prusak 1998).

⁶ Although the word "*knowledge*" has a broad and complex meaning, the term here refers to the comprehension of a phenomenon, and is originated from "minds at work" (Davenport and Prusak 1998). For more information see section 2.3.

the last one was carried out four years after the earthquake. The methods and the reasons for choosing each time interval are discussed below.

- The first visit to Bam in February 2005, for 10 days, a year after the earthquake, provided an opportunity to observe and gather information regarding building failures. In addition, the fieldwork enabled the start of the formal reconstruction process to be described, based on interviews with the HFIR inspectors, and with the providers of the selected model houses.
- The second visit in February 2007, for fourteen days, gave an overview of experience with the formal reconstruction program and its outcome just before its official termination in March 2007.
- The third and final field trip in the winter of 2007-2008 - after the HFIR's three-year presence in Bam, lasted 40 days. This trip involved obtaining information from small building contractors and their clients on how they chose their building techniques once the HFIR's control had been removed. The gathering of this delicate information was performed through hands-on participation in construction work.

The information obtained from these three field studies in Bam enabled a view of the reconstruction process to be composed, and provided the platform for responding to the research hypothesis. It was learnt that information about techniques acquired during the formal supervised reconstruction period were not internalized and were not transformed into operational knowledge and skill. As a result, construction practices started to revert back to relatively unsafe methods.

The methods employed for this research consist of a combination of three strategies of: 1) literature review; 2) archival studies; and 3) direct observations made at three stages of the reconstruction process. The approach and emphasis on each method, however, vary in each fieldwork

visit, as the objective of study on each trip differed. This will be further elaborated on later.

During the fieldworks, care was taken to avoid any resemblance to procedures that might be adopted for governmental investigations or research. Behaviour that could make the local population suspicious of a connection with the government (or HFIR) could seriously bias the information collected.

1.3.1. First fieldwork, ten days, February 2005

The first fieldwork was carried out almost a year after the earthquake, when the *temporary shelter* stage of the recovery effort was over and the reconstruction program had just started. At the time, the destroyed buildings were, to some extent, intact enough for one to study the construction techniques used by the locals before the disaster. This state of ruin provided the opportunity to observe the failures and the defects that led to the extensive destruction in the Bam earthquake. The timing of this first visit made it possible to not only observe the starting point of the reconstruction program, but also to study the way people used to build in Bam prior to the earthquake.

This field study took ten days; the goal was to find evidence that could demonstrate the construction knowledge in Bam before the earthquake, in order to shed light on the causes of the extensive destruction. In addition, nearby villages were visited to attain a better understanding of the traditional building practice in the area, since the villages had been hardly influenced by modern construction techniques before the earthquake.

The methodology employed in this part was based on studying archival records as well as direct observations of the damaged structures in the city. The archives and documents of three major organizations were used. These organizations are:

- Housing Foundation of Islamic Revolution (HFIR), which was the foremost player in reconstructing the city.
- Building and Housing Research Centre (BHRC), which is an affiliate of the Ministry of Housing and Urban Development of Iran.
- Statistical Centre of Iran, which has detailed statistics on this earthquake.

The administrative documents, reports, and records concerning this earthquake, in particular photos taken by all the parties involved, along with the photos taken in-situ by the author at the time of visit form the basis of analysis of the first field work. However, a review of pertinent literature was used as well, in order to determine other scholars' points of view on this specific disaster and its reconstruction program.

For this part of the research, literature concerning the earthquake of Bam was studied, photos were taken and gathered, parties involved in the reconstruction program were interviewed, and observations were recorded systematically for subsequent processing.

1.3.2. Second fieldwork, 14 days, February 2007

The second fieldwork was conducted three years after the earthquake, when the reconstruction program was about to end, in March 2007 (it should be noted that the first day of spring, March 21st, is the first day of the Iranian New Year). Therefore, the reconstruction program of Bam was scheduled to end by the New Year, i.e. March 2007, shortly after the second fieldwork visit.

The time chosen for the second fieldwork was crucial, since it could illustrate the influence of HFIR's efforts and policies on the construction techniques of the city and the people's perception of them. This stage was comprised of observing the formal building practices in Bam. Since the

reconstruction of the city was highly controlled and strictly inspected by HFIR, a unique opportunity to examine the impacts of a completely formal reconstruction process over an extended period was created. Further observation during the third visit (see below), would then be able to demonstrate the extent of the respect for the construction knowledge acquired by the residents during the formal reconstruction program.

The main method employed during the second field visit was direct observation, encompassing formal and informal data collection, as well as taking photographs of the reconstruction process in the city. The goal at this stage was to depict the progress of the reconstruction program hitherto, and to explore the techniques used and their impact on the built environment. Therefore, no archival records were used. However, statistical data, inspection forms, and plans and drawings were collected from HFIR, which were used later to help analyze the observations.

1.3.3. Third fieldwork, 40 Days, December 2007 to February 2008

In order to study the after-effects of HFIR's activities and the approach they took in the reconstruction of Bam, the final fieldwork was conducted at an interval of about nine months after the official termination of the reconstruction program. It should be noted that the more time that elapsed between the end of the program and this third fieldwork, the greater the likelihood of accuracy of the study. The objective was to define a lapse of time that would give the popular sector enough time to develop again, and to allow the citizens to practice construction on their own with little or no formal control. It is important to note that the free inspections offered to the citizens were no longer available since nine months earlier, when the HFIR had officially terminated the reconstruction program. In addition, another key issue that had to be taken into account was the climate. The harsh climate of Bam slows down the pace of construction in

summer, so distancing this third period of fieldwork from the summer season seemed sensible. Therefore, the period of December 2007 to February 2008 was selected for the third fieldwork.

The method employed in the third fieldwork was totally different from those of the previous ones. While the first two visits were designed to observe the tangible and visible aspects reflecting the prevailing construction knowledge before the earthquake and after it under the direction of HFIR, the last visit focused on the local master builders' and their building practices. The objective of the study at this stage was to find out how well the earthquake-resistant building techniques proposed by HFIR were adopted by these craftsmen. In other words, the goal was to examine whether the explicit knowledge disseminated by HFIR and other involved parties, had been successfully turned into tacit knowledge, and been applied intelligently.

As discussed in the previous section, theories of knowledge transfer suggest that tacit knowledge is best understood through close relationships, effective communication, and socializing between the informant and the recipient. Therefore, to examine the tacit knowledge of the local builders, one must build close relationships with them, become a part of their community and eventually work with them in order to get a fairly comprehensive understanding of what they do and how they build.

As will be described later on, the work of the builders in Bam was being closely supervised during the formal-reconstruction time (HFIR era) by means of official inspectors. The approach of the third survey, then, was to observe the post-HFIR building practice, but from an informal point of view. One of the main weaknesses of direct observation as a method of study is, as Yin (2003) points out, that the presence of the observer may weaken the validity of the results as the "event may proceed differently because it is being watched." To avoid this situation, an

attempt was made to conduct the observations in an informal manner and to make as many connections with the locals as possible. The third field study was therefore carefully planned to appear as an informal study of the informal building sector.

Overall, two strategies were felt to be the most effective in gaining the trust of the local builders. First, getting to know the master builders through the citizens, and second, to work with them for a certain period of time. When combined, these two approaches can create a sense of reliability and trust-worthiness towards the observer in the local builders' community. Nonaka and Toyama (2007) believe that "practice lays a foundation for sharing tacit knowledge through shared experience." Thus, practicing construction with the local builders seems to be the best tactic if one wants to learn about their tacit knowledge.

The inspection methods in Bam during the HFIR involvement period were very strict and followed a straight-forward procedure defined by a 14-page checklist. Besides confirming administrative information, the checklist was used to control three aspects of a building, namely: architectural design, architectural implementation, and structural implementation (see appendix D). This checklist was employed as a concealed⁷ guideline for the observations in the third fieldwork. By using the same inspection checklist that HFIR had used for controlling the construction, exactly the same assessment tools were employed for the informal observations, when the driving forces of formal procedures and outside pressure no longer existed. It should be noted, however, that the scoring system of the checklist was not employed; it was unclear, even to the inspectors, how the system worked.

⁷ In this context, "concealed" means that the checklist was neither shown to the parties being observed, nor used explicitly in any interview or observations.

Another objective of the third field study was to determine how the builders in Bam were initially trained and became masters, and how they used to obtain construction knowledge before and after the earthquake. The answer to these questions could then demonstrate whether or not the method of knowledge transfer in the reconstruction program actually fitted into the reality of the learning patterns of the targeted builders. To answer the above questions, informal interviews with the builders were conducted in the form of casual conversation during breaks. The builders were led to talk about how they initially got into the practice, how they progressed and eventually became masters, whether they received any training of any sort after the earthquake, and from whom. All information gathered through these conversations was transcribed into written form daily.

1.3.4. Comparison with other cases and validating the findings

Finally, once the research had reached a point at which conclusions could be envisaged, the findings were validated through a comparison with somewhat similar cases in other countries. Besides the availability of sufficient information, the criteria for selecting these cases were one or both of: 1) the program of reconstruction adopted a similar approach to that of Bam in terms of construction supervision and/or decision-making, 2) there were training and safe-construction educational programs provided during the official reconstruction project. Literature review was the only method employed for this part of the research.

Chapter 2: ANTECEDENTS

This chapter reviews the background of this research, laying the foundations for the discussions set forth in Chapter 4. It is important to recall that this research concerns itself with the transfer of knowledge after disasters in developing countries, with Bam as its case study. Therefore, there are three distinct subjects involved in this research, namely i) its context, ii) the issues of post-disaster reconstruction programs in general and the approach adopted in Bam, and iii) the problem of knowledge transfer. Thus, the first part of this chapter gives an overview of the antecedents of each of these subjects separately, in order to draw a picture of the general discourse as well as the specific setting of the study. Following this, a summary of the background studies is provided, emphasizing important points that will lead to the research statement and the research question.

2.1. The Context

It is a common public misconception that natural hazards are disasters. In fact, natural hazards become disasters by human act, as Paton and Johnston (2006) point out.

Most disasters require human input, ranging from bad planning decisions to inadequate mitigation, preparedness and response (p. 20).

This statement demonstrates that the human factor plays a crucial role in disasters. In other words, natural hazards turn into disasters only in a context of human negligence. Oliver-Smith and Hoffman (2002) define disasters as a result of the combination of "a potentially destructive agent/force from the natural, modified, or built environment, and a population in a socially and economically produced condition of vulnerability." They believe that disasters are embedded in vulnerable social systems and will emerge when hazards occur. Therefore, the context in which disasters

happen must be researched carefully in order to study and take action towards reducing community losses from natural hazards. The context of the city of Bam is reviewed in this section. It is studied in terms of the characteristics of its built environment and the building trades that produce this environment, which can be considered to be subsets of the broader Bam community. The objective of this section is to demonstrate the state of the building culture of Bam both before and after the earthquake.

2.1.1. The earthquake of Bam and its aftermath

Located in the southeast of Iran, the city of Bam was hit by a 6.7 magnitude earthquake on December 26, 2003, which severely damaged the city. According to the International Federation of Red Cross and Red Crescent Societies, approximately 35,000 people died ($1/4$), and more than 75,000 residents, out of a population of 120,000- that is $2/3$ of the population- were left homeless; as many as 85% of the city's buildings were destroyed or damaged (Walter 2004).

It is well known that building with earth has a long history in Bam, dating back some 2500 years to when the city was founded. Earth architecture, therefore, was the traditional form of construction in Bam; the majority of older houses in Bam were built out of adobe and earth. Therefore the high level of destruction throughout the city was first thought to be the result of these supposedly poor construction materials. Early reports about the earthquake stressed that the construction material - composed mostly of earth and adobe - was at the root of the high level of destruction. The idea that adobe brick was not an appropriate construction material was so prevalent and influential among citizens and authorities that the head of the Bam reconstruction effort asserted that "there will be no more mud brick in Bam" (Murphy 2004).

A closer look at what remained of the city, however, revealed that this was not the whole story. First of all, while the majority of earth buildings in the *new* city were demolished, a number of earth structures in the *old* city were still standing.⁸ Furthermore, although it appeared to visitors and reporters, who visited the ruins of Bam immediately after the earthquake, as if almost all of the city was constructed of adobe brick, the statistics show that 54 percent of the houses were made of adobe, and the rest (46 percent) were built using modern materials like steel and concrete (Ghafory-Ashtiany and Hosseini 2007). Another report states that only 30 percent of the buildings were built out of adobe and mud-bricks (Mehdi 2004). In fact, there were many newly built buildings that were also destroyed or seriously damaged (Murphy 2004) (see Figure 2.2. following page).

The offices of the governor and the municipality, Bam's three hospitals, its schools, the central bank building: all were less than 30 years old, yet were badly damaged, if not completely destroyed. Expensive residences suffered the same fate as the hovels of illegal Afghan workers. For once, rich and poor found themselves in the same boat. Bam's governor, who lost his sister and nephews in the quake; was among the homeless (Walter 2004, p.80).

All of the aforementioned buildings were built employing steel- or concrete-frame systems combined with masonry walls and roofs (Manafpour 2004). The three hospitals of Bam were constructed with either "unreinforced brick masonry," or concrete-frames with brick infill walls, all of which were badly damaged (Eshghi and Naserasadi 2005). The governor's Building was built of "confined brick masonry with horizontal ties," which collapsed partially (Eshghi and Naserasadi 2005). The structural system of the Central Bank was composed of a steel frame

⁸ The Citadel, one of the world's largest earthen structures (Figure 2.1. next page), was badly damaged; it appears that recent inappropriate repairs are likely to be the reason.

with masonry walls, which was extensively damaged. Another newly-built bank with the same structural system collapsed completely (Ibid).



Figure 2.1. Bam citadel before the earthquake, one of the biggest earth complexes in the world



Fig. 2.2. Aerial photo of Bam taken one day after the quake (IKONOS 2003), IKONOS Image Courtesy of GeoEye

Raeis Ghasemi and Parhizkar (2004) explain that the majority of buildings in Bam collapsed because of the failure of their structural system, and not necessarily as a result of the construction materials employed. They further assert that the most common failures they observed in the remaining structures stemmed from a lack of safe-construction knowledge and disregard for seismic building codes (Ibid). This ignorance of safe-construction practices can be seen in all types of construction methods, from masonry to concrete-frame (Khorrami and Majid-Zamani 2004; Masoumi 2004).



Figure 2.3. Close-up of the aerial photo of Bam one day after the quake. The collapsed roofs of both old and new houses can be seen. The upper section of the photo shows the old fabric while the lower part is mostly composed of relatively new constructions (IKONOS 2003), IKONOS Image Courtesy of GeoEye

From a proper examination of the evidence that could be observed in the ruins of the city, it can be concluded that poor workmanship and lack of construction know-how were the main causes of the devastation, regardless of whether the buildings were made of earth, concrete or steel (Naeim et al. 2004; Manafpour 2004).

2.1.2. Building culture in Bam before the earthquake

Like many small cities⁹ in Iran, the building trade in Bam is basically run by an informal network of relationships among master builders and labourers.¹⁰ There is no specific guild or organization associated with those involved in the construction business in small cities and towns. This is partly due to the seasonal nature of the trade, which necessitates that the master builders and labourers have other jobs when the building market is down or when the weather does not permit construction. In the case of Bam, almost all of the builders and labourers have at least one other job on the side –usually agricultural pursuits- or construction is considered their second job and farming is their main source of employment.

Furthermore, the building team is in any case very complex, which makes the popular building trade difficult to organize. In the case of small cities like Bam, the building team usually comprises of people from outside the city (seasonal farmers and gardeners who live in smaller villages), who make a trip to the city only when they receive a job offer

⁹ By UN-HABITAT (2007) definition, cities with population of less than 500,000 are considered as small cities. Besides the size factor, the term small cities here also relates to qualitative factors, and refers to remote towns that are far away from the more developed and somewhat modernized cities; therefore, the traditional way of life and practice has prevailed among their citizens.

¹⁰ "Reference will never be found to the informal system for it is not based on documentation but rather on the network of interpersonal relationships which exists between individuals in the resource organizations. It is a system based on familiarity..." (Roberts 1972).

from a master builder or a general contractor. Therefore, communication among the building community remains very limited to small groups of individuals as opposed to a community of practice. Marchand (2001) explains this informal network of master builders and labourers, noting that "the nature of their work requires that they are dispersed throughout the city (or region) and not necessarily in (regular) communication with one another."

It can be said that those involved in the building trade in Iran, and in small towns in particular, do not feel the need for a formal guild or regulating body of any sort, since everything is managed and controlled within an informal network of builders. There is no central order or establishment among the construction community in the town where the builders would gather for necessity or for association. Therefore, there is no opportunity for social learning or community practice for construction workers in Bam; indeed, this situation holds true for all other small cities of Iran. It is worth noting that these small towns constitute approximately 92 percent of the human settlements of Iran, in which roughly 58 percent of the nation resides. According to UN-HABITAT (2007), such small cities in developing countries are highly prone to complete destruction in a single strike of a natural hazard. Moreover, the building trade in many larger cities of Iran is organised in a similar fashion as well.

Unlike the present situation, in the ancient tradition of architecture in Persia (Iran) a strong controlling system existed which was enforced through a powerful community of practice that continuously and strictly supervised and regulated the building practice. In this controlling system, which can be named the guild of masons,¹¹ it was traditionally the master

¹¹ "There is no clear distinction in traditional Persian crafts between builder, mason, and bricklayer. They all start as apprentices of a master builder. Those

builders' responsibility to ensure that the knowledge of construction was passed along to the younger generations of builders through a process of apprenticeship (Marchand 2001). A very long and arduous course of apprenticeship was required in order to gain access to the higher ranks of the guild. However, actually becoming a master builder involved much more diligence to convince a jury of three master builders that the apprentice had gained the required intellectual and ethical competence (Shaykhli 1983). It was impossible to practice architecture without going through this process (Ibid).

The strict and difficult process of becoming a master builder, as well as the coherence of the guild, created an authoritative community of practice in the traditional building community in Iran. Consequently, an invisible self-controlling system for the practice developed. Any flaw or negligence in the work of a member of this community would jeopardize his reputation, which was critical in a society where reputation was considered the most valuable asset. The loss of reputation would subsequently lead to the loss of recognized competence (Shaykhli 1983).

Generally speaking, the traditional master-apprentice system of knowledge transfer (education) in developing countries was a comprehensive process that covered all the knowledge required to advance to higher levels, which could eventually lead to mastery in a given practice (Marchand 2001). This process was broken down by the arrival of the modern, western education system; in addition, the task of education partly became the responsibility of the government and schools (Ibid). This change eventually resulted in inconsistency in the process of education in those trades originally associated with apprenticeship, such

who were more talented than the average bricklayer made Persian architecture famous throughout the Islamic world" (Wulff 1966).

as the building practice (Ibid). Consequently, the process of knowledge transfer in Iran during the past few decades, especially in small cities and remote areas, has been in a state of transition from a strong tradition to a new (western) modernity. The traditional master-apprentice system of education has been replaced by an ill-conceived western educational system (Ibid).

Not surprisingly, this transitional status is reflected in building practice as well, resulting in construction methods that are neither completely traditional nor completely modern. With the ancestral method of knowledge transfer fading away after the introduction of the new western-style educational system,¹² the role and the authority of master builders in controlling construction and construction knowledge weakened, too. This resulted in a lack of a quality-controlling body in the building trade (Ibish 1980). Subsequently, the traditional controlling system of the building trade has disintegrated, but it has not yet been replaced completely and successfully by any new organization or establishment.

As Ibish (1980) states, the adoption of western educational models has had a weighty impact on the traditional crafts and the way they used to be transferred through generations. Working in a context very similar to that of Bam, Sana'a in Yemen, Marchand (2001) explains that one crucial factor that has impeded the complete change of the educational system in such a context is the authoritarian mentality embedded in the tradition of such cultures. In other words, western-style education has its roots in democracy, a notion that is foreign to almost all of the old cultures. Marchand (2001) states:

¹² While the western-style educational system was brought to Iran in 1850, it only reached Bam in 1914, when the first "formal school" in the area was established (Parsizadeh and Izadkhah 2005).

Teachers have acted primarily as authority figures rather than in perhaps the contemporary idealised role of Western-style educators, and the school has functioned as a disciplinary establishment rather than instilling young minds with an aptitude for critical judgement and responsibility... (p.21).

As will be seen in Chapter 3, the breakdown of education in Bam resulted in a half-traditional-half-modern process of knowledge acquisition among the three master builders who were observed during the third field study. The three master builders were all trained and educated in a hybrid educational system. All had apprenticed with different master builders for various periods of time and all had studied in formal schools as well, although the level of education each had accomplished differed from one to another.

Another factor which contributed to the degeneration of construction knowledge in Iran, and in small cities in particular, was the introduction of modern construction materials like steel and concrete to the market. The problem was that the builders had very little or no knowledge about these new materials and their proper usage; however, the building market was eager to demand modern and supposedly better-quality buildings. In the absence of any controlling body in the building practice, appropriate knowledge about employing new construction materials and methods was not developed, and ill-informed notions of the new structural systems emerged among the builders. It will be shown in Chapter 3 how this degeneration of traditional construction knowledge transfer, along with the new, misinformed construction know-how, dramatically contributed to the huge loss of life and buildings in the earthquake.

Additionally, in the small towns of Iran, such as Bam before the earthquake, there was no drawing involved in the process of popular housing, which constitutes the largest part of the housing market in such communities. While creating drawings and specifications for building a

house is a relatively new practice in the bigger cities of Iran¹³, it is rarely practiced in the remote areas and small cities. After the earthquake, the reconstruction program of Bam introduced to the local builders the practice of using drawings and specifications. However, although the local builders learned well how to read the engineer-prepared drawings, as will be seen in Chapter 3, these drawings were in fact thought about as means of obtaining a construction permit rather than instructions that should be followed. Once again, the know-how was present, but the know-why was not.

2.2. On Post-disaster Reconstruction

2.2.1. Post-disaster programs in developing countries

Post-disaster reconstruction programs in developing countries generally fall into one of the two following "extreme paradigms," as Gonzalo Lizarralde and Colin Davidson (2001c) state:

1. A community-based approach: Usually supported by the so-called 'enabler' policy, with almost total reliance on aided self-help reconstruction (based [...] on the argument that this approach helps build self-reliance into the affected communities).
2. A technology-based approach: Usually supported by a 'provider' policy, with great reliance on the import of dwellings from the developed donor countries (promoted because of the alleged speed with which housing can be completed) (p.2).

The technology-based or top-down approach is essentially based on exporting materials and technology to the affected area. In other words, the community is provided with almost everything needed for reconstruction by external parties and from external resources. In this approach, the reconstruction actors (i.e. government, NGOs, relief

¹³ Describing the building culture in Iran during the 1930's to the 1960's, Wulff (1966) declares: "To this day no drawings are prepared for the building of an ordinary house. The common practice is that owner and builder 'draw' the plan on the actual site by marking the walls with powdered lime or gypsum."

agencies) *provide* the community with what they need to recover. As this method is "based on the interveners' perception of what should be done and how it should be done," it almost always fails, not only in addressing the victims' needs but also in ensuring continuity and sustainability (El-Masri 1997).

Like many other scholars, Lizarralde and Davidson (2001b) highlight the major defects of top-down (imported technology-based) approaches as: "the use of designs that are too far from traditional typologies and indigenous distribution of spaces, the use of materials foreign to the local building practices and extremely high costs of logistics and transportation of materials."

Unlike the top-down approach, the community-based or bottom-up approach highly depends on community participation and intends to fully involve the stricken community in the reconstruction process. The concept of this method is to *enable* the community to build itself up from within, and as a result, understanding the milieu of disaster and the victims' needs is the base of action in this ideology. Subsequently, as Sliwinski (2006) mentions, "the success - or failure - of participatory methodologies depends on their appropriateness to the local context." Thus, fieldwork has "an essential role in planning for reconstruction, managing resources, organizing activities, and projecting alternative actions" in this concept (El-Masri 1997).

Overall, the technology-based approach is characterized by "building *for* people" (El-Masri 1997) and "external provision of resources" (Lizarralde 2004), whereas the community-based approach stresses "building *with* people," self-help, and community participation. While in the former approach quantities and speed are the main concerns, the latter approach places more emphasis on "priorities, opportunities, problems and alternatives" (El-Masri 1997). The main difference, however, lies in the

process of decision-making: in the technology-based (top-down) approach, all decisions are made by the authorities, whereas in the bottom-up approach the decisions are, as much as possible, left up to the community to make.

By and large, it seems that in many developing countries, the technology of building and/or the quality of construction materials usually become the main concern and focus of the actors and the authorities in post-disaster reconstruction programs; and they are well addressed in many instances. However, it appears that in the majority of these programs –if not all- the complexity of transferring new technologies and the knowledge required to use them to the locals is underestimated, thus hampering the capability of the stricken community "to develop their own capacities of generating resources to cope with the destruction caused by the disaster." As a result, not only is the sustainability of the reconstruction program jeopardised in the long run, but the community is turned into a receiver of help from outside and therefore has an increased dependency upon "foreign imports" (Martirena and Olivera 2006).

Although the bottom-up approach was thought to be the appropriate and perfect solution for post-disaster reconstruction, seemingly addressing all the defects of the top down approach, Lizarralde and Davidson (2001c) characterize such reconstruction programs as being insufficient. Their criticism is that the bottom-up approach employs only one of the aforementioned approaches instead of using "a blend of them." They believe that "a pluralist approach in reconstruction strategies improves the performance of post-disaster housing programs" (Ibid). This strategy is intended to take full advantage of local resources as well as external aid and technology. These authors believe that the flexibility of such an 'open' system- as opposed to the two 'closed' systems mentioned earlier- would lead to "different build[ing] forms which are initially

adapted to the user's requirements and may also be changed as these requirements themselves change" (Lizarralde and Davidson 2001a).

2.2.2. Reconstruction program in Bam

After the "emergency shelter and recovery" stage of the post-earthquake response,¹⁴ the reconstruction effort was begun at all levels, from the local to the national government. Within one month after the disaster, the Housing Foundation of the Islamic Revolution of Iran (HFIR) "was put in charge of the reconstruction of Bam, including housing, commercial units and infrastructure" (Astaneh-Asl et al. 2006).

HFIR is a publicly funded, non-governmental organization that is directed by a principal designated by the Supreme Leader of Iran. HFIR was founded a few days after the Islamic Revolution of 1979 in Iran by the decree of the Supreme Leader of the Islamic Revolution. Since then, HFIR has gradually established head offices in all 30 provinces of Iran, in addition to another 120 branches around the country. HFIR's initial purpose was to provide housing for the poor, especially in rural areas. However, its considerable logistical strength, in conjunction with its widespread presence throughout the country, has made the HFIR the best organization to respond to an emergency. Therefore, the duty of post-disaster efforts in rural areas officially became one of the HFIR's responsibilities by the Parliament amendment in 1987. The Parliament amendment officially put HFIR in charge of the following duties (HFIR 2009):

- 1) Studying the housing needs of the poor in the rural areas as well as in the cities, and subsequently preparing the ground for satisfying

¹⁴ Quarantelli (1995) categorizes the post-disaster shelter and housing provision into four different stages: a) emergency sheltering, b) temporary sheltering, c) temporary housing, and d) permanent housing. During the Bam reconstruction efforts, however, the two stages of temporary sheltering and temporary housing were merged into one.

those needs through community participation and with the help of pertinent organizations,

- 2) Defining and preparing projects for low-cost housing in the cities and villages, and implementing the projects either directly or through community participation , while other pertinent organizations should contribute and cooperate properly if need be,
- 3) Preparing and developing land that is needed for the aforementioned projects,
- 4) Provision and distribution of construction materials needed throughout the country,
- 5) Supervision of loans and mortgage to be allocated to low-cost housing in rural areas or to the urban poor,
- 6) Provision of comprehensive plans for rural areas (villages), and implementing the plans through community participation,
- 7) Preparing necessary proposals and plans for the reconstruction and revitalization of the rural areas that are affected by manmade or natural disasters¹⁵, and implementing those projects through community participation, while cooperation of pertinent organizations is highly advised.

The decisions and policies in HFIR are made by a committee composed of five members; one (the head) assigned by the Supreme Leader of the country, the Minister of Housing and Urban Development, and three experts selected by the first two. The wide spectrum of HFIR's responsibilities along with their public appearance as "the developer for the vulnerable" have made HFIR a highly politically loaded and

¹⁵ It should be noted that many scholars believe that disasters are always manmade, and there is actually no natural disaster, rather, we have natural hazards that can turn into disasters when combined with human input (for more see Paton and Johnston 2006; Oliver-Smith and Hoffman 2002).

strategically weighted organization, with whom all organizations are advised to cooperate.

As can clearly be seen from the outline of HFIR's mandate, two points are highlighted and stressed in the goals of the organization; namely low-cost housing (for the urban and rural poor¹⁶), and community participation. However, what actually happened in the practice of HFIR on the ground was the elimination of community participation. HFIR always took a top-down (provider) approach and happily built houses and developed plans for the target people. Houses were designed remotely in the HFIR branches in the cities and were then implemented in the villages.

At the heart of HFIR's efforts was their desire to upgrade the lives of the poor and diminish their vulnerability. Nonetheless, the fact that a traditional appearance in contemporary Iranian society has been considered a sign of poverty belonging to the supposedly low class of "villagers" led to the HFIR's mindset that the lives of the poor can be enhanced if they do not look poor in the first place. Therefore, traditional construction methods were never part of HFIR's interest, as it seemed not to fit with their ultimate goal.

As mentioned earlier, HFIR is the organization in charge of post-disaster reconstruction in rural areas. Although Bam was not a village, the remarkable experience of HFIR in post-disaster response compelled the authorities to put them in charge of post-disaster reconstruction program of Bam. After the earthquake in Bam, HFIR summoned help from its head offices to the stricken area.

¹⁶ The Islamic revolution of Iran owed its victory, for significant part, to the power of poor people's movements in Iran at the time. Not surprising therefore, most of the promises after the revolution were aimed at improving the lives of the poor. For more on the remarkable power of the poor in the Islamic Revolution of Iran see Bayat 1997.

Within four weeks after the earthquake, about 30,000 survivors were placed in tents and other emergency shelters while removal of debris and construction of temporary housing continued. Within 8 months, about 30,000 temporary houses, [...] were built and replaced the emergency shelters. In the meantime the master plans for urban development of the cities of Bam and Baravāt and 260 villages were outlined (Astaneh-Asl et al. 2006, p.1).

Taking into consideration the experiences of previous post-earthquake reconstruction programs, HFIR tried to implement the reconstruction plan of Bam as fast as possible. Therefore, the program was scheduled to be "finished by mid-2007," meaning the entire project was expected to be completed within a 3-year time frame (Ghafory-Ashtiany and Hosseini 2007).

Building upon their experience and the lessons drawn from previous post-disaster reconstruction programs, HFIR took a relatively open approach this time - an approach that had never been used before in post-disaster programs in Iran. Whereas earlier programs had top-down characteristics, and were relatively closed to the participation of the stricken community, a combination of top-down technology-based and bottom-up community-based approaches was employed in the Bam reconstruction project. In other words, it seemed that the reconstruction program of Bam employed an approach that somehow reconciled the leading theories of post-disaster reconstruction in developing countries.

This approach aimed at three objectives: a) "participation by the people involved, b) preserving the historical and Islamic character of Bam, and c) designing and constructing seismically safe buildings" (Astaneh-Asl et al. 2006). The approach provided citizens with the opportunity to choose from a variety of reconstruction methods and materials, in such a way that new technologies and materials were introduced to the locals, who were involved in the decision-making process to a certain extent (Gharaati 2007).

In this approach, it was intended that four parties would be involved: owner, architect, contractor, and HFIR, with emphasis placed on the owner. After the preparatory stages, such as filling out administrative paperwork and cleaning the site from debris, were completed, the owner would choose the construction technique and material that best suited his or her needs and budget. The owner would then approach an architect of his or her choice, to design the house as desired. Alternatively, an owner could choose from over 500 pre-designed sets of plans that were readily available at the HFIR's head office in Bam, if he or she wanted to speed up the process of getting the house rebuilt (for sample of these plans see appendix E). The owner would then find a general contractor from the list provided at the HFIR office, approach him and introduce him to HFIR to take on the job (HFIR 2005). Since the small numbers of local builders and contractors could not meet the huge construction demand needed for the reconstruction project, HFIR made a public call for contractors and builders from around the country. Subsequently, a large number of contractors, builders, construction tradespersons, and labourers rushed into the area. In order to increase their chance of obtaining commissions, general contractors would register their names at the HFIR's head office. Although only certified contractors were allowed to practice in Bam at first, the high demand of construction forced HFIR to permit non-certified contractors work in Bam as well, as long as their work met the required standards that were enforced by the HFIR inspectors.

The role of HFIR in the process was then "to help the surviving owners of the quake with finances, architectural and engineering services, construction materials and the contractors" (Astaneh-Asl et al. 2006). Not surprisingly, however, the architectural side of this effort faded out as the program progressed, since the majority of the owners favoured the pre-prepared drawings.

All of the proposals for reconstructing houses in the city of Bam considered the earthquake-resistance of buildings in one way or another. However, as indeed in the majority of reconstruction programs, these proposals had "mistakenly focused on how to improve the resistance of building materials and constructions" (Wamsler 2006). Lack of construction process knowledge among the local masons appeared to be the main obstacle to the implementation of these imported methods in Bam.

In his article "Organisational Design, Performance and Evaluation of Post-Disaster Reconstruction Projects," Gonzalo Lizarralde (2002) enumerates three variables that, if increased, would highly improve the performance of post-disaster reconstruction projects in developing countries:

[...] by increasing one, two or all of the following variables: (i) multiplicity of choice offered to residents; (ii) users' responsibility in decision making; (iii) the articulation of local and external resources through an intermediate organization (p.1).

The way the reconstruction program of Bam was carried out not only controlled the above-mentioned variables, but also appears to have improved on their interpretation, resulting in what was called the "successful undertaking" of the program, according to the reconstruction officials (Astaneh-Asl et al. 2006). Nonetheless, a close look at the building practices in Bam before the earthquake attests to the fact that technology itself cannot solve the problem of making better earthquake-resistant houses; rather, it is necessary that the construction knowledge of the locals be improved as well.

In conclusion, a combination of top-down / technology-based and bottom-up approaches was employed in the Bam reconstruction project, providing citizens with the opportunity to choose from a variety of

construction methods and materials. This means that although new technologies and materials were introduced to the locals, they were still involved in the decision-making process to a certain extent. Furthermore, the HFIR, which is powerful both politically and economically, had full control over the reconstruction efforts of Bam; therefore, disruptive factors from outside the program, such as price speculation or political changes, barely affected it. In other words, the Bam reconstruction project enjoyed a pluralistic, yet highly controlled approach: on one hand, it allowed a diversity of building methods and materials, and on the other hand it strictly controlled the influential elements from outside and inside.

2.3. The Problem of Knowledge Transfer

When one talks about knowledge, it is always confusing what exactly this word means; whether it means data, information, belief, or understanding. Generally, knowledge can be divided into two modes of *tacit* and *explicit*. As Ichijo and Nonaka (2007) explain, explicit knowledge refers to the knowledge that can be expressed in the form of words, numbers, or any other form of "hard data." Unlike explicit knowledge, tacit knowledge is very personal and context-specific and "involves intangible factors" such as personal experience and belief, and therefore, tacit knowledge "is not easily visible and expressible" (Ibid).

This distinction is important in the context of post-disaster reconstruction programs in developing countries, where a lot of effort is put on importing explicit knowledge about safe-construction techniques to the affected communities. However, one problem in such programs is that this emphasis on the transfer of explicit knowledge presupposes that explicit knowledge is sufficient as a source for the tacit knowledge, which is going to have to be available for day to day use subsequently. The reason for this emphasis lies in the difficulty of transferring tacit

knowledge; for tacit knowledge of safe construction to be transferred, the knowledge that is imported into the community must be initially absorbed by the local builders, so that it becomes part of their routine practice. This absorption of knowledge, called "comprehension of knowledge" by some scholars, is a very time-consuming process that can happen only through hands-on practice by the recipients of the information.

The issue of knowledge transfer in relation to practice seems to have been first brought up in the literature by Gilbert Ryle (1949). In his book, *The Concept of Mind*, Ryle makes a distinction between "know *how* and know *that*" as two interdependent aspects of knowledge (Ryle 1949). He challenges the intellectualist belief that action indicates the presence of intelligence only if "the agent is thinking what he is doing while he is doing it, and thinking what he is doing in such a manner that he would not do the action so well if he were not thinking what he is doing" (Ryle 1949). He argues that this notion suggests that there are two separate actions involved in a meaningful performance, theory and practice; Ryle considers this to be a false perception.

Ryle (1949) believes that "when we describe a performance as intelligent, this does not entail the double operation of considering and executing." He concludes that "knowing *that*" does not necessarily lead to being able to do a job properly and correctly, and therefore, know-*that* is "neither actionable nor useful on its own" (Brown and Duguid 2001). It is know-*how*, from Ryle's perspective, that makes know-*that* useful. This idea was later echoed in Polanyi's concept of the tacit dimension. Polanyi (1966) builds on Ryle's idea that "we learn *how*... by practice," and argues that the acquisition of knowledge, which he calls "comprehension," is both intellectual and practical (Polanyi 1983). In both Ryle's and Polanyi's philosophies, "knowledge is two-dimensional and practice underpins its successful circulation" (Brown and Duguid 2001).

Although neither Ryle nor Polanyi talk specifically about knowledge transfer, their views on the two-dimensional characteristic of knowledge laid the foundation for the later theories of knowledge transfer, especially those that emphasize the direct effect of practice on knowledge transfer. For example, Davenport and Prusak (1998) assert that knowledge transfer occurs only when knowledge is transmitted *and* absorbed *and* used as well, which means that "knowledge that isn't absorbed hasn't really been transferred." In the case of Bam, the imported explicit knowledge (of earthquake-resistant building) has to turn into the tacit, actionable knowledge of the locals.

Furthermore, the distinction between the tacit and explicit notions of knowledge led to a dominant school of thought in the area of knowledge creation and management, focusing on the characteristics of each type of knowledge as well as on the conversion of one type to the other. This body of work was led by Ikujiro Nonaka and Hirotaka Takeuchi, who believe that "tacit knowledge is personal, context-specific, and therefore hard to formalize and communicate" (Takeuchi and Nonaka 2004).

The transfer of tacit knowledge calls for a great deal of person-to-person communication and close relationships (Li-Hua 2004). In fact, converting explicit knowledge into tacit knowledge is a very time-consuming process, which is also hard to achieve. Davenport and Prusak (1998) emphasize that "tacit knowledge transfer generally requires extensive personal contact," and it cannot be transferred in any other way. Unlike tacit knowledge, however, explicit knowledge can be easily packaged for transfer.

Explicit knowledge can be expressed in words and numbers, and is easily communicated and shared in the form of hard data, scientific formulas, codified procedures, and universal principles (Nonaka and Takeuchi 1995, p.8).

But tacit knowledge is "sticky," in Ichijo and Nonaka (2007) words, and thus very hard to express and therefore to transfer. Exchanging tacit knowledge involves close personal contact, relationships, and "physical proximity" (Nonaka and Toyama 2007). As Maznevski and Athanassiou (2007) describe, while "explicit knowledge travels easily from one person to the next, tacit knowledge is much more difficult to share;" sharing tacit knowledge involves considerable personal relationships.

Therefore, attaining tacit knowledge requires practice and is "closely related to *learning by doing*" (Nonaka and Toyama 2007). Experience gained through practice is vital to embodying tacit knowledge in the learners.

The key to acquiring tacit knowledge is experience [...] The mere transfer of information will often make little sense, if it is abstracted from associated emotions and specific contexts in which shared experiences are embedded (Nonaka 2000, p.12).

The problems associated with tacit knowledge transfer can explain why participants in reconstruction programs in developing countries often fall into the trap of believing that the knowledge of safe-construction can be transferred by publishing technical pamphlets, showcasing techniques, and/or bringing new materials in. The fact is that these measures can only transfer the knowledge that is "transmittable in formal, systematic language," which is essentially *information* rather than *knowledge* (Takeuchi and Nonaka 2004). As Richard Li-Hua (2004) points out, the transfer of any new technology to a person involves three stages, namely "acquisition, adaptation, and use" of that technological knowledge. He further asserts that "without knowledge transfer, technology transfer does not take place as knowledge is the key to control technology as a whole" (Li-Hua 2004).

Dorothy Leonard (2007) classifies modes of transferring knowledge into a spectrum ranging from "passive reception" to "active learning."

According to this classification, presentations, lectures, and manuals are considered the least effective means of knowledge transfer, whereas "learning by doing" is the most effective (Figure 2.4, next page).

Furthermore, according to the model of knowledge creation and transfer proposed by Nonaka and Toyama (2004) (Figure 2.5), tacit knowledge is accumulated and shared through socialization. Maznevski and Athanassiou (2007), also emphasize that "important knowledge travels best through personal relationships," and point out that the most effective way of sharing tacit knowledge is "through deep dialogue that comes with personal relationships."

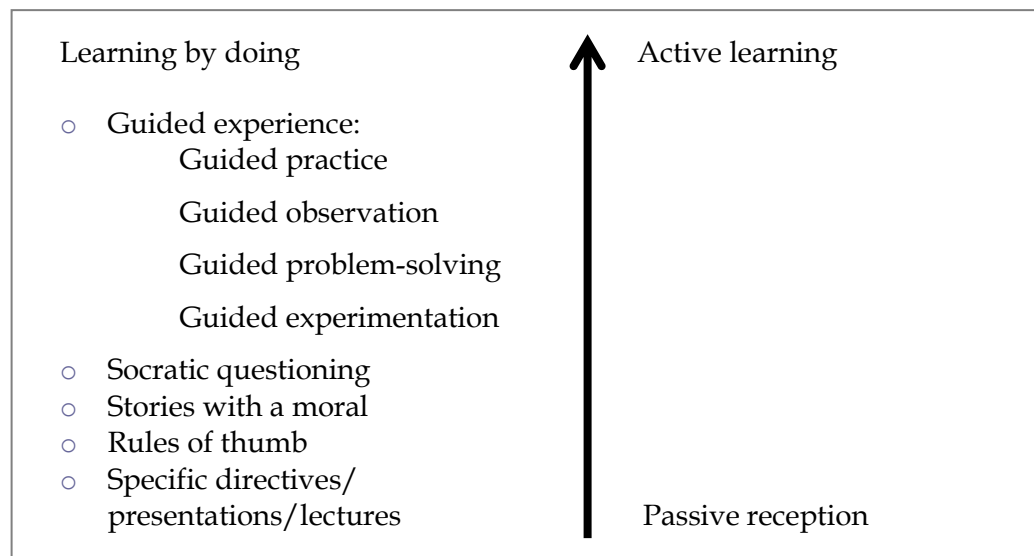


Figure 2.4. Modes of knowledge transfer (Leonard 2007)

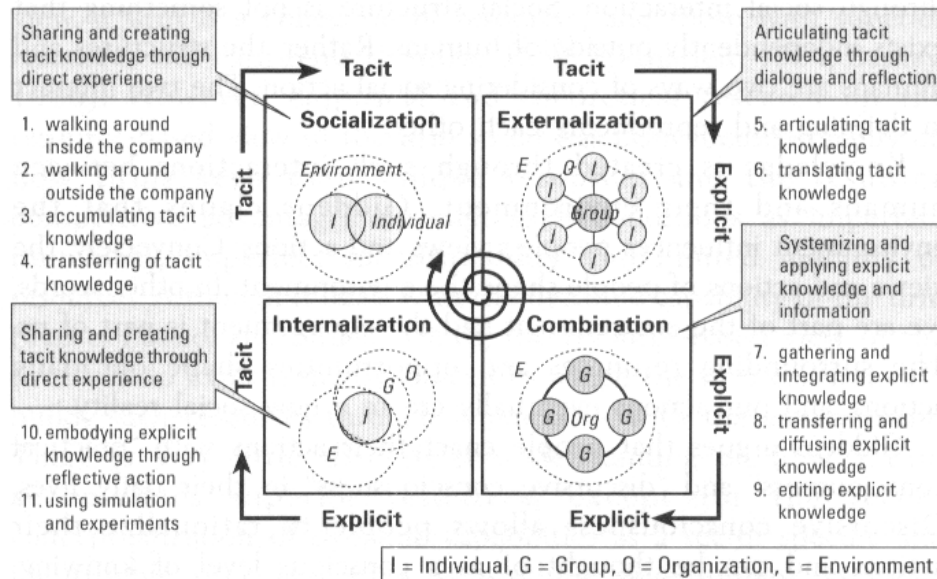


Figure 2.5. The model of Knowledge creation (Nonaka and Toyama 2004).
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Although all of the aforementioned theories about knowledge transfer are in the domain of *knowledge creation* and *knowledge management*, they can be equally valid in many other areas of human knowledge, including construction knowledge. Knowledge of construction, as Kretser and Wilkinson (2005) state, "refers to work that relies on the accumulated knowledge, experience, and judgment of the individual, rather than the ability to be trained to learn and execute simple procedures." In fact, they believe that the physical outcomes of any construction body are a "representation of the knowledge" that the group holds (Kretser and Wilkinson 2005).

Kretser and Wilkinson, in writing about the construction practice and building tradesmen, build their interesting arguments on the general theories of knowledge management by quoting very frequently from well-known scholars like Nonaka and Takeuchi. They argue that knowledge of construction cannot be transferred by imposing it or forcing it on the recipients. Rather, "it will be more effective and efficient to actively

encourage it; facilitate it through strategy, frameworks, guidelines, and training; then let it happen, and monitor its progress and development" (Kretser and Wilkinson 2005).

In their research on construction firms and the ways in which knowledge is transferred and internalized among them, Kretser and Wilkinson (2005) conclude that the key to avoid knowledge loss and to absorb meaningful knowledge is through continuous communication among the parties. They state that even explicit knowledge can be converted into tacit knowledge and thus transferred successfully through continued supervision by the holders of that knowledge (Ibid). This constant supervision, they argue, can "create a culture of open knowledge communication" within the community of participants, which would then lead to "opportunities for improving the knowledge" in that community of practice¹⁷ (Ibid). They conclude that people of a given community (of practice) "must be put in touch with each other and encouraged to communicate" as much as possible, to maximize the opportunities of informal knowledge transfer (Ibid). Although Kretser and Wilkinson (2005) mainly address the inherent problems of middle to large construction companies, it is reasonable to suggest that similar problems arise with small firms, particularly when they are considered as a group, that is to say as a "building community" or "building team."

It is evident that Kretser and Wilkinson's research on the construction business echoes, to a large extent, Nonaka and Takeuchi's ideas about *knowledge management*. In fact, many other researchers in the area of

¹⁷ The term *community of practice* refers to the process of collective learning that emerges from social interactions within a group of individuals (Wenger 1999). As Wenger (1999) explains, "we all have our own theories and ways of understanding the world, and our communities of practice are places where we develop, negotiate, and share them." It is important to note that the term *community* here does not "imply necessarily co-presence, a well-defined, identifiable group, or socially visible boundaries" (Lave and Wenger 1991).

knowledge management in construction support the idea that construction knowledge can be effectively transferred in a community of participants only through "effective communication structures" and "a supportive culture [...] that encourages knowledge sharing" (Dainty et al. 2005). However, it is stressed that time is always a great hurdle for the transferral of knowledge, especially in the construction business, where knowledge should "flow across both project and professional interfaces" (Ibid).

Another interesting study on knowledge transfer in the domain of construction has been performed by Richard Li-Hua (2004), who has investigated how know-how is transferred "between foreign and local managers within international joint ventures," by examining construction firms in China. By studying several exemplary cases and on the basis of his findings, he concludes that in the process of technology transfer, the nature of the technology is not a major factor, but that it is the "quantity of knowledge transfer that predominantly affects the success of the technology transfer." He then clearly declares that in this process of technology transfer, "tacit knowledge is considerably more haphazard and it is in this area that knowledge transfer can falter and technology transfer can be impeded" (Li-Hua 2004). In other words, Li-Hua believes that tacit knowledge holds the key to a successful technology transfer, stressing that "without knowledge transfer, technology transfer will not work" (Ibid). He further states that there is a remarkable relationship between knowledge transfer and the economic development of a community, suggesting that "in a developing economy, people are more thirsty for explicit or hard knowledge such as a specific technology to manufacture a product that enables people to survive rather than for tacit or soft knowledge, such as management know-how that enables an economy to have sustainable growth" (Ibid).

Garud (1997) categorizes knowledge into three components: know-how, know-what, and know-why. He contends that although the term "know-how" is commonly used when people refer to knowledge, "there are at least two other components of knowledge," know-what and know-why. He describes these three components of knowledge as follows.

Know-why represents an understanding of the principles underlying phenomena. *Know-what* represents an appreciation of the kinds of phenomena worth pursuing. *Know-how* represents an understanding of the generative processes that constitute phenomena (p.5).

Graud (1997) further explains the characteristics and properties of each component in order to explore the "inter-relationship" among them. He asserts that "knowledge of why something works does not necessarily translate to a knowledge of how it is put together," and vice versa: the knowledge of how something works does not necessarily correspond to the knowledge of why it works (Ibid).

To sum up, it can be said that while explicit knowledge is easy to codify and gather, tacit knowledge is hard to capture, express, "codify, communicate, and transfer, because these processes are intellectually very highly energy intensive" (Jewell and Walker 2005). Unlike explicit knowledge such as technology, tacit knowledge cannot be transferred easily through pamphlets, instruction manuals, lectures, or presentations. This is because the transfer of tacit knowledge "involves dealing with people and their motivational drives and inhibitors. It can be argued that people have more complex and unpredictable (and hence unmanageable) characteristics than programmable machines that characterise technology" (Ibid). The transfer of tacit knowledge calls for a great deal of close relationships, human interaction, and hands-on practice. Explicit knowledge must be practiced in order to convert it into tacit knowledge.

2.4. Overview and Remarks

As is the case with many post-disaster projects in developing countries, the reconstruction program of Bam focused on improving the quality of building materials and introducing new construction methods. A number of new earthquake-resistant building techniques were imported and showcased to the locals, with the aim of replacing the traditional building methods and materials with the new ones. Focusing on improving the earthquake-resistance quality of buildings, the reconstruction program of Bam took a fairly pluralistic approach that gave the citizens flexibility to choose from various options. The technique chosen by the owner was then enforced by HFIR via continuous and critical inspections during the construction process. Since the reconstruction program was scheduled for a period of 3 years, at the end of that period (2007) HFIR was discharged of its duties and left the city after the prescribed time. With HFIR gone, the inspections, as well as the funding incentives and grants, were gone too. Consequently, the likelihood of faulty implementation of earthquake-resistant construction principles plus the risk of "cutting corners" (technically speaking), especially in the popular housing sector, increased.

The crucial point, therefore, is to find out to what extent the local builders had come to change their way of working during the period in which HFIR was present. In other words, had the new knowledge of building been internalized, i.e. explicit knowledge become tacit and actionable?

Earlier experiences in Iran show that importing new construction materials and modern techniques is not the answer by itself, as demonstrated by the example of another earthquake-stricken town, Ghaen. An earthquake struck Ghaen in 1981 and led to the death of about 1,500 people. The city was reconstructed, using new construction

materials and methods; all houses were designed by engineers to withstand earthquakes. Nonetheless, when another earthquake hit the city 16 years later (1997), again, more than 1,500 people lost their lives (Murphy 2004; Shaoul 2004); apparently, the majority of casualties were living in the rebuilt houses. Indeed, many observers believed that the high death toll was the result of inconsistency in implementing the seismic building codes (Murphy 2004), though Iran had established seismic building codes as early as 1989 (Ghafoory-Ashtiany and Hosseini 2007).

Moreover, a comparison between the Bam earthquake and one in California is enlightening. The California quake struck a few days prior to the one in Bam, and had a slightly higher magnitude; however, only two people died. The fact that there are many earthen buildings in California demonstrates that the presence of supposedly weak materials (earthen materials) was not the only, and probably not the main, cause of the vast destruction and huge loss of life in Bam. It confirms the possibility that lack of construction knowledge might have contributed significantly to the disaster. Earthen buildings, it seems, may be a problem if and only if they were not initially built with the appropriate methods.

Although the physical outcome of the reconstruction program of Bam might appear to be a great success, as the authorities in charge claimed (Astaneh-Asl et al. 2006), its long-term success is yet to be seen. It is true that the houses built in Bam during the official reconstruction period meet the earthquake-resistant building requirements of Iran, due to the close inspections made by HFIR. Nonetheless, there is a demonstrable risk that the proper practice of earthquake-resistant construction in Bam is limited to that specific reconstruction period (because of the difficulties associated with knowledge acquisition), and will not be continued indigenously after the termination of the program.

In fact, when examining the building practice in Bam before the earthquake, it can be seen that traditional construction knowledge had been replaced by poorly understood new construction techniques, inadequately supported by proper know-how. These problems are explained and illustrated in detail in chapter 3.

After the earthquake, the construction trade faced another similar situation: replacing a construction method that, up to that point in time, had been frequently used, for all its (unrecognized) problems, with new one(s). While the previous experience of a misguided change in the locals' building know-how yielded tragic results, one has to ask whether the chances of the native population adopting new construction-related knowledge seems remote; the likelihood of this adoption is precisely the subject of this research.

Looking at the reconstruction program of Bam in retrospect, it appears that all the new houses built in the reconstruction period have been built according to the seismic building codes and one could therefore assume that they would withstand earthquakes if only because of the HFIR inspectors' work. However, the long term continuity of producing earthquake-resistant construction was not given due thought. While the seismic building codes were severely enforced by continuous inspections during the reconstruction period, a driving force for maintaining the appropriate implementation remains unaddressed. This situation raises questions such as:

- How can it be ensured that people will maintain the proper practice of implementation when external constraints are removed?
- What are the driving forces required to maintain the correct practice?
- How can the continuity of earthquake-resistant building techniques be achieved in a context such as Bam?

2.5. Research Statement

As discussed above, explicit knowledge is absorbed and adopted only when it becomes tacit knowledge, and the way to accomplish this is through practice, communication, and close relationships. Furthermore, as Takeuchi and Nonaka (2004) mention, it is the tacit knowledge that generates "human action." Nonetheless, it seems that when enforced by external forces (controls), explicit knowledge can cause action as well. This notion forms the core of this research, which is summarized in the Figures 2.6 to 2.9 (next page).

Figure 2.6 depicts the traditional construction practice in Bam, in which knowledge was transferred mainly from person to person through apprenticeship (tacit knowledge to tacit knowledge). The acquired tacit knowledge then became the source of action (building). As the traditional method of knowledge transfer faded, so too did the construction expertise. When what remained of the traditional building techniques was mixed with the new explicit knowledge, which brought along new materials, a faulty hybrid knowledge resulted (Figure 2.7). Figure 2.8 illustrates the state of knowledge and action in the formal intervention period of the reconstruction project: explicit knowledge is widely disseminated and rigorously enforced by means of external forces (or controls), such as inspections and grants. In this case, each action needs the presence of both explicit knowledge and external force(s). The last figure (Figure 2.9) represents the situation after the termination of the reconstruction project. No external force is present, and while the explicit knowledge is imported and assumed to be acquired, the presence of tacit knowledge is in question. Nonetheless, the action, in the form of building houses, is present, too.

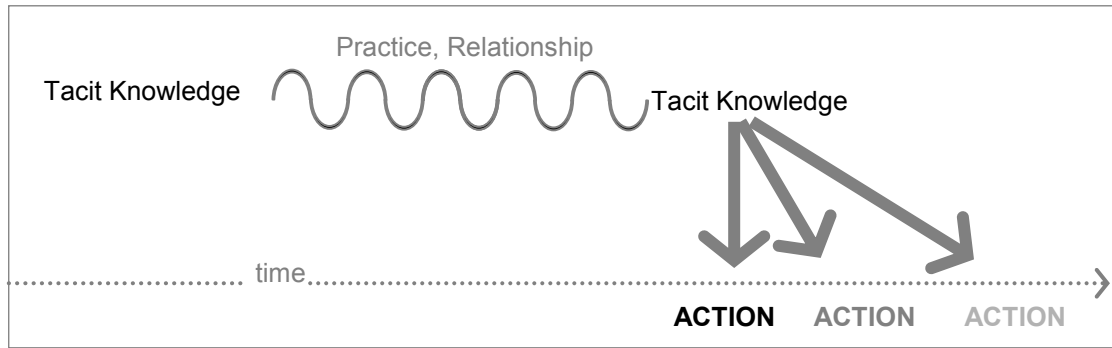


Figure 2.6. The traditional construction practice in Bam

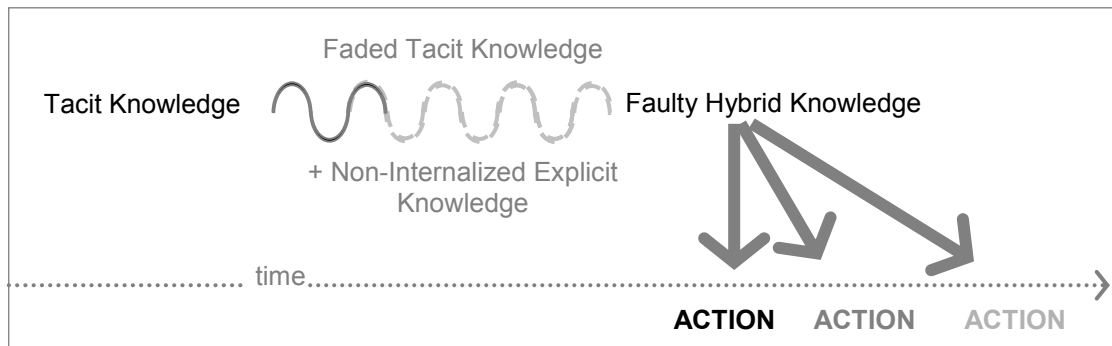


Figure 2.7. The construction practice in Bam before the earthquake

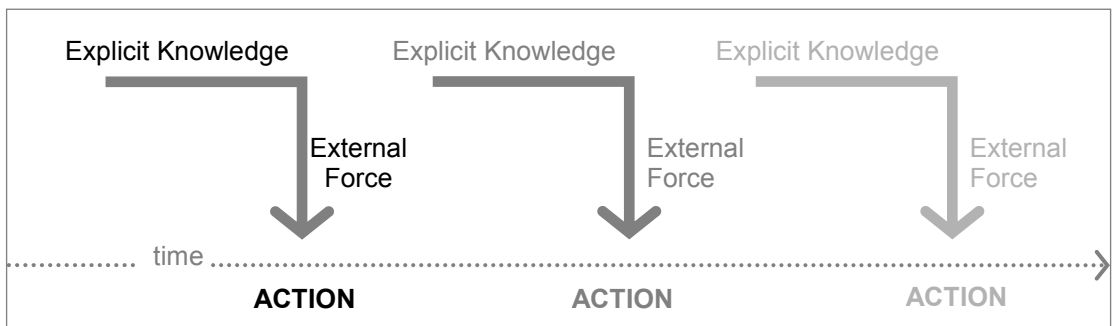


Figure 2.8. Construction practice during the HFIR era; external forces (controls) make the explicit knowledge get implemented

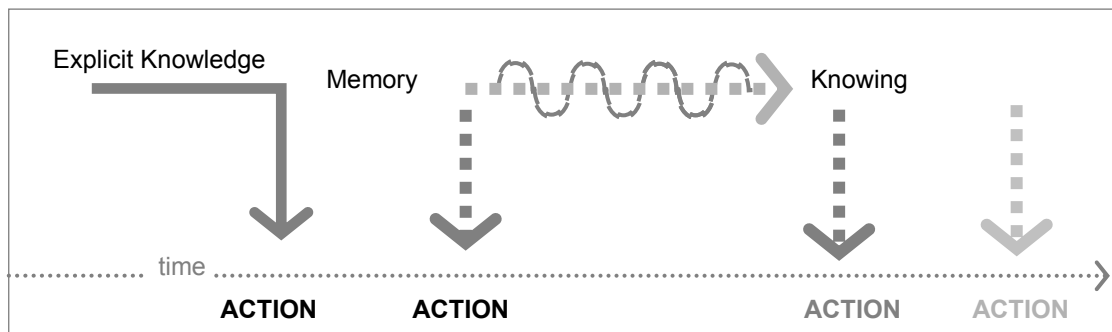


Figure 2.9. Construction practice after HFIR has left; external forces (controls) are out, action comes from memory and *knowing*

As these illustrations show, there exists two ways for explicit knowledge to be put into practice: a short and relatively quick way that requires enforcements (e.g. Figure 2.8), and a complex, time-consuming way that involves human interaction (e.g. Figure 2.6).

It is helpful to recall the three components of knowledge that Raghu Garud (1997) enumerated: know-how, know-what, and know-why. It can be concluded from his study that either know-what or know-how alone can sufficiently result in action. However, to ensure continuity and development of the action in the long run, the third component of knowledge, know-why, is needed. In other words, *action* can emerge from either know-how or know-what, but a *sustainable action*, which will be repeated over time, demands the presence of know-why.

Typically, due to the emergency nature of the efforts in post-disaster reconstruction programs, the short approach is chosen (Figure 2.8). In this scenario, the *results* (buildings built) become the ultimate objective of the program, rather than the *processes* themselves. Although the outcome of such programs often appear to be satisfactory, at least to the authorities concerned, the overall end results are often criticized for failing "in achieving long term development over time," regardless of the approach chosen (Lizarralde 2004). Among other issues, one considerable concern is the failure of reconstruction programs in addressing the continuity of safe construction in the long term. This is where the subject of this research lies.

Like many other reconstruction programs, the reconstruction of Bam can be divided into three phases: a) temporary shelter and temporary housing; b) permanent reconstruction (controlled by HFIR); and c) the subsequent period of final reconstruction and general building which is referred to here as the *post-post-disaster* period (as opposed to the *post-disaster* period, the term generally used for the first two phases). The key problem, and therefore the focus of this research, is the post-post-disaster

reconstruction practice and how the construction knowledge disseminated in the formal post-disaster period can be embedded in the informal construction knowledge of the local residents.

2.6. Research Question

Although the physical outcome of the reconstruction program of Bam has been acclaimed as a great success, according to Astaneh-Asl et al. (2006), its long-term success is open to debate. It can be asserted that the houses built in Bam during the official reconstruction period meet all earthquake-resistant building requirements of Iran, due to the use of the preferred construction model and rigorous inspection procedures by HFIR and other pertinent parties. Therefore, it might be possible to apply the lessons learnt in this program to future post-disaster projects. On the other hand, one can hypothesize that the proper practice of earthquake-resistant construction might be limited to the specific time-frame of HFIR's presence in Bam. Moreover, one could argue that these practices may or may not be continued indigenously after the termination of the formal reconstruction program. Therefore, questions arise concerning the sustainability of the methods practiced during the formal reconstruction program.

Research questions:

- When there is a regulated program of reconstruction with administered controls, how readily do the survivors and their contractors learn and retain the "appropriate practices" proposed by the program?
- Once the formal reconstruction program has finished and the supervising authorities withdraw, are the lessons forgotten and are the previous faulty methods of construction adopted again?
- Will the imported safe-construction methods be sustained and repeated in the long run?

It is important to clarify that the focus of this study is on knowledge transfer in post-disaster programs in developing countries. Bam and the earthquake-resistant construction knowledge that was required serve as an example for small, isolated towns in developing countries that are facing a transition from their traditional building culture to modern construction methods; this shift is quite significant in most cases. The breakdown of traditional building practices, which occurs before modern techniques are fully and correctly adopted, has led to ill-informed knowledge of construction with the new materials; this situation can turn natural hazards into severely devastating disasters¹⁸.

It is axiomatic that each post-disaster reconstruction program should be designed and implemented in accordance with its specific context. Consequently, each case is unique and has its own characteristics that will, hopefully, address the specific problems of that case. Therefore, the *product* or outcome of each reconstruction program is solely specific to its context and may not work in another context. However, the *processes* used for a particular reconstruction program can be successfully applied to another program, provided that the context and needs are carefully taken into consideration.

In other words, in a post-disaster reconstruction program, there are two aspects to the program: the *product* and the *process*. While the product is context-specific and therefore unique, the process can provide lessons for future programs. In this sense, Bam is an interesting case because all the reconstruction efforts were apparently highly isolated from inhibiting external factors and therefore, outstanding end results were expected. It is important to mention that although the construction methods employed

¹⁸ It is important to recall that there is a great distinction between disaster and hazard. Hazards carry a "potential for social, infrastructural, or environmental damage," whereas disasters are events caused by a combination of hazards and vulnerability in a society (Oliver-Smith and Hoffman 2002).

in the reconstruction program were not cost efficient and did not address energy concerns, nor did the methods correspond to the vernacular architecture of Bam, the construction practice per se was deemed to be effective in terms of withstanding future earthquakes.

Since the focus of this research is concerned with the earthquake resistance of buildings and the transfer of pertinent knowledge, other architectural aspects of the houses in Bam are not engaged with in this study. This research is strictly concerned with knowledge transfer, taking earthquake resistance as its focus. Other aspects of the built environment in Bam are not examined, and there is no implication about, or approval of, the design and construction methods practiced in Bam.

Chapter 3: RESULTS

The Bam earthquake of December 26th, 2003, cruelly illustrated the inadequacies of the then-prevailing construction methods- as discussed in the first part of this chapter. It is important to mention here that the main goal of this chapter is to depict the extent of earthquake-safe construction knowledge among those involved in the mainstream (popular) building trade in Bam, namely master builders, contractors, and masons. The technical aspects of construction practice were taken as an indicator for the degree of knowledge of earthquake-resistant construction. In other words, the ultimate purpose of this chapter is to illustrate the extent of, or lack there-of, earthquake-safe construction knowledge among the builders of Bam during the three time periods mentioned above, and how this knowledge was disseminated.

It is helpful to recall, in this context, that the reconstruction program of Bam was scheduled for a period of three years, after which HFIR was discharged of its duties and left Bam. Since the strict inspections and grant incentives were removed when HFIR departed, it was possible that Bam would revert to faulty implementation and "cutting corners" in construction. This relapse was especially feared in the popular housing sector, which had had such a deplorable history of bad construction and inadequate knowledge prior to the earthquake. The three-part field study was precisely designed to detect whether this was the case. As mentioned earlier, the scope of study in all of the fieldworks was deliberately focused on, and concerned with, earthquake-resistant construction knowledge and the issue of knowledge transfer.

3.1. First Field Study (February 2005): collecting information concerning the potential problems related to knowledge

Bam presented an image of desolation in the immediate aftermath of the earthquake (see Figures 2.2 and 2.3). Many buildings which had been erected with "new" methods of construction (hybrids of concrete or steel frames, brick masonry infill, and concrete and hollow tile floors) simply broke apart. Essential junctions between structural elements failed, and heavy secondary elements fell. An examination of the typical failures revealed that reinforcing was inadequate or virtually non-existent; bonding between different materials was not installed properly or left completely out. This examination also revealed the extent to which a proper understanding of novel construction knowledge was absent.

The first fieldwork was conducted just over a year after the earthquake. Although some of the destroyed buildings were still in the condition as they were after the quake, the majority of damaged buildings had been bulldozed at the time of visit. Fortunately, there were many pictures taken by others in the weeks following the earthquake. These photos constitute the main source of information in this part of the research. In the following section, the different types of buildings in the city and their devastation in the earthquake will be studied by focusing on two main problems: one, design (construction) knowledge; and two, implementation. This section reviews the observations made in the first visit, aiming to uncover the major problems that existed in the construction practices in Bam before the disaster, and to draw a picture of the efforts made for the start of the reconstruction (the reconstruction phase was observed during the second visit and is described in section 3.2).

Design Knowledge

Here, the term *design knowledge* refers to any sort of formal or informal knowledge of construction applied to the building by the builder. In other words, the *design* does not only address the technical and engineering aspects of construction; but includes the formal and popular knowledge employed. Taken together, these elements comprise the *design* of a building. This section examines certain design failures that resulted in the destruction of certain buildings in Bam and is divided into two general categories: first, structural components, and second, implementation. Each of these is then divided into several subsections.

It is important to stress that the observed building failures illustrate the pervading state of knowledge (or, rather, ignorance) displayed by the local builders during the transition period, that is to say, during the previous three decades. The whole issue of knowledge to be acquired hinges on the baseline state just before the earthquake.

3.1.1. Design knowledge about structural components

Although the stability of a building depends on how well all the parts of a building work together, the following section examines different components of a building that play a role in the resistance of a structure, and are studied separately. Each component will be categorized to better understand the local builders' image of each part and its importance in the earthquake performance of structure.

3.1.1.a. Foundation

As is well known (or at least should be), the foundation anchors the entirety of a building to the ground, reducing the movement of the building during earthquakes. The lack of an appropriate foundation seemed to be a common problem among the buildings destroyed in Bam,

and a number of houses did not have any sort of foundation at all (Figure 3.1).



Figure 3.1. Lack of a decent foundation was a common problem among the buildings destroyed in Bam. Photo: ISEO 2004

3.1.1.b. Walls

Walls analyzed after the earthquake revealed that none were reinforced. The reinforcement of load-bearing walls was not a common practice in Bam, and even simple measures such as placing vertical and/or horizontal reinforcement bars were non-existent. Furthermore, some of the load-bearing walls were not thick enough to resist the bending and the shear force caused by earthquakes. Even where the walls seemed to have the appropriate thickness, the length of the wall and/or its height weakened its resistance to lateral forces.

Moreover, the inappropriate placement of openings (windows and doors) and/or their proportions in relation to the overall wall area greatly reduced the strength of the wall. Since openings weaken the stability of walls, the location, size, proportions, and the number of openings in wall-bearing structures must be carefully designed and often require special

attention. Generally, the length of opening should not exceed one-third of total length of the wall, and it should not measure more than 1.2 m in any dimension (Blondet *et al* 2003). Lintels should extend at least 40 cm from either sides of the opening and it is better to avoid loads on top of the lintel (Minke 2003).



Figure 3.2. Placing reinforcements in load bearing walls is not common practice in Bam. Photo: HFIR archive



Figure 3.3. Even thick walls are destroyed when there is no pilaster along a long wall. Photo: HFIR archive

3.1.1.c. Columns, beams, bracings

The majority of post-and-beam buildings in Bam were built without adequate attention to engineering codes. In fact, only 31 buildings out of a total of 34,531 houses (0.09 per cent) in Bam respected engineering principles (Astaneh-Asl et al. 2006). For the most part, local masons or even the owners themselves were the builders, many of whom lacked knowledge about effective construction techniques. Their knowledge was very limited in this area because post-and-beam construction was a relatively new building type in Bam. In contrast, in the past, the people of Bam were knowledgeable about the type of construction that had been used for over two thousands years, which includes wall systems composed of load-bearing earth walls, barrel vaults, and domes.

Weak steel columns and beams and a lack of cross-bracings were the dominant mistakes in the cases of steel-frame buildings destroyed in Bam (Figures 3.4 and 3.5). Concrete buildings had inadequate numbers and/or size of reinforcement steel bars. In one case, surprisingly, the steel bars of a beam were totally omitted (Figure 3.6). This lack of knowledge about concrete construction is generally a serious problem in Iran, but in smaller cities, it is much more pronounced.



Figure 3.4. Weak columns and beams with no bracings.
Photo: HFIR archive



Figure 3.5.
Inadequate design
and weak steel
profiles have turned
the entire building to
rubble. Photo: HFIR
archive



Figure 3.6. Absence of steel bars from a reinforced concrete beam. Photo: ISEO
2004

3.1.1.d. Roofs / floors

Generally, roofs and floors play an important role in the resistance of a building towards earthquakes because they constitute the main load of the building and can also act as a stiffening diaphragm. Logically, there is a smaller chance that a structure will collapse during an earthquake if its roof is light. The residents of Bam used to redo the insulation of their roofs every two to three years by adding a layer of straw-mud plaster, without removing the old layer. This practice is common among the majority of homes in Bam, creating very heavy roofs (Figures 3.7 and 3.8). In addition, a number of houses were structurally overloaded by the addition of new stories on top of the existing ones. These extensions, built on structures lacking properly engineered load-bearing walls, led to the destruction of many buildings and the loss of entire families (Maheri 2004).

In addition, some roofs were incompatible with the rest of the structural system in terms of material employed, leading to inconsistency of the structural behaviour in the earthquake, remarkably intensifying the damage to the structure. The uneven distribution of the load of the roof was another problem, resulting in forces being exerted on some particular parts of the structure while other load bearing elements took comparatively less of their share of the structural system (Figures 3.9 and 3.10).



Figure 3.7. An earthen roof collapsed due to its heavy weight. Photo: HFIR archive



Figure 3.8. A flat roof collapsed due to its heavy weight and poor shear connection. Photo: HFIR archive



Figure 3.9. Roofing system incompatible with the load bearing elements (walls). Photo: ISEO 2004

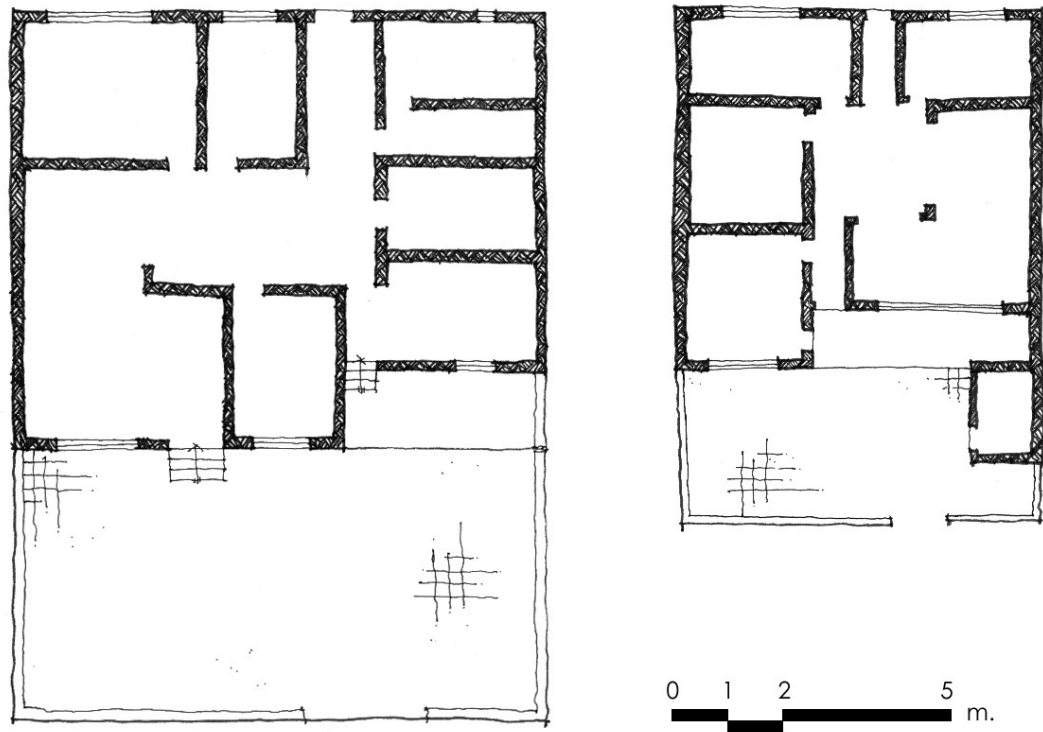


Figure 3.10. Roofing system incompatible with load bearing walls. Photo: ISEO

3.1.1.e. Building plan

A building plan must always account for potential lateral forces that occur during earthquakes and include design elements to *resist* these forces. In order for a building to gain more resistance against earthquakes, it is useful to follow two general rules: first, the plan should be as simple

and compact as possible, and second, complex shapes must be avoided (Weldelibanos 1993; Minke 2001). These two essential considerations were ignored during the planning phase of the majority of the recently built homes, increasing the likelihood that they would consequently be destroyed (Figures 3.11 and 3.12).



Figures 3.11 and 3.12. Examples of building plans in Bam before the earthquake; showing complex plans. (Naqsh-e-Jahān-Pārs 2004)

3.1.2. Design knowledge and implementation

No matter how well-designed a building is, it will collapse in an earthquake if proper care is not taken in the construction process. A lack of construction knowledge among a majority of the labourers and masons, along with inadequate building inspections made many buildings in Bam vulnerable to the earthquake (BHRC 2004).

Moreover, the lack of decent yet affordable construction materials worsened the situation, since the majority of Bam's citizens are poor or lower middle-class. It was difficult for them to afford quality materials,

that were imported from other parts of the country (Astaneh-Asl et al. 2006).

Through an analysis of the photos taken from the collapsed houses after the earthquake, it can be seen that largely, the problems associated with implementation can be divided into two general categories: first, problems due to improper or poor construction materials, and second, problems due to poor workmanship and construction details.

3.1.2.a. Building materials

The quality of construction materials has an indisputable effect on the resistance and strength of a building to exerted forces. Buildings in Bam ranged from traditional earth buildings to those made of concrete and steel. However, due to the poor quality of construction materials employed, severe destruction could be seen amongst all types of buildings, regardless of the building material (BHRC 2004). In the following section, the destroyed buildings are studied in terms of the quality of their construction materials; the materials are categorized into four groups: 1) earthen, 2) steel frame, 3) concrete, and 4) hybrid buildings.

Earth buildings

Building with earth has a long history in Bam, dating back some 2500 years to when the city was founded. This traditional mode of construction is common throughout Bam, which is well known for its magnificent earth architecture. In fact, Bam had one of the biggest earthen complexes in the world, the Bam Citadel. Its survival for such a long period of time up to then indicates the strength and durability of earthen materials; the Bam Citadel had survived many earlier earthquakes. The citadel, however, was destroyed in the December 2003 earthquake. It appears that recent inappropriate repairs were the reason behind its massive destruction

(Langenbach 2005). However, a number of earthen buildings remained intact, demonstrating that the use of appropriate materials, along with adequate maintenance (in the case of old buildings) enables earthen buildings withstand severe earthquakes.

Since the soil used for making earthen buildings is naturally diverse in composition, and since each type of soil suits a specific construction technique, great care must be taken in choosing the appropriate soil for each construction method (Doat and Norton 1991). For example, if one wants to build with adobe, the soil contents must be suitable for making adobe bricks. Otherwise, the strength of the building will decrease remarkably. The poor resistance of the many earth buildings in Bam was due in part to the inappropriate soil content for various earthen architectural techniques; this fact illustrates that the traditional knowledge of building had already been lost to the point that it was no longer applied (PWJ 2004).



Figure 3.13. Poor quality of adobe, crushed into small pieces. Photo: HFIR archive

Steel frame buildings

The material problems of steel frame buildings in Bam result primarily from the incompatibility of masonry materials, used as wall infill and/or as roofing material, with steel. Masonry construction materials in Bam, mainly burnt brick and sand-cement mortar, fit together with fairly good cohesion if skilfully executed. However, the adhesive agent (cement in the case of sand-cement mortar) does not bond well with steel, and is often incapable of providing holistic cohesion in the building. This problem appears in walls where the wall directly meets a column or beam, and in roofs composed of steel beams with jack arches in between (although the mortar is soil-and-powdered chalk in this case).

In both situations, a lateral force such as an earthquake tremor can easily make the walls or jack arches spring apart from the steel frames, detaching the brick mass from the structure, causing it to collapse. Many houses were observed in Bam where the body had collapsed while the skeleton of the frame (posts and beams) remained standing (Figure 3.14).



Figure 3.14. A weak bond between steel and brick resulted in the collapse of this roof. Photo: HFIR archive

Reinforced concrete buildings

Construction with reinforced concrete is a relatively new practice in Bam. Therefore, Bam was just beginning to gain knowledge about how to produce good-quality reinforced concrete and how to build effective structures. In concrete practice prior to the earthquake, essential aspects of making concrete, such as the proper mix of aggregates or efficient reinforcement, had been ignored; and the importance of careful inspection during the production of concrete was overlooked. The destruction of the majority of concrete buildings in Bam was the result, many of which had been built very recently (BHRC 2004).

The defects of concrete structures in Bam can be traced to the high price of materials necessary for quality concrete buildings, including cement, aggregate, and steel reinforcement bars. The price of cement for the average citizen is relatively high because the cement must be imported from other parts of the country; shipping and handling costs increase the price. For a non-educated builder or owner, this increase in costs would likely lead to a reduction of the percentage of cement and steel in the concrete mix, in order to reduce the total cost. In addition, the lack of construction knowledge of concrete among local builders and masons resulted in the use of unsuitable concrete fillers; ingredients such as construction waste and debris were added, ultimately reducing the strength of the structure (Figures 3.15, 3.16).

Moreover, the high price of steel bars, imported from remote parts of the country, intensified the problem. Many builders and owners reduced the steel bar reinforcements in size (diameter), quantity and quality, while increasing the distance between stirrups for the sake of minimizing costs.



Figure 3.15. Poor quality of concrete indicates lack of concrete construction know-how. Photo: HFIR archive



Figure 3.16. Very poor quality concrete mix was made using construction waste and broken brick as aggregates. Photo: ISEO 2004

Hybrid buildings

The term *hybrid*, in this context, refers to buildings employing two or more different structural systems. For example, a number of buildings in Bam were built using steel columns with flat concrete span roofs, or reinforced concrete columns with steel beams or girders, or load bearing earth walls with steel girders resting on the walls. The combination of different structural systems, with various materials and methods, was often the consequence of efforts to reduce the cost of building. Owners often sought out the cheapest materials, as well as building methods that were simple enough to be executed by ordinary labourers. Sophisticated methods would require skilled masons, who would command higher wages.

Generally, the major problem with hybrid buildings is the incompatibility of different building materials and designs, which are unsuitably mixed together in one structure. When an external lateral force, such as an earthquake, is exerted on the different parts of the structure, they do not behave in the same way: they react differently, thereby intensifying the destruction rate and reducing the resistance capacity of the building (Figure 3.17).



Figure 3.17. Incompatibility of materials in hybrid building results in the reduction of strength. Photo: ISEO 2004

In addition, the difference in materials of the walls and roofs in wall-bearing structures, common in many kinds of hybrid buildings in Bam, requires relatively sophisticated construction methods at the joints where the two systems meet. If joined improperly, these junctions are often the starting points of collapse (Figure 3.18). Furthermore, it was very common in Bam, and still is in many other Iranian cities, to reuse construction materials such as bricks, obtained from demolished buildings, in the construction of new ones. Used bricks often do not bond properly with mortar, and therefore, walls made of such bricks cannot withstand earthquakes.



Figure 3.18. Poor bond between the bricks of the wall and the steel beams: load bearing brick walls with steel girders and a jack arch roof were destroyed completely, while the beams have remained intact. Photo: HFIR archive

3.1.2.b. Workmanship and details

One of the most important aspects of any construction process, which directly affects the strength of the building, is the actual implementation of the construction. It can be said that the most serious problem with pre-earthquake buildings in Bam was the poor quality of construction details and/or faulty implementation. In other words, it seemed that builders and masons in Bam, especially those who built with new construction materials such as concrete and steel, either did not pay attention to the execution and workmanship during construction, or simply did not have the appropriate knowledge of construction and detailing. The latter possibility seemed most likely the case in the majority of houses in Bam, since a great percentage of houses, if not all, were built by local masons. The majority of these masons had no education in modern construction materials, neither formally nor informally.

When new construction materials had been introduced to the local population, masons and builders tried to adapt those new materials to their traditional construction methods. The result was a variety of construction methods that were rarely appropriate, and never implemented correctly. In the following paragraphs, the defects and mistakes are discussed in two categories: first, poor workmanship, and second, weak junctions.

Faulty or poor workmanship

No matter which construction method was employed, almost all of the destroyed buildings in Bam somehow suffered from faulty or poor workmanship, which is reflected in improper assembly of building elements. Some simple yet essential considerations were ignored by labourers and masons during the construction of buildings. For instance,

much of the masonry in the city, typically adobe or burnt bricks, was severely damaged because of inappropriate bricklaying.

Although Bam has achieved fame for its adobe buildings and earthen structures, the knowledge of bricklaying has seemingly been forgotten among local masons over the last few decades. For example, the simple though important practice of soaking dry bricks in water before laying them was ignored in the construction of many buildings in Bam (Figure 3.19). Serious problems occur when dry bricks absorb the water from the sand-cement mortar, which requires adequate moisture to be cured and to make a strong bond.



Figure 3.19. When bricks are laid without being soaked, they make a very weak wall. Photo courtesy of Peace-Winds Japan

Another dominant failure in the craftsmanship is the faulty work in almost all aspects of steel frame buildings; often, the welding is inadequate and too weak to hold together during earthquakes. Joints within a steel structural system are one of the most critical points of the structure and very little attention had been paid to them in the majority of

steel-frame buildings in Bam (Figure 3.20). The lack of gusset plates, stiffener plates, and reinforcing plates were very common problems of such structures in Bam; these problems were intensified by the poor quality of welding in the joints and anywhere else that reinforcement plates were placed (Hosseini Hashemi 2004) (Figure 3.21).



Figure 3.20. Inadequate welds at the joints was the most prevalent problem. Photo: ISEO 2004



Figures 3.21. Poor quality of welding in steel construction in Bam. Photo: ISEO 2004

Poor workmanship in reinforced concrete buildings was also common, though not many concrete buildings had been built in Bam. Firstly, the quality of concrete was usually far below the acceptable standard because it was mixed on-site by unskilled labourers with no understanding of concrete dosage, and consequently, the quality varied over time. A large percentage (approximately three-fourths) of the volume of concrete "is occupied by aggregates consisting of such materials as sand, gravel, crushed rock;" it is axiomatic that such a large-proportioned constituent would directly contribute to the strength properties of the concrete (Legg 1998). Nonetheless, due to the lack of knowledge about concrete mix, there was a misconception among the builders that any crushed construction material can be used as aggregate in the concrete mix. So, it was typical to find concrete columns and beams, most of which were destroyed in the earthquake, with crushed or broken bricks as aggregate or filler (Figure 3.22 next page). This lack of knowledge extended to the use of steel reinforcing bars. Since hardened concrete is a relatively brittle material with a low tensile strength by itself, it must be reinforced by using steel bars embedded inside the concrete element (Mindess 2008). However, builders in Bam had mistakenly reduced the quantity of steel re-bars by increasing the distance between stirrups, reducing the girth and number of re-bar, or even eliminating bars from the beam altogether (Figures 3.6 and 3.16 above, and 3.23 next page).



Figure 3.22.
Reinforced concrete
column with poor
concrete mix,
inadequate steel
bars, and poor
execution. Photo:
HFIR archive



Figure 3.23. Reinforced concrete column with inadequate steel bars. Photo: HFIR archive

Weak junctions

Some points of a building are more vulnerable to earthquakes due to the diversity of forces exerted on them. Thus, a thorough construction system should reinforce these critical points. It must be emphasized that all structural joints are critical locations, including wall intersections, corners, roof-wall junctions and the junctions between foundations and walls. These vulnerable points need more attention and close inspection during the construction process. As was the case of the majority of buildings in Bam, ignorance of the important role these critical joints play in the resistance of buildings to seismic forces resulted in fragile buildings. This problem could be seen in all types of construction methods in Bam, including earthen, steel-frame, concrete, and hybrid buildings (Figures 3.24, 3.25).



Figure 3.24 . Weak junctions in a hybrid building; steel beams resting on adobe walls. Photo: HFIR archive



Figure 3.25. Weak junctions in a reinforced concrete-frame building. Photo: HFIR archive

As can be seen in the examples above, the quality or the kinds of material chosen were not the only causes of destruction. Rather, lack of construction knowledge was the principal problem. Even buildings built with the most appropriate and strongest materials available sustained major damage or collapsed completely in the earthquake. This was due to faulty knowledge that led to lax building practices.

The question then, after the first field study, was how the reconstruction program would deal with the lack of construction knowledge among the local builders. The second field visit was planned to investigate this issue.

3.2. Second Field Study (February 2007): collecting information concerning the reconstruction program and its impacts

The second visit was made in February 2007, three years after the disaster. The purpose of this visit was three-fold: firstly, to establish an update on the progress of the reconstruction program; secondly, to determine what the HFIR had done during the reconstruction period, since the formal reconstruction program was scheduled to officially end in March 2007; and thirdly, to observe the socio-cultural changes following from the use of imported techniques on rebuilding the city as the result of the HFIR's program. Therefore, construction techniques and details proposed and imported by HFIR, and the way these technical considerations were disseminated among the local builders became the focus of this stage of the research.

The HFIR had succeeded in launching the reconstruction program and had developed its two-prong strategy: design and promotion of a standard steel frame and the display of earthquake-safe model houses prepared by invited companies from Iran and overseas. Both approaches were accompanied by a tight program of technical monitoring and financial control.

In order for the HFIR to implement the reconstruction efforts smoothly, the city was divided into ten quarters and, for the convenience of management, was distributed among the branch offices of HFIR staffed with HFIR personnel drawn from different provinces. In other words, ten headquarters of HFIR in various provinces of Iran, according to their strength in logistics, were given the responsibility of reconstruction of one of the ten quarters of the city.

In the following section, the reconstruction program is described in terms of the approach adopted by the HFIR. Then, how the program was implemented and its progression up to the time of the second fieldwork

visit, which was shortly before the official termination of the project, is illustrated. Again, the focus of the studies in this visit was on knowledge transfer and how it was dealt with in the post-earthquake reconstruction program.

3.2.1. The reconstruction efforts

After the earthquake, the reconstruction program became the main concern of the government and local authorities. Soon after the disaster, the Housing Foundation of Islamic Revolution (HFIR) was given control of all reconstruction efforts in Bam. HFIR is a publicly funded, yet non-governmental, organization directed by a principal designated by the Supreme Leader of Iran. All activities pertaining to the reconstruction of Bam were subject to approval by HFIR from their initial stages. This situation made the process of reconstruction time-consuming because of the numerous bureaucratic steps the citizens faced. Not surprisingly, few houses had been rebuilt by the time of the first visit, some 13 months after the earthquake, although quite a few reconstruction projects had been initiated. Consequently, people who had lost their homes in the earthquake were still living in shipping containers or other types of temporary accommodations; some were living in first-aid tents.

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. Adjacent to this building, HFIR had 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

local residents. Each prototype offered earthquake-resistant features, according to their creators, who tried to convince the citizens to use their specific techniques in the reconstruction of their house. In the following paragraphs, the construction techniques proposed by HFIR and the various building companies are briefly reviewed in order to illustrate the general reconstruction concepts offered for the reconstruction of housing units in Bam.

It should be noted that HFIR focused its efforts on the technical and financial aspects of the reconstruction and, as will emerge from this report on the second visit, did not place much emphasis on the teaching and learning aspects of the processes and future sustainability. Training sessions offered by HFIR, as well as by some NGOs like Peace-Winds Japan, were not pursued seriously by the local builders.

3.2.1.a. Houses proposed by the Housing Foundation of Islamic Revolution (HFIR)

A house of 9x9 m² had been designed by HFIR engineers and architects as the standard size of a house for an average-sized family in Bam. All construction companies and architects were thus advised to design and build within those fixed dimensions. In addition, HFIR had designed a pre-fabricated steel-frame structure that conformed to the 9x9 m² area. HFIR recommended the use of this structure in the new buildings that were to be built in Bam.

The structure proposed by HFIR consisted of prefabricated steel posts, beams, and bracings that were designed for ease and speed of assembly, using only bolts and nuts for fastening the elements together (Figure 3.26). For example, the structure of a typical house (9x9 m², as HFIR recommended) could be installed in place in just a few hours, employing only two labourers. Aside from the quick installation time, the concept

behind this design had been that using bolts would remarkably reduce the number of failures caused by inadequate welding.

HFIR had 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 was connected using bolts and nuts (Figures 3.26 and 3.27, also C.7, C.8, C.9 in Appendix C). The roofing system and wall infill technique remained flexible to the constructor or owner's discretion. HFIR, however, was building a number of publicly funded buildings using ordinary bricks and/or hollow blocks as wall infill, and a reinforced concrete slab roofing system.

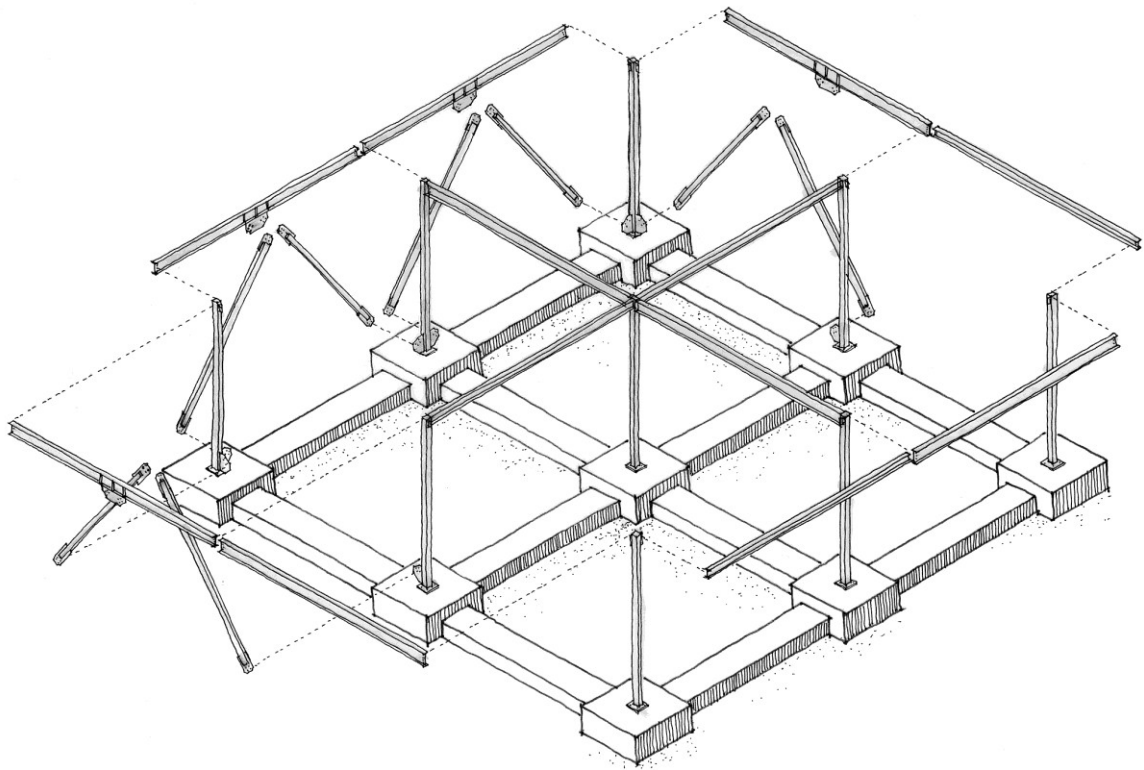


Figure 3.26. The structure proposed by HFIR; steel columns and beams are fastened together by bolts and nuts

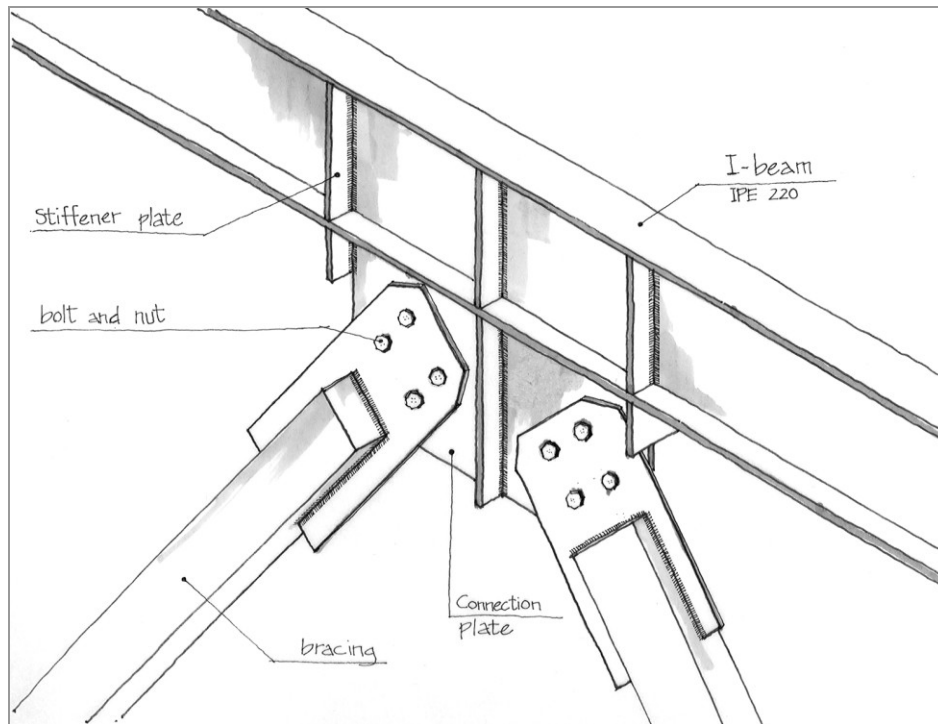


Figure 3.27. Detail of the HFIR's structure; posts and beams are connected by bolts and nuts

To strengthen the bond between bricks and steel columns and prevent bursting corners during earthquakes, either L-shaped steel bars were used to reinforce corner joints, or the columns were wrapped with chicken wire to enhance the bond with the sand-cement mortar. The roofing system proposed by HFIR consisted of prefabricated steel I-beams as girders, which would hold a seven to ten centimetre concrete slab moulded on corrugated galvanized steel sheets as permanent shuttering. Small Z-shaped steel laths were welded to the girders, connecting the concrete slab to the girders at every 50 centimetres (Figure 3.28, and Figures C.14, C.15 in Appendix C). HFIR had built a sample house with its recommended techniques at the demonstration site. This sample house, which at the time of visit was still up for demonstration, employs the HFIR prefabricated steel structure; hollow blocks are used as wall infill and the roof is a concrete slab. This proposed construction method could change, however,

when citizens or other builders in the city began to make decisions concerning their building. For instance, the wall infill could vary from double-side-meshed polystyrene sandwich panels to ordinary burnt bricks or hollow blocks. The roofing system also could vary from thin concrete slabs on steel girders to a block-joist system.

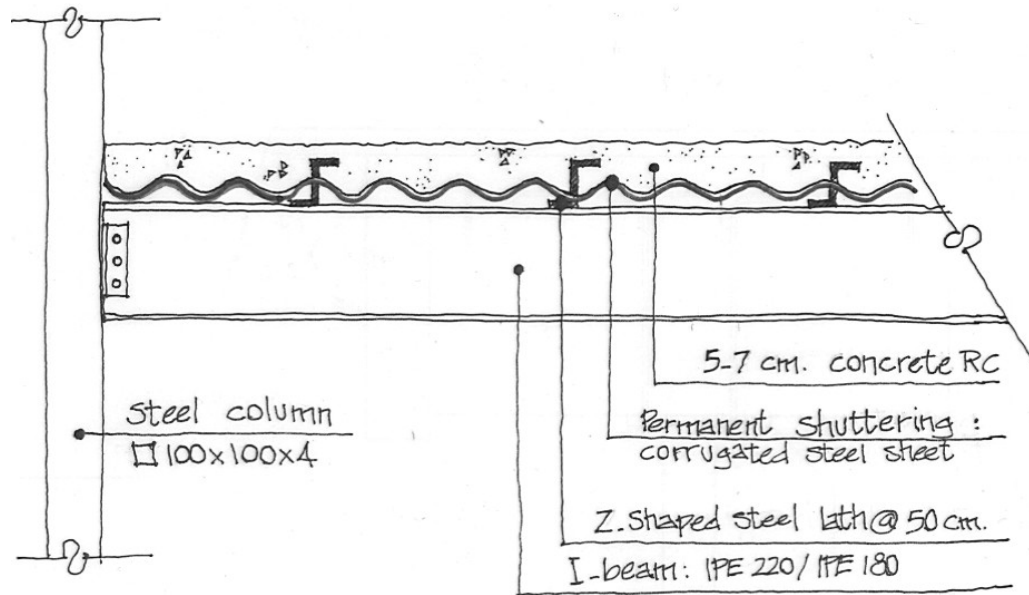


Figure 3.28. Roofing system suggested by HFIR

3.2.1.b. Houses proposed by other construction companies

The construction methods offered by building practitioners other than HFIR fall into one of the following categories:

a) HFIR's structure with different components:

The construction method employed by this group consisted of the steel frame structure that HFIR had recommended but with different building components, such as roofing or wall infill systems. For instance, some building companies had offered drywall and steel stud systems for walls with the option of pre-stressed concrete slabs for roofing the HFIR's steel frame structure.

b) Prefab structure and components:

Some construction companies proposed prefabricated structures such as sandwich panels, prefab trusses, or cold-formed joists and studs as the structure of their building method. Prefabricated components such as drywall panels and pre-cast concrete roofs usually complemented these systems.

c) Conventional steel-frame structure and lightweight materials:

This category consisted of techniques that employed a conventional steel-frame structure, with the use of welding to join the structural components (posts and beams) together. In order to increase resistance against earthquakes, these models used lightweight materials for roofs and walls, such as sandwich panels (polystyrene panels between two steel meshes) and corrugated steel sheets.

d) Reinforced masonry:

There were two foreign institutions, Auroville (India) and Peace-Winds (Japan), who had proposed masonry-based construction techniques. In these methods there were three essential elements responsible for consolidating the building, thereby increasing its resistance to earthquakes. These three components were horizontal reinforcement elements (ring beams), vertical reinforcements (steel bars), and buttresses alongside the openings (Figure 3.29). Horizontal reinforcements consisted of reinforced concrete beams placed around the building wherever the load-bearing walls are located, usually at four levels: plinth, sill, lintel, and roof height. Vertical reinforcements were comprised of steel bars placed within the walls, which ran from the foundation to the upper ring beam at the roof level (Figure 3.30).

One of the aforementioned institutes, Peace-Winds, taught its proposed method to four local masons during the implementation of the first two buildings in order to disseminate the knowledge of such

reinforcing method among the local builders. For a complete overview of the proposed construction techniques, see appendix C.



Figure 3.29. Horizontal reinforcements (ring beams) Photo courtesy of Peace-Winds Japan



Figure 3.30. Vertical reinforcements. Photo courtesy of Peace-Winds Japan

3.2.1.c. Advantages and disadvantages of proposed techniques

Quick and easy installation and resistance to earthquakes are the two main elements of the HFIR structural system's concept, which well addresses these concerns. The construction cost of this scheme, however, remained a major obstacle. In addition to the high price of the prefabricated steel components, which were being imported from far away (from Tehran, which is some 1100 kilometres away), some parts of the structure were over-designed, which wastes money and materials. For instance, the X and V bracings employed are unnecessarily thick. The 9 x 9 cm² hollow-section steel bars employed for these bracings could be replaced with smaller steel rods or cables; even a well-done brick wall could suffice. A rough estimation indicates that these bracings constitute approximately 30 percent of the total steel used in the proposed structure. Moreover, earthquake forces rarely affect one-story buildings if properly constructed. In the case of the one-story buildings that HFIR had proposed, the placement of thick walls between the steel frames, in order to consolidate the structure against earthquakes, would have obviated the need for bracings.

Another problem that persisted was the lack of knowledge about building with concrete. This was a problem for all construction methods that used concrete because the local masons were not educated on how to make a suitable mix. Although the HFIR's structural system did not need skilled workers for the skeleton (posts and beams), the concrete roofing system could pose a potential risk during earthquakes if constructed improperly. HFIR recommended flat concrete decking roofs for its proposed structure; however, the residents normally used block-joint roofs, which consist of prefabricated reinforced concrete joists with hollow blocks on which five to seven centimetres of concrete is poured (see Figures 3.32, 3.33). This system is less expensive than HFIR's proposed

concrete-slab. However, a block-joist roof makes a poor bond with steel beams; they are connected by means of only a few welding points. Clearly, such a bond would break easily during strong earthquakes.

3.2.2. The progress of reconstruction

To rebuild their houses, the citizens of Bam were provided with funding (loans and grants) totalling 150M Rials (Iranian funds, approximately CAD\$20,000 at the time), which, at the time of the program launch, was nearly enough money to construct 90 m² (approximately 970 ft²) of rough-finished building. The funding was granted to the homeowner in unequal instalments; each instalment became available at a certain stage of the construction process.

The approval of an inspector was mandatory at all stages of construction. The inspector's authorization was needed for the grant to become payable to the owner. In total, the inspector was required to inspect and approve the construction process at 14 different stages. Consequently, there was a great demand for additional inspectors, which attracted many young building engineers to the city.

To begin the construction of a house, the owner had to report to the appropriate HFIR office to obtain the permits for building and to fill out the grant and loan application forms. A bank account was opened on the owner's behalf, and the funding instalments were deposited as the construction progressed.

Like anywhere else, construction starts by excavating. Once the digging was done, the subsoil was mixed with lime mortar to make it harder. This is an old technique for making foundations¹⁹, but currently it

¹⁹ Investigating the building crafts in Iran during the period of the 1930's to the 60's, Wulff (1966) describes this technique as follows:

"Common laborers dig the trenches for the foundation, about 18 inches deep and slightly wider than the planned thickness of the wall. Whatever earth is dug out is

is not common in Iran, nor was it suggested by the Iranian building codes. It appears that the residents wanted to be extra cautious. Establishing the lines of the house and the excavation had to be approved by the inspector. At the end of this stage, assuming everything was approved by the inspector, the first instalment would be made payable.

The next step was building the foundation. Usually the foundation formwork was made of brick walls (Figure 3.31). These bricks were usually recycled (reused) from the debris of the destroyed house. During this stage, the inspector was required to frequently check the construction process and express his or her approval by signing a progress report sheet. When the progress at the site was approved by the inspector, the second instalment became available to the owner.



Figure 3.31.
Foundation
formwork made of
brick walls

carefully gathered at a spot where it is mixed with burnt lime and water into a soft paste. A layer of about 6 inches of this paste is placed in the trench and coarse stone ballast is thrown into it. These stones ... are about 6 to 8 inches in size. With one layer of stones in the trench a second layer of mud paste is worked over the stones, ballast follows, and this is repeated until the trench is filled. Within three to four weeks these foundations have sufficiently set to begin building the walls. In due course the lime-mud-stone mixture becomes as hard as rock" (p.108).

In the next stage, the brick walls were covered with plastic sheets to prevent the concrete from losing water too quickly, since the bricks would absorb a great quantity of the water in the concrete if left exposed. After the base plates or dowels were put in place, the concrete was poured into the forms (Figure 3.32). Concrete mix was either ordered from one of the 10 concrete plants established nearby or mixed on site. In either case, the inspector was required to supervise the process.

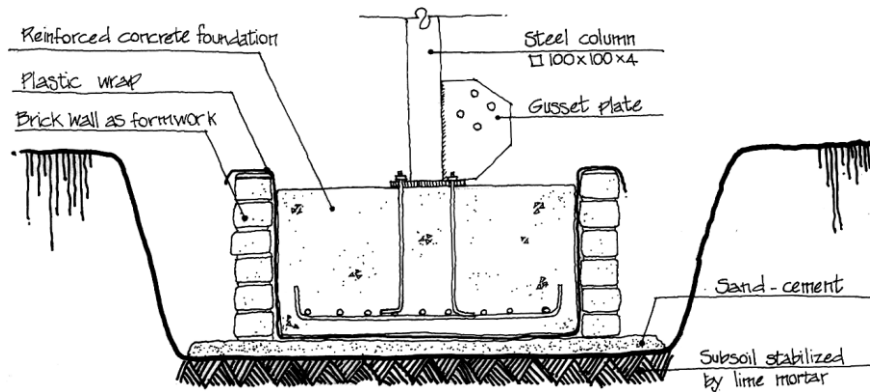


Figure 3.32. Foundation detail

Then, the inspector would pour a test sample from the concrete mix and take it to the lab. If the concrete sample met the required two-week-strength, the construction would be allowed to continue and the third funding instalment would be granted. Otherwise, the concrete contractor would be obliged to re-pour the foundation.

It was evident that the supervision was very strict. For instance, the welders had to be accepted by the inspector. To receive approval, the welder's work was scrutinized by the inspector at the end of the first day. If considered acceptable, the welder was eligible to complete the rest of the job. Once the framework was erected completely and approved by the inspector, the fourth instalment was made available.

The next stage comprised of building of the roof. The composition of the roof also had to be approved by the inspector before the concrete was

poured. Once joists, blocks, and other details were completed, the inspector would examine it all before the concrete was poured (Figure 3.33). After approval, the concrete remained under the supervision of the inspector. After pouring the roof, the final funding instalment was authorized. This last instalment was intended to cover the rest of the construction. However, this money usually covered rough finishing only.

The most commonly employed roofing system was composed of concrete joists, between which blocks made of various materials were placed. A two-inch (almost five-centimetre) thick concrete mix covered all the components (Figure 3.34 next page). Other roofing systems were rarely employed in the housing of Bam.

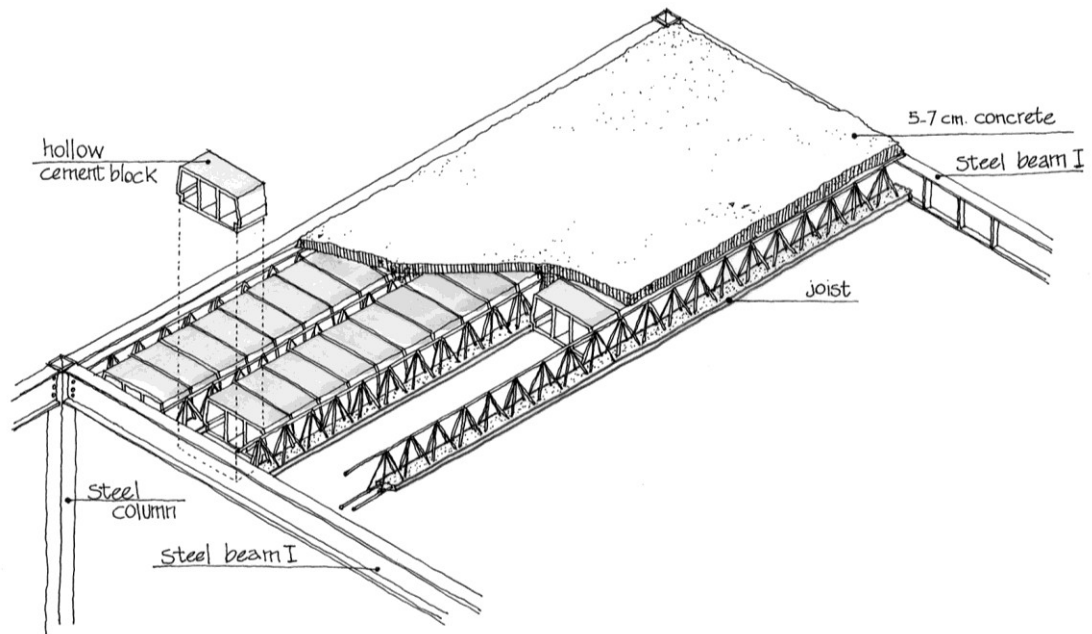


Figure 3.33. The most common roof composition in Bam: concrete joists infilled with hollow cement (or terracotta) blocks

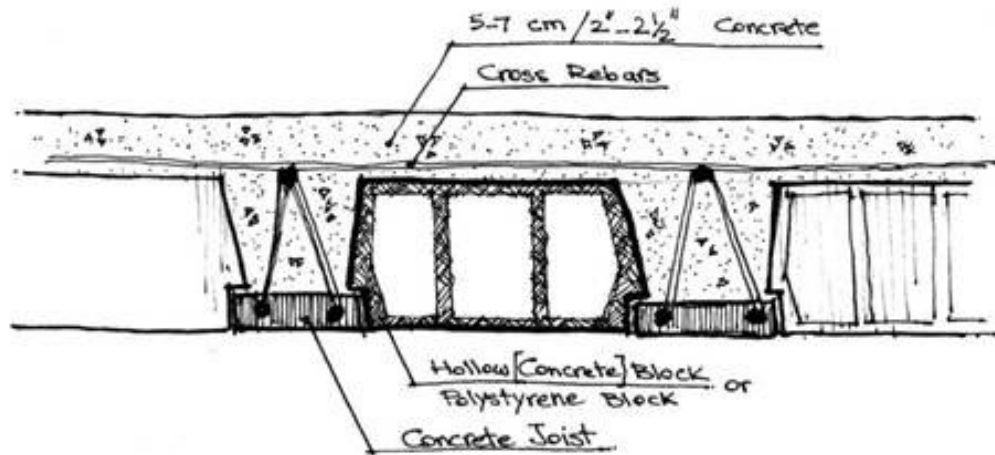


Figure 3.34. Detail section of concrete joist and block roofing system

By observing the new construction in the city, it could be seen that low-weight materials were the favourite choice of the citizens. It was common practice to use light, hollow blocks as wall infill or as roofing blocks, or both. It was also apparent that the quality of implementation and workmanship had improved remarkably. Welding techniques showed a great deal of improvement, and high concrete standards were strictly adhered to. Vulnerable points of structures like joints received close attention, and reinforcing them was a common practice.

The brick walls were tied to the steel columns by means of steel rods, which reinforced the bond between the wall and the column. These rods were welded to the column at one end and extend approximately 90 cm (3 ft) into the wall. Weak points of the building, such as openings and joints, were highly reinforced. For instance, windows and doors were tied to the structural frame by steel rods, rendering them resistant to lateral force. Stiffener plates and clips were welded to the columns and beams to reinforce the joints; this is a practice that was totally ignored before the earthquake. In the end, all details were fully inspected to comply with the Iranian building codes, although in many cases these details were over-designed.

Naturally, the tendency to over-design resulted in higher construction costs. In almost all the buildings, the framework structure was purposely over-designed. Gusset plates, base plates, clips and links, and stiffeners were overdone and steel plates were used excessively (Figure 3.35).



Figure 3.35.
Over-designed
framework of a
two-storey
house

Steel-frame construction, cut and welded on-site, was very prevalent in the city. From observations and statistics (see Figure 3.36), it was clear that steel-frame construction garnered the most attention from the citizens in comparison to prefab steel-frame, despite similarities in material and design. While on-site steel-frame work constituted 84.4 percent of the reconstructed houses in Bam, the prefab steel-frame method was chosen by only 6.3 percent of the home owners. Concrete-frame building was the second favourite at 8.5 percent, although the gap between the first and the second favourite is considerable. Bearing-wall construction was the least used method (0.7 percent), which shows a dramatic change in the construction culture before and after the earthquake; bearing-wall design was one of the most popular building methods prior to the earthquake, employed in almost 97 percent of all constructions before the earthquake.

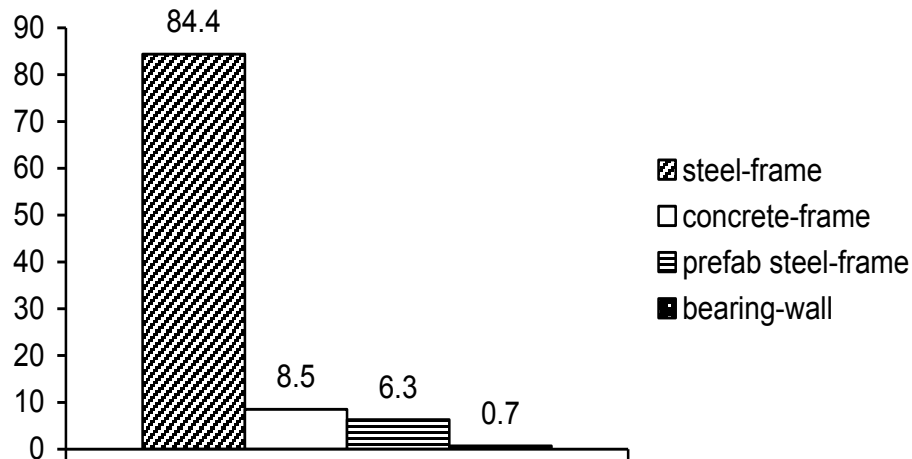


Fig. 3.36. The percentage of use of each technique adopted by the residents during the reconstruction project (Source: HFIR)

Almost all of the roofs were made of concrete, although the techniques varied in terms of the components. For example, some roofs were composed of terracotta hollow blocks placed between concrete joists, some used polystyrene blocks, and others were made solely of a five-inch thick concrete span. It is interesting to note that absolutely no jack-arch-roofs were constructed; these roofs caused the most casualties in the earthquake of Bam.

It could be seen that reinforcing became a common practice, not only in new buildings, but also in those that survived the earthquake. Those buildings that had not been destroyed in the earthquake were being strengthened by adding reinforcements. Reinforcing walls were being employed properly by the local builders to the extent that in the majority of cases, extra precautions were taken by over-sizing the reinforcements.

Overall, it can be concluded that adopting the standard frame allowed for a certain degree of design choice for the beneficiaries, while adopting a model house approach did not provide this option. The statistics regarding the use of the standard houses seems to indicate that the implied "package product" quality of HFIR's prefab structure, along with

the flexible approach of HFIR resulted in many citizens opting for other designs, since the HFIR's proposed houses did not meet the specific lifestyle and ensuing functional requirements that were important for the citizens of Bam. It appeared that very few of the standard houses were actually chosen; however, it was impossible to verify this information. Presumably, the "package" homes were not used because of their lack of flexibility and the incongruity between the house designs and the preferences of the users.

3.2.3. Socio-cultural changes in the architecture of the city

According to the HFIR statistics at the time of the second visit (February 2007), approximately 65 percent of the houses were completely finished, and a further 20 percent of the houses had been rough-finished. Glancing at the city, it was evident that the new buildings did not resemble their former vernacular architecture, although some structures had tried to mimic its details. Essentially, no vernacular architecture existed in the city after the disaster. Although attempts had been made to create earthquake-resistant housing prototypes that would suit the vernacular architecture of the city, none of these designs had been chosen by the populace in the reconstruction effort. This was despite the fact that HFIR's policy included accepting such designs, thus ensuring that these types of houses could be funded equally with the others. For instance, a prototypical house and construction method (Figure 3.37) that was thoughtfully designed to suit the vernacular architecture of Bam, developed and built by UNDP in collaboration with CRATerre (Grenoble, France), was not selected by a single home owner.



Figure 3.37. The prototypical house developed by UNDP and CRATerre

Another observation of interest was that the majority of households were planning to extend their houses in the future. Many of these homeowners had prepared the ground for further construction and had built their current homes accordingly. One of the most common practices was to extend the columns of the building above the roof line so that the house would be ready for an addition of another floor in the future (Figure 3.38).



Figure 3.38.
Columns extended
above the roof line,
ready for the future
extension of the
house

In addition, it appeared that residents were inclined to use lightweight materials. Therefore, the use of polystyrene roofing blocks and polystyrene sandwich panel walls had become increasingly common. The fear of collapse pushed homeowners to try to make the second floor as lightweight as possible, in order to reduce the dead load.

3.2.4. State of informal construction

Since the construction in the city was highly controlled, there were only two cases of informal building in the entire city at the time of visit. These constructions were not permanent housing units. One was a shelter for temporary stay, and the other was a storage room built on the roof of a formally inspected house. The reason for this lack of informal building stems from the fact that the reconstruction program encouraged or forced citizens, by means of loans and grants, to employ an inspector during the construction. Moreover, employing the inspectors was free of charge for those who followed the formal procedures, which also rendered them eligible for loans and grants. The inspectors were paid for by the government through the Iranian Construction Engineering Organization, which is essentially the "Order of Construction Engineers," with branches in all provinces.

It was interesting to discover that although the two informal buildings were not inspected during construction, nonetheless measures were taken to strengthen the structures against earthquakes. For instance, steel rods were welded to the steel frame to make a stronger bond between the wall and the column, resulting in a higher resistance against earthquakes. As mentioned earlier, the Bam citizens were much more inclined to use lightweight roofing systems, in an attempt to make their roofs as light as possible. As a result, corrugated steel sheets insulated with polystyrene (foam) sheets were used to form a light roof for these informal buildings.

Just like the formal constructions throughout city, the quality of the welding in this construction had been improved remarkably too. In fact, the owner employed a welder whose work had been approved by various inspectors during the construction of other buildings.

These examples of informal building, at first glance, seem to demonstrate that the importance of adequate welding and proper connection details were well understood by some people. The extent of this understanding, however, would require further research to be verified.

The overall findings of the examination of this main phase of the reconstruction program in Bam confirmed that although all the new houses that were erected during this period were built in compliance with the national seismic building codes and would definitely withstand earthquakes, the long term continuity of producing earthquake-resistant construction was apparently not considered. While the seismic building code requirements were strictly enforced by the HFIR's continuous inspection policy during the reconstruction period, the driving force for ensuring proper implementation procedures over a longer-term future remained unaddressed. In the context of this research, this situation brought forth the following questions:

- Have the lessons of earthquake-safe construction been learnt?
- How can it be ensured that citizens will continue with the appropriate practices of implementation?
- What are the driving forces that will maintain the proper practices?
- How can the continuity of earthquake-resistant building techniques be achieved in Bam?

The third field study was conducted to address these questions.

3.3. Third Field Study (December 2007- February 2008): collecting information concerning the transfer of construction knowledge

The objective of the third field study was to ascertain whether, in fact, the lessons had been learnt during the time period covered by the HFIR's control and whether these lessons were translated into safe construction methods over the longer term. Gathering the relevant information could not be based on an explicit survey or questionnaire, since it was assumed that respondents would slant their responses to provide "good" answers. Instead, a more subtle but time-consuming strategy was required. In this approach, the author took on tasks with several small construction "companies" (that is to say, artisans organized in informal networks), enabling him to see how construction work was really performed and how decisions were made and on the basis of what principles. The tasks involved in this fieldwork were basic labour, including any sort of low-importance construction job such as carrying bricks, moving materials and so on. The intention was to disrupt the normal performance of the builders as little as possible, and not to exert any influence on their regular practice. Instead, the objective was to identify how well the experience acquired while working under the supervision of the HFIR was translated into a new form of knowledge-based practice.

According to the model of knowledge creation and transfer proposed by Nonaka and Toyama (2004), tacit knowledge is accumulated and shared through socialization. Maznevski and Athanassiou (2007) also emphasize that "important knowledge travels best through personal relationships," and point out that the most effective way of sharing tacit knowledge is "through deep dialogue that comes with personal relationships." Therefore, to examine the tacit knowledge of the local builders, it was necessary to build close relationships with them, become a

part of their community and eventually work with them, in order to determine a comprehensive understanding of how they build.

Two strategies were felt to be the most effective in gaining the trust of the local builders. Firstly, familiarizing oneself with the local (master) builders and general contractors through their clients (the citizens), and secondly, to work with them for a certain period of time. Employed together, these approaches can create a sense of confidence and trust towards the researcher among the local builders' community – the researcher then ceases to be perceived as an observer. Nonaka and Toyama (2007) believe that "practice lays a foundation for sharing tacit knowledge through shared experience." Thus, practicing construction with the local builders appeared to be the best way to learn about their tacit knowledge.

The builders chosen were from three different generations; Builder A in his thirties; Builder B in his fifties; and Builder C was in his seventies. It is acknowledged that gaining their trust and becoming inconspicuous to them was very difficult at the beginning, especially with Builder A.

After several days of failing to obtain access to their circle, it was realized that some very minute things were inhibiting a close relationship. For instance, the builders did not like the presence of a camera on the first couple of days. Also, they never asked for help if not initiated first by the "new guy."

Among the three builders, the youngest one, Builder A, had accomplished the highest level of schooling, reaching the third grade of middle school (equivalent to grade eight of the current Canadian educational levels). He apprenticed building practice with his paternal uncle from the age of 12, and became a master builder at the age of 27. He was considered a master builder once he felt that he could practice independently, and so he parted from his uncle.

The middle-aged Builder B finished the fifth grade and quit school to work on his father's garden, and work as a labourer for his oldest brother in the off season. He apprenticed with his brother for over 15 years, since the approximate age of 12 (he did not remember precisely at what age he began to work for his brother). When his brother decided to move to a larger city, Builder B had enough confidence to practice by himself. He took over his brother's jobs and became a master builder.

Builder C was the most senior of the three. He had only a limited ability to read simple texts. However, he could easily read and understand technical drawings, almost all of which had dimensions and codes written in English characters. He learned construction through an apprenticeship with his father, who had mastered the construction of vaults and domes using mud and brick. He remembered that his father received many commissions for work in the nearby villages as well for repair work in the few buildings still in use in the Citadel at that time.

Although all three builders had received formal education to varying degrees, none of them had actually learnt anything about construction practice at school. Rather, they each apprenticed with a master builder and informally learned the trade through practice. They all acknowledged that their knowledge of building with new materials, such as steel and concrete, was very limited before the earthquake. They noted that they have learned a great deal from the inspectors (hired by HFIR) in the official reconstruction period. While the observations made during the third field study confirm that the builders actually did learn from the HFIR inspectors during the time they were in contact, as will be demonstrated below, it was revealed that there should be more to this learning than just simply comprehending the know-what.

In this study, it was observed that:

1. During the reconstruction period, the citizens and the local builders were provided with hundreds of housing designs with complete sets of drawings and engineering specifications. Subsequently, each builder had a large archive of different-sized houses, readily available for future clients. After the HFIR was discharged of its duties, these builders had a number of engineer-approved drawings and specifications that they could use for building new buildings for new clients (examples of these drawings can be found in Appendix E). It is interesting to note that all of the builders and general contractors in Bam could easily read and understand technical drawings. This skill was acquired from the inspectors, with whom they had had close relationships on a daily basis during the official reconstruction period. However, the specifications and instructions on the drawings seemed to be considered the minimum by the builders, as opposed to the optimum design and use of elements. Therefore, major changes were made either by the client or the builder, or sometimes both, in order to match the existing drawings to the needs of the client. These interventions ranged from major changes in the layout of the interior spaces and rooms to changes in the size of structural elements. Typically, the structure was overdone, under the assumption that the bigger the structural elements, the stronger the building. This misconception had resulted in huge, oversized structures in almost all of the popular buildings (Figure 3.39). Gigantic bracings, overuse of stiffeners and gusset plates, and oversized (and usually doubled) columns were reinforcements often demanded by the owner (Figures 3.40 and 3.41). Unnecessary use of reinforcement highlights the citizens' fear of building collapse; it also illustrates the presence of a "blind" knowledge of safe-construction in the community. However, this

knowledge is not meaningful know-how. In other words, the local builders knew what to do, but not why to do it. The locals/ builders knew about the measures they should take to reinforce the structure against earthquake, but they did not know to what extent it should be done, which demonstrates, as Sanbamarthy (2005) expresses, the "great distinction between knowing and knowledge."



Figure 3.39. An oversized structure: there is little load to bear, yet the posts are highly reinforced; double I-beams are welded together, reinforced by a longitudinal steel plate welded all the way to the two beams



Figure 3.40. Overuse of stiffeners and gusset plates represents the citizens' fear of building collapse



Figure 3.41. Improper use of reinforcement illustrates the presence of a blind knowledge of safe-construction.

2. Reinforcing had become a general notion in the building practice in Bam. It was common practice to use vertically reinforced-concrete pillars (every 3 meters/ 10 feet) to which horizontal steel bars were connected (every 5 courses of brick) in order to strengthen brick walls. However, although this reinforcement technique was being practiced in Bam quite predominantly, one could still find buildings that illustrated faulty knowledge. For example, in one building the space left for pouring the concrete of a wall pillar (the vertical reinforcement component) was filled up with bricks instead, which demonstrated a lack of understanding of the concept (Figure 3.42). Other reinforcing techniques that were properly employed included wrapping chicken wire around steel columns in order to make a solid bond with the sand-cement plaster (Figure 3.43). Another reinforcement measure that the builders considered was anchoring brick walls to steel columns by means of steel rods welded to the column on one end and extended to the courses of brick on the other end (Figure 3.44).



Figure 3.42.
The space that was supposed to be poured with concrete to form the vertical column. Here, reinforcement is filled with bricks instead. This demonstrates an absence of proper understanding.

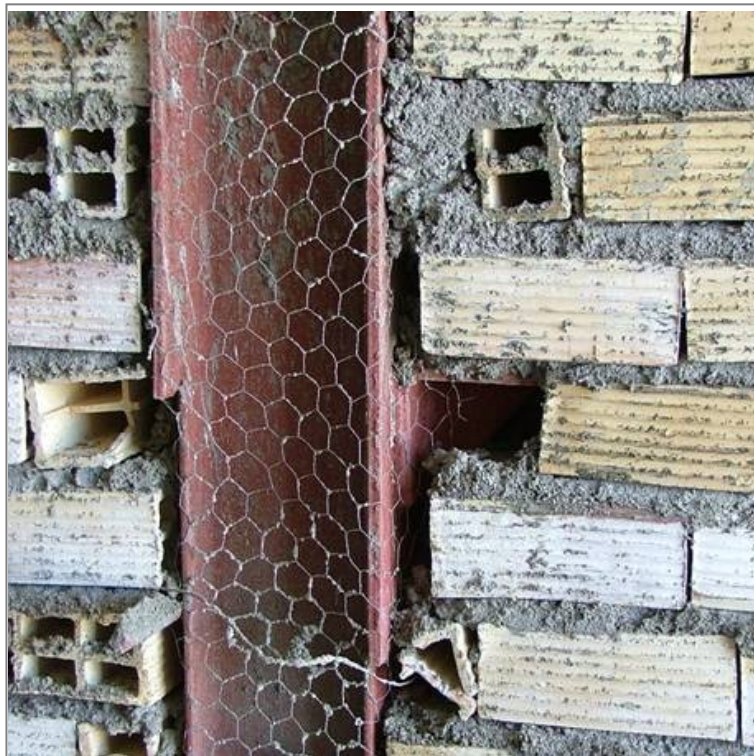


Figure 3.43.
Chicken wire wrapped around a steel column to make a strong bond with the plaster.

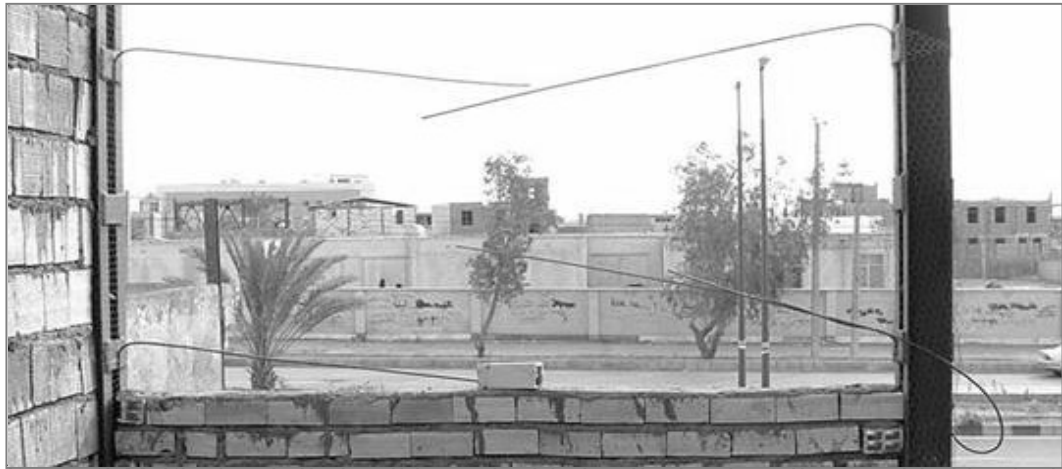


Figure 3.44. Steel rods that will be embedded in the brick wall are welded to steel columns, in order to tie the brick wall to the column.

3. The quality of bricklaying was considerably improved, with attention being paid to the importance of using wet bricks, as opposed to dry bricks, which absorb water from the mortar, causing the mortar to cure improperly. However, instead of soaking the bricks, builders tended to sprinkle some water onto the pile of bricks, which seemed to be barely effective (Figure 3.45). Again, this malpractice demonstrated a lack of understanding "why," although the builders knew "what."



Figure 3.45. Sprinkling water onto the pile of bricks instead of soaking them

4. A large variety of materials were available to the locals. For example, a wide range of sizes of concrete fillers (aggregates such as washed sand and gravel) was available to the builders. Such materials were not known to the local builders before the reconstruction program, which had resulted in people using construction waste as concrete fillers instead (see Figures 3.46 and 3.47).



Figure 3.46. A wide variety of aggregates and fillers was available



Figure 3.47. A wide variety of aggregates and fillers was available to the construction market

5. Curing cement-based material with adequate water for a few days seemed to become a common practice in Bam, a concept that was foreign to the local builders before the reconstruction program.

This observation in Bam resulted in surprising findings. It was not just the builders and contractors who appeared to understand earthquake-safe construction; the ordinary citizens of Bam appeared to have obtained this information as well. The citizens admitted that they did not have this knowledge before the earthquake. In discussions held with the ordinary citizens of Bam, the general notion of safe-construction was prevalent. As mentioned above, this situation shows that although know-what existed, know-why was lacking. As Glazer (1998) describes, there are four stages in the transfer of knowledge: acquisition, sorting, distribution, and interpretation.

After information is acquired, sorted, and distributed, it is interpreted. Interpretation organizes data, giving it structure or context and thus meaning (Glazer 1998, p. 184).

What appeared to be the case in Bam was the absence of *meaning* in the transfer of earthquake-safe-construction knowledge. Brown and Duguid (1998) stress that "know-how is critical in making knowledge actionable and operational." The observations noted in Bam suggests that it is *know-how* that makes the knowledge actionable, while *know-why* gives it meaning.

Another surprising finding was that the popular buildings appeared to be more cautiously built in comparison to the formal ones; all parts of a structure were considerably oversized. In contrast to what was expected (the expectation being that residents might cut corners in the popular building sector to save money) owners actually overdid the construction

to ensure that their building would be safe. In fact, during the official reconstruction time period, the inspectors were not concerned with the overuse of steel or concrete in the construction. However, the local population assumed that overuse of steel and concrete would create a stronger building. Consequently, the interventions of the owner or builder, with the aim of fortifying the structure beyond necessity, could be seen in almost all of the popular buildings constructed after the HFIR era. Heavy frames for single- or double- storey houses were erected, which had too much steel, too many gusset plates, and thicker than required cross bracings and reinforcement plates. To be on the safe side, in the minds of the citizens of Bam, even those who had engineer-designed drawings and specifications for a building would increase structural elements by one or two sizes more than what was specified on the drawings.

3.4. Comparison with Other Cases

Post-disaster reconstruction programs in developing countries are usually claimed successful, since a physical (visible) end result, i.e. new houses, has been achieved. However, the real success or failure of such projects should be assessed in the long term. Since the focus of this study is on the sustainability of safe-construction knowledge and repeatability of construction methods that were practiced during the official reconstruction period, three post-disaster projects that share similarity in some aspects with that of Bam are studied in the following section, focusing on the aforementioned sustainability concerns.

3.4.1. Gujarat, India

One of the reconstruction programs that shares many similarities with that of Bam is the reconstruction program of Gujarat, India. The project was launched after the severe earthquake of Gujarat (magnitude 7.7) on

January 26, 2001, and approximately one million houses were damaged; among those, three thousand completely collapsed (Thiruppugazh 2004; Shaw et al. 2003). The approach taken by the authorities was very similar to that of Bam. According to Thiruppugazh (2004), the approach and process of Gujarat earthquake reconstruction "was so successful" that it was then "being looked at as a model for reconstruction in the earthquake affected areas in Bam and Tsunami reconstruction in Sri Lanka, Indonesia and in the tsunami affected south Indian states."

What occurred during the earthquake in Gujarat is similar to what occurred during Bam's earthquake. Like Bam, both new and old structures in Gujarat were destroyed, while "properly constructed buildings in the epicentral region, whether engineered or non-engineered" sustained no damage or minor damage (Shaw and Sinha 2003). Moreover, as Jigyasu (2006) illustrates, traditional construction methods performed very well in many cases in Gujarat, which like the case of Bam, clearly points out the importance of proper construction know-how for the seismic safety of buildings (Shaw and Sinha 2003).

After a series of long discussions concerning the method of reconstruction, the government of Gujarat adopted an "owner-driven" approach, as opposed to a "contractor-driven" one.

Furthermore, the Gujarat reconstruction program was quite similar to that of Bam in terms of providing households with financial and technical assistance. Ongoing supervision of the construction process was mandatory for the homeowners if they wanted to receive the allocated financial aid. Supervision was strict and frequent, and the local masons were trained in safe-construction practices as well (Barenstein 2008).

Although the Gujarat reconstruction project had largely been praised for its apparent success during the time period immediately after the completion of the project (see Barenstein 2005; Shaw et al. 2003;

Thiruppugazh 2004), criticism emerged later, after the long-term impact of the program became evident. Like the Bam reconstruction program, there were three construction options available for homeowners to take: the contractor-driven process, the NGO- driven process, or the owner-driven process. While the failures of the contractor- and NGO-driven approaches have been brought up by the aforementioned authors, only a few have looked at the problems of owner-driven model.

Just two years after the earthquake, while the reconstruction project was still ongoing, Shaw and Sinha (2003) studied the program and noted its future challenges and the role of different players in dealing with those challenges. They state that the most important role for professionals and academics in this situation would be to contribute to the sustainability of the reconstruction process by "transferring knowledge and technology to those who need it" (Shaw and Sinha 2003). Their study highlights the importance of "understanding of scientific and technological findings, for actual implementation" by the people, and they suggest training programs as the means of implementation, therefore "bringing technology to the people" (Ibid). In their point of view, "this should be a process of implementation technology, which can be defined as the interaction of knowledge, implementation and sustainability" (Ibid).

Another scholar who examined the long term impacts of the Gujarat reconstruction project is Rohit Jigyasu. Through a comparison of the three approaches available in the context of post-earthquake Gujarat, Jigyasu (2006) questions the appropriateness of the contractor-driven model, the sustainability and authenticity of the NGO-driven model, and most importantly, the effectiveness of the owner-driven approach in truly improving the quality of construction techniques in the long run. In other words, while Jigyasu (2006) - like other scholars- criticizes the contractor- and NGO-driven reconstruction practices, he believes that putting "less

emphasis on the quality of technical know-how" in the owner-driven approach would lead to poor quality houses in the long term. Subsequently, he concludes that in programs like that of Gujarat, since earthquake-resistant technology was conceived as a "package product" for the sake of "fast transfer," what he calls "cultural incompatibility of external interventions" emerges, which eventually leads to the failure of such projects over time (Jigyasu 2006).

3.4.2. Peru

Peru is an earthquake-prone country that experiences severe earthquakes almost every year. Consequently, much research has been done on safe-construction methods with an emphasis on improving the traditional indigenous building culture. Much effort has been put on promoting these improved methods by showcasing a number of prototype housing units in various communities. Specimens of the proposed techniques, such as improved-adobe houses, were built "in different locations of the country" in 1999 (Blondet 2007).

When an earthquake struck Pisco, Peru in 2007, "more than 80% of the adobe houses collapsed or sustained heavy damage," although the specimen improved adobe buildings "did not suffer any damage" (Blondet 2007). The fact that the locals had been presented with the improved adobe techniques approximately eight years prior to the earthquake clearly indicates that the safe-construction method failed to be adopted by the mainstream residential construction market.

Another case study in Peru is enlightening. The Alto Mayo region, Peru, was hit by an earthquake of magnitude 6 in 1990. 3,000 houses were severely damaged. An NGO, called Intermediate Technology Development Group (ITDG), developed a construction technique based

on the indigenous traditional technique of quincha²⁰, a method akin to wattle and daub (Lowe 1997). ITDG improved the technique, and in partnership with local organizations and through their staff who were "well known by local people," they built 70 houses for the local homeowners in order to promote the improved technique (Ibid).

However, in communities where disaster has struck, a bias exists against methods that resemble in some ways the traditional building techniques, because those techniques apparently failed in the disaster and thus, people will not risk their lives and spend money on the old methods or anything similar to them. Lowe (1997) clearly describes this situation:

Despite these efforts to explain and promote this technology scepticism towards improved quincha remained – it was after all an unknown technology that had little social standing (seeing is not always sufficient to be convinced of the value of new technologies, especially when resources are very limited) (p. 8).

However, a real-life test came along and convinced the local people of the safety of the technique. Another earthquake hit the region one year later and damaged 9,600 houses (ITDG 2006). All of the 70 improved-quincha houses "that had been built since May withstood the tremor so well that a further 4,000 houses were built together with several schools and community centres" (ITDG 2006).

Although the outcome of this experience seems promising, one should bear in mind two important points. First, the promoted "improved" method did not attract public attention until it was tested by a real earthquake, not by shaking tables or through experimental simulations. Second, even after the second earthquake and the consequent jump in the

²⁰ "Quincha technology has been used in parts of Peru for many centuries. Traditionally, a quincha house would have a round pole frame which was set directly into the ground, infilled with smaller wooden poles and interwoven to form a matrix which is then plastered with one or more layers of earth" (Lowe 1997).

"popularity and acceptance" of the improved method, the total number of houses built with this method after three years (in 1994) in the region did not exceed 30 percent of the total housing market (Lowe 1997). This implies that despite the apparent success of the technique, the improved quincha did not become the conventional building method after all.

3.4.3. Posočje, Slovenia

After the 1998 earthquake of Posočje, Slovenia, which damaged 3,000 buildings, the government of Slovenia set up a State Technical Office to take care of the reconstruction. The objective was to provide the affected homeowners with technical assistance and construction supervision (Gostič and Dolinšek 2008). Despite the apparent success of the reconstruction project of Posočje, when another earthquake of an even smaller magnitude (4.9 versus 5.6 on the Richter scale) hit the region again in 2004, 1800 buildings were seriously damaged, some of which were built in the previous reconstruction project (Ibid).

Chapter 4: DISCUSSION and CONCLUSION

4.1. Discussion

This section discusses the issue of knowledge transfer in a post disaster framework on two levels. First, the observations made during the three field studies in Bam are analysed with the knowledge transfer as the focal point. Then, similar cases of post-disaster reconstruction programs are examined in terms of their success in transferring the pertinent knowledge. Only those programs that took the transfer of knowledge into consideration are examined here. Finally, the theories of knowledge transfer are applied to the post-disaster context in general, and to Bam in particular, in order to establish a general analysis.

4.1.1. The Case of Bam

Bam represents an example of a small city in a developing country, which is moving rapidly towards modernization. Bam is not alone in this sense: there is a significant number of towns and communities like Bam around the world. Take for example the 2005 Kashmir earthquake in Pakistan or the 2008 Sichuan earthquake in China, each of which left tens of thousands dead, hundreds of thousands homeless, and thousands of millions of dollars in damage (Miyamoto 2008; Mumtaz et al. 2008). Having taken Bam as representative of this type of communities and as the framework upon which this study is founded, this research examined the challenges of social, economic, and technical sustainability in such communities, and the mechanism of communities of practice as a means of transferring and building knowledge (of safe construction).

One specific characteristic of societies like Bam is their strong desire for explicit –as opposed to tacit- knowledge and technology that would make them *look* modern and developed while neither the physical nor the social

infrastructure is ready and developed yet. The emphasis on and thirst for rapidly achieving technology (explicit knowledge) rather than gradually acquiring the underlying principle-based knowledge (tacit) would result in unsustainability at all levels of development, from industry to culture. A dramatic event like a disaster or an economic crisis may viciously prove, like it did in Bam, the serious inadequacy of relying solely on the appearance instead of first creating an appropriate foundation. The earthquake in Bam provided ample evidence to substantiate this statement, and therefore, it can be employed as a model of study for other places in a similar state of confusion, lying between tradition and modernity.

In addition, the reconstruction program of Bam provided an exceptional opportunity for post-disaster research, as it was highly controlled and protected from external interruptions that could cause unwanted changes to the program. This controlled situation could potentially lead to an outstanding end result of a "better and stronger" city for the citizens (HFIR 2005). This research investigated this process in three phases.

The first field study demonstrated the widespread lack of earthquake-safe construction knowledge among the local builders before the earthquake. Contrary to the popular belief that weak construction materials were the main reason for the vast devastation, the first field study revealed that construction materials merely contributed to the catastrophic toll of the earthquake. Faulty knowledge of good construction, embodying, of course, earthquake-resistant construction, was actually the main cause. It was depicted that not all traditionally-built constructions were destroyed in the Bam earthquake, while many newly-built modern buildings collapsed. The then-prevalent construction technique in Bam was a hybrid of new and old materials and construction

methods, where the knowledge of modern techniques and materials has not been properly put into practice, which subsequently resulted in widespread destruction.

The second field study examined the program of reconstruction and described the planning process and how the reconstruction progressed. It was shown that the reconstruction program of Bam adopted a fairly open approach, with emphasis placed on the householders' participation on all levels, within which certain structural principles were consistently respected. In other words, within the "open" approach, the reconstruction process was closely supervised by the HFIR to ensure that the new houses were built in compliance with the earthquake codes of Iran. It was further demonstrated that new construction knowledge was put into practice in the reconstruction project: There were multiple and diverse building methods proposed by various parties from which the local residents could choose. However, the citizens were inclined towards a method that could provide them with flexibility during the construction phase, and the possibility for future extension as well. Therefore, none of the proposed ready-made houses or techniques was chosen. As a result, a hybrid design and construction method was developed, which was eventually approved by HFIR's inspectors. Employing various building components taken from different proposed options in combination with an in-situ welded steel-frame, the hybrid method won the favour of the majority of households.

All of the houses built in the reconstruction era were erected according to Iran's national seismic code of construction. There were almost no popular constructions in the city at that point in time, due in part to the incentives that were offered to the citizens if they decided to rebuild their houses. But the question was: how much of the knowledge of safe-construction, which was practiced and enforced during the reconstruction period, was actually internalized by the local community of builders so

that the repeatability (sustainability) of safe-construction practice would be ensured *after* the reconstruction and in the long term.

Therefore, the particular objective of the research during the third phase of the field study was to determine how well the earthquake-resistant building techniques proposed by HFIR were adopted and practiced by the local builders. Did the builders' work experience under the control of the HFIR translate into usable tacit or explicit knowledge? Did the imported explicit knowledge (of earthquake-resistant building, familiar to the HFIR designers) turn into the tacit knowledge of the local builders and their clients? In other words, the goal was to examine whether the local builders had successfully turned the explicit knowledge disseminated by HFIR into tacit knowledge which they would use in their day-to-day work.

To find the answer, the work of three local master builders in Bam was closely followed through working alongside them on construction sites. It was observed that the builders had acquired a great degree of information about safe-construction, but their practice of safe-construction lacked meaning: they knew which components were important for reinforcing the structure against seismic shocks, but they did not necessarily understand what the underlying principles of these components were, nor what the appropriate amount of reinforcement was really necessary. In other words, although it seemed that the local masons and general contractors well knew what measures to take in order to reinforce a building against earthquakes, but they did not appear to completely comprehend the concepts behind these measures. Once again, new techniques were put into practice within the community of builders without knowing sufficiently why they were doing what they were doing. That means know-how and know-what was transferred, but know-why was not, which would lead to the unsustainability of the safe-building practice in the long run.

After the earthquake, HFIR came to Bam with a set management strategy of certain potentialities; from head managers with strong political ties beneficial to the protection of the project from political fluctuations, to the myriad of young inspectors who could have efficiently established interpersonal and informal relationships with the (local) builders and homeowners in order to improve their grasp of how buildings and materials behave. After HFIR inspectors left Bam, however, it appeared that some of these potentialities had been overlooked and subsequently wasted: it was evident that earthquake-safe building *techniques* have been transferred to the local builders and their clients, but it seemed that the *knowledge* underlying those techniques had not been conveyed adequately. The close and frequent relationship between the inspectors and the local builders during the formal reconstruction period resulted in the locals' understanding of the earthquake-resistant construction (*what to do*). However, the process failed to transfer the knowledge of earthquake-resistant construction (*why to do it*).

After a disaster, various parties representing diverse interests with different strengths get involved in a reconstruction project; from governmental organizations to international aid agencies to the local labourers and builders. Although these parties are motivated by good intentions, the outcome is often not as successful as expected. This is due partly to the lack of appropriate knowledge at different levels of role players, as well as inadequate cooperation among them (Shaw et al. 2002).

This condition can be improved if the strengths and weaknesses of all the parties are recognized by the reconstruction managers and decision-makers. For example, there are naturally two managerial forces at work: One, is the government which usually makes a top-down effort, typically in the form of governmental interventions; and the other is bottom-up efforts, which take place at the level of people in communities and is a less

formalized form of intervention, frequently occurring through mutual help among the citizens affected by the earthquake. This latter group occurs organically and needs no government involvement. In this scheme, NGOs can play an important role "as the interface between the people and the government, by communicating community's needs and priorities to the government" (Shaw 2003).

In the case of Bam, HFIR's considerable strength in logistics and power was a great advantage, while their concept of top-down development was a great drawback. The HFIR's perception of housing and development has its roots in the organization's ideology of "building for the poor," as has been mentioned. Coupled with the popular belief that a traditional appearance symbolizes a certain degree of poverty, this view has resulted in the HFIR's tendency to always push for modern looks, and to remain unsympathetic to the traditional practices.

Not surprisingly then, what was observed in Bam demonstrates a lack of sensitivity by HFIR to the local building culture and the learning habits of the local builders. Although it was well known that houses in Bam were built for the most part, if not all, by the popular sector before the earthquake, little or no recognizable attention was paid to upgrading the local builders' knowledge of construction. Rather, entirely new construction methods were brought in and imposed on them through a regulatory process which can be described as "package product."

4.1.2. Other Cases

Every time a disaster causes considerable loss of human life and property, the blame is placed on unsafe construction methods as the cause of the calamities. Therefore, it is not surprising that a considerable amount of effort and energy is expended to improve the construction practice of a stricken community. Depending on the approach adopted by the

reconstruction program, this improvement may range from importing new construction methods to helping residents build earthquake-safe buildings themselves. However, it seems that neither approach provides sustainable safe-construction solutions in the long run. As Lizarralde (2004) points out:

The major problem with which we are confronted now is that either by adopting one approach or the other (the community- or the technology-based), there is evidence that shows that existing housing reconstruction strategies have failed in enabling vulnerable communities to recover in the short run and in achieving long-term development over time (p. 15).

Lizarralde (2004) further enumerates multiple examples of failure of these strategies reported by various authors²¹. Nonetheless, the bottom-up approach still seems to be the favourite in today's post-disaster reconstruction programs, with the aim of upgrading the construction knowledge of the local citizens.

An examination of reconstruction programs that claimed to have had success in transferring safe-construction knowledge reveals that the programs achieved success to a certain extent, but this success was limited to the relatively short period of reconstruction; long-term success was not achieved. In other words, the success of a program is often assessed at the end of the program, while the long-term impacts of the program are overlooked.

4.2. Conclusion, Recommendations, and Contribution

In general, this research highlights the importance of ensuring that the post-disaster reconstruction period allows for the generation of tacit knowledge among the community and its builders. However, a complete transfer of knowledge may take longer than the time available within the

²¹ Anderson and Woodrow (1989), Davis (1978), Dudley (1988), Oliver-Smith (1990), Salazar (1999), Solo (1991), Tjahjono (1999), and Wisner (2001).

short- to mid-term horizons of reconstruction programs. To be more precise, it appears that the transfer of new safe-construction technology in post-disaster programs in developing countries might even be beyond reach, due to the conflicts between the nature of this knowledge transfer and the characteristics of such programs. Some of these characteristics and conflicts are listed below.

1. Reconstruction programs are always limited to relatively short time-periods; these periods are often too short for the transfer of required knowledge that is, by its nature, a very time-consuming and difficult process.
2. The rushed atmosphere of a post-disaster environment is the most impeding factor that restrains the transfer of knowledge. Indeed, the transfer of knowledge is in conflict with speed. On the other hand, speed is an important characteristic of post-disaster reconstruction programs in developing countries, where, as Kennedy (2008) points out, success is "measured by the number of houses built" during a certain period of time, and therefore "projects must be completed as quickly as possible to foster recovery and to satisfy donors who want to see results" (Davidson et al. 2006). Lloyd-Jones (2006) writes:

In the aftermath of a natural disaster there is considerable pressure for quick results. Part of this is a natural concern to attend to the immediate and pressing needs of those who are suffering. At the same time, other institutional factors come into play. Donors are keen to see both quick results and a rapid disbursement of the allocated funds – to get the money out the door. Many agencies have a mandate that is limited to short-term humanitarian relief and are anxious to do their job and be prepared to move on to the next emergency (p.56).

3. The technology of safe-construction is imported to a new social context; but, as Brown and Duguid (1998) explain, for knowledge

"to spread easily," a suitable social context must be present. The required suitable context usually does not exist for several years following the disaster. In fact, the human dynamics that exist after disasters hinder the transfer of knowledge, especially in developing countries where disaster preparedness and planned response are usually lacking. In addition, the building team is characteristically a temporary organization in itself²², which becomes more complex in a post-disaster context where the environment is chaotic and disordered, "with simultaneous projects being launched by numerous local and international organisations for housing and infrastructure repairs, for livelihoods creation, and for a range of other social programmes" (Davidson et al. 2006).

4. Close interpersonal relationships are necessary for transferring construction knowledge. Such relationships cannot be established and implemented by formal procedures. Although not intentional, the reconstruction program of Bam illustrates a certain level of success in this regard in creating these relationships by employing a large number of inspectors who were in contact with the local builders on a daily basis. Consequently, this situation resulted in the transfer of some knowledge to the builders, although not transferred completely and correctly. It seems that more time would be required for the builders/ masons to interpret the information that they had gathered through communication with the inspectors, and to fully interiorize it as tacit knowledge.
5. In the aftermath of disasters, a community's fear of disaster becomes such a strong force that it can distort their ability to think

²² "Building Team is a term generally but somewhat loosely used to describe the group of professional and commercial enterprises which design and construct a building project" (Davidson 1988).

objectively. A community will not take risks if those risks will put their lives in jeopardy; they would rather be extra cautious. Subsequently, as in the case of Bam, for example, structures were over-reinforced, to the detriment of economic performance and technical efficiency. The optimized engineer-designed structures employed for the first time in an old society used to massive, load-bearing structures, were not felt-instinctively- to be strong enough. Another earthquake would be required to validate these structures' performance for the local residents. However, this real-life test may never happen during the life-span of the generation who now partially understands the consequences of lax construction practices.

In summary, a disaster can create a traumatic atmosphere; this environment is often intensified in developing countries where usually no up-front planning for post-disaster programs exists. This situation creates an extremely unsuitable environment for knowledge transfer. In fact, as summarized in the table below, the post-disaster context in developing countries is often associated with characteristics that are the opposite of what is required for knowledge transfer.

Characteristics of post-disaster environment in developing countries	Knowledge transfer prerequisites (according to Ko et al. 2005)
Extremely chaotic/ human dynamics	Suitable context, absorptive capacity, close relationship
Push for quick results	Long-term process, person to person experience
Trauma added to an old social context	New social context for new knowledge

Therefore, it can be concluded that:

- Transferring technical knowledge is easier than creating an understanding of the reasons for it.
- Creating tacit knowledge in the receiving community and its builders requires more time than is usually available, suggesting the need for careful advanced planning or a long term, informal apprenticeship-like education process after the reconstruction program is over.
- In a reconstruction program, it is essential to allow for the informal transfer of pertinent knowledge to the receiving community. A *process* of creating the construction knowledge must be formed in addition to the reconstruction *program* to allow for a long period of informal training.
- Unless there is careful planning in advance, the transfer of knowledge through post-disaster programs in developing countries will remain only a myth. Such planning should: 1) reflect the building culture and learning habits of local builders, 2) focus on the popular construction sector, as it accounts for the most part, if not all, of the housing construction in small towns in developing countries, and 3) allocate a considerable amount of time to the process.

As discussed in Chapter 2, when a developing nation is facing a transition from a traditional way of life to a more modern one, the ancestral building craftsmanship is lost or faded out, surviving only in small and remote villages; the modern methods are improperly adopted in regional towns like Bam. Consequentially, an incomplete hybrid of both traditional and modern methods is practiced there. This situation creates the potential for disaster when natural hazards occur. In other words, the traditional building skills have been replaced by new, misunderstood

construction knowledge; in exceptional occasions, such as the occurrence of a natural hazard, this faulty construction will fail.

The situation is worsened by what Alexander (2006) calls "an extraordinary lack of architectural Darwinism" in the history of disasters in developing countries. In fact, Alexander implies that the building practice in developing countries hardly evolves with experience learnt that would improve its flaws in resistance against disasters. Builders do not actually retain the lessons that they learned from disasters about how to build safely; there is a tendency towards losing the experience and knowledge acquired. Several reasons can be named to explain why this evolution rarely takes place.

Firstly, when the old methods of construction fail in disasters, an understandable bias against those methods emerges among the victims. This bias very often extends to all the construction methods that somehow resemble the old techniques, although they may actually have been improved and safe²³. In fact, the people's trust in such construction techniques is destroyed after structures that employed apparently similar techniques collapsed. It is very hard to convince the community that those methods have been improved and made safe, unless the new method can somehow prove itself in a real-life test²⁴.

²³ For instance, in Bam there were three NGOs who promoted improved masonry construction techniques which employed local materials as well as indigenous forms. They built demonstration buildings as well as a few public structures to showcase their methods to all levels of the community. Two of these NGOs even set up training programs for the local builders to teach them how to build safely with these tradition-inspired methods. In spite of all these efforts, none of the homeowners chose to build with any of these methods.

²⁴ As illustrated in the case of the improved quinchá in Peru, residents began trusting the improved method only when another earthquake hit and the new, improved structures performed well. But even so, only 30 percent of new houses were built with the improved method.

Although disasters are likely to happen again some time in the future, the chances of one occurring during the period of the reconstruction project, and therefore serving as a test, is very slim. Not surprisingly, a real test after the first generation of construction workers who experienced the initial disaster are gone would not help the new generation draw lessons. In other words, when it comes to improving vernacular construction methods, there is a need for a real-life test of the proposed methods during the reconstruction period so that the community will believe that it is possible to build safely with old but improved techniques. The problem is that the occurrence of such a test is highly unlikely. As demonstrated in this study, even simulation tests cannot help convince citizens to choose the improved methods that look similar to the old methods²⁵. Conversely, while a community has a bias against the old methods and favours the apparently modern techniques, knowledge of those modern methods is not embedded in the practice of the local builders. So the question is whether the lessons and methods of safe-construction that were imposed in the reconstruction program have actually been learnt in Bam (or similar cases). The answer seems to be negative if we are looking at long-term horizons.

In point of fact, in the absence of incentives -like grants- or forces -like inspections- the popular building industry would need an alternative controlling body of some sort to ensure the continuity of safe-construction practice. This is exactly where non-governmental parties²⁶ can play a

²⁵ UNDP, with the cooperation of the National Society for Earthquake Technology-Nepal (NSET), showcased a shake table test three times in Bam, with the aim of illustrating the idea of earthquake-safe masonry construction in Bam. The show was open to the public, who widely participated in the program. Nonetheless, no one actually built their houses using the reinforced masonry methods.

²⁶ The term "non-governmental parties" here includes all the role players in the efforts that are not financially supported by the local or state government. This

weighty role by encouraging and supporting communities of practices that would facilitate building practitioners' communication and networking.

As stressed earlier, however, a sustainable transfer of knowledge is in conflict with formality. As Takeuchi and Nonaka (2004) have pointed out, "tacit knowledge is personal, context-specific, and therefore hard to formalize and communicate." The creation of operationally effective tacit knowledge calls for a great deal of person-to-person communication and the establishment of close interpersonal relationships – this may or may not have been the case between HFIR officials and the local builders, particularly since converting explicit knowledge into tacit knowledge is a very time-consuming and difficult process. Davenport and Prusak (1998) emphasize that "tacit knowledge transfer generally requires extensive personal contact," adding that it cannot be transferred in any other way. Transferring tacit knowledge involves close personal contact, relationship, and physical proximity (Nonaka and Toyama 2007; Maznevski and Athanassiou 2007).

Examining the findings of this research in Bam and the similar cases in the context of the abovementioned concepts suggests that those in charge of reconstruction programs are very often led to believe that the knowledge about safe-building is adequately transferred by importing new concepts into the community where they can be seen. Contrary to this belief, this approach can only convey the knowledge that is "transmittable in formal, systematic language," which is essentially information rather than "know-how" (Takeuchi and Nonaka 2004). In fact, one key problem in many reconstruction programs, if not all of them, is that the transfer of experience and knowledge is imposed on the citizens in the disaster-

also includes those parties that are funded or supported by foreign governmental aid programs.

stricken area from the outside (in the Bam case, by the HFIR), which creates a "subservient" situation where the builders have to do what they are told to do.

This study shows that new construction methods cannot be adopted by local builders simply through the importation of the techniques in question. Rather, the transfer of new construction technologies must become part of the local builders' tacit knowledge; this process calls for a great deal of interpersonal education and learning-by-doing, which make this process very time-consuming. This research concludes that the prerequisites needed for knowledge transfer do not exist in the aftermath of disasters, given the atmosphere and the dynamics existing after natural hazards strike developing countries. Neither the physical nor the psychological contexts are ready, and subsequently, it is unlikely that safe-construction knowledge will be transferred to the community. In short, the post-disaster context is too imperfect for transfer of tacit knowledge, which is essentially what is needed for ensuring the sustainability of good practices. There is so much to do just to get work off the ground first, that there is no time for the transfer of tacit knowledge that is hard and very time-consuming by its nature.

It was further demonstrated that although training programs for local builders may show improvements in the practice of the builders at some point, the effectiveness of these improvements seems to be minor, especially in the long run. Therefore, this study suggests the need for a *process*, as opposed to a *program*, of reconstruction, which would start with the physical reconstruction and continue after the physical reconstruction is over. In this process, it is imperative to address the sustainability of the safe-construction building culture by providing the local builders with interpersonal training on a daily basis, especially *after* the termination of the physical reconstruction phase. In this process, the reconstruction of the

building *culture* continues even after the physical reconstruction is completed. Such process would allow for establishing a context that is ready for the transfer of tacit knowledge, when inhibiting factors such as the urgent need for housing have been satisfied.

On the basis of the findings of this research, it can be suggested that the two-pronged responsibility of quality-control and training in post-disaster reconstruction programs should be shifted from governmental organizations to organizations of a non-governmental nature, whose long involvement in the process after the termination of reconstruction project is somehow ensured. In other words, the quality control of building trades should be left in the hands of non-governmental parties who would be remaining involved in the practice, regardless of the official reconstruction timelines. Such organizations should accommodate building practitioners of diverse expertises.

Building upon the above conclusions, the following recommendations can be made. In a post-disaster situation in a developing community, the responsibility of government should remain limited to overall policy-making at macro level, and its intervention should lose weight as we go down towards the community level. Local government should be in charge of formal training, while NGOs would be responsible for informal training of the existing community of builders. Foreign aid agencies may take a long-term financial-support role for the aforementioned NGOs. However, care must be taken in this relationship, as many governments in developing countries can be extremely sceptical to organizations that receive financial support from outside. Through monitoring for a while, NGOs can ensure that local networks and communities of practices are formed and the good practices are adopted broadly. In this concept, informal and community-based inspection regimes can be formed during

the official reconstruction period, and must be extended to the post-post-disaster time.

The questions arising immediately from the above recommendations concern how to apply these concepts to the practice on the ground. An examination of post-disaster programs in developing nations, where the community is already facing a transition from their traditional way of life to a more modern one, suggests that in such a context, traditional craftsmanship is lost or faded away while the modern practice is not properly adopted. Rather, a hybrid of traditional and modern methods is being practiced. This situation lays the foundation for disaster when a natural hazard hits. In other words, traditional skills are replaced with improperly understood (i.e. incomplete) knowledge, creating a vulnerable context which makes disaster possible. How can safe-construction knowledge be transferred then? What exactly should be transferred? What are the basic principles to be transferred to the local builders?

To answer these questions, it is helpful to first stress again the importance and effectiveness of informal approaches in the transfer of safe-construction knowledge to the community of builders. As mentioned earlier, NGOs would be the best to undertake this mission by continuous on-site interactions with the local builders, during and after the reconstruction period. These NGOs can initiate and facilitate networks of local builders and subsequently create an operational community of practice through arranging regular gatherings for the construction practitioners. Simultaneously, formal training of new generation of builders can be pursued by the local government through creating and advocating local vocational schools.

Simple rules of thumb for safe-construction can be taught to the local builders through informal training. To find out what these simple principles might be, a look at the HFIR inspectors' checklist (Appendix D)

would be enlightening. It is interesting to note that those who formulated the checklist have subtly embedded the principles in question into the inspection process by allocating remarkably higher points to the basic elements of safe-construction, namely: 1) good foundation, 2) high quality of concrete including aggregate, mixture and rebar, 3) well made connections and junctions, and 4) solidity of roof. A fifth element needs to be added for the compatibility of different materials and how different materials behave differently against forces.

Architects and NGOs (or architects through NGOs) can simplify the technical principles of safe-construction and thus make it easier for the local builders to absorb. Frequent and continuous hands-on practice on construction site with the local builders can facilitate the application of these principles to the popular housing sector. Following the above recommendations, however, one should consider the context in which they are applied and changes to the role of different parties should be made accordingly. The key point is that the governmental interventions and control should be diminished on community level, and most specifically, in training programs for the local builders.

4.3. Insights for the Future

While there has been much research done on the issues surrounding *post-disaster* operations, this research highlights the importance of *post-post-disaster* issues. Further research in this area is needed to investigate the adequate length of time required for this post-post-disaster process to be effective. Moreover, pre-disaster (preventive) strategies should be developed, with the aim of improving construction practices in developing countries with knowledge about safer construction methods. In this regard, it is important to pay close attention to the context. Since popular construction constitutes a large portion of the housing in

developing countries, particularly in remote areas, any attempt to improve the safety of building methods would fail if made strictly formal. Given the informal nature of the construction trades in small towns in developing countries, the improvement must be implemented informally as well, starting from within the informal networks of builders. To determine how these informal connections could be made and how the informal training could be implemented, careful planning and extensive research is needed.

Many questions arise from the concept of *post-post-disaster* reconstruction: Who should take responsibility for incorporating the *safe-construction knowledge* into the informal community of local builders? Who guides the local builders to understand and use these practices? What are the basic and essential rules of thumb and guidelines that need to be transferred? Who facilitates bringing the respective parties to ensure these simple guidelines are integrated with local, traditional knowledge, and how? What is the role of existing local knowledge in this scheme? Further research is needed at the local-to-global levels to answer these questions; research that stresses the need for informal communities of practice among the local builders; and research that aims at incorporating informal learning into such communities of practice.

Another interesting area of potential research that could follow from this discussion would involve new online technologies, which "provide a range of opportunities for collaboration and knowledge building not previously afforded" (Ramondt 2008). The literature on communities of practice (CoP), which was introduced by Lave and Wenger in 1991 and further developed by Wenger in 1994, builds its foundation on the concept of social learning through informal networking among "groups of people who share a concern or a passion for something that they do"

in order for them to learn "how to do it better as they interact regularly" (Wenger 2008).

In recent years, the concept of virtual communities of practice (vCoP) has attracted much interest. Virtual communities of practice are places that can facilitate an informal network for its participants and make possible "the merging of informal and formal learning" (Laferrière and Gervais 2008). In fact, with the rapid development of online technologies, researchers have now realized that the characteristics of internet-based (virtual) network places are congruent with those required for physical (actual) CoPs. This realization has led to the speedy emergence of numerous vCoPs, many of which existed physically before moving to cyber space (Koch and Fusco 2008).

Although it may seem surreal, the ever-increasing growth and accessibility of online services and the facilities and possibilities they provide make it reasonable to imagine that one day such technologies may become widely used, even in communities like Bam. While the concept of virtual space is alien to the majority of its citizens, new generations of builders in a remote town in a developing country such as Bam, may benefit from these new technologies. Consider that the idea of online (virtual) communities of practice was never what Wenger, who first introduced the concept of CoP, could have imagined at the onset of his research (Laferrière and Gervais 2008).

Appendix A: Brief history of Bam

Located in the southeast of Iran, on the historic Silk Road caravan route, the city of Bam was one of the important trade centres during the Middle Ages (Merriam-Webster 1997). The ancient citadel of Bam, Arg-i-Bam in Farsi, is believed to be the core of the city, from which the current city began its growth. Although signs of even earlier settlements have been found on other historic sites outside of and near the citadel, the origins of a civilized settlements was found on the citadel site, dating back to the Parthian dynasty (248 B.C. to 224 A.D.), according to the latest excavations at the citadel (Sadigh and Tabeshian 2006). This proves that the citadel of Bam is about 2,250 years old. However, some historians believe that the citadel of Bam was "originally founded during the Sassanid dynastic period (224-651 A.D.)," and that the earliest remains were ruins of a small settlement, not of a remarkable structure like a fortress (Ibid).

Due to the "lack of adequate studies on the origins of Bam, not much archaeological information exists about the Bam Citadel during the pre-Islamic period - that is before 651 A.D." (Sadigh and Tabeshian 2006). The name of Bam (the citadel), however, was repeatedly mentioned in historical documents since the 10th century, when the city flourished and occupied an important role not only in the economy of the region, but also in the historical silk road route (Ibid).

Embracing the entire city, the citadel complex consisted of residential units (houses) of various sizes (see Figures A.8, A.9), a bazaar, a mosque, public gathering spaces, a military barrack, a governor's palace, and so on. The strategic location of the city was always attractive for intruders; therefore, the inhabitants erected a very sophisticated passive defensive system by building seven layers of fortified walls within the city. The most

important buildings were located closer to the center of the citadel, and subsequently protected by more walls.

The golden era of the city was in the Safavid dynasty period (1502-1722), when the population significantly grew, to the extent that new houses had to be built outside the citadel walls (see Figure A.1). After the Afghan invasion in 1722, the city and the citadel were abandoned for years, and the role of Bam in the region declined thereafter. Although the city was gradually resettled, it never regained its flourishing economy.

The city continued its steady growth outside the citadel boundaries as the economy of the city shifted from trading to agriculture at the turn of the 20th century. This led to the development of gardens of palm trees, which subsequently turned Bam into a garden city during the time (1900-1950, see Figure A.1). Limited by a seasonal river on its north, Bam spread westwards and eastwards, where better agricultural land was available and the slope of the area worked better for irrigation.

The growth of the city continued until the 1950s, when two areas on the east and west ends of the city were developed by the government to prepare land for future housing for the growing population (Naqsh-e-Jahān-Pārs 2004) (Figure A.1). This put an end to the garden-city urban style, since the newly developed land was divided into small lots with a geometrical network of streets, like all new urban developments at the time. Further developments followed this geometrical-pattern of design from the 50s and the city continued spreading towards the west and east.

The citadel, however, was gradually abandoned after the new interventions in the city were made (1950-60), as people became more inclined towards new construction. Nonetheless, the wonderful architecture of the old city, and the citadel in particular, attracted the attention of the Cultural Heritage Organization of Iran, and it soon became one of the tourist attractions of the country. Built entirely out of

adobe and mud, the citadel, which is a complete city by itself, was known as one of the biggest earthen structures in the world. Restoration work has been continuous at the complex for the past 40 years. Sadly, approximately 80 percent of this magnificent citadel, as well as most of the city, were destroyed completely in the earthquake of December 26, 2003.

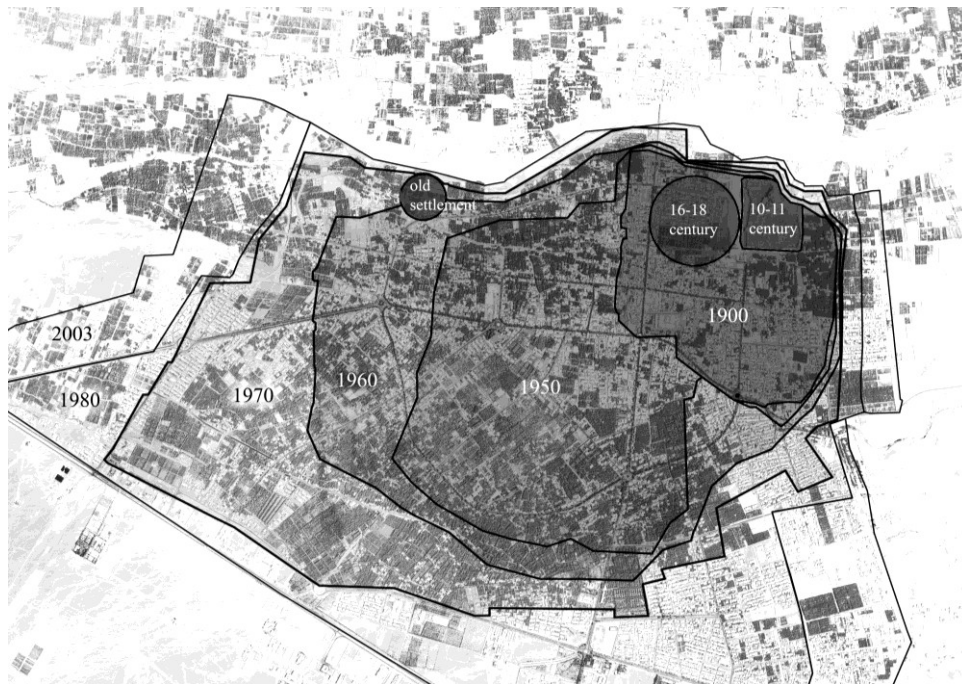


Figure A.1. The growth of Bam over time (Naqsh-e-Jahān-Pārs 2004)



Figure A.2. Evolution of Bam during the ages (Naqsh-e-Jahān-Pārs 2004)



Figure A.3. Aerial photo of Bam in 1946 (Naqsh-e-Jahān-Pārs 2004)



Figure A.4. Aerial photo of Bam in 1954 (Naqsh-e-Jahān-Pārs 2004)

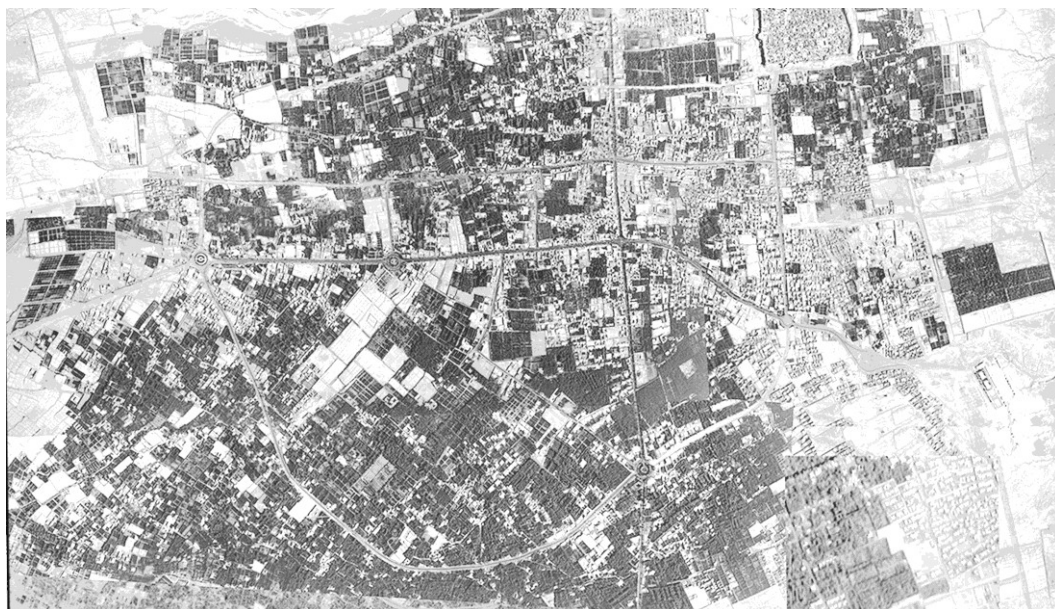


Figure A.5. Aerial photo of Bam in 1967 (Naqsh-e-Jahān-Pārs 2004)



Figure A.6. Aerial
photo of Bam in
1983 (Naqsh-e-
Jahān-Pārs 2004)

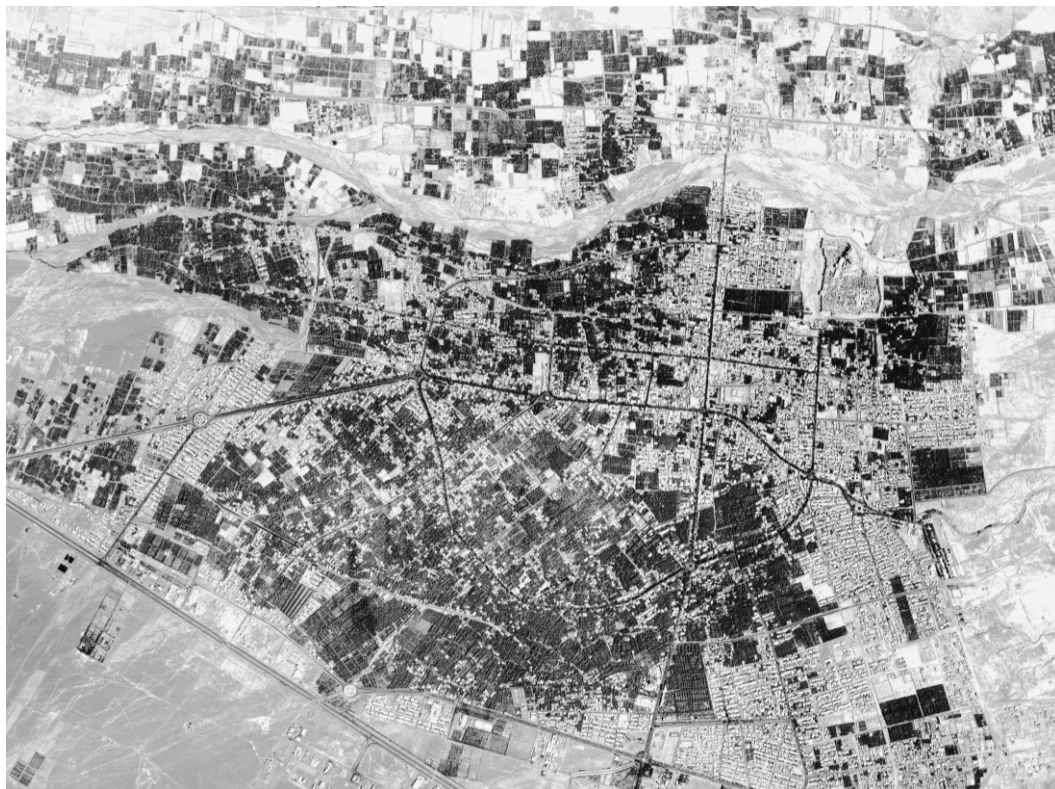


Figure A.7. Aerial photo of Bam in 1988 (Naqsh-e-Jahān-Pārs 2004)

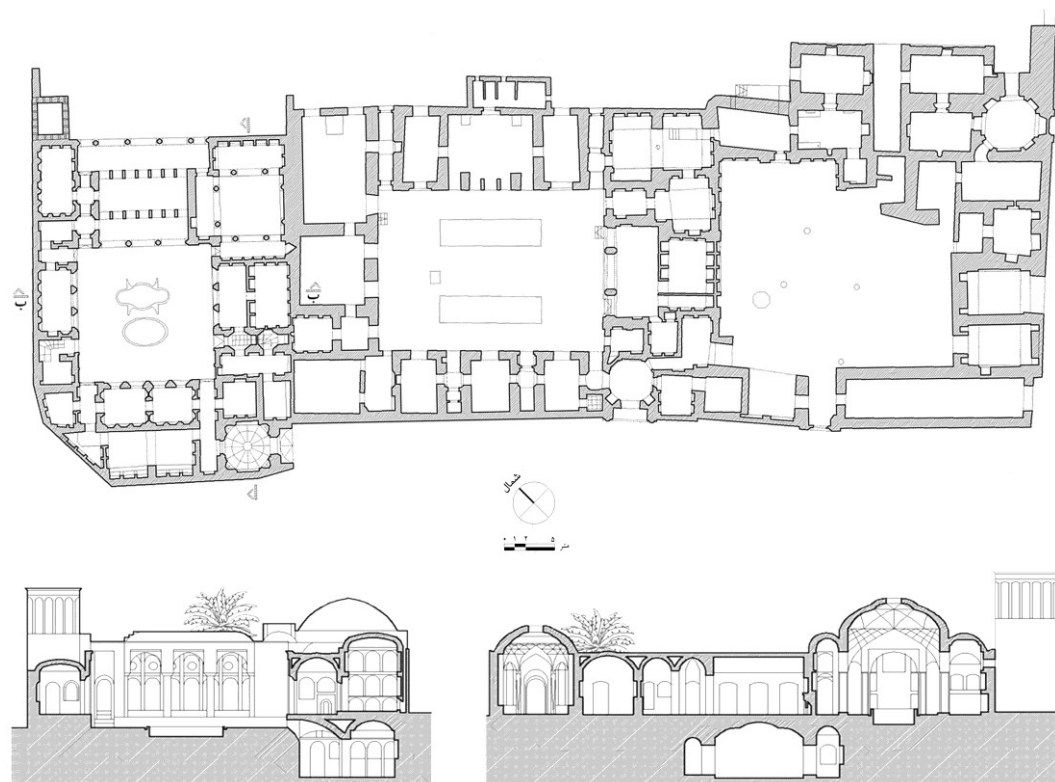


Figure A.8. Example of a large house in Bam (Naqsh-e-Jahān-Pārs 2004)

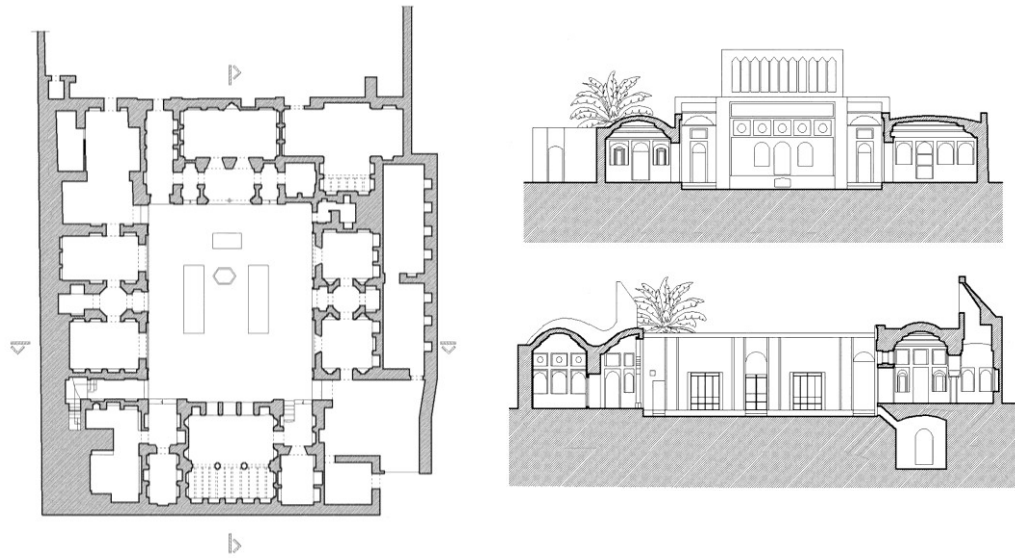


Figure A.9. Example of a large house in Bam (Naqsh-e-Jahān-Pārs 2004)

Appendix B: Climate of Bam

Bam is situated on the periphery of the Lūt desert, which is one of the hottest deserts in the world; a NASA satellite recently recorded surface temperatures as high as 71 °C (159 °F) (Engber 2007). Located on the southern edge of this desert, Bam has a hot and arid climate with high daytime and low night-time temperatures, due to very low humidity. Figure B.1 illustrates the average monthly highest and lowest temperatures of Bam during a 30-year period from 1970 to 2000. To provide a more meaningful understanding of the graph, the average monthly highest and lowest temperatures of Montreal during the same period of time is graphed.

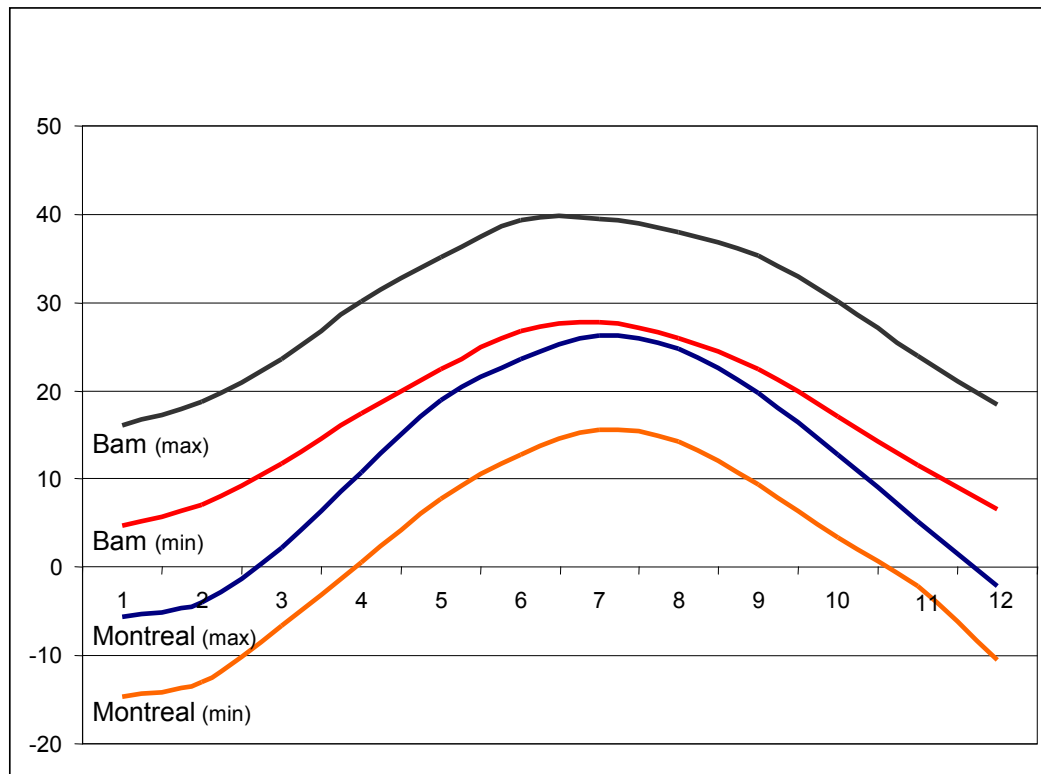


Figure B.1. The average monthly highest and lowest temperatures of Bam are plotted in comparison with those of Montreal (average of the years from 1970 to 2000). Sources: IRIMO (2008); Environment Canada (2008)

Appendix C: Construction methods proposed in the reconstruction program of Bam – Observations made during the Second Field Study

After the earthquake in Bam, the reconstruction program became the main concern of the government and local authorities. As said before, the Housing Foundation of Islamic Revolution (HFIR) was assigned to take all the reconstruction efforts of Bam under its control. It was required that all activities in regards to the reconstruction of Bam had to be submitted to and accepted by HFIR from the project's first stages. This requirement, in conjunction with the fact that some of the initial steps had to be taken at the municipality of Bam made the process of the reconstruction very lengthy, due to the numerous bureaucratic steps citizens faced at the outset of their project. As a result, few houses had been completed by the time of visit, approximately 15 months after the earthquake, although many had been initiated.



Figure C.1. After 15 months, not many houses were completely reconstructed.
Photo: HFIR archive

Consequently, people who had lost their homes in the earthquake were still living in containers or other types of temporary accommodation, such as first-aid tents in a few cases.



Figure C.2. After 15 months, not many houses were completely reconstructed. Photo: HFIR archive



Figure C.3. Many families still lived in containers or other types of temporary accommodation, such as first-aid tents in a few cases.



Figure C.4. Many families still lived in containers or other types of temporary accommodation, such as first-aid tents in a few cases.

In order to contribute to reconstructing the city, a number of construction factories, building contractors, and architectural consultants either moved to the city or established a representative office there, the majority of which were housed in a building provided by HFIR at the periphery of the city. This building (Figure B.5. next page) was essentially the central headquarters for the reconstruction engineers and architects. Adjacent to this building was an extensive HFIR-specified lot, on which construction companies and architectural firms could build a sample of their proposed building, to demonstrate their proposed construction method to the local citizens. Each building offered a method or methods that were earthquake-resistant, according to the designers, who tried to convince the citizens to use their specific technique in the reconstruction of their house.



Figure C.5. The building that HFIR built for construction firms' offices. Photo: HFIR archive



Figure C.6. Each construction company could build a demonstration unit showcasing its proposed method. Photo: HFIR archive

As mentioned before, a house of $9 \times 9 \text{ m}^2$ was designed by the HFIR engineers and architects, and was introduced as the standard size of a

house for an average-sized family in Bam. All construction companies and architects were advised to design and build within these fixed dimensions. In addition, HFIR introduced a pre-fabricated steel-frame structure that fitted the 9 x 9 m² house. HFIR recommended the use of this structure for all buildings that were to be built in Bam.



Figures C.7, C.8, and C.9. The structure designed and recommended by HFIR, left incomplete at the exhibition site to teach the local population how to implement this method.

In the following section, the building methods proposed by HFIR and other construction firms are studied and briefly analyzed in terms of their advantages and disadvantages. Each method is introduced by the name of its company or organization.

C.1. Housing Foundation of Islamic Revolution (HFIR)

The structure proposed by HFIR consists of prefabricated steel posts, beams, and bracings that are designed for ease and speed of assembly, using only bolts and nuts for fastening the elements together. For example, the structure of a regular house ($9 \times 9 \text{ m}^2$, as HFIR recommends) can be installed in place in just a few hours, and requires only two labourers. Aside from the quick installation time, the employment of labourers only to fasten the bolts is supposed to remarkably reduce the number of structural failures caused by inadequate welding jobs.



Figure C.10. The structural system proposed by HFIR can be easily and quickly assembled with bolts.



Figure C.11. The structure of a 9x9 m² house can be installed in its place in few hours by only two labourers.

HFIR built an educational sample of the proposed structure on the exhibition site, where citizens could visit and learn essential construction details by looking at the structure. The whole structure was placed on a reinforced concrete pad foundation, to which it was connected by means of bolts and nuts (Figures C.7 to C.11). The roofing system and wall infill remained flexible, left up to the constructor or owner to decide. HFIR, however, built a number of publicly funded buildings; ordinary bricks and/or hollow blocks were chosen as wall infill, and a reinforced concrete slab roofing system (see Figure 4.28 on page 79) was employed in all of them.



Figure C.12. A publicly funded building being built by HFIR, employing its recommended structural elements.

To strengthen the bond between bricks and steel columns and prevent bursting corners during earthquakes, either L-shaped steel bars were placed in the corner joints, or columns were wrapped with chicken wire to create a proper bond with the sand-cement mortar (Figure C.13).



Figure C.13. Chicken wire is used to make a good bond between the mortar and steel column.

HFIR built a proposal house employing its recommended techniques at the demonstration site. The house displayed the HFIR prefabricated steel structure and used hollow blocks as wall infill and had a concrete slab roof.



Figure C.14. Small Z-shaped steel laths are welded to the beams, connecting the concrete slab to the beams every 50 centimetres.



Figure C.15. Corrugated galvanized steel sheets are used as permanent shuttering.



Figure C.16. Hollow blocks are employed as wall infill, and are fixed to the column by means of L-shaped steel bars that are welded to the column.



Figure C.17. The wall infill and roofing system may change from the HFIR recommendations. Here, hollow blocks were used as wall infill and a joist-block roofing system was employed. Photo: HFIR archive

This construction method would change, however, in practice among the citizens or other builders in the city. For instance, the wall infill might range from double-side-meshed polystyrene sandwich panels to ordinary burnt bricks to hollow blocks. The roofing system might vary also, from a thin concrete slab on steel girders to a block-joist system.



Figure C.18. The demonstration unit that HFIR has built at the exhibition site; the building uses its recommended construction method.

C.2. BONYAD-BETON Organization of Iran

Bonyad-Beton Organization of Iran, BBOI hereafter, "is one of the organizations affiliated to Housing Foundation [HFIR]," whose aim is to improve the quality of construction materials while developing new construction methods (BBOI 2005). In Bam, this organization introduced a construction method that was quite new to the citizens.



Figure C.19. Part of the board placed next to the demonstration unit, introducing sandwich panel technique to the visitors

This new method was composed of sandwich panels as the main structure of the house, onto which concrete was shot. These sandwich panels are comprised of nine centimetre-thick polystyrene sheets covered with steel mesh on both sides, which are connected together by means of steel wires placed through the polystyrene sheets.

BBOI built two demonstration houses at the exhibition site. The first one was a small incomplete hut built entirely with sandwich panels; the final stage (i.e. shooting concrete on the panels) was not done in order to let the visitors see the details of implementation of this technique (Figure C.20). The building was placed on a concrete slab foundation, from which steel bars were projected to connect the building to the foundation later on. All critical areas such as corners, around openings, and joints were reinforced by additional steel bars (Figures C.21 and C.22).



Figure C.20. The hut built of sandwich panels, left incomplete to show the construction details to the locals.



Figures C.21, C.22. Reinforcements are created in the corners as well as other critical joints by additional steel bars.

The second sample house built by BBOI was a complete building with an area of around 102 m², also built with sandwich panels. The house was fully furnished luxuriously, with hardware and finishes to catch the eye of visitors.



Figure C.23. The demonstration house built out of sandwich panels by BBOI at the exhibition site.



Figures C.24, C.25. The sample house was equipped with all the facilities, in an attempt to catch the eye of visitors.

Advantages and disadvantages

At first glance, this construction method looked easy to build quickly, yet earthquake-resistant. These conditions seemed to fully meet the needs of the citizens for a fast earthquake-resistant reconstruction. A closer look, however, demonstrated why this construction method failed to become

prevalent in the popular housing sector of Bam, although several government-funded buildings were under construction at the time of visit, using these sandwich panels as partitioning walls.

The major disadvantage of this method was the price. Compared to conventional construction materials, such panels were too expensive for the middle-income families of Bam. Moreover, the cost of shooting concrete was very high and needed sophisticated machines as well as skilled labourers and technicians to apply concrete to the panels. In addition, the risk of fire for polystyrene sheets is very high, though the company claimed that these sheets are non-flammable. In this case, even if the polystyrene did not catch fire, it would most likely produce poisonous fumes. Ultimately, the high expense of this method was a great obstacle, preventing it from gaining popularity among Bam citizens.

C.3. KAVOSH BETON Company

Kavosh Beton was a private corporation investing in construction in Bam. The main feature of the structure proposed by this firm was its light roof, composed of corrugated steel sheets placed on roll-formed, Z-shaped steel girders (Figure C.26). This structure is essentially a steel post and beam system for the skeleton, filled with burnt brick walls in between. The foundation and footings were made of reinforced concrete.



Figure C.26. Corrugated steel sheet on Z-shaped girders.

Advantages and disadvantages

The light roof was the main advantageous feature of this structure, which reduces the amount of steel bars used in the foundation by 15 percent, according to Kavosh Beton. Nonetheless, the price of the roofing sheets, made of corrugated galvanized steel, was very high. In addition, the roof would be disastrous in a hot and dry climate like Bam's, unless appropriate insulation was provided. However, proper insulation was very costly for average income families.



Figure C.27. The house proposed and built in Bam by Kavosh Beton Company

C.4. AZAR-MAHD Construction Company

Azar-Mahd was another private construction company working in Bam. The housing method proposed by this company consisted of the HFIR's steel frame structure with a block-joist roofing system. Walls were made of drywall sheets hung on steel studs.



Figure C.28.
The block-joist
roofing system and
drywall on steel
studs

Advantages and disadvantages

The pros and cons enumerated for the HFIR method hold true for this method too, along with the fact that drywall is a very expensive construction material in Bam, like in other parts of Iran. The use of conventional brick/block walls is the predominant partitioning method and the most popular one, and the drywall system is a relatively new technique.



Figure C.29. The sample house built at the exhibition site by Azar-Mahd Construction Company. The house was not finished at the time of visit.

C.5. AUROVILLE Earth Institute (India) and International Blue Crescent (Turkey)

Auroville Earth Institute is an Indian non-governmental organization (NGO) working on earth construction with more than 30 years of experience. This organization, in cooperation with the International Blue Crescent from Turkey, built a sample house with interlocking compressed earth blocks. These compressed earth blocks were the main material that Auroville had the expertise to build with and produce.



Figures C.30, C.31. Interlocking CEB and inter-wall reinforcements

The demonstration house was built on a reinforced concrete foundation. The walls were made of interlocking CEBs (compressed earth blocks), consolidated by reinforced concrete ring beams at three

levels: sill level, lintel level, and the top of the wall (Figure C.32).

Interlocking CEBs were connected together by vertical steel bar reinforcements placed inside the walls, running from the foundation to the roof level ring beam. The roof was composed of concrete joists with hollow blocks in between, resting on load-bearing CEB walls.



Figure C.32. The house is reinforced by ring beams at three levels.

Advantages and disadvantages

Building with CEB has shown to be promising in terms of cost efficiency and earthquake resistance in many parts of the world, especially in India where Auroville is renowned for developing earth buildings and new methods of using earth in earthquake-prone regions. Nonetheless, the main problem of this prototypical house, which might have impeded the absorption of this method into the popular housing sector of Bam, was the heavy roofing system employed. The experience of heavy roofs collapsing during the earthquake spread fear of living under such roofs among the citizens. In addition, since this method was very new to the local residents, it would take some time to be absorbed into the community and the builders.



Figure C.33. The house built cooperatively by Auroville and the International Blue Crescent, using CEB and vertical steel bar reinforcements along with ring beams at three levels: sill, lintel, and roof.

C.6. QATA'AT e FOOLAD (Steel Segments Corporation)

Qata'at e Foolad Corp. was another private company that built a demonstration house in Bam. The house utilized a reinforced concrete foundation, on which steel frame posts and beams and a steel trussed roof system were placed.

The roof was composed of roll-formed hollow steel profiles covered with corrugated steel sheets. The interior walls were formed with drywall sheets on steel studs.



Figure C.34. The structure of the roof

Advantages and disadvantages

Similar to the techniques reviewed before, the use of steel sheets for covering the roof in a climate like Bam's is troublesome, especially during the extreme weather of summer and winter, unless proper insulation is provided. It is obvious that the insulation would significantly increase the costs of construction. Moreover, pitched roofs are not appropriate for this climate because there is very little rain during the year; in addition, the shape of this roof did not suit the vernacular architecture of Bam. Furthermore, this method of construction would require special skills if further additions on the home were desired in the future.



Figure C.35. The unit built by Qata'at Foolad Corporation.

C.7. MEHRSA Prefabrication Company

Mehrsa is a private company that used a method of construction that was new to the population of Bam. This method employed cold-formed studs for all components of the structure, including walls and roof. The cold-formed truss-like studs hold drywall sheets while taking the load of the roof to the foundation. The roof was composed of wider cold-formed joists, serving as girders for the prefabricated, pre-stressed hollow-core concrete slab roof. The exterior façade was waterproofed by sand-cement plaster finish applied on drywall.



Figure C.36. Cold-formed truss-like studs serve as drywall studs and roof girders.

Advantages and disadvantages

This method can be implemented very quickly and the weight of the roof is low in comparison with conventional methods. The construction cost, however, remained the main problem, and was very high due to the relatively high-tech method employed. Another major disadvantage of this method was that the local builders would be unable to implement and/or extend this kind of house themselves.



Figure C.37. The sand-cement plastered exterior of the demonstration unit built by MEHRSA Company.

C.8. PEACE-WINDS JAPAN

Peace-Winds is a Japanese NGO (PWJ hereafter) that began its activities in Bam within the very first days following the earthquake. In addition to providing first aid and emergency relief efforts, PWJ undertook the task of housing the victims of the earthquake in both temporary and permanent shelters. The latter option consisted of improving the local construction techniques, with the aim of making buildings more resistant to earthquake by applying some simple considerations to the local conventional construction methods.

PWJ built four buildings in Bam. Although the materials used and the construction methods employed in each building varied slightly from one another, the concept (technique) was the same in all four. This concept involved reinforcing wall-bearing buildings by means of concrete ring beams placed around the perimeter of the building at four levels, namely: plinth, sill, lintel and roof height (Figure C.38), along with the insertion of vertical steel bars within the walls, running from the foundation to the

roof (Figure C.39). In addition, openings were reinforced further by piers (buttresses) that project from the walls.

In summary, this technique strengthens the three essential elements responsible for consolidating the building, thereby increasing its resistance to earthquakes. These three components are the horizontal reinforcement elements (ring beams), the vertical reinforcements (steel bars), and the buttresses alongside openings.

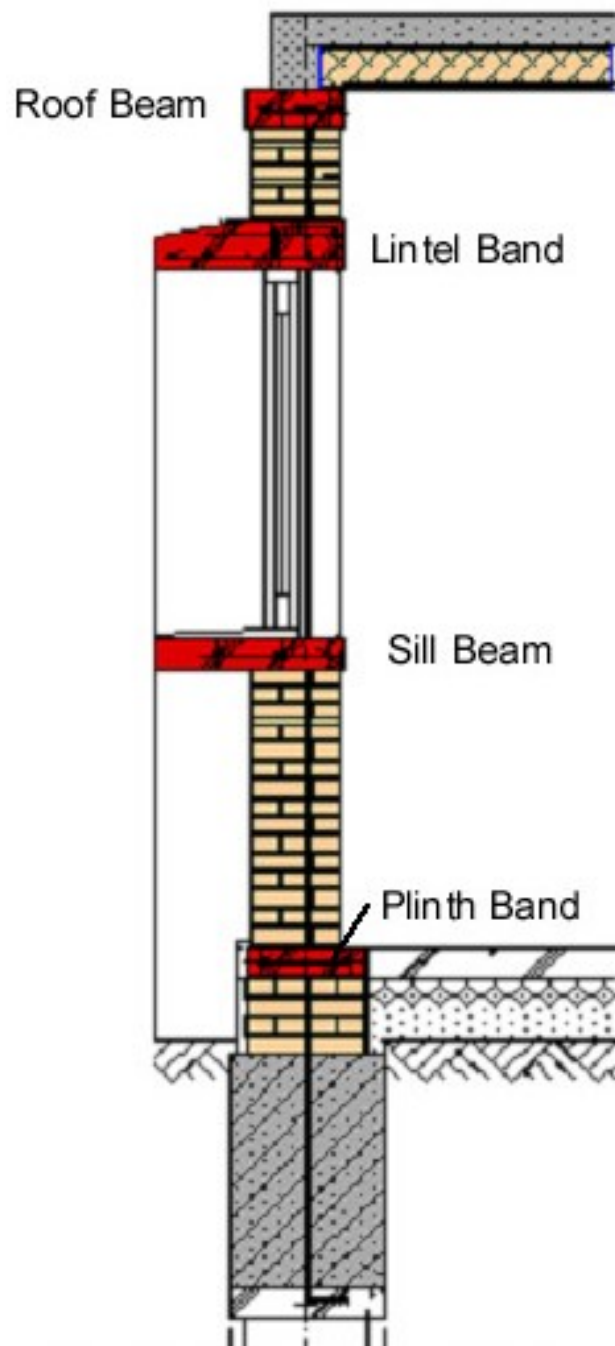


Figure C.38. A wall section shows the detail of reinforcing method employed by PWJ.



Figure C.39. Steel bars placed within the walls as vertical reinforcements
Photo: PWJ



Figure C.40. Implementing the first ring beam at the plinth level. Photo: PWJ



Figure C.41: The third ring beam is being prepared for the pouring of the concrete. Photo: PWJ

In all four buildings that PWJ built, those three techniques to increase earthquake-resistance in buildings were applied, although the construction materials differed slightly from one unit to another. The first

two buildings were built simultaneously for the use of HFIR staff and were identical in plan, yet different in the roofing system and the construction techniques used. One was built out of stabilized rammed earth blocks and the other was built with ordinary burnt bricks (Figure C.42). The latter employed a masonry flat roof, using jack arches and steel I-beam girders, whereas the first unit had a domed roof made of burnt bricks. PWJ taught these proposed method to four local masons during the implementation of the first two buildings in order to



Figure C.42. The two office units PWJ has built for the use of HFIR. Photo: PWJ



Figure C.43. Rammed earth blocks used for constructing the domed unit. Photo: PWJ

disseminate the knowledge of such reinforcing methods among the local builders (Figures C.40 and C.43). The third building PWJ built was a demonstration house at the HFIR's exhibition site; burnt brick was used as the main material for this house (Figure C.44). The last building constructed was a school located in the centre of the city, in which CEBs are employed instead of ordinary burnt bricks.

Advantages and disadvantages

The methods proposed by PWJ were the most practical among the other options suggested by other practitioners in Bam. The simplicity of

learning this technique, which aimed at improving upon the local construction methods rather than introducing completely foreign techniques, made this method promising for absorption into the popular housing sector in Bam. However, the heavy roof employed in this method was fearsome for the Bam citizens and could potentially impede this technique from gaining wide-spread appeal.



Figure C.44. The demonstration house that PWJ was building at the time of visit. The four horizontal reinforcements (ring beams) are clearly shown in the picture.

C.9. RASHESTAN Co.

Rashestan is a private company manufacturing prefabricated, lightweight structures. They instantly built their suggestion for accommodation: a two story building. The structure was composed of rectangular hollow-section steel posts and beams as the skeleton elements, covered with wave flat (corrugated) galvanized steel sheets for the floor or roof. The exterior walls were made of sandwich panels with steel mesh on both sides, covered with façade bricks or stucco. Drywall sheets and steel stud framing were used for interior walls. The roofing system consisted of prefabricated triple Howe trusses installed in place by crane, covered with corrugated steel sheets.



Figure C.45. Prefabricated triple Howe trusses installed in the place by a crane.



Figure C.46. The demonstration building built by the Rashestan Company.

Advantages and disadvantages

Similar to other cases, this technique was relatively expensive for the average-income citizens of Bam. In addition, this method was comparatively sophisticated; the local masons were unable to understand and absorb it easily. It required specially-trained labourers and masons.



Figure C.47. The façade is being covered with slim façade bricks. The steel mesh makes a good bond between the façade bricks and sandwich panels. Photo: HFIR archive



Figure C.48. The fancy interior aiming to catch the eye of visitors

C.10. Reconstruction in the Villages

A number of villages surrounding Bam suffered varying degrees of damage, none to the extent that Bam did, however. HFIR actually began its very first reconstruction efforts in the surrounding villages, where minor destruction had occurred and buildings, the majority of which were built of adobe or earth, were still standing intact due to their distance from the epicentre of the earthquake. To determine how the reconstruction process was progressing, one of the villages in which the reconstruction works were ahead of the others was observed in the first visit.

Kürk is a village located approximately 20 kilometers northeast of Bam. Almost all of the buildings in Kürk were built of adobe brick (or burnt brick in some cases) with mud used as mortar and roofed with barrel (Nubian) vaults.



Figure C.49. The vernacular architecture of Kürk consisted of adobe load bearing walls and barrel vault roofs.

The local vernacular architecture was ignored, however, and HFIR had built houses according to the HFIR's proposed construction method of

prefabricated steel posts and beams. Although the majority of the existing buildings of the village received no damage or little damage during the earthquake, HFIR erected new houses in courtyards or on the lots of open barns. HFIR's intent was to move the inhabitants to the new houses and abandon the old, seemingly vulnerable ones. There were some difficulties, however, that seemed to have obstructed this construction method from being widely disseminated.



Figure C.50. HFIR is constructing new houses in the existing courtyards of the old houses of the villagers.

Firstly, the proposed method was very expensive for the villagers; they could not afford the new homes without government subsidies or loans. Moreover, the method was relatively sophisticated and new to the local residents and consequently, it was impractical for them to construct on their own. In addition, the new buildings were being built with no attention to the local climatic concerns and criteria. For instance, a number of windows of the new buildings were filled with bricks because of the uncomfortable conditions they produced inside the house; the prevalent wind together with the unpleasant sunshine from windows facing west were undesirable to the homeowners.



Figure C.51. The new house took the place of the courtyard. The windows of the new house were bricked due to the climatic problems they created.

Furthermore, these new houses occupied the space of the courtyard, where the majority of a village housewife's activities take place. The fact that these new constructions replaced one of the most active and useful parts of the house and community resulted in serious problems in using the new spaces, social concerns aside.



Figure C.52. The HFIR's recommended structure used for the construction of new houses in Kürk.



Figure C.53. A view of Kûrk showing its vernacular architecture and landscape.

Appendix D: Inspection checklist used by HFIR construction inspectors

1. Postal Code:

Registration Information

Table 1

2. Province:
3. City / Town:
4. Lot number:
5. Name of the owner: ID No.
6. Lot address
7. Ownership:
8. Lot dimension as appear in the original record North: South: East: West:
9. Lot dimension on site (reality) North: South: East: West:
10. Lot Area (m ²):
11. Lot dimension after applying the changes by the Bam Comprehensive Plan North: South: East: West:
12. Width of the flanking streets/ alleys North: South: East: West:
13. Width of the flanking streets after the changes by the Bam Comprehensive Plan North: South: East: West:

Architectural Design Control

Table 2

Architectural Drawings' Control	Designer's opinion				Inspector's opinion			
	C	I	A	R	C	I	A	R
14. Initial studies, site visits, other pertinent studies								
15. Provision of plan of location, site plan, with accordance to the records and codes, with dimensions								
16. Floor plans for each level, with dimensions								
17. Roof plan with height codes and dimensions								
18. Cross sections								
19. Elevations of all sides								
20. Details and specification table for every space								
21. Light and ventilation for kitchen and services								
22. Plan of landscaping and drains								
23. Mechanical drawings for ducts and ventilations								
24. Access to parking (slope %, max. 15%)								
25. False ceiling in sections with dimensions								
26. Cost estimate and construction schedule								

C: complete I: incomplete A: acceptable R: revision needed

Architectural Implementation Control

Table 9 (table 11 in the new forms)

Architectural Control	Builder's opinion				Inspector's opinion					
	C	I	A	R	C	I	A	R	score	Max.
1. The lines of plan conforming with the land survey record, codes, bylaws										0.75
2. Design follows the slopes of the lot										0.25
3. Excavation area, volume and limits										0.25
4. Height and relative levels of the foundation (top and bottom)										0.75
5. The plan follow the structure plan										0.75
6. Columns' location conform with the architectural plan										0.25
7. Insulation of basement / foundation										0.25
8. Partitions and walls follow the plan and the details										2.75
9. Landscaping										1
10. Implementation of false ceilings										1
11. Width and height of openings										1
12. The finishes as in the table of specifications										3
13. Location and installation of windows										0.25
14. Stairs, steps, railings										1
15. Sufficient cover of expansion joints and ducts										0.25
16. Installation of nosing and sills										0.25
17. Access for handicapped										0.25
18. "As-built" drawings										1
Total										15

C: complete I: incomplete A: acceptable R: revision needed

.....

Table 11

Overall quality of implementation	9-10.5	10.6-12	12.1-13.5	13.6-15	Overall	
	Weak	Medium	Good	Great		

Structure Implementation Control

Table 12

Structural Control	Builder's opinion				Inspector's opinion					
	C	I	A	R	C	I	A	R	score	Max.
1. Implementation drawings coordinate with arch. and mechanical drawings/ timetable and schedules										2
2. Establishing construction site boundaries and lines of excavation										2
3. Considering safety codes in the site										3
4. Demolition and excavation guidelines, soil strength test										4
5. Correct location of foundation, subsoil preparation, formworks, reinforcements (rebar), installing base-plates										14
6. Separation joint done										1.5
7. Quality of concrete: mix, ingredients and proportions, casting, curing										18
8. Location and height of structural components, quality/ method of connection										21
9. Quality of roofing										20
10. Load-bearing walls following the specs as in document/ drawing										1.5
11. Quality of implementation of load-bearing walls/ conforming to codes										3.5
12. Roofs follow the drawings										2
13. "As-built" drawings										1.5
Concrete Buildings										
14. Concrete has sufficient lab tests										2.5

15. Quality of rebar, quality of implementation, sufficient overlaps,...											8
16. Moulding (formwork) for columns, beams, roof, walls, stairs											6
17. Thickness of concrete over rebar											3
18. Shearing beams (joist & block roofs)											3.5
Total (concrete structures)											100
Steel-frame Buildings											
19. Location and size of columns, beams, bracings, stiffeners, gusset plates and clips											2.5
20. Connections (bracings' ends, columns to base-plate, column to beam, bolts and nuts)											8
21. Welds' size in all joints											6
22. Removing rust from profiles, and applying anti-rust											3
23. Structural components being levelled, straightened, aligned in all directions											3.5
24. Welds have sufficient lab tests											2.5
Total (steel-frame structures)											100

C: complete I: incomplete A: acceptable R: revision needed

Table 13

Overall quality of implementation	60-69.5	70-79.5	80-89.5	90-100	Overall	
	Weak	Medium	Good	Great		

The Designer(s)

Table 7

No.	Name of Designer/ Firm	Registration / Licence No.	Type of Licence	Responsibility	Stamp & Sign.
1					
2					
3					
4					

Urban Planning and Permit Information

Table 8

88. Comprehensive Plan ☐Yes ☐No 89. Unitary Development Guidance (Land Use Plan) ☐Yes ☐No 90. Rural Area Comprehensive Plan ☐Yes ☐No 91. Occupied Area (m²): 92. Density: 93. Land Use identified in permit: ☐ Residential ☐ Commercial ☐ Industrial ☐ Sanitary ☐ Healthcare ☐ Education ☐ Services ☐ Administrative/Office ☐ Other (name) 94. Aerial Photo Code: 95. Type of Permit: ☐ Construction ☐ Renovation ☐ Repair / Addition ☐ Demolition ☐ Other 96. Permit issued by: ☐ Municipality (go to 98) ☐ Other 97. Name of the Place / Authority that issued the permit: 98. File No. 99. Permit No. 100. Date issued

Sign and Stamp of the permit-issuer

Date

Appendix E: Example of a set of plans used by the master builders (collected during the Third Field Study)

During the reconstruction period, the citizens and the local builders were provided with hundreds of housing designs with complete sets of plans and engineering specifications. Subsequently, each builder had a large archive of different-sized houses, readily available for future clients. After the HFIR was discharged of its duties, these builders had a number of engineer-approved drawings and specifications that they could use for building new buildings for new clients. However, each time they used a drawing for a client, major changes were made either by the client or the builder, or sometimes both, in order to match the existing drawings to the needs of the client. These interventions ranged from major changes in the layout of the interior spaces and rooms to changes in the size of structural elements.

As can be seen in the following examples, a complete set of drawings and specifications that had previously been used for another house was reused for a new client, but with some changes in the layout as well as in the size of the structural elements. For example, while the specifications indicate the use of two IPE 140 I-beams for all columns (Figure E.7), what was actually implemented was two IPE 180s (Figure E.13). Also, while the two I-beams were welded together as the specifications asked, steel plates were welded all the way along the flanges of the profiles in order to further reinforce the column (same Figures).

[illegible][illegible]

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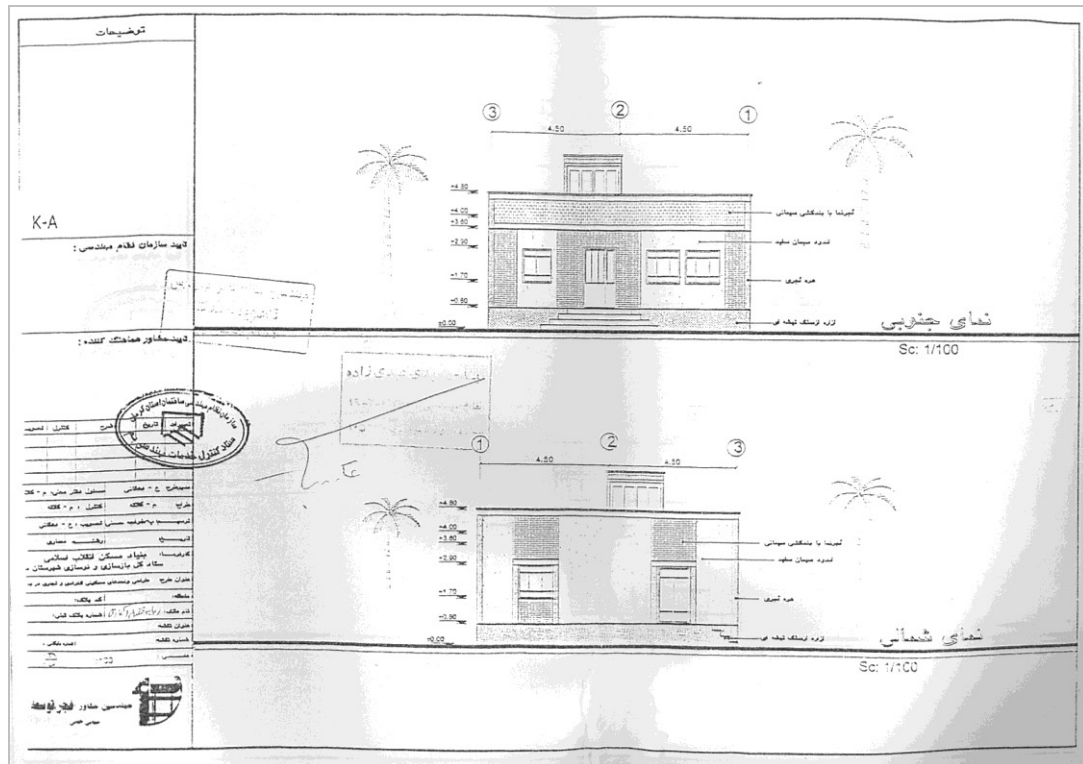


Figure E.3. Set 1: Façade and rear elevation

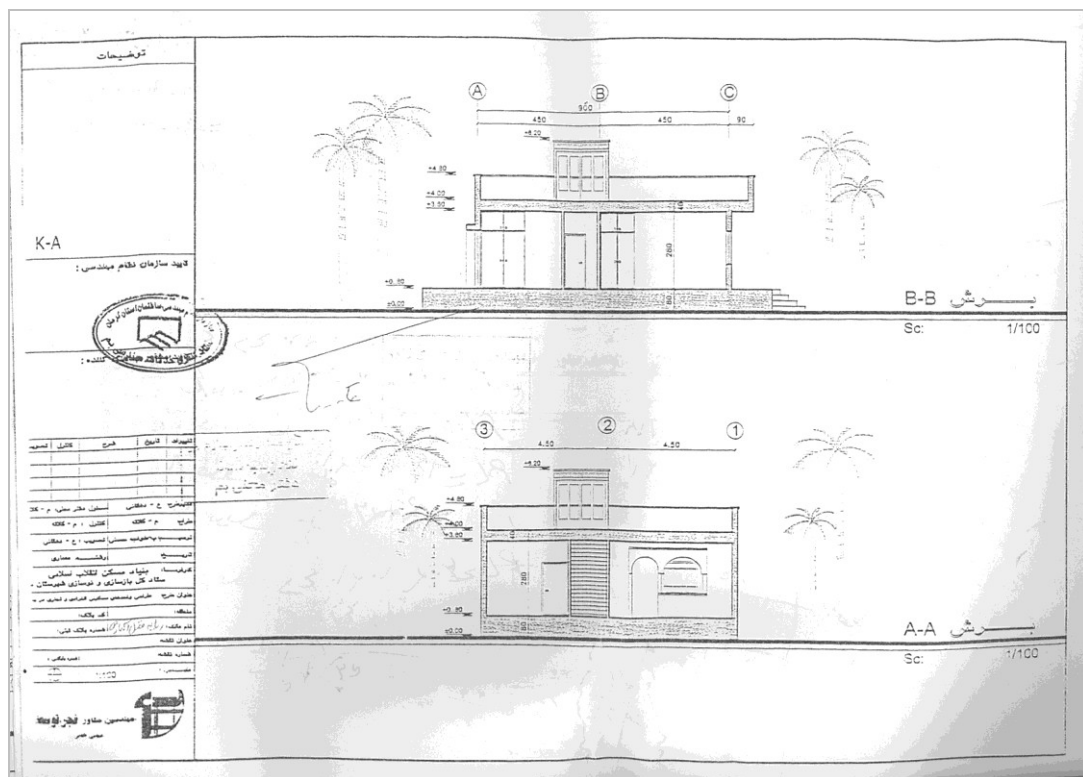


Figure E.4. Set 1: Cross sections

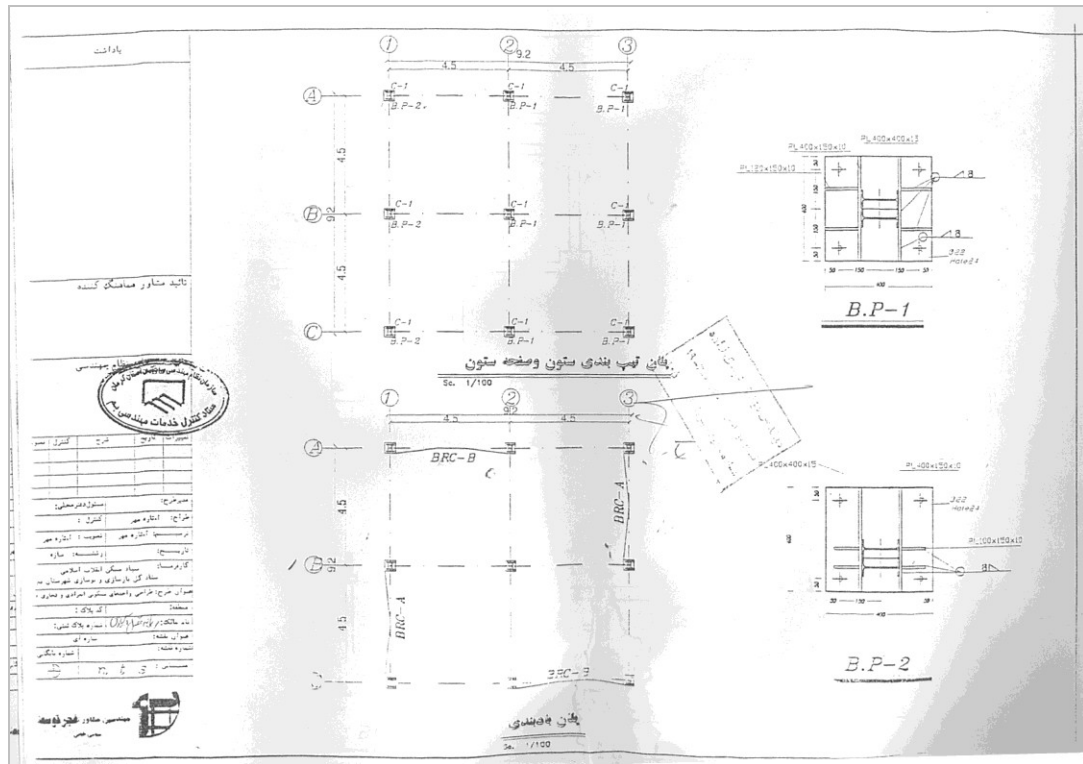


Figure E.5. Set 1: Columns and base-plates

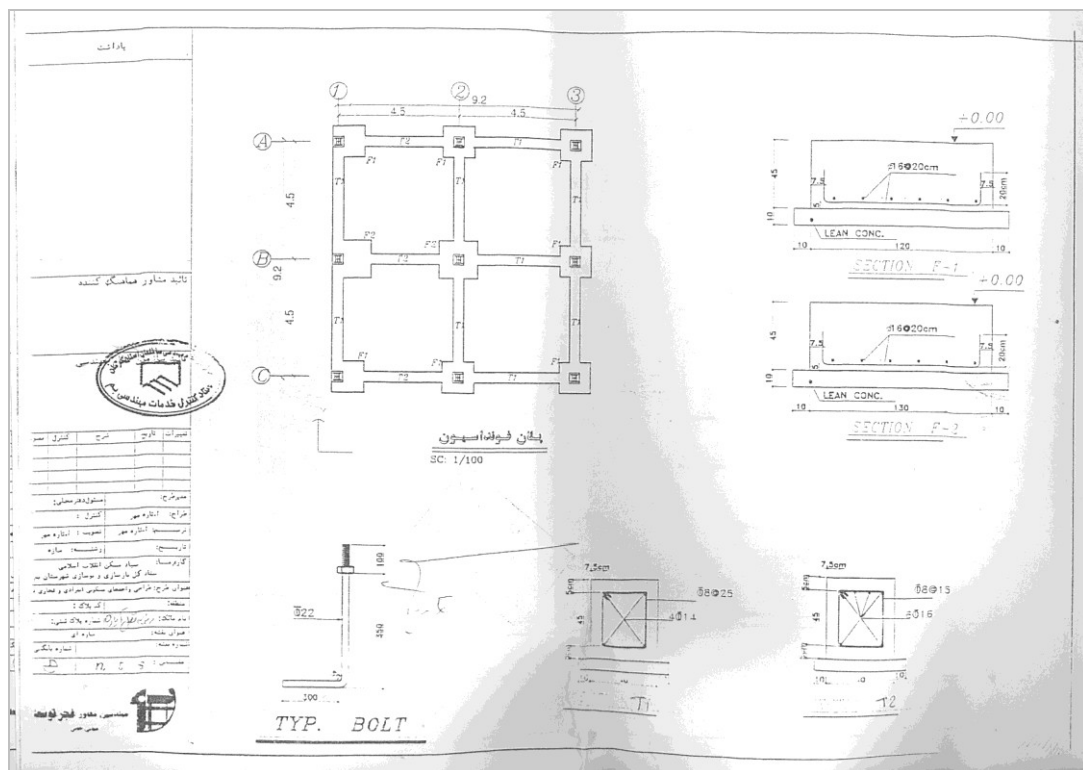


Figure E.6. Set 1: Plan of foundation

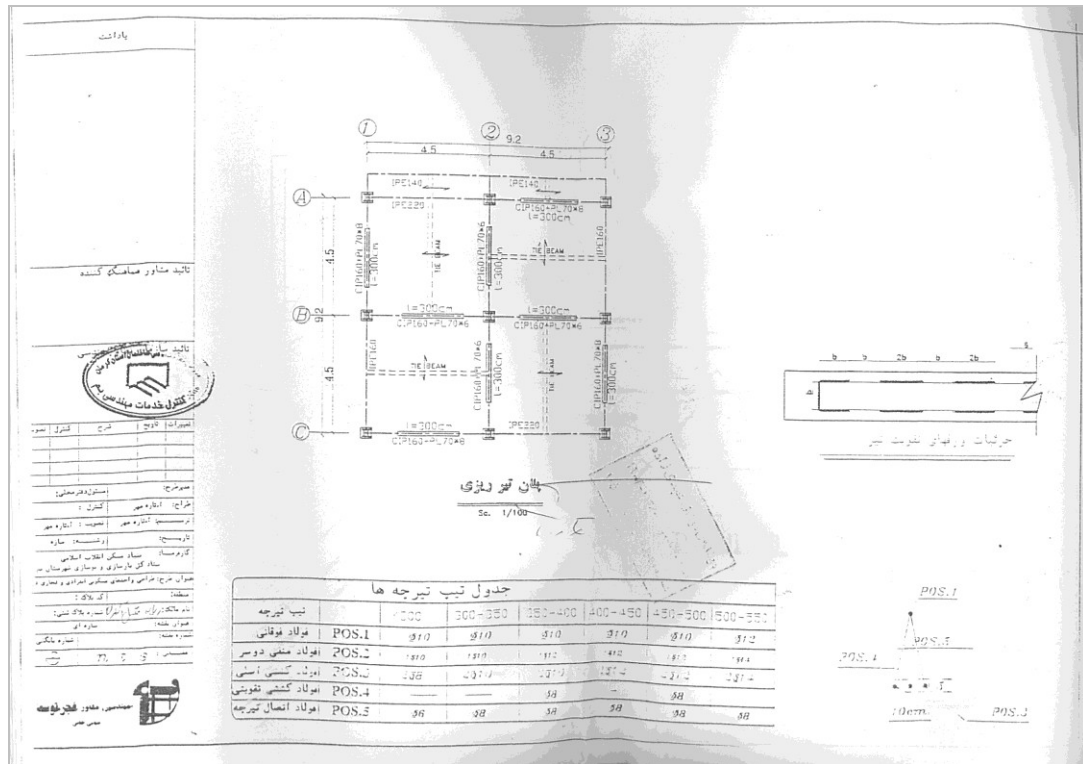


Figure E.9. Set 1: Plan of roof joists

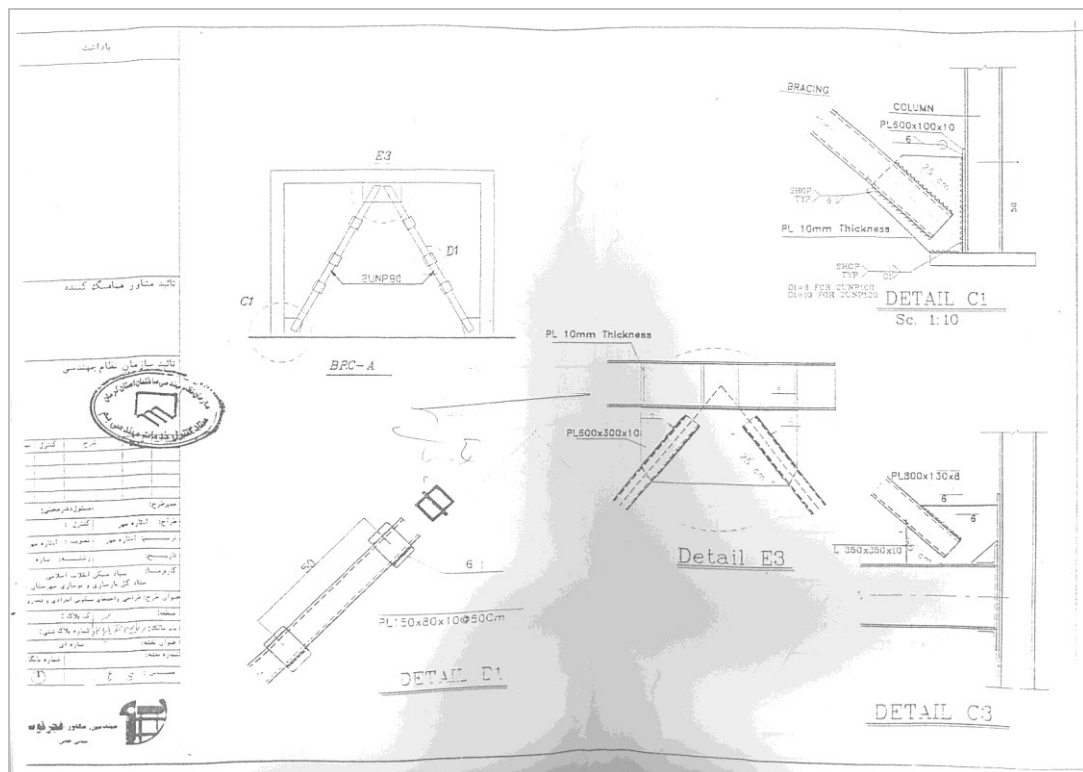
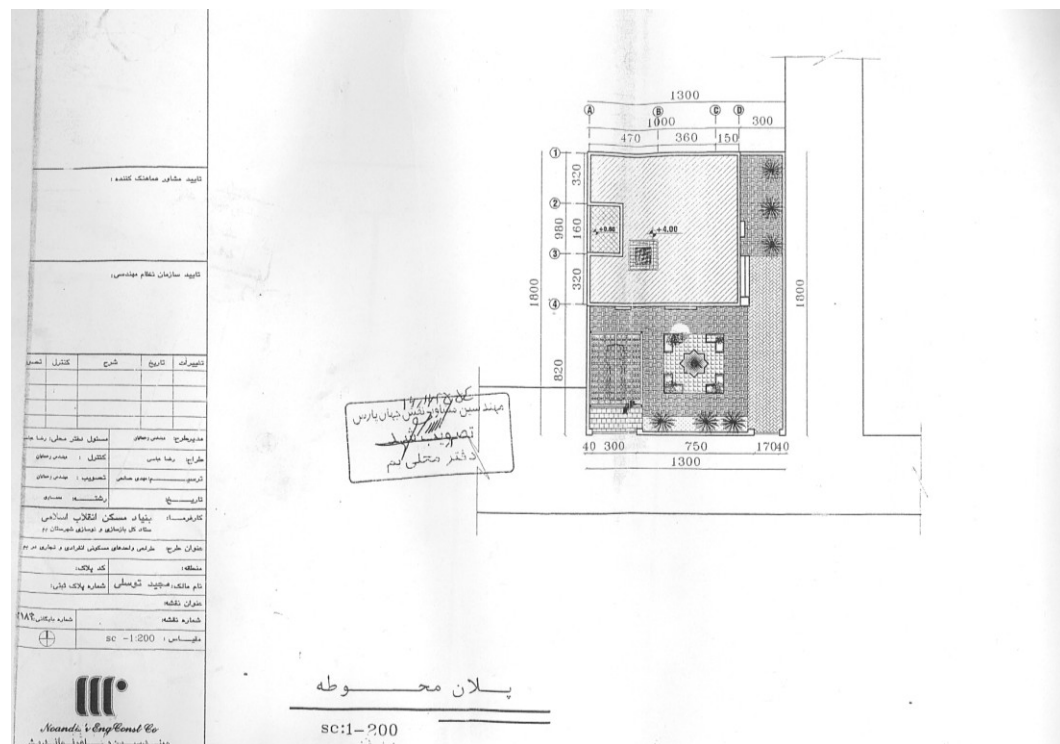


Figure E.10. Set 1: Technical drawings of bracings and gusset plates



Figure E.13. An example of a column, oversized and overdone by the builder for the sake of a stronger structure

[illegible]

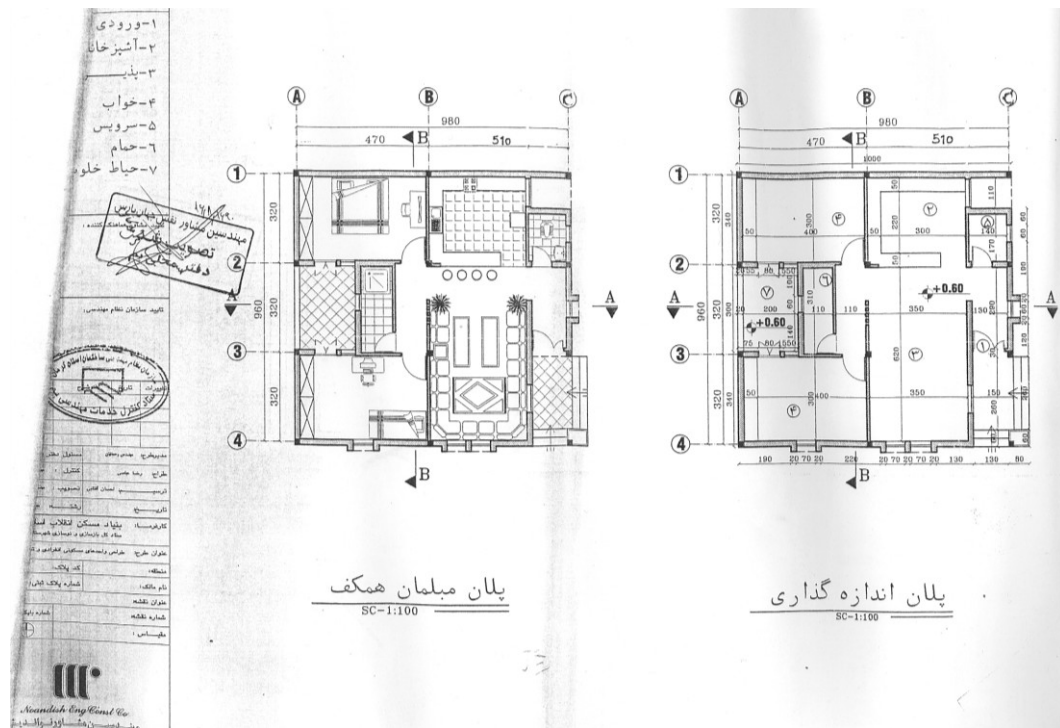


Figure E.16. Set 2: Floor plan and furniture plan

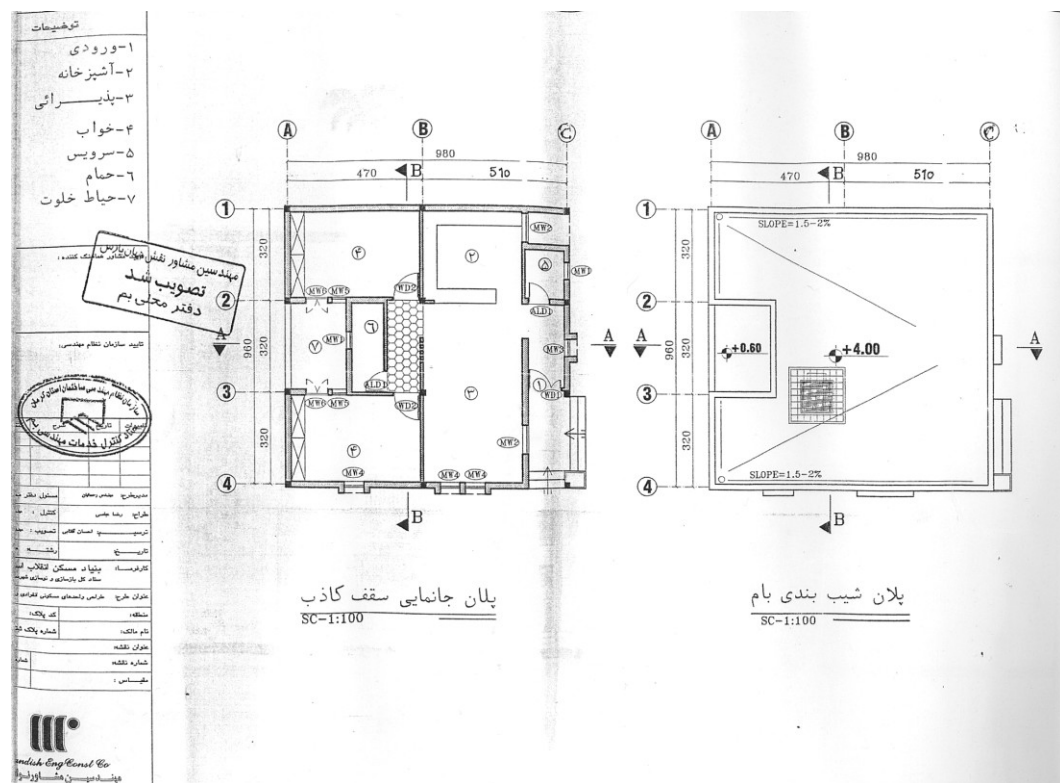


Figure E.17. Set 2: Plan of conduit ceiling and roof plan

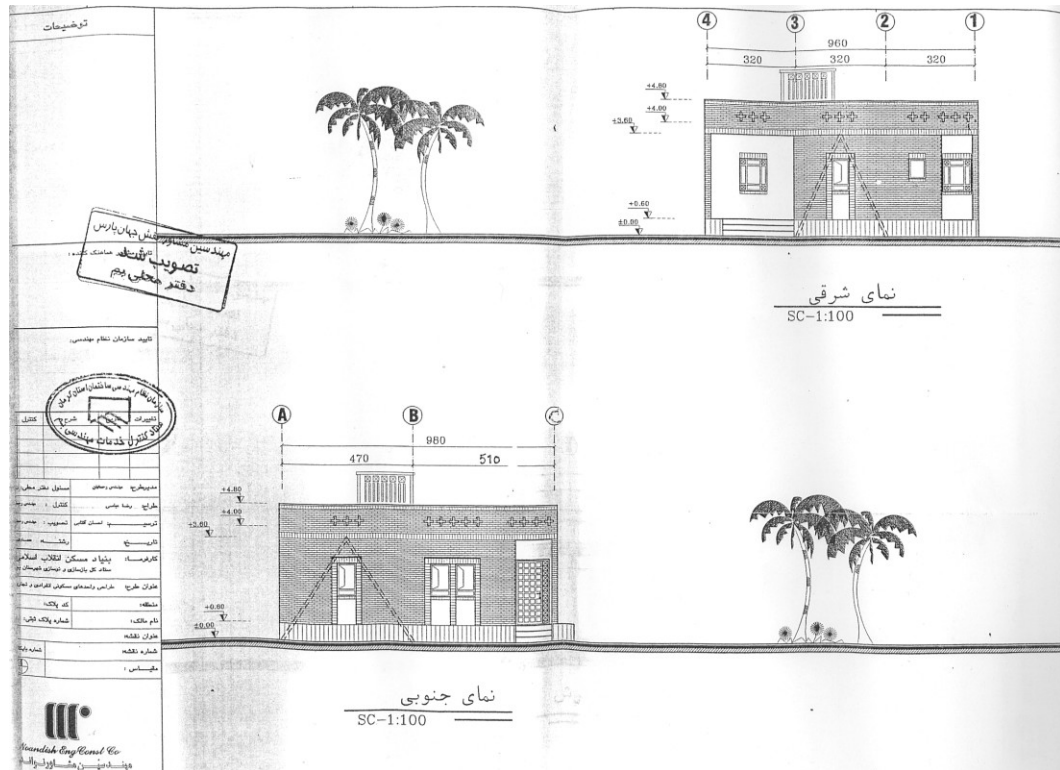


Figure E.18. Set 2: East and south elevations



Figure E.19. Set 2: Sections A-A and B-B

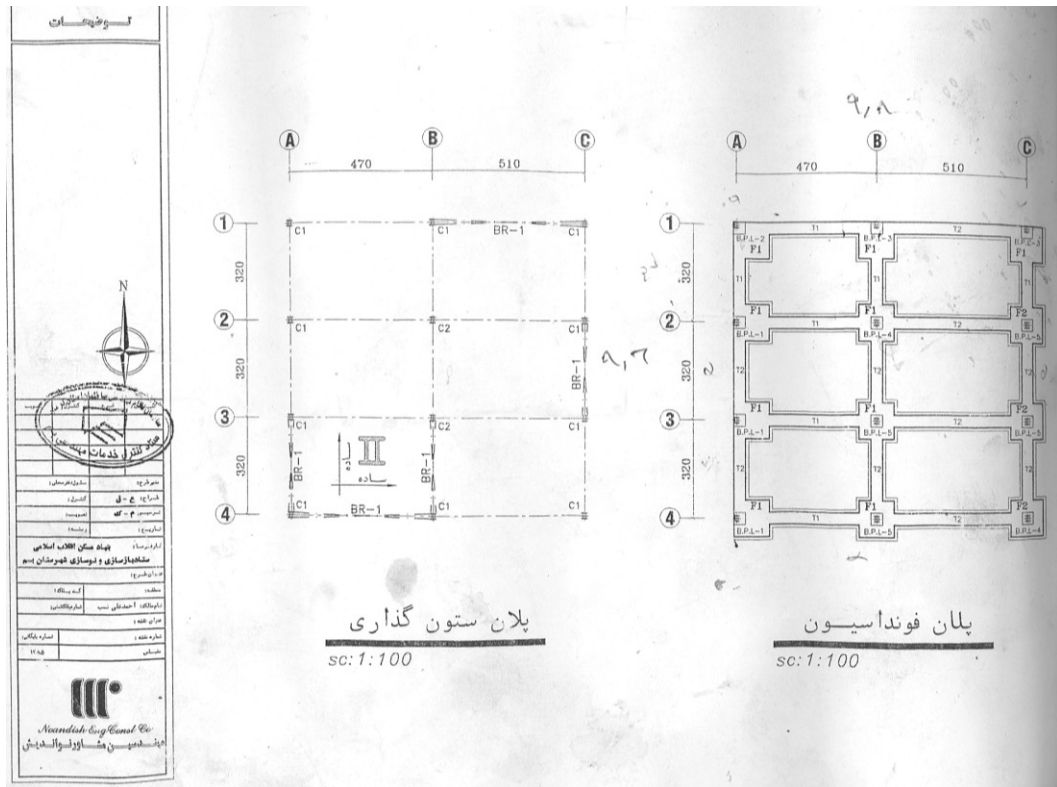


Figure E.24. Set 2: Plan of columns and plan of foundation

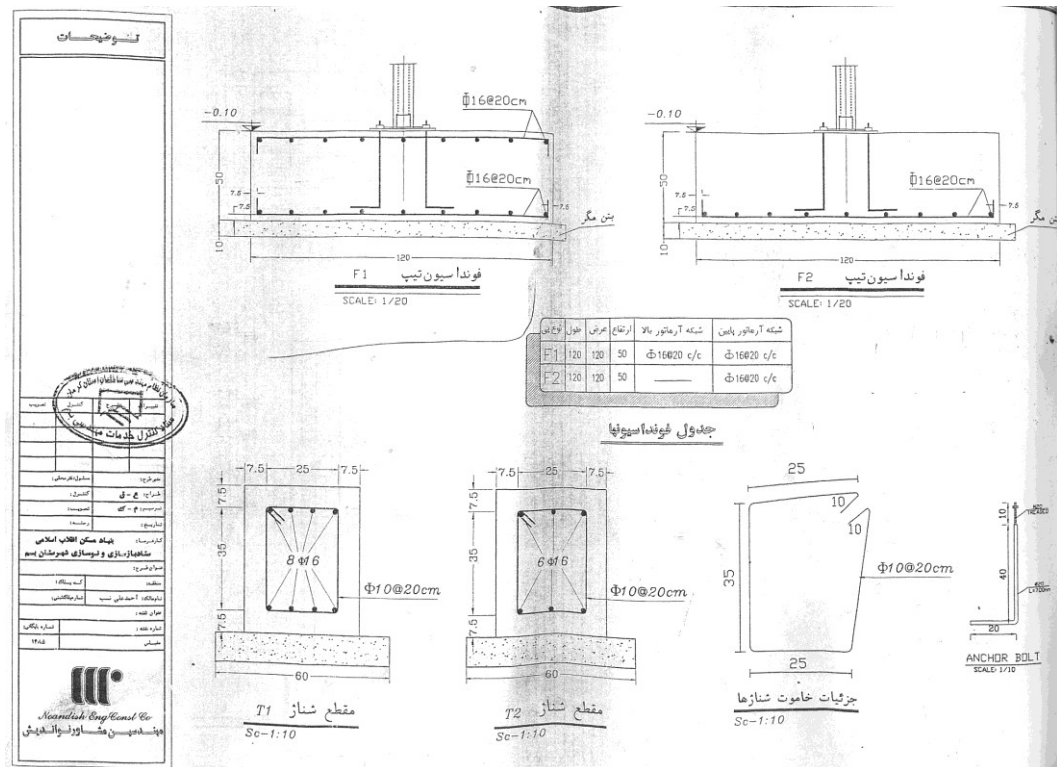


Figure E.25. Set 2: Details of foundation

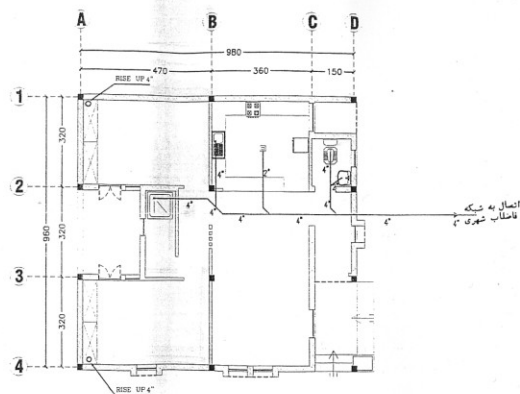


Figure E.30. Set 2: Plan of water piping

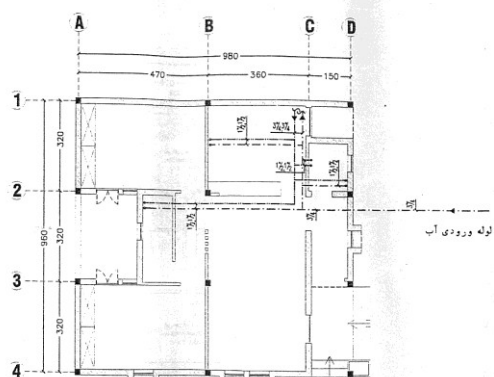


Figure E.31. Set 2: Plan of plumbing

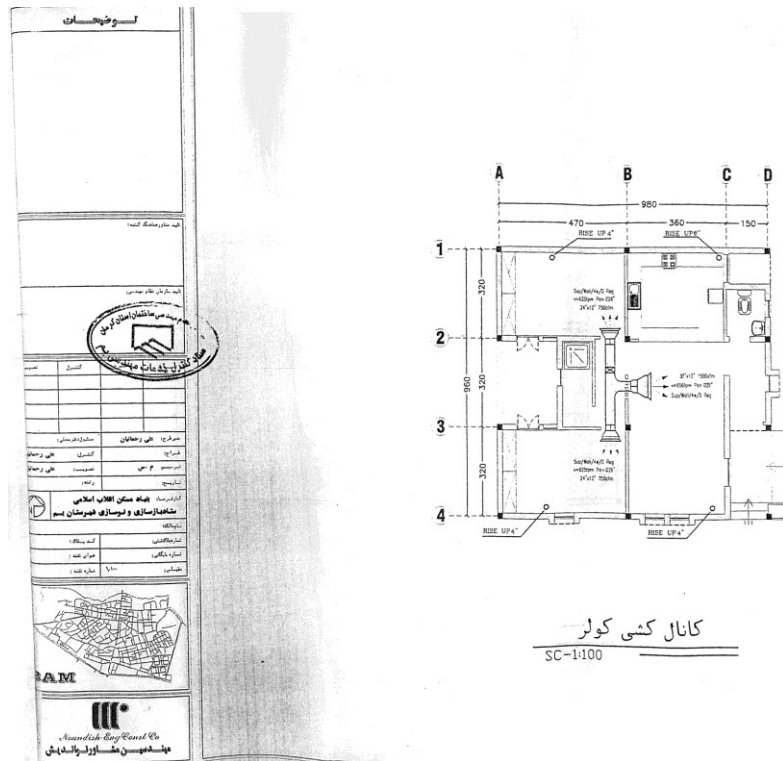


Figure E.32. Set 2: Plan of ventilation ducts

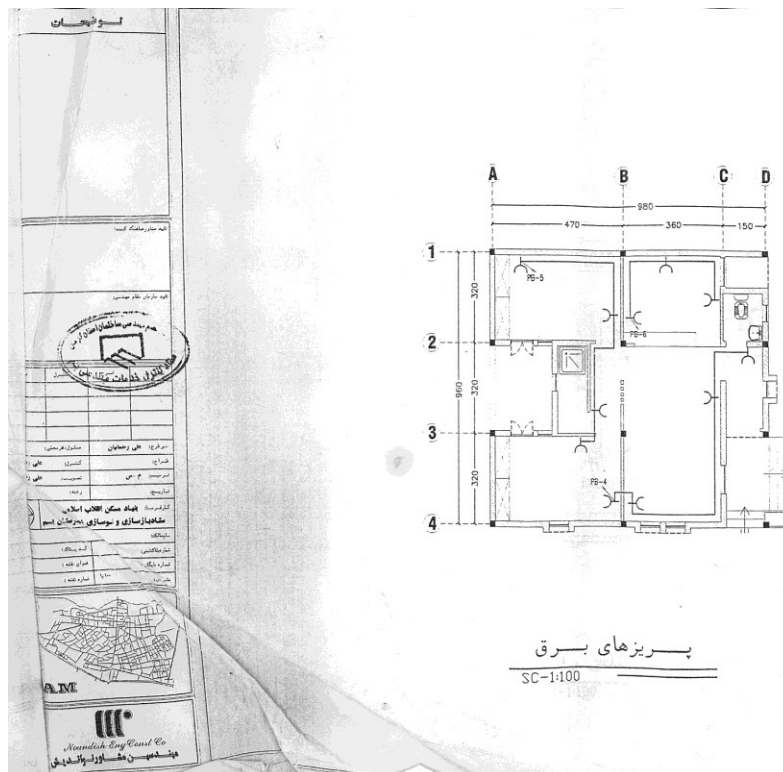


Figure E.33. Set 2: Plan of electrical

Set 3:

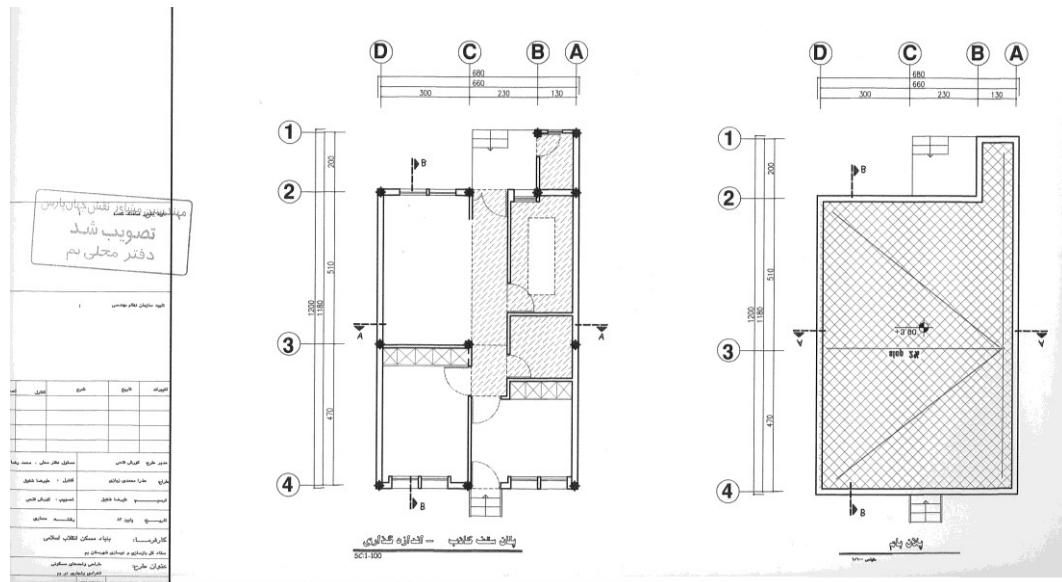


Figure E.34. Set 3: Floor plan and roof plan

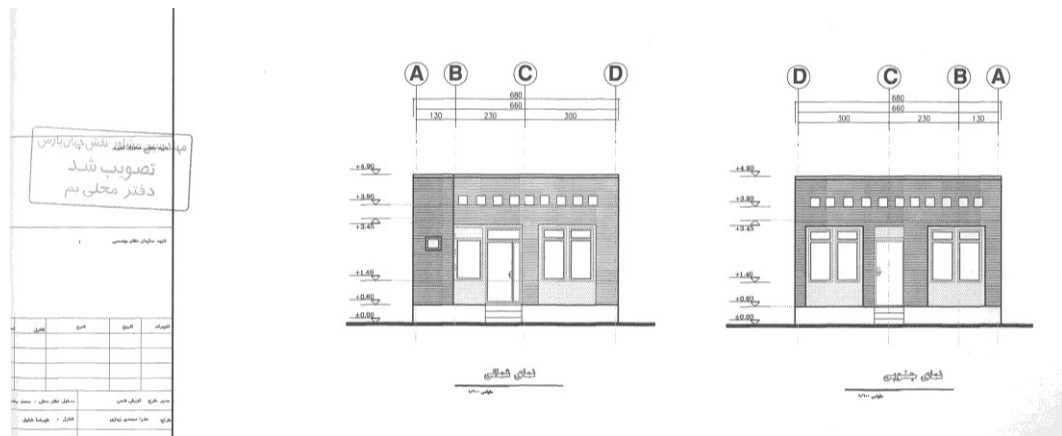


Figure E.35. Set 3: North and South elevations

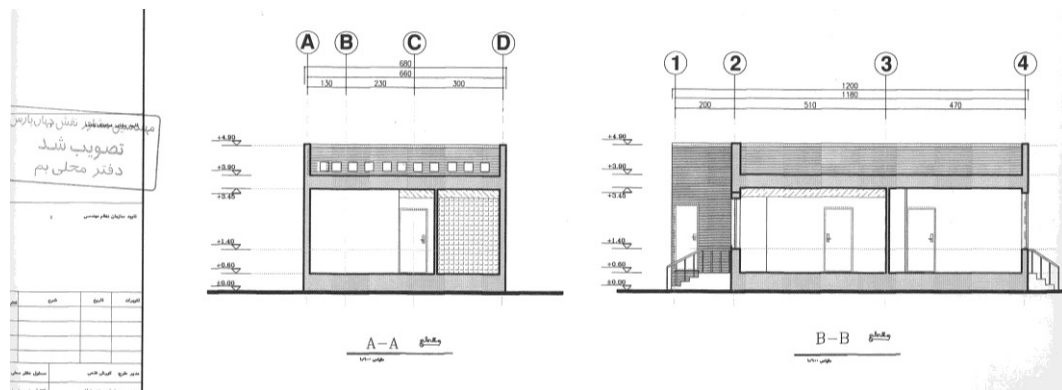


Figure E.36. Set 3: Sections A-A and B-B

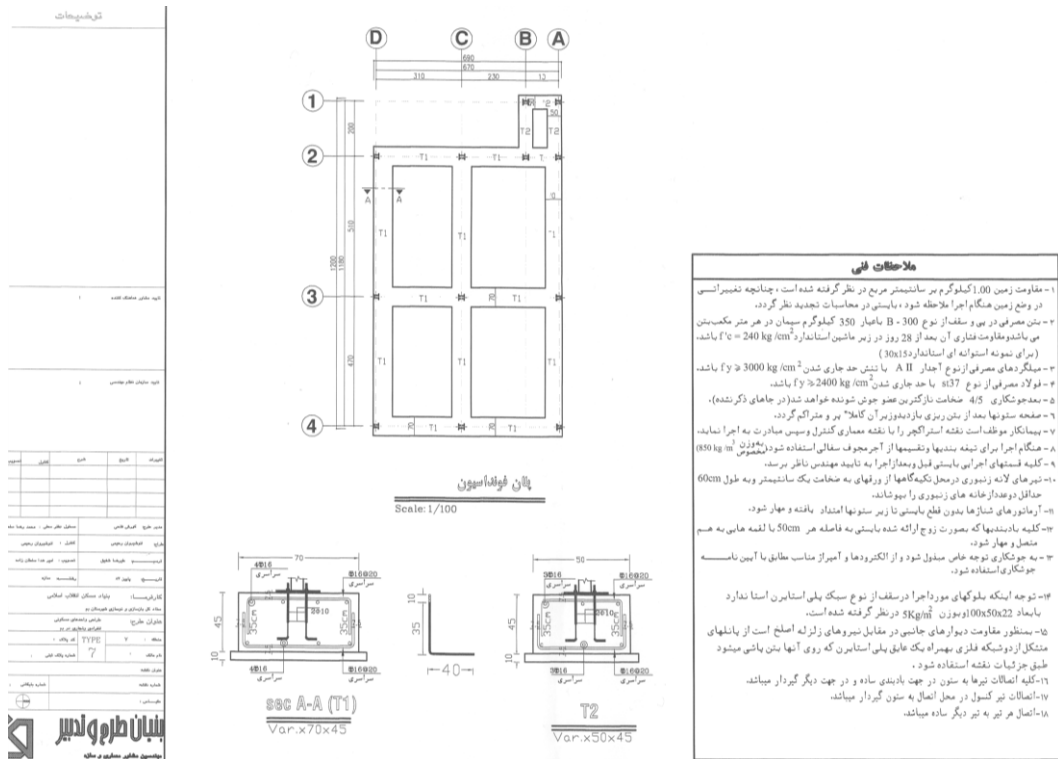


Figure E.37. Set 3: Foundation plan and details

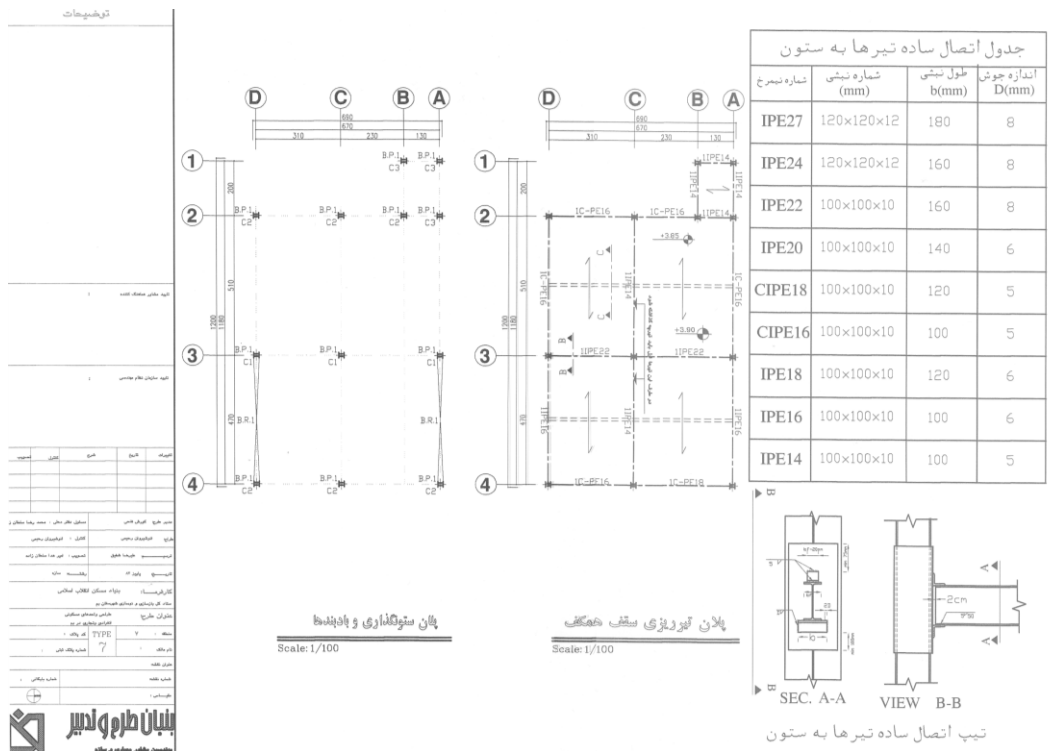


Figure E.38. Set 3: Plan of columns, plan of roof joist and details of joints

Appendix F: Authorizations for the use of copyright materials used in this study

F.1: Firenze University Press: Authorization to use parts of the paper "An Overview of the Reconstruction Program after the Earthquake of Bam, Iran," published in the book "Post-disaster reconstruction: meeting stakeholder interests"

Mehran Gharaati

From: "Patrizia Cotoneschi" <cotoneschi@unifi.it>
To: "Mehran Gharaati" <mehran.gharaati@mail.mcgill.ca>
Cc: "Mercurillo Maria" <maria.mercurillo@unifi.it>
Sent: January 13, 2009 11:19 AM
Subject: Re: Inquiry concerning Copyright materials

dear Mr. Gharaati,

we authorize you to insert the content of your contribution AN OVERVIEW OF THE RECONSTRUCTION PROGRAM AFTER THE EARTHQUAKE OF BAM, IRA to the conference entitled "I-Rec 2006 International Conference on post-disaster reconstruction" (Florence, 17-19 May 2006) in your PhD dissertation.

Best Regards and Good Lucks

Patrizia Cotoneschi

Patrizia Cotoneschi
Direttore
Firenze University Press
Borgo Albizi, 28
50122 Firenze
cotoneschi@unifi.it
www.fupress.com

Il giorno 13/gen/09, alle ore 15:58, Mehran Gharaati ha scritto:

Dear Sir or Madame,

I am writing to inquire about copyright matters. I am doing my PhD at McGill School of Architecture. My study concerns construction-knowledge transfer after disaster. I submitted a paper to the "i-Rec 2006 International Conference on post-disaster reconstruction" in Florence, which was accepted and subsequently published in the conference proceedings that is published by you. Since I want to partially use the same information within my PhD dissertation, I am writing to ask for your permission to use parts of my paper in my thesis. I would appreciate it if you grant me this permission.

Cordially,

Mehran Gharaati

McGill School of Architecture
Montreal, Canada

Book:

Post-disaster reconstruction: meeting stakeholder interests.
Proceedings of a Conference (Florence, 17-19 May 2006)
edited by D. Alexander, C. H. Davidson, A. Fox
Published by Firenze University Press, 2007
ISBN 888453612X, 9788884536129

Title of the paper: AN OVERVIEW OF THE RECONSTRUCTION PROGRAM AFTER THE EARTHQUAKE OF BAM, IRAN

F.2. GeoEye: Authorization to use the aerial photo taken by IKONOS satellite

Mehran Gharaati

From: "info" <info@geoeye.com>
To: "Mehran Gharaati" <mehran.gharaati@mail.mcgill.ca>
Sent: August 26, 2008 3:45 PM
Subject: RE: Copyright inquiry

Hi Mehran

Thank you for your interest in GeoEye.

If your use of this jpeg is for display purposes only, we can grant you permission to display the image given the appropriate image credit is given. Please use, "IKONOS Image Courtesy of GeoEye" as the credit line either somewhere on the image or in the caption.

If the use of this image is to analyze or extract information, it may be necessary to purchase this data. If an imagery purchase is necessary, we recommend working with our valued-partner out of Montreal, Viasat Geotechnologies.

Let us know if you have any questions.

Thanks
GeoEye Customer Support

From: Mehran Gharaati [mailto:mehran.gharaati@mail.mcgill.ca]
Sent: Tuesday, August 26, 2008 3:43 PM
To: info
Subject: Copyright inquiry

Dear Sir or Madame,

I am writing to inquire about copyright matters. I am doing my PhD at the McGill School of Architecture. My study concerns the reconstruction program of Bam, Iran, which was destroyed in the earthquake of December 26, 2003. I would like to use the aerial image taken by IKONOS satellite on the day after the earthquake, which I found on the website at the following address.
http://www.spaceimaging.com/gallery/spacepics/bam_quake_SI_12_27_03.jpg

This address, however, redirects automatically to a new website after showing an error message. Anyway, as I know these images are copyrighted, I wanted to get permission from you to use the aerial image of Bam taken by IKONOS satellite. I would appreciate it if you could grant me this permission.

Cordially,

Mehran Gharaati

McGill School of Architecture
Montreal, Canada

F.3. John Wiley & Sons Inc.: Authorization to use the *SECI Model of Knowledge Creation*, from the book "Hitotsubashi on knowledge management"

Mehran Gharaati

From: "Li, Feifan - Singapore" <fli@wiley.com>
To: <mehran.gharaati@mail.mcgill.ca>
Sent: September 3, 2008 11:14 PM
Subject: Granting of Permission_Hitotsubashi on Knowledge Management_0470820748

Dear Mehran,

Thank you for your request. Further to your email below, we hereby grant you FREE permission to the below usage.

Permission is granted except that you must obtain authorization from the original source to use any material that appears in our work with credit to another source.

Permission is limited to one-time, non-exclusive use and does not extend to further editions of your work. In addition, permission does not include the right to grant others permission to photocopy or otherwise reproduce this material.

Appropriate credit to our publication must appear on every copy of your work. The following components must be included: 0470820748 / Hitotsubashi on Knowledge Management Copyright 2003 by Hirotaka Takeuchi and Ikujiro Nonaka, Reproduced with permission of John Wiley & Sons, Asia.

If your work do not conform to any of the above, this permission shall be void.

Best regards

Feifan Li

----- Forwarded by Audrey Wee-Chiang/Asia/AusAsia/Wiley on 08/27/2008 08:53 AM --

From: "Mehran Gharaati" mehran.gharaati@mail.mcgill.ca
To: <enquiry@wiley.com.sg>
Sent: 08/27/2008 03:26 cc AM
Subject: copyright permission

Dear Sir or Madame,

I am writing to inquire about copyright matters. I am doing my PhD at the McGill School of Architecture. My study concerns construction-knowledge transfer after disaster. One of my most cited references is "Hitotsubashi on knowledge management", published by your company. I would like to use one of the figures, namely Figure 4.2. on page 98; The SECI Model of Knowledge Creation), and wanted to ask your permission. I would appreciate it if you grant me this permission.

Cordially,

Mehran Gharaati

McGill School of Architecture
Montreal, Canada

Appendix G: Ethics approval



Research Ethics Board Office
1555 Peel Street, 11th floor
Montreal, Quebec H3A 3L8
Tel: (514)398-6831 Fax: (514)398-4644

December 9, 2008

Mehran Gharaati Koapei
School of Architecture

RE: Knowledge transfer in post-disaster reconstruction

The above research project received retrospective ethics review and was found to have been conducted in an ethically acceptable manner.

A handwritten signature in cursive script, appearing to read "Catherine Lu".

Catherine Lu, Ph.D.
Chair, Research Ethics Board-1

cc: Prof. Vikram Bhatt

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