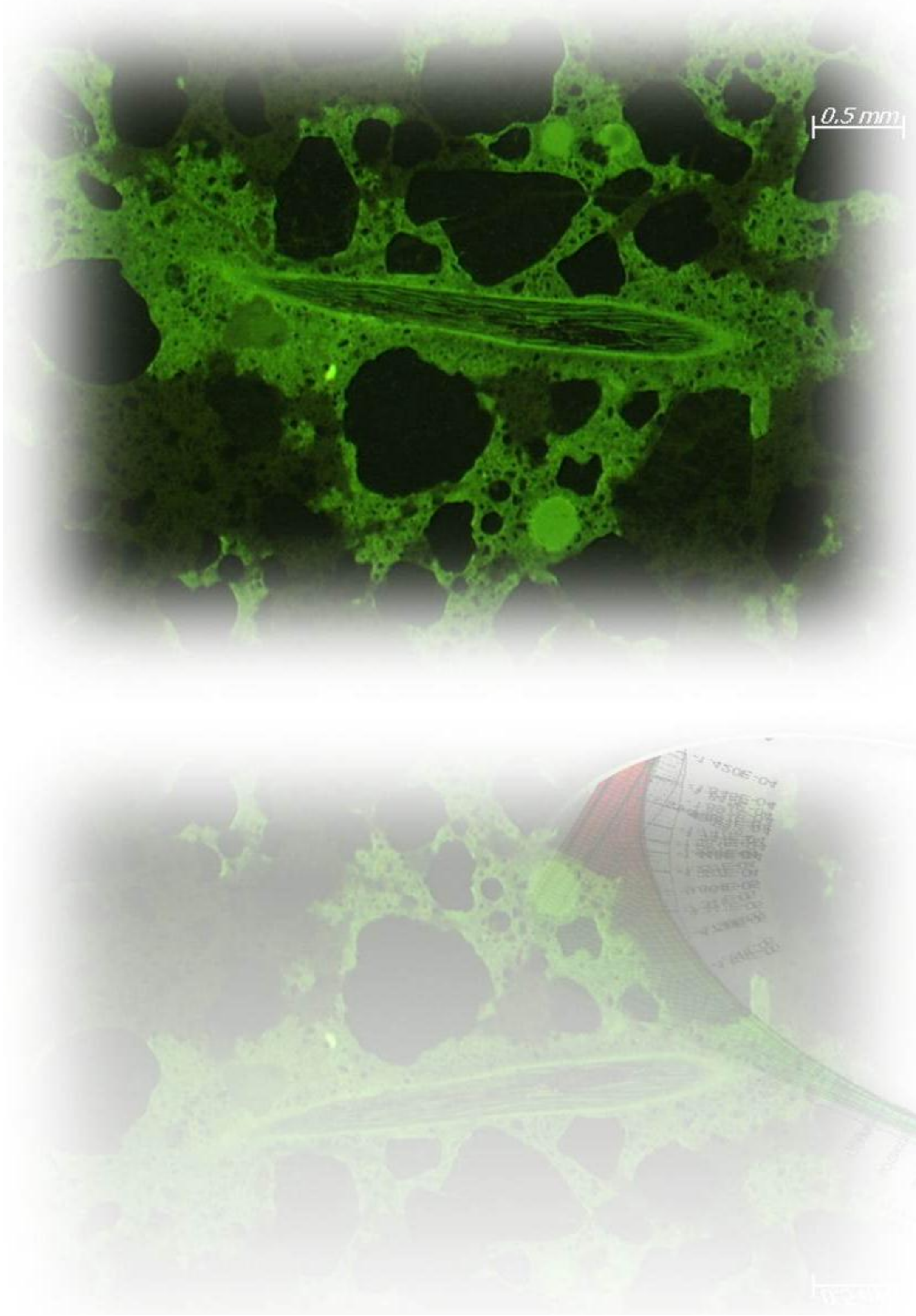

Sustainable Reconstruction of Houses in Seismic Desert Areas

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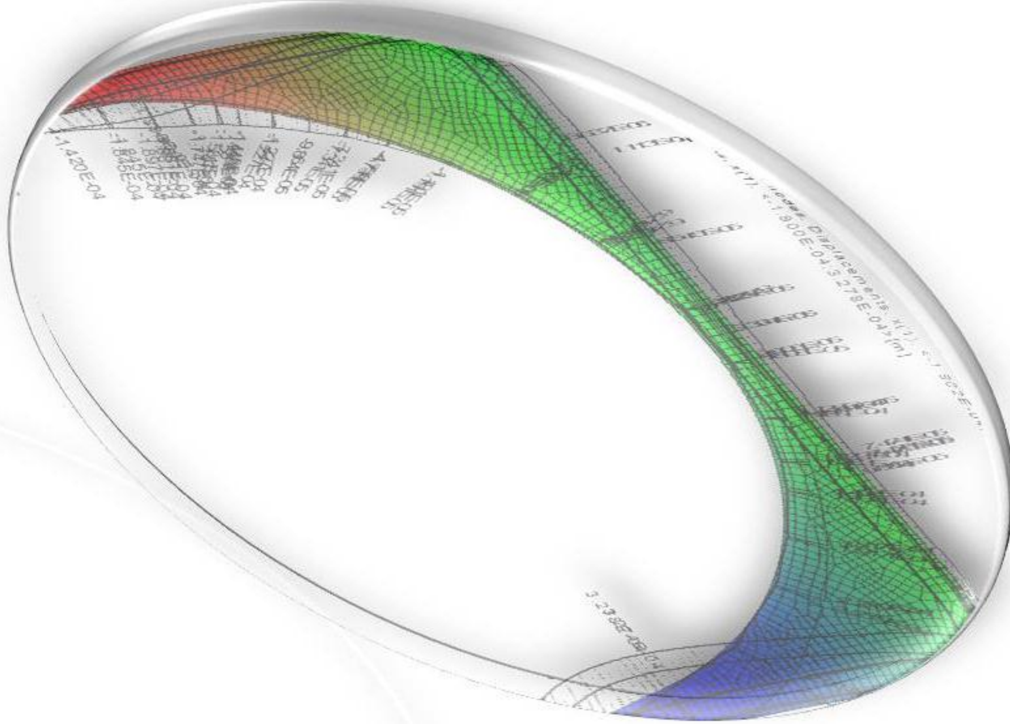

Shohre Shahnoori

Technische Universiteit Delft

Sustainable Reconstruction of Houses in Seismic Desert Areas

Proefschrift

Ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft
op gezag van de Rector Magnificus Prof. ir. K. C. A. M. Luyben,
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door

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To Siavash

PREFACE

This PhD thesis is the result of the research on an exceptional area; proceeding every challenging step of which brought enormous pleasures. Years of teaching and working at offices and different organisations arose plenty of questions that needed deeply diving in science and design. A few of these were relevant to the subject of this PhD research; answering them brought countless satisfactions. Of course it was not possible without commitment of others, not only my family but also friends and colleagues. Working at the department of Building Technology at TU Delft was a privilege. I use the opportunity to express my deep gratitude to my promoters Prof. dr. ir. Andy van den Dobbelsteen and Prof. dr. ir. Klaas van Breugel. The candidate is deeply thankful to Prof. van den Dobbelsteen for accepting to support my research and continually conducting the research towards writing this thesis. His excellent perspective regarding the environment greatly influenced this work to express the necessity of sustainability for seismic desert areas. I wish to thank Prof. van Breugel for his outstanding comments and guidance in the field of structural design and concrete materials towards defragmentation. I am thankful to my co-promoter Dr. Lara Schrijver for her continuous comments on my thesis.

The candidate is greatly thankful to the University of Hormozgan for sponsoring the initial research, and to Prof. Mick Eekhout for providing the first welcoming working environment in the Netherlands and his supports during that working period. I am deeply indebted to Prof. Jacob Fokkema who was the best of bests for a researcher like me. I also wish to thank Dr. Liek Voorbij for her efforts to group the researchers and for her comments and guidance, Dr. Karel Vollers for his kind friendship with the PhD candidates and for always being there, Prof. Wim Poelman for his commitment in organising the International Symposium of Sheltering in Seismic areas and the relevant publications. My special thanks go to Prof. Adriaan Beukers, Dr. Elma Durmisevic, ir. Joop den Uijl, and Dr. Alex Fraaij for the kind fruitful meetings at the beginning of the research. Working with the Dutch colleagues in the room 7.17 as well as the colleagues in the chair of sustainability, was a great pleasure. Particular thanks to my former colleague, Martijn Veltkamp, who was a thoughtful help for me to start being a student again, and to my former roommate Hester Hellinga who provided me not only a pleasant work space, but also the Dutch translation of the abstract. I appreciate the sympathy of the colleagues in the Electronics Dept. of EWI, providing me a working space right after the fire destroying the BK. I truly appreciate the patience of the colleagues in the Beton- Lab of CiTG and the old BK- Lab during my long lasting experimental research, and the administration sector of the Building Technology Department, in particular Bo Song and Françoise, and other colleagues of the BT, and the ones that I did not name in here. My heartfelt thanks go to my family and friends for their unconditional love and supports; and to my trip-mates to the seismic desert cities for their wonderful company. Finally, I would like to thank the committee members Prof. Fokkema, Prof. Maheri, Prof. Lichtenberg, Dr. Vermaas and Prof. Vambersky.

Although working on seismic desert situations in the Netherlands sometimes appeared hopeless, but never giving up, it brought countless gratifications. Certainly the next researcher in this subject starts with a clearer perspective to the complexity, as (s)he is one step further and the ground under his/her feet is more solid now. This research addresses issues that are sometimes so tiny that may not be considered as serious, but they may have great influences on the design conclusion. Therefore, it is provided not only for building technologists and designers, but also for decision makers. It is a contribution to safeguard the environment and society by showing the potentials of sustainability in the reconstruction of houses.

Shohre Shahnoori, September 2012, Delft

CONTENTS

ABSTRACT

Sustainable Reconstruction of Houses in Seismic Desert areas

Shohre Shahnoori

This thesis is mainly a product of the research of a complex design situation, and in particular of a Sustainable Reconstruction of Houses in a Seismic Desert area, in short SRH-SD. Procuring an accurate understanding of this complexity was a major responsibility and integrating the design on multiple scales under the leadership of sustainability was a critical task. To this end three topics were given weight in this thesis: Sustainability, Complexity, and Seismic deserts.

(i) The concern for the environment is crucial to society. Issues relevant to sustainability are not simply limited to problems such as air pollution and CO_2 emission, material use and the embodied energy, and costs but should rather be seen by means of its broad definition. Although sustainability is already a worldwide concern, for seismic desert cities it is a fundamental need, and conditional for their survival. Therefore, exploring the ways to define the boundaries for the reconstruction of houses that meet the requirements of sustainability is crucial. In order to achieve this, two significant parts are included. First, an investigation into issues of sustainability in this particular situation. The second was identifying the requirements/criteria for the sustainability of the reconstruction through case studies. The cases in this study may be divided into various categories. For example in the research and design on the urban level first a global measure has been taken; for instance, cases in America have been compared to cases in Asia. In this regard some cases are provided from the USA, Peru, Mexico, etc., together with ones from China, Mongolia, India, as well as Zanzibar, Morocco, Egypt, Algeria, Saudi Arabia, Yemen, Iraq, and Iran, In the meantime and on a smaller scale, cities in different countries have been compared. However, Bam as an appropriate sample of a desert town was always a constant case. Sustainability was addressed in many ancient or at least old desert towns/cities, whereas it was lost in the design and development of many modern cities. To benefit from the traditional knowledge with the possibilities provided by modern technologies and global knowledge were additional considerations towards an optimum use of local opportunities. The involvement of social, cultural and local issues in achieving sustainability of the reconstruction has been identified as critical. In this respect items as political and local limitations were found as significant influences. The relevant exploration and analysis resulted in providing example proposals for a sustainable town development. This approach has also been applied on the smaller scales of building design, building components and element design, as well as for the materialisation of buildings.

(ii) Complexity of the design has been addressed through the use of the case of a SRH-SD. The complexity of architectural design in general is significantly increased due to the influences of the two major constraints, seismicity and the desert context. The numerous elements entail a large number of relationships (i.e. linear as well as nonlinear) making the consequences unpredictable, by which the design conclusion may fail to satisfy the need. Thus, in order to avoid complications in such a design environment, several methods and systems are proposed. First, the design processes have been modelled in a general summary backbone system. Secondly, each phase of this system has been assumed as a subsystem, for which the most critical one has been selected as a sample sub-systemisation. The proposed models were validated throughout the chapters from 3 to 11. On the other hand, application of only quantitative methods does not satisfy the urban and architectural design. Therefore, a combination of qualitative and quantitative techniques is necessary; examples have been provided in this dissertation. Although with this organisation and

application of techniques the complexity is manageable to a high extent, still the direction of the design may be lost in this demanding design situation. Therefore, a general and overall strategy will greatly help the design to stay always in its planned direction. Because of the sensitivity of a design context, such as a seismic desert area, sustainability is certainly an appropriate overall strategy. This means the design on all of the levels of scales is conducted towards sustainability at present as well as for the future.

(iii) As was indicated the seismicity in addition to the problems with a desert context, has serious effects on almost all the design aspects and their relationships. Currently earthquake resistant systems attract attention, since many earthquake disasters strike different places on the earth every year. Moreover, it is well-known that in catastrophic earthquakes houses are claimed as the most vulnerable buildings, and are the most used buildings, while they are not counted as the most important ones in most regulations. Most design improvements that involve costly sophisticated systems applied in the design of houses, if any, are focused on high-rise buildings and residential complexes. Thus town houses and single-family dwellings, which comprise most of desert residences, still experience heavy destruction when undergoing strong seismic actions. Besides, sustainability is hardly addressed in most of the known structural concepts. It is believed, therefore, that earthquake engineering of desert town houses under the umbrella of sustainability, - a focus in this thesis -, is a necessity. In this respect providing simple but practical methods was the aim. The proposals on various levels of the design are the results of the surveys, explorations, analysis and evaluations in this regard. On the urban design level, the location of the reconstruction in a seismic desert town has been argued with reference to a case study of the city of Bam. As an important outcome safer locations for the reconstruction, that were technically sound and also offer basics requirements for life, have been found in some case studies. However, an evaluation of the result of a local survey revealed that due to social boundary conditions, in many cases the reconstruction must take place on the same site. This was also experimented in the design of houses that changed the concept as a result of an evaluation of the social wishes of local people. For the design of building components, in addition to their ability to withstand earthquakes, also durability, transportation, repair and upgrading were considered. For the materialisation, materials minimisation and optimisation, local availability, transportation, strength and ductility, durability and thermal mass were of significant consideration.

Materials De-Fragmentation was the final research topic and the focus of the materialisation. Determination of the time required for escaping from houses subjected to strong earthquakes was one of the major research tasks. The rescue time is a serious design criterion for designing a De-Fragmentation Element (the DFE). The DFE, as a highly effective system to reduce the vulnerability of the inhabitants, was designed to delay the fragmentation moment. By finding the required rescue time, the DFE can be further optimised and the delay of the fragmentation can be extended to the required rescue time. The study indicates some promising research directions for developing effective DFE’s.

Although sustainability is greatly achievable in this integrated approach, application and enforcing the use of DFE’s are required to increase the safety of people and the environment under seismic actions.

SAMENVATTING

Sustainable Reconstruction of Houses in Seismic Desert areas

Shohre Shahnoori

Dit proefschrift is het resultaat van onderzoek naar een complexe ontwerpsituatie en gaat in het bijzonder over een duurzame reconstructie van huizen in een seismische woestijnstad, in het kort SRH-SD.(Sustainable Reconstruction of Houses in Seismic Desert areas). Het verschaffen van een nauwkeurig begrip van deze complexiteit was een grote uitdaging en het integreren van het ontwerp op meerdere schalen met duurzaamheid als leidende factor was de belangrijkste opdracht. Om die reden hebben drie onderwerpen de nadruk gekregen in dit proefschrift: duurzaamheid, complexiteit en seismische woestijnen.

(iv) De zorgen voor het milieu zijn cruciaal voor de samenleving. Kwesties die relevant zijn voor duurzaamheid zijn niet simpelweg beperkt tot problemen zoals luchtvervuiling en CO2 uitstoot, materiaalgebruik het totale energieverbruik en de kosten, maar zouden meer beschouwd moeten worden vanuit hun bredere betekenis. Terwijl duurzaamheid inmiddels wereldwijd een bron van zorg is, is het voor woestijnsteden in seismische gebieden een fundamentele noodzaak en essentieel voor hun overleving. Daarom is het van groot belang om methoden te ontwikkelen om de randvoorwaarden te definiëren voor de reconstructie van huizen die aan de eisen voor duurzaamheid voldoen. Om dit te bereiken, zijn twee belangrijke onderdelen beschouwd. Ten eerste, onderzoek naar de vraagstukken ten aanzien van duurzaamheid in deze specifieke situatie. Ten tweede, het identificeren van eisen/criteria ten aanzien van het duurzaam reconstrueren aan de hand van casestudies. De cases in deze onderzoeken zijn te verdelen in verschillende categorieën. In het onderzoek naar het stedenbouwkundig ontwerp is eerst een wereldwijde vergelijking gedaan; cases uit Amerika zijn vergeleken met cases uit Azië. Sommige cases kwamen uit de USA, Peru, Mexico, etc., en daarnaast uit China, Mongolië, India en Zanzibar, Marokko, Egypte, Algerije, Saoedi Arabië, Yemen, Irak en Iran. Tegelijkertijd zijn er op een kleinere schaal steden in verschillende landen met elkaar vergeleken. Bam was echter, als een goed voorbeeld van een woestijnstad, altijd een constante casus. In veel oeroude of op zijn minst oude woestijnsteden werd het aspect duurzaamheid wel degelijk beschouwd, terwijl dit is verdwenen uit het ontwerp en de ontwikkeling van veel moderne steden. Het combineren van deze traditionele kennis met de mogelijkheden die moderne technologieën en wereldwijde kennis verschaffen, maken het mogelijk optimaal gebruik te maken van lokale mogelijkheden. Het betrekken van sociale, culturele en lokale vraagstukken in het realiseren van een duurzame reconstructie is van cruciale betekenis gebleken. Hierin bleken zaken zoals politieke en lokale beperkingen significante invloedsfactoren. De relevante vooronderzoeken en analyses hebben geresulteerd in voorstellen voor een duurzame stadsontwikkeling. Deze benadering is ook toegepast op de kleinere schaal niveau's van het gebouwontwerp, gebouwcomponent- en elementenontwerp, evenals op de materialisatie van gebouwen.

(v) Complexiteit van het ontwerp wordt behandeld aan de hand van de casus van een SRH-SD. De complexiteit van architectonisch ontwerpen in het algemeen wordt significant vergroot door twee belangrijke beperkingen de seismische activiteit en de woestijncontext. De talloze elementen hebben grote aantallen relaties tot gevolg (zowel lineair als niet-lineair), die de consequenties van bepaalde keuzes onvoorspelbaar maken. Het uiteindelijke ontwerp zou daardoor kunnen falen in het vervullen van de behoefte. Om complicaties in een dergelijke ontwerp omgeving te voorkomen, wordt daarom een aantal methoden en systemen voorgesteld. Ten eerste worden de

ontwerpprocessen gemodelleerd in een algemeen, samenvattend “ruggengraatsysteem”. Ten tweede wordt iedere fase van dit systeem ondergebracht in een subsysteem, waarvoor het meest kritische exemplaar is geselecteerd als een voorbeeld van sub-systematisering. De voorgestelde modellen zijn gevalideerd in hoofdstukken 3 tot 11. Aan de andere kant is de toepassing van uitsluitend kwantitatieve methoden niet voldoende in het stedenbouwkundig en architectonisch ontwerp. Daarom is een combinatie van kwalitatieve een kwantitatieve technieken noodzakelijk; voorbeelden daarvan worden gegeven in dit proefschrift. Hoewel met deze organisatie en toepassing van technieken de complexiteit tot een bepaald niveau te managen is, kan de richting van het ontwerp verloren gaan in deze veeleisende ontwerpsituatie. Om die reden zal een algemene en algehele strategie enorm helpen om het ontwerp altijd in zijn geplande richting te laten blijven gaan. Vanwege de gevoeligheid van een ontwerp context zoals die van een seismisch woestijngebied, is duurzaamheid zeker een geschikte omvattende strategie. Dit betekend dat het ontwerp op alle niveaus of schalen wordt geleid naar duurzaamheid, zowel in het heden als in de toekomst.

(vi) Zoals aangegeven heeft de seismische activiteit, in aanvulling op de problemen met een woestijn context, serieuze effecten op bijna alle ontwerpaspecten en hun onderlinge relaties. Tegenwoordig trekken aardbevingsbestendige systemen de aandacht, omdat ieder jaar verschillende plekken op de aarde door aardbevingsrampen worden getroffen. Bekend is dat in catastrofale aardbevingen woonhuizen de meest kwetsbare gebouwen zijn. Ofschoon het de meest gebruikte gebouwen zijn, worden ze in de regelgeving niet gerekend tot de belangrijkste constructies. Om die reden wordt er betrekkelijk weinig geld besteed aan het verbeteren van het aardbevingsbestendig ontwerpen van woonhuizen. De meeste ontwerpverbeteringen die betrekking hebben op de toepassing van kostbare geavanceerde systemen in gebouwen concentreren zich, als ze al worden toegepast, op hoogbouw en wooncomplexen. Het gevolg van deze situatie is dat kleine stadswoningen en eengezinswoningen, die in woestijnnederzettingen veel voorkomen, nog steeds zwaar beschadigd raken wanneer ze worden blootgesteld aan sterke seismische belastingen. Daarnaast wordt het duurzaamheidsaspect in de meeste toegepaste bouwsystemen vaak niet beschouwd. Daarom is het aardbevingsbestendig bouwen van woestijnstadhuizen onder de paraplu van duurzaamheid de focus van dit proefschrift noodzakelijk. Tegen deze achtergrond was de subdoelstelling van deze studie het geven van uitvoudige praktische methoden voor het verbeteren van de aardbeving-bestendigheid van woestijnstadhuizen. De voorgestelde methoden zijn gebaseerd op enquêtes, verkenningen, analyses en evaluaties van een breed opgezet onderzoek. Op stedenbouwkundig niveau wordt de locatie van de reconstructie in een seismische woestijnstad beargumenteerd aan de hand van een casestudy van Bam. Een belangrijke uitkomst van sommige casestudies was dat veiligere locaties zijn gevonden voor de herbouw van Bam die technisch gezond zijn en ook basiscondities bieden om te leven. Echter een grondig onderzoek inclusief een gebruikersonderzoeken onder de lokale bevolking, heeft laten zien dat vanwege sociale rand voorwaarden, in veel gevallen de herbouw moest plaatsvinden op dezelfde plek. Dit experiment werd ook uitgevoerd op het ontwerp van huizen waarvan het concept werd gewijzigd als een gevolg van een evaluatie van de sociale behoefte en wensen van de lokale bevolking. Voor het ontwerp van gebouwcomponenten en elementen waren - naast het bestand zijn tegen aardbevingen en het geschikt zijn voor het woestijnklimaat - duurzaamheid, transport, reparatie en upgrading ontwikkelbaarheid, assemblage etc. de leidende onderwerpen. Voor de materialisatie waren minimalisatie en optimalisatie van de materialen, lokale beschikbaarheid, transport, sterkte en taaiheid, duurzaamheid, en thermische massa significante overwegingen. Materiaal de-fragmentatie (Materials De-Fragmentation) was het laatste ontwerp in deze studie. Het bepalen van de tijd die nodig is voor het ontvluchten van huizen tijdens strenge aardbevingen, kreeg veel aandacht. Deze vluchttijd is een serieus criterium voor het ontwerp van een de-fragmentatie element (De-Fragmentation Element, DFE). De DFE, als een effectief model om de kwetsbaarheid van de inwoners te verkleinen, moet het moment van instorten van gebouwen kunnen vertragen. Aan gegeven is in welke richting materiaal technologische en constructieve oplossingen gezocht kunnen worden om effectieve de-fragmentatie elementen te realiseren.

Hoewel duurzaamheid in grote mate bereikbaar is bij deze integrale benadering, zijn het toepassing, respectievelijk het afdwingen van het toepassen van de voorgestelde oplossingen (de DFE's) noodzakelijk om de bescherming van mens en milieu echt te verzekeren.

CHAPTER 1

Introduction

Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.' (WCED, 1987)

Houses are built all over the world in all sorts of circumstances. Some circumstances are more demanding for the designers than others. Some areas are at risk for natural phenomena to occur such as seismic or desert areas (desert expansion). Each of these phenomena has consequences on humans. These consequences always include economic and sometimes include social impacts (e.g. fatality or injury) as well. For example, building on windy locations causes extra effort regarding calculations, design considerations, structural enhancement, stability for the buildings, etc. Otherwise, possible human injury or fatality is predictable. However, devastation of people after such phenomena, although not directly, also influences the building construction sometimes. For that reason, design for building or rebuilding in these areas is more sensitive as it is loaded with additional items and aspects to be taken into account. This thesis investigates, explores, enhances, and develops knowledge to support architects and building technologists to work in a multi-demanding area.

1.1. Background and problem statement

"S*cience needs the same values and precepts as commerce."* Jane Jacobs

This doctoral study discusses issues related to overall architectural design in a complex situation, and indicates general problems caused by the complexity. It concentrates on the consequences of seismicity relevant to buildings and construction in a desert environment. For example, earthquakes are known as the most destructive and most fatal natural phenomena in the world (USGS, 1997; SRTF, 2000; HS, 2009). Thus, it influences all the design segments and makes the environment complex. The other problematic case, which will be similarly stated, relates to the desert environment, because it is a hostile environment to humans and presents challenges to the construction industry. Therefore, combining the two situations embodies a complex design situation. The two influential situations are independent, but are set in relation to one another. Generally, when construction is to be set in a seismic area located in the desert, design solutions should be suitable for the desert situation while responding to the problem of seismicity. Therefore, the gap in earthquake engineering for desert areas will be clarified in some details. Conducting a complex design from a building technology point of view under the leadership of sustainability is also a dominant issue within the study.

The problem defined in this study is discussable on two levels. On a general level, the main problem of designing in an extremely complex situation has a core, which relates to the process of design and its constituent elements. This question of design process is investigated on a specific level through case-oriented research. The problem relates to the case of sustainability of the reconstruction of houses in a seismic desert area, as a very demanding design situation.

1.2. Complexity of the design: The seismic desert environment

Earthquakes cause houses to collapse, leading to fatalities all over the world. Building in seismic areas is still a difficult task for engineers. Scientific studies on earthquakes show that even though there have been a considerable number of earthquakes, it remains problematic to find a technological answer to build houses in seismic areas. Nevertheless, studies on earthquakes are now advancing rapidly (Naeim, 2001). However, many of these researches did not concentrate on the consequences of this natural phenomenon (e.g. building destruction). The main goal in most of these studies was to explore the phenomenon itself. Thus, first generations of instrumental application and improvement concentrated on observational equipments, recorders, and registration facilities. So, much effort was put into instrumental developments. This can be seen for example in the Strong Motion Instrumentation Program in California by the year 2000, in which 800 monitoring and recording instruments in the free field, and 130 buildings and 45 other structures were instrumented (Naeim, 2001). In spite of this, the knowledge and developments on the effects of earthquakes on buildings has a comparatively less scientific basis.

After the earthquake of San Francisco in 1906, designers observed that buildings, which were constructed to withstand a wind force of 30 lb/ft^2, performed better under the seismic load. Although the knowledge was very limited and primitive at that time, this was the starting point for earthquake resistant engineering to consider seismic load as an increase of lateral force on buildings (Booth, 2006) and to recognise this as a potential for the seismic design. However, there was no research performed at that time to prove this theory scientifically.

Related to houses, the applied methods, which were mostly vernacular, resulted sometimes in solutions on the urban level and sometimes on the building level. An example of methods applied on the urban level is the typology for housing (i.e. more than just separate houses) in some seismic areas. Living in cheap houses, easy to build and rebuild, in some regions is considered as a vernacular solution (for instance the traditional way of housing in rural areas of south and south-eastern coastal regions in India, subjected to tsunamis in addition to strong winds, or tents in Mongolia). These typologies for housing are not only caused by poverty, but also the unreliability of the possible use period or duration (uncertainty for long-lasting periods) according to the natural phenomena. People in difficult areas have to cope with both the positive and negative characteristics of that area. Japanese timber-framed houses with lightweight thin wood panels suffice, not just because of availability of the wooden products but also based on living in an earthquake-prone zone for a long time. In addition to the availability of wood for a large-scale application, these panels are relatively good to resist earthquakes. Moreover, they are lightweight, so that consequent injuries are lower.

As the research on the effects of seismicity on building technology is very young, there is a long way to go. An increase in the reliability of houses in terms of constructive stability or resilience rests with the improvement of the technology or a transfer of technology from other fields of expertise. However, even with a sufficient body of research this needs to be translated and transferred into practice with more velocity. An example of such a demanding situation is the earthquake of Hyogo-ken Nanbu (1995) in which even buildings that were designed for strong earthquakes underwent severe damages (Mikam, 2007). Nevertheless, the very recent practice shows that on a general level, there already are signs of a growing practical knowledge of earthquake-resistant structures (e.g. applied knowledge in Orange County bridge part 37, 2005; Glorio Roppongi residential complex, 2007; Oklahoma City Bridge 1-40 first phase, 2007). It has to be mentioned that this knowledge is mostly concentrated on the creation of large or especial (e.g. high-rise) buildings regardless of the consequent environmental impacts. It is required that this latest technology to improve earthquake resistance be implemented on a broader scale and placed within the frame of sustainability. The focus of research in the field of seismic resistant systems is mostly on infrastructure, especial and highly important buildings, or residential complexes and high-rises. Examples of efforts, research, and studies of seismic design problems and solutions can be found in NISEE 1998; Kitagawa, 1998; PEER, 2003; EERI, 2004; PEER, 2005; EERC, 2007, Aroup, 2007; Kajima, 2007; Wilford et al., 2008; UC, 2009. There has been minor consideration for housing, and even so, these works have not concentrated on normal individual houses, while most houses in seismic areas are low-rise and single houses (EERI, 2003). Although some studies (e.g. EERI, 2002; T4SL-ITDG, 2003; Blondet, 2005; Khalili: Cal-Earth 1986-2008; IF, 2009) have worked on earthquake resistance of low-rise houses, they are mostly concentrated on either strengthening the existing buildings, or their designs focuses on adobe and similar structures. The latter can be referred to as local studies and does not include the majority of global desires. Therefore, to respond to the greater demand, first, translation of the current state of the available research into the practice is needed. Secondly, the technology transfer, and thirdly, suitable research and development for low-rises and single houses are required. Finally, these all need to be developed in line with sustainability for the least negative impacts on the environment.

Apart from seismicity, harsh climates such as deserts are also difficult to cope with. Over time, social circumstances and environmental risks have changed. However, as ever with these changes, new challenges pop up. These are mostly related to sustainability, which needs extra consideration to the desert environmental conditions and the risk of increased desertification. Desertification, which points at further expansion of dried out soil and reduction of woodlands and forests, must be seen as the biggest threat for desert margins and a bad development for the environment worldwide. For example, the beautiful ancient city of Nazca in Peru is turned to a dry desert now. For the architects and building technologists this term loads an extra constraint of social and professional sensitivity. These involve more dependency on the local conditions and demands more awareness of the effect design has on the inhabitants.

As mentioned, designing under difficult conditions such as earthquakes or desert climates puts a burden on designers. Consequently, if they were to build sets of houses in a seismic desert area this would be even more complicated. They would need to cope with a very complex set of design requirements and criteria and it is very likely that they will not succeed in dealing with such a set of constraints. As was indicated, the available data that can be directly used by designers on the two phenomena is not sufficient yet, while a combination of these two creates a new field. Areas that suffer from a combination of the two problems do exist (e.g. Ocotillo in California desert; Bam & Tabas in Iran, Calama & San Pedro in Chile; Uygur & Jiayuguan in China; San Diego & Arizona in the USA, Lima & Ilo in Peru, Uyuni & Rio Grande in Bolivia). Without practical support, it will be very hard to build earthquake-resistant, desert-suited houses for an acceptable price, within an acceptable time, and with a long-lasting desirability. Finally, it can be summarised that there is not a defined area in the field of architecture to address problems and solutions for an extremely complex situation as a seismic desert context concerning sustainability.

1.3. Aim of the study

This study hypothesises a system that includes an array of design steps and phases, segments, environment, and circumstance through a design process model towards sustainability in a complex situation. This organising system frames the design and limits design solutions from having harmful consequences on the environment. With this supporting system and the emerging knowledge, an extremely complex situation can be dealt with by avoiding impacts on the environment as much as possible. Defining a domain with the characteristics required for design in a complex situation, as a seismic desert context for sustainable houses, is a major task. In the methodology developed in the underlying study, the strength of a knowledge-based systemised design for avoiding the possible complications in a complex of multiple disciplines is proven through analytical discussions and design and engineering case studies. In these processes of development the growing complexity, not only by the broadness of the design area but also by the interactions of the multiple disciplines is evident. Additionally, the loads of external constraints lead the design to an extraordinarily complex situation. Therefore, a first attempt was made to formulate and/or simulate the required knowledge for such a design, in addition to general as well as particular cases of applications. In this approach the constraints, consequent increase of complexity, and the degree of this complexity are integrated. Recognition of the level of complexity led to organising and classifying the processes to avoid the possible chaos; diminishing the risk of failure for the design conclusions was one of the initial intentions for such a complex situation. It is therefore assumed that the evolution is sometimes hierarchical, while in the other situations or cases it is elaborated in a variable settlement (e.g. organic and natural evolution) or iteratively. The study provides a set of requirements and necessities essential for sustainable construction or reconstruction of a house in a seismic desert area as a case representing a complex design situation. The set of requirements should be general and embedded in the different phases of the design process as well as in the practical construction work. This may be proposed and rationalised through a limited number of cases in this dissertation. However, it opens a way for designing and developing further products for this unique context as well as similar cases of multi-factorial problems. Hence, the knowledge emerged fills the stated gap for architecture and building technology, it also enhances the connectivity of design domains between knowledge and practical design from architect (conceptualisation), building technologists (performance/construction) and civil engineers (calculations) in a particular situation. Within this framework sustainability is leading. The practical goal is declining vulnerability of the inhabitants of desert houses in earthquakes, both in a large long-term and a detailed short-term perspective.

The methodology developed during this study should be applicable in a modern architectural agency or building engineering company. Since the research is aiming at modern solutions for housing, it also concentrates at determining the sustainability aspects that might interfere with optimisation for building (in some aspects) in a seismic desert area. The fact that this study aims at providing a global solution requires paying attention to sustainability aspects as well. Because of the separation that often exists between the domain of architecture (and exceptionally building technology) and civil engineering, seismic design is not very often counted as a normal and important factor in architectural design, particularly in the reconstruction of houses in a desert environment. Hence, sustainability is a rather new criterion (i.e. recent decades), which has not been included as the main target of design methodology on a multiple discipline scale with this particular situation, or if so, it has not been scientifically argued yet.

As the research aims to contribute to multi-disciplinary knowledge the method developed contains both qualitative and quantitative information. On the one hand it has to be a tool for designers (architects, building technologists, and scientists). On the other hand it has to be also a practical guideline for builders and other parties involved in building realisation (e.g. executive board, investors, developers). Furthermore, the study contains scientific information for researchers to enhance their knowledge on the subject. The goal therefore is to conceptualise the design varieties for an extremely complex context in an identical frame, among which the evolutionary system and processes emerged during completing the research. This organises and structures a model of interactions and influential or effective interventions in the design to accelerate its evolution. Therefore, the main research question was “How to develop a suitable system for a complex situation such as sustainable reconstruction of houses in a seismic desert area?”

To find the answer, three main areas need to be discussed and covered within this dissertation:

- Complexity of the design situation, and systemisation of the design to avoid chaos
- Problem of application (research to practice, technology transfer etc.),
- Sustainability

In this case, the *‘Complex design situation’*, is a demanding situation in which the architectural design has to be based on normal requirements and loads but involve extra loads of energetic or severe external elements, called design constraints. The resulted complexity meant by this study is an extreme design environment, heavily populated by items. For such a situation, in addition to the high number of involved items, their interactions and interferences need to be taken into account.

‘Systemisation’ includes the development of an appropriate organisation and structure for architectural design in a demanding complex situation. However, it denominates a more general approach to systematic design in such a situation. For this systematic approach organisation and modelling of the design and knowledge are the tasks in this dissertation. Hence, the processes may also be applied inside the systems, and if so, they will be called sub-systems and thus, sub-systemisation. Finally, controlling the design segments and conducting the design to avoid chaos is an important approach in this systemisation. It is crucial due to the current state of sustainability and sensitivity of seismic desert areas.

‘Application’ includes all the general as well as particular knowledge, methods, and techniques that are useful in research, design, and practical in-situ implementation. This includes not only technology transfer from other fields of expertise into the building design, but also application of research and design in practice and performance. Therefore, it covers the design and application on multiple levels. These levels start for instance from a general upper level of modelling and organising the design processes and environment to the detailed level of design practices as enhancing the robustness of the structure of houses and materialisation.

‘Sustainability’ as applied in this study, is a leading principle with a concern about the environment, mainly leading the integrated design on the highest scale (i.e. urbanism). On a general level of design in a complex situation, it applies to checking the design solution with the long-run consequences. For example, for the seismic desert case study, this is a crucial checking criterion, mainly to avoid the risk of desertification in habitable seismic cities located in deserts. However, this wide perspective and the long-time effect is a consequence of integrated short-term effects and the influence on the lower levels of the design (building design, materialisation, and material development). Therefore, this environmental concern is sometimes observable on smaller scales as well, ending to checking criteria and sample indexes.

1.4. Approach and methodology

“Theory is a body of principles that explains and interrelates all the facts of a subject knowledge research is the tool by which the theory is advanced.’ (Martin, 1958)

The approach in this study is comparable to a design research approach in addition to an iterative crucial role for analysis and deduction in the entire study as well as through the case studies.

Dealing with designing artefacts (systems), March and Smith (1995) discern the Design Science (DS) from the Natural Science (NS). They claim that the activities of the DS are Build and Evaluate and its products are Constructs, Models, Methods, and implementations. Transferring the approaches of March and Smith (1995) to architectural design will adjust the Build and Evaluate activities to two levels of conceptual and practical architecture. The architectural approach resulting then is the basic background for this study as well. With the theory proposed in this dissertation, design processes are completed iteratively as well as organised stepwise. Martin and Turner (1986) state "Grounding theory is an inductive, theory discovery methodology that allows the researcher to develop a theoretical account of the general features of a topic while simultaneously grounding the account in empirical observation or data." The dynamic aspect of this grounded theory is that it also facilitates the generation of theories on design thinking and processes on different levels. However, modelling the knowledge of design in a complex situation as an important production of the whole study provides this dynamic atmosphere while modelling the design processes is more attempting to a static aspect. Nevertheless, the openness and flexibility of a process model moderates/balances the strictly static aspects to a high extend. Hence, as the proposed processes are also iterative they may complete only at the end of the design.

The grounding theory is the support for a system in which a flexible model organises the design and is capable of reducing the risk of failure of the design conclusion in a complex situation. This methodology (grounded theory), different from a normal research method, sometimes includes but does not always start with a theory or hypothesis to be tested during the research. However, the theory development is mostly based on a continuous interplay between data collection, design, comparison, analysis, and evaluation. This methodology is iterative, requiring a steady movement between concept and data, as well as comparative, requiring a constant comparison across types of evidence to control the conceptual and scope of the emerging theory (Kocaturk, 2006). General characteristics of the grounded theory can be summarised in three characteristics of inductive, contextual, and processive (Boland 1985). The interpretive approaches of these characteristics fit the nature of architecture. Although this study develops a context-based, process-oriented description of the phenomenon, the objectivity is very important. The action of key players that are often omitted in knowledge modelling studies (Kocaturk, 2006) is the other issue. Based on these all, in addition to the theoretical framework that is being discussed in the next chapter, and the overall systemisation as a common issue, the complexity of the subject of this study requires that the work is roughly dividable in four categories.

●Firstly, the study concentrates on modelling the design processes for organising an extremely complex situation, mainly discussed in the second chapter. This part of the study, similar to the nature of an architectural design, completes gradually throughout chapters, starting from chapter three and ending with the final chapter of this dissertation.

● Secondly, the research concentrates on elements that enforce the design for sustainability

(i) on seismic aspects. In this context, the complex technical and procedural hierarchy concerning the sustainable housing in such situation is determined.

(ii) on characteristics from the desert. In this context the conditions for housing or re-housing in the desert are evaluated that follow from the socio-economic aspects related to the upper frame of the social and physical urban structure also regarding sustainability aspects. In this viewing leading aspects such as (building) design and construction details, in addition to material implementation are considered for sustainability.

(iii) the situation of combination of seismicity and desert characteristics is studied. Part of this step concentrates on the fact that seismicity and the desert environment do also result in interfering requirements. Therefore, the separate sets of requirements need to be integrated.

● Thirdly, the study intends to control the numerous segments of the complex design by further systemisation and sub-systemisation.

● Fourthly, through the research and design cases, analysis and the achieved knowledge, the thesis defines a new domain in the field of architectural design and building technology

● Finally, the work is evaluated to produce the knowledge model for global applicability. Schematic model of the relationships from the problem to the solution is shown in figure 1.1.

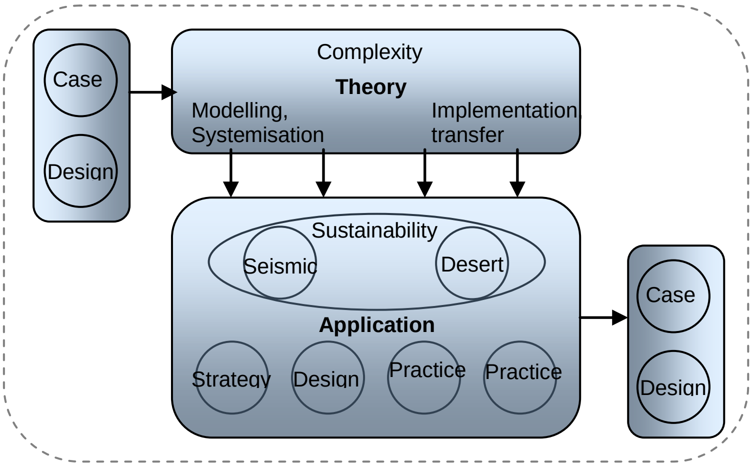


Figure1. 1. Schematic model of the relationship between the starting and end of the theses.

Furthermore, it should be mentioned that architectural design in a desert environment (in regards to several aspects) has been elaborated in some other studies (e.g. Dion et al., 1971; Guthrie, 1995; Pearlmutter, 2000, 2003; Pirnia, 2005; Bryan, 2005; Sadler, 2006). Therefore, the work is not quantitatively concentrated on the desert environment aspects much as the earthquake-involved aspects, but on an abstract level of overview. Moreover, the information in this study is presented bottom-up and top-down as one of the proposed approaches for designing in a complex situation. This approach plays the role of a general checking criterion in many occasions within the design processes as well. For rationalisation by the cases, local information is used to come to the decisions about the requirements. Therefore, it is necessary to come to an upgrade from local solutions to global solutions. The main requirements will be studied for that purpose and if necessary enhanced in an evolutionary process.

1.5. Organisation of chapters

This first chapter was a general introduction to the entire study and problem statement on two levels, shortly on the design level and more successively on the case level. Therefore, chapter two will focus on the problem on the design level, discussing the theory and hypothesis of the study. Based on the phases of the Glocal Process Model in a Complex Design Situation (GPM – CDS), developed in chapter 2, after a short background on the subjects of earthquake and desert in chapter three, the thesis will go in depth about them separately in chapter four and five. In chapter six, a new approach in systemisation, also based on the technology transfer will be proposed. The study concentrates on modern building construction aspects such as sustainability and the use of enhanced materials from six to chapter eleven. From chapter seven, validation of the process model continues while evaluation of sustainability as a result of chapter six will be done through practical design cases. Therefore, the fundamental theoretical issues of domains are mainly discussed in chapter two and partly in chapter six. Furthermore, the chapters, being sequenced according to the theory developed in chapter two, contain case studies. With which chapter 7 concentrates on proposal solutions on the urban, more specifically on a neighbourhood level. This chapter is followed by chapter 8, with a focus on proposing solutions for buildings. Structural components and elements are the main subject of chapter 9. To materialise the building elements chapter 10 discusses the sustainability criteria. However, the proposed case of materialisation is further completed in chapter 11, in which, as with other chapters, the focus is reducing vulnerability of the inhabitants of houses in a Sustainable Reconstruction of Houses in a Seismic Desert (SRH-SD) town. These have been modelled in the scheme of figure 1.2.

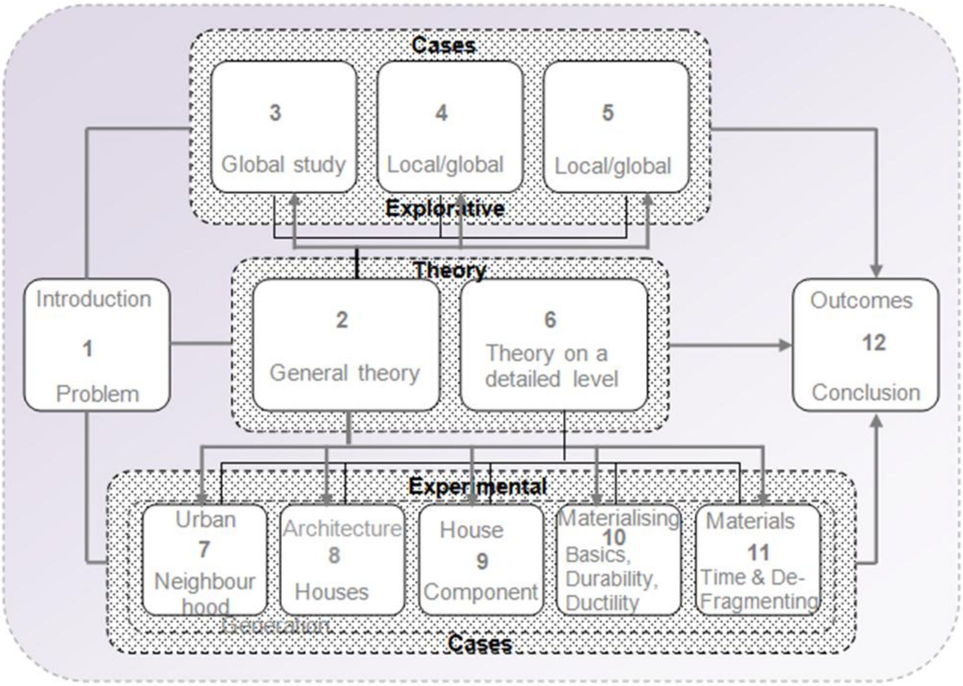


Figure 1.2. Model of the chapters and their main task.

CHAPTER 2

THEORETICAL FRAMEWORK

This chapter discusses critical design related problems, design variables, and knowledge requirements in a complex situation in order to integrate, assist, and enabling the procedure of solution finding for a design driven problem. As stated in the previous chapter, the problem is definable on two levels. In general, this design related problem of a complex situation should lead to a design process model. The specific case will be developed through Sustainable Reconstruction of Houses in a Seismic Desert context, SRH-SD. The next chapters will address the difficult situation of the houses on the mentioned case study level, while this chapter concentrates on theoretical and global level of design. Therefore, the general aim of this chapter is to base the theory, introducing, adjusting, and developing a simplified model to organise the complex design. The emphasis is on showing the crucial role of the understanding of a complex design situation, the complexity of which may be due to a combination of two or more extremely difficult conditions. These conditions may tremendously load the design and may affect all the design elements and aspects. Although such forcing issues are not the subject of the current chapter, their consequence on a broad scale (i. e. interactions, interferences, and conflicts), causing a complex situation, is the main subject. For evaluations, case studies to represent such severe conditions as seismicity and a desert context are discussed from the chapter 3 on. These extreme conditions and severe loads that influence the entire design are called design constraints in this study. Objectives on an application level include developing a global system that is as open as being suitable for the nature of architectural design. However, in the meantime, it has an organising role that controls and conducts the design segments from relevant domains in a multiple discipline towards the aim of preventing the obvious chaos.

Insufficient design knowledge, involvement and impacts of severe influences, in the meantime lack of appropriate methodologies for designing in demanding areas have been identified in previous chapter as some serious causes of complexity for the design situation. The knowledge gap for such a design situation will be covered and modelled throughout the various levels within the coming chapters and the case studies. Although the broadness of the knowledge area demands more than a limited research, the knowledge model in this study will aid further study and emerging knowledge qualitatively on a global level, and quantitatively on the scale of application and cases. Therefore, the current chapter discusses some critical issues in architecture as causes of failure for design solutions. This includes the role and the state of methods and systemisation in architecture as sources of some major problems, and will be finalised by development of solutions.

2.1. Background

Scientific approach, methodologies, and systemisation have been interpreted in contradiction with creativity and the nature of architecture. In order to show that this contradiction does not exist, first the past and present state of these in architecture will be discussed. It will be shown that instead, a proper systematic approach fits perfectly with architectural design. Yet, the developed system may not be applied immediately. In this development procedure, the similar existing knowledge and experiences are helpful and may be efficient. For this, an overview and summary of theory establishment procedure in architecture that sometimes have been studied from opposing points of view, will be proceeded. These analyses and background of the history of theories and other relevant issues are mostly placed within the frame of a complex design situation. Accordingly, the bases for required transferring and development of a model for a design process in complex situations will be established. Hence, because scientific approaches are effective to avoid the risk of failure in a complex situation it has also been briefly looked through.

Assessing value or specification to design variables is the main task of design. However, excessive number of relevant items from various disciplines in an architectural design causes unclear criteria for prioritisation and selection towards the design conclusion. This is different from engineering design, even building related engineering such as structural and construction design, estimations, time planning, and cost analysis. These engineers mostly work with precise numbers in prescriptive methods (calculations, simulations and modelling). Therefore, they harvest more reliable results, either negative or positive. However, the unpredictability of a design conclusion has always been expressed as uniqueness of it and thus, an important strength for its greatness. Nevertheless, for a complex design, although sticking to quantitative criteria, measuring, and calculations in the details may limit the flying wings of architects, qualitative criteria are crucial to avoid being lost in between various domains, several disciplines and too many segments. This is unavoidable in a modern design; where tremendous change of needs and wishes for human society (i.e. dynamic), and modern technologies are examples of necessity for teamwork. Besides, quantitative methods can be partly incorporated without limiting the design freedom.

In a traditional design the whole information and knowledge was supposed to be collected in the head of the architect. With which two different approaches existed. The first group supposed that the knowledge conducts the architect to come up with rational design concepts. Instead, some other people did not appreciate this knowledge, and relied only on intuitions. However, the greatness of an architecture depends on intuitions, but as ‘one’ important item not ‘the only requirement’ for it. This later issue is more obvious in the modern design. For example, in digital design many part of the design is being a result of an evolution processed by the machine. In this sense, the computer is not just a tool, but knowledge co-operator/collaborator. For both of these roles (i.e. tool or co-operator), although intuitions are very important, they play their significant role only if they apply correct, useful, and relevant knowledge in an appropriate organisation. Finally, the subjects of the following discussions can be summarised as:

● The situation of scientific, systematic, and methodical approach in architectural design,

● The state of knowledge requirement in the design, especially for a complex situation,

● The beginning and procedure of the phenomenon of methods’ interval in the architectural design,

● Requirements specific to modern complex deign (e.g. in a seismic desert situation),

● Method analysis and development of a backbone summery model,

2. 2. Methodology, scientific approach, and systemisation in design

Most problems (e.g. social and economic) related to buildings, such as cases mentioned in the previous chapter, derive from design inappropriateness. This may relate to the lack of information and knowledge prior to the actual design, design method, or to the design itself. Theories strongly support objectivity and rationality of design procedures, and normally apply to more than one case. For this, Bunge (1967) states that 'individual concepts apply to individuals, whether definite (specific) or indefinite (generic)'. Methodologies that include systematic design processes and cover objective methods are prominent for a generic design. Van Doesburg (1923) says, "in order to construct a new object we need a method, that is to say an objective system". For such methodologies rationalisation, integration, and systemisation, rather than limiting the freedom of the design, are important bases of the theory. The requirements for these principles have been also indicated in the studies such as Alexander (1996) and Salingaros et al. (2007). According to Bunge (1967), theories are important as they form the core of sciences.

Although a century ago great methodological turning point has initiated by Sir Patrick Geddes (Braco Music, 1982), it has very often been observed that theories for urban or building design have been avoided or not established. For instance Krabbendam (2001) states "architects are not used to theories that can be tested and discussed, they may be afraid that the design will be limited by the theories". Hence, many designers continue to prefer to see design as an intuitive, largely visual, and artistic process (Punter et al 1997). Besides, the rejection of design theories and methods is not restricted to the field of architecture, even though it seems less intense amongst product designers. In this context Cross (2008) states that he feels that: "many designers are suspicious of rational methods, fearing that they are a 'straitjacket', or that they are stifling to creativity. This is a misunderstanding of the intentions of systematic design, which is meant to improve the quality of design decisions, and hence of the end product.

2.2.1. Supportive knowledge for design

The growing theories, in similar fields, show that matters like supportive knowledge, and organisation are already recognised and incorporated in process descriptions. Lawson (2006) insists, for instance, that the map of design processes (e.g. schemes) should be supported by theoretical information. Similarly, Roozenburg et al. (1995) point at the incompleteness of a design process when it lacks proper theoretical support. Hence, they put forward that design is more than drawing: "Designers cannot do without operative knowledge. However, knowledge of the design process itself is not sufficient; designers should have the necessary substantive knowledge".

Bunge (1967) argues that there is a difference between scientific knowledge and common knowledge. He defines common knowledge as "the accumulation of loosely related bits of information". This preference for scientific knowledge can also be found in the work of Schön (1986) who mentions that excellent professional practitioners solve well-formed instrumental problems by applying theories and techniques that are derived from systematic, preferably scientific knowledge. Notwithstanding the importance of knowledge, the importance of a carrying theory is judged to be even higher. According to literature, theories are fundamental support for the achievement of an ideal rationality. They are expected to deliver a coherent systemisation of grounded and testable statements (Bunge, 1967).

Irrespective of the obvious need for knowledge, structuring, and systemisation, architects often reject theoretical or scientific supports, even well-known architects as Hertzberger (2002) state "Inventiveness is an inverse proportion to knowledge and experience. Knowledge and experience keep forcing us back into the old grooves of the old record of meaning". Lawson (2006) adds to that "our best designers are more likely to spend their time designing than writing about methodology." The idea that science and theories are to the opinion of many architects in conflict with creativity is discussed in several studies (Cross, 1975 and 2004/2008; De Vries, 1984; Jones, 1992; Klassen, 2003, Shahnoori et al., 2010). The main argument is that every design is unique and cannot be seen as a process of problem solving and therefore not be described in methodology. This argument leads to the conclusion that some architectural solutions are the result of intuitions and visualisations, in which problems are dealt with likewise. This is very unfortunate for all those people on the planet that have to suffer from inappropriate design solutions.

Even though research shows that organisation and planning are very important aspects in design (Van Aken, 2005), designers tend to underestimate the potentials of professional design processes. In this context, Van Aken (2005) states that: "the potential of professional process design to produce effective and efficient design processes is still underestimated as well as the potential of prescriptive design knowledge to support that professional process design." This leads to the conclusion that without systemisation of the design processes the reliability of the interpretations and conclusions is seriously hampered. Nevertheless, practice shows that in many cases designers still choose to individually interpret the necessary design steps instead of coordination along theories and scientific systemisation. This individual approach to design creates the risk of blurring the professional vision. This was formulated by Schön (1986) as: "Depending on our disciplinary backgrounds, organisational roles, past histories, interests and political/economic perspectives, we frame problematic situations in different ways. Specially, for a modern task organising the design processes assists to find clearer visions."

2.2.2. Organisation in modern and traditional design

According to Van Aken (2005), organising and planning the modern design processes differ significantly from traditional approaches. Traditionally a product, and particularly a building, followed an evolutionary pattern; every new product was in most aspects similar to the previous one. In modern design products tend to be rather more revolutionary (i.e. entirely new) than evolutionary. Therefore, in many cases there is no experience or knowledge from the past that could assist in the design of the new product. In architecture this newness of designs and incompleteness of the old and traditional ways is also occurring. Moreover, in this field particularly, many new functions have been added (e.g. interior design, cladding and facade) while new methodologies, construction and design methods have not been equally established (Kalay, 1992). This unbalance is a clear indication that there is a requirement for new methods as going back to the mentioned old habits would decrease the positive effects of contemporary building design resulting in opportunities for the transfer of new technologies and methods.

According to Bunge (1967), the consciousness about methods starts with the failure of a personal method. This suggests that many architects will only become conscious about methods when their own method is obviously failing, but for that, they have to be willing to notice the effects first. Raising the consciousness of such architects for design methodologies is vital because building designs demand more than just aesthetic appreciation (Lawson, 2006). Especially in complex situations that are more demanding to handle and at the moment have the highest risk for design failures, the need for architects to follow scientifically based methods is crucial.

Architectural design is a highly complex and sophisticated skill as it is composed of art, science and technique (Sariyildiz et al., 2003; Achten, 2004; Lawson, 2006). Modern architectural projects are often multidisciplinary and of large scale. According to Van Loon (1998), the involvement of several experts in the decision- making stage adds extra complexity to an architectural design. Carrara et al. (1991) also point out that the difficulty in architectural design is generally magnified by the growing complexity of the buildings together with the growing complexity of the process that leads to their construction and management. Van Aken (2005) notes: "As the scale of design processes increases, as well as their knowledge's intensity and organisational complexity, the traditional approaches may no longer suffice." Ferguson (1993) states "engineering design is a contingent process, subject to unforeseen complications and influences as the design develops". Hence, Garcia-Diaz et al., (2007) citing Rattle (1968), point at the nature of the design problem, which makes it complex from the beginning. They state the definition of the design problem or scope of work is a most difficult undertaking, because to define the design problem is tantamount to indicating its solution. In fact, design problems are often called wicked problems (Churchman, 1967; Rittel, 1972; Bazjanac, 1974) because of their complexity and intractability.

These suggestions lead to the idea that the complexity will be further raised by any circumstantial complication that interferes with well-known solutions. Such complications might be referred to as design constraints when they interfere with all aspects of designing and building (e.g. use of sources, selection, and prioritisation). In case there are two or more design constraints interfering with a specific design project the resulted complexity might become too high to reach for any conclusion. This interference could go up to the point that the design utterly and completely fails and the whole building process collapses

2.2.3. Methods of dealing with complexity and teamwork in modern design

Based on the arguments mentioned, it is expected that theoretical bases and methods are likely to support the overview of the process (Van Aken, 2005) and the conclusion of complex projects. Bunge (1967) writes "Methods are means devised to attain certain ends". This can be interpreted as if methods are supportive in ensuring the goal. When the number of elements involved in a design has become too large, it becomes insufficient and risky to rely on traditional methods (Van Aken, 2005). Cross (2008) adds to this that "there are also too many errors made with conventional ways of working, which are not very useful where team work is necessary too". This confers also with the findings of Carrara et al. (1991): "The need for constant and extensive professional updating, and the growing difficulty of communication between experts in different fields (even those that are seemingly closely allied), further complicate the building design process." In the general design field Cross (2008) says "many modern design projects are too complex to be resolved satisfactory by the old conventional methods". An important point in his view is that the designer's traditional approach is to try to move fairly quickly to a potential solution or a set of solutions, and to use these as a means of further defining and understanding the problem.

2.2.4. Modelling, the role of intuitions, and effects of architecture on human

Based on the above discussions it can be concluded that methodologies for modelling, that organise and reorganise the design processes and knowledge are professional supports for designing in complex situations. Roozenburg et al. (1995) mention three conceptual tools to organise the design process effectively and efficiently:

● Models of the structure of design and development process;
● 'Methodics' being the body of rules and methods for (parts of) the design process; not only descriptions of rules and methods but especially recommendations for their meaningful application;
● Concepts as they are important for the thinking about and studying of design processes and for the communication between experts,

Several models that describe the design process are available (e.g. Cross, 1994; Roozenburg & Eekels, 1995; Pahl & Bietz, 1996; French, 1999). These provide guidance to deal with the complexity of the design process. However, the methodological systemisation needs to be appropriately grounded for the design processes. Most of the models describe product design or have a much more general view on design. There are currently not models that provide an accurate support for particular complex architectural designs. Especially the projects that face design constraint are not sufficiently supported by those models. This leads to the conclusion that even though the necessity of theoretical supports for designing in extremely complex situations has been well argued these supports have to be emphasised and re-modelled to suffice architectural design. A method for design in a complex situation should offer architects the insurance that their artistic wishes are not neglected when using the method. It should offer guidelines that prevent them from creating inadequate and inappropriate designs in complex situations while the acquired knowledge through experience should be appreciated as well.

Architectural design (i.e. urban, building and construction design) plays an important role in human's life (Fry, 1992). Regarding this issue, Lawson (2006) says "Designers in this field generate objects or places, which have major impact on the quality of life of many people." Mistakes can cause seriously inconvenience, may well be expensive, and can even be dangerous." Duijvestein (2005) confirms this when he states that designers of districts, neighbourhoods and buildings are not only constructing objects, but are contributing to conducting the lives of dwellers and users. The role of architectural design in human life differs substantially from other design fields, and should therefore, be addressed differently. Existing models that are not generated from the direct field of architecture and do not concentrate on extremely complex design situations, are not sufficient. However, they can be used to serve as a basis for the development of a new theory and model.

2.3. Historic principles, practices, and procedures

Technology has advanced in a rapid pace during the last decades. Collins (1965) and Benson (1996) have both indicated that technological development of the last century is comparable to all previous technological developments. Benson specifies that the improvements from 1850-1950 are bigger than those in the previous 2000 years are. It can be argued that the improvements after 1950 are bigger than those of the previous 100 years. This means the field of architecture should put a lot of effort in keeping up with these developments. It can also be argued that turning to methods like 'craft- oriented design' is not the appropriate way to do that.

Cross (2002) refers the emerging of new design methods to the simultaneous emerging of knowledge and development in some areas in the 1960s, which derived from the problem solving attitude in the post war (WWII) period. Of course, the novel approaches of 1960s acted as igniting the debates on knowledge, logic, system and methodologies in design, by studies as Hansen (1974). Examples of the mentioned developments about the design are shown in table 2.1.

Table 2.1. Examples of developments in design methodologies around 1960s (source: Pahl/Bietz, 1995)

Year	Author	Theme/Title	Country
1953	Bischoff, Hansen	Rationelles Konstruieren	DDR
1955	Bock	Konstruktionsystematik-die Methode der ordnenden Geschtspunkte	DDR
1956	Hansen	Konstruktionssystematik	DDR
1963	Pahl	Konstruktiontechnik im thermischen Maschinenbau	DE
1966	Dixon	Design Engineering: Inventivenss, Analysis and Decision-Making	USA
1967	Harrisberger	Engineermanship	USA
1968	Roth	Systematic der Maschinen und ihrer mechanischen elementaren Funktionen	DE
1969	Glegg	The Design of the Design, The Development of Design, The Science of Design	GB
	Tribus	Rational descriptions, Decisions and Design	USA
1970	Beitz	Systemtechnik im Ingenieurbereich	DE
	Gregory	Creativity in Engineering	GB
	Pahl	Wege zur Losungsfindung	DE
	Rodenacker	Methodisches Konstruieren (4th Edition 1991)	DE
1971	Fench	Conceptual Design for Engineers, 1st Edition (3rd Edition 1999)	GB
1972	Pahl, Beitz	Series of articles, fur die Konstruktionspraxis (1972-1974)	DE

These finally resulted in another new approach that Hubka et al. (1987) described as “Engineering Design” which was again a step forward in systematic design. Despite the aims of the roaring activities in design and design methodology and the tendency towards science and theories, the 1960s are mostly recognised for the Flower Power movement. The gained insight and knowledge that it is valuable to support design by theories and established methods was a significant and constant achievement. The potentials and necessity of design methods, especially in engineering, product and industrial design, was soon proven (e.g. Fox, R. L. 1971; Furman, T. T. 1982; Hubka, V. 1983 in computer and system engineering, and Optiz, H. 1965; Tjalve, E. 1973 in industrial design). As a result of this proof the evolution of design methods continued albeit at a slower pace. This effect was described and mentioned by several researchers (Schön, 1983; Cross, 1984; De Vries, 1984; Pugh, 1991, Cross, 2002). The scheme in figure 2.1. shows the most remarkable steps in methodology and the development of the subject as research matter.

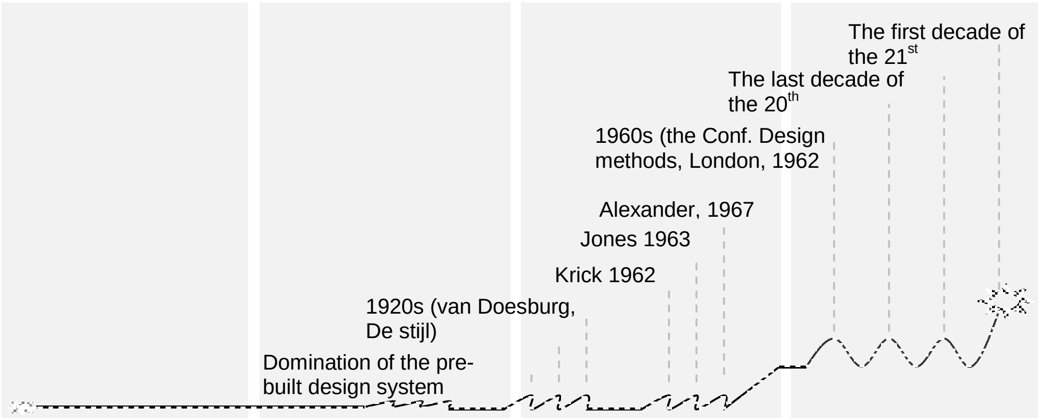


Figure 2.1. Historical evolution of design methodologies

Gradually the point was reached in which design methodology was used and explored for the possibilities of analysing or even predicting certain developments in design (Roozenburg et al., 1995; Schön, 1967; Jones, 1977; Cross, 1981; Glynn, 1985; Hubka et al., 1987). This aim for total rationalisation and dissection of the design and its process to gain more advantages became more and more the core business. Even though this approach has proven to be significantly valuable to the more contemporary design fields (e.g. industrial design), it may seem too far off track for architecture, because it has an ancient touch with traditions and mastership. The theories that aim at supporting architectural design should consider this background.

2.4. Evaluation of the dominant methods used in the profession

The twentieth century brought enormous developments in the available technologies, which was started after the industrial revolution (Cross, 2008). It allowed designers to experiment and innovate on all levels. Because of this rise in options and innovations the complexities in design grew at a huge pace. The complexity and the newness of the designs initiated the search for new design tools such as graphical computer programs. Since the complexity of products has outgrown the brain capacity of most designers, the trust in the supporting computers became immense. Sometimes this resulted in extremely unwanted failures such as the one with the Apollo 13 space module (Ferguson; 1992).

Since the start of the digital era, the computer has also intervened in the architectural practice. Vernacular architecture is changing into more daring and radical architecture, the distance between the builder and the architect has been enlarged. Besides, the new styles, for instance Sustainable

Building or Free Form Building, have more innovative design elements than one builder can handle and teams of specialist builders are needed to realise the designs. This change in profession of builder and architect might lead to a significant rise in the amount of miscommunications or misinterpretations (van Loon, 1998; Lawson, 2006; Shahnoori et al., 2010), which sometimes endangers the quality of the building. In this procedure, the role of the architect changed from cooperative craftsman into directing designer. In the more extreme cases the artistic inspiration of the individual architect overgrew other aspects as functionality and human well-being. This transition also raised the number of inappropriate designs. In these designs the buildings gradually lost their human scale and generally became mostly architect and sometimes technology- centred.

2.4.1. Orientation of the problem, the central role and intuitions

Generally, the 'design by drawings', in the way that it was experienced, sometimes ended in failures (Cross, 1984; Lawson, 2006). Nevertheless, the drawing method has great qualities, if it is not to be the only method applied in the entire design process (Ertas, 1996). Because of the central position of the architect in the design by drawing system, it gives an enormous freedom that seems not to be limited by anything than his intuitions (Lawson, 2006). This unlimitedly acting on intuitions may be the starting point of emerging possible mistakes. Although intuition is important for an innovative design (Alexander, 1964; Simon, 1977; Schön, 1983; Johnes, 1992; Hertzberger, 2002), generalising it as 'everything we need' creates a random-wise risky design conclusion.

Another problem associated from the architect centred design conclusions was that the succession or failure of the design conclusion is highly dependent on the designer. Hence, due to the involvement of a large range of new and old knowledge, contribution of several experts (i.e. team work) in an architectural design is unavoidable (Ferguson, 1993; Ertas; 1996; van Loon 1998); whereas, in the 'design by drawing' team work is problematic (Cross, 2008). However, this method, if applied correctly has great potentials as well. For example, Leupen et al. (1997) states "when designers or critics must describe how a design is composed without the aid of drawings, they resort to technical terms". Regarding its potentials, this system can be used as a counterpart in the design methods with for instance a new approach. This progressed approach is to limit the drawings as a language (e.g. a conversation or communication method between the experts) for design or for conceptualising the design (Ertas, 1996). Other applications by new developments in the system to make it more inclusive are also possible.

Referring also to many scientists (e.g. Ferguson, 1993; Lawson, 2006; Cross, 2008…), it can be stated that the modern design has generally potential for complexity. Due to many new design tasks (e.g. producing a design conclusion) that the designer never experienced such cases reliability of the intuition is random-wise and not guaranteed. The risk becomes more dangerous in cases that for instance the first prototype is the real sample of the product such as airplanes (Cross, 2008). For example, a severe sensitive case for architectural design is battling with earthquakes while acquiring the normal design task in the conclusion. Beside, new materials, new machines, technologies, modern ways of living and therefore new desires, and so on are reasons of the need for developing new design methods. Alexander (1977) argues that contemporary methods fail to generate product that satisfies the true requirement placed upon them by individuals and society, and fail to meet the real demand of real user, and ultimately fail in the basic requirement that design and engineering improve the human condition.

Many failures occurring in modern architectural design have already occurred in some other fields (e.g. industrial and product design). The causes of such failures are also similar in many cases. For example, the override of manufacturing requirements to users' need is very similar to a leading position for construction and assembly facilities. Therefore, as it was experienced and proven in similar fields, for complex architectural design a grounded theory and a design methodology can effectively decline the risk of failure as well.

However, as intuitions are necessary but not sufficient to guarantee a complex design conclusion, the design methods cannot guarantee a great design conclusion themselves (French, 1999), too. Hence, although design by drawing is not sufficient to cover the entire process of design, it is an appropriate tool for conceptualisation, which is the core of the design. Intuitions are crucial prominent to achieve an appropriate design conclusion. Involvement of visionary and artistic aspects and intuitions does not cause any interfere or conflicts with establishment of theories, methodologies, and systems .Therefore, optimum solution is to incorporate these all in the design methods. Similarly, French (1999) says "Design methods cannot replace the gift of talented designer, nor provide step by step instructions for the production of brilliant designs". They can improve the quality and speed of the capable designer's work. They may also speed the development of the young designers and, perhaps most important of all, improve the co-operation with specialists inside and outside the design office. He roughly classifies the ways these help into:

1. Increasing insight into problems, and the speed of acquiring insight,

2. Diversifying the approach to problems,

3. Reducing the size of mental step required in the design process,

4. Prompting inventive steps, and reducing the chances of overlooking them, and

5. Generating design philosophies (synthesising principles, design rations) for the particular problem in question.

The current study, analogous to the studies of Hansen (1974), Hubka (1987), Jones (1992), Ferguson (1993), Ertas (1996), Alexander (1996), Moughtin (2003), van Aken (2005), Lawson (2006); Salingaros (2007), Cross (2008) and so on emphasises that design theories, new methodologies, and process models are highly required, and are crucial for complex situations. Of course, these need to include an appropriate place for intuitions and visionary aspects through the design processes.

2.5. Towards modelling an architectural design process

It has been already indicated that for a demanding and complex design situation, to avoid the chaos, and to structuring, organising, and taxonomising the design, modelling the design processes is very important (Garcia-Diaz et al., 2007). In addition to the fact that modern architectural design is complex, there are situations that involvement of two or more constraints causes an extremely complex situation for design. A severe case representing such situations is a design context that is dealing with seismicity and the limitations existing in a desert environment. For such situation in addition to organising the design processes, segments, and elements in a clear system, the content knowledge that this particular design entails need to be identified and become available.

To ground the mentioned theory and apply it to support the design, aiming at a clearer conclusion, one of the basic steps is to develop a process model for design in demanding situations. This model should be operational and precise, it needs to be concrete enough and specific enough so that it functions practically (Alexander, 1964). However, in the architectural design field a fixed detailed model does not practically survive (Lawson, 2006). The combination of disciplinary systemising and an architectural way of organising the impression of Alexander (1979) seems interesting. He states: "we must first learn a discipline which teaches us the true relationship between ourselves and our surroundings. Then, once this discipline has done its work, and pricked the bubbles of illusion, which we cling to now, we will be ready to give up the discipline, and act as nature does. This is the timeless way of building: learning the discipline and shedding it".

Although no models that provide a thorough support for architectural design in a complex situation facing two or more severe constraints were found, studies as den Otter (2000) indicates complexity, but as a side issue. Furthermore, these models sometimes have been categorised differently as well. For instance the model developed by Van Aken (2000) is domain independent while the one by Bax & Trum (1996) is set according to domain theory. A number of such studies are shown in table 2.2.

Table 2.2. Examples of available models for design process by the name of developers

Proposed process model	
Action-based	Phase-based
Archer	Asimow
Cross	Clausing
Harrsi	French
Jones	Hubka
Kirck	Pahl & Beitz
Marples	Pugh
Wilson	Ullman
Roozenburg & Eekels	VD!2221
Leupen et al.	Watts
Buijs	Bax & Trum
Van Aken	Moughtin

*method applied by Tate & Nordlund (1996) has also been incorporated

The simultaneity, taxonomy, and organisation of the components of a design process differ in various models. For example the model introduced by French (1999) is one of the earliest and most cited references for design. The bases of French's model are on four activities including: (i) Analysis of problem, (ii) Conceptual design (iii) Embodiment of schemes (iv) Detailing (French, 1999), and he developed this basic series of items with further details. However, other studies (e.g. March and Smith, 1995; Kalay, 1994; Roozenburg et al., 1995; Leupen et. al, 1997; Buijs, 2003 ...) have different approaches. For example Ferguson (1993) opens another view to design processes. He states that the process of design and construction is the same, no matter how small or large, how simple or complex.

However, Carrara et al. (1991) defines two fundamentally different approaches to design that can be adopted for the purpose of developing computational systems to support design including (i) prototype refinement and (ii) prototype generation. In this division, the prototype means the developed design solution. The first approach is based on the adaptation in context of a previously developed design solution. In the idea of Carrara et al. (1991) this adaptation eliminates much of uncertainty concerning performance prediction and evaluation, and provides a holistic framework for solution finding. They call this approach 'Beaux Arts tradition'. The second approach that they call 'Bauhaus approach' is a solution finding- process and is object- oriented. However, Carrara et al. (1991) later combine them in the statement that the two approaches are complementary, practically indivisible, and often interchangeable.

For developing an organising system for modelling a complex design, a combination of these two approaches is preferable. There can be two ways of combining these two approaches together. The first is similar to the method that Carrara et al (1991) applied. In the second way, which is 'having a data/information- driven approach in addition to an object- oriented approach', does not necessarily need a previously developed prototype. However, such combination without an existing prototype requires a systematic approach. These rules and laws may be derived from experienced and designed buildings, such as design standards and building regulations. Since architecture's relationship with human life that substantially differs from other design fields, issues should be addressed with care when transferring these models in the architecture. Finally, a similar attitude to the scientific approach of the current study has been found in Moughtin (2003). The similarity is not only in his scientific approach to the design but also to the modelling of the design process.

2.5.1. A back-bone for modelling the complex architectural design processes

In modelling the design processes a fixed concept does not fit the nature of architectural design field. Different projects may require variations that may include additional steps or elimination of some other steps (Ertas et al., 1996). Similarly, Ferguson (1993) states the process of engineering design is not a totally ‘formal affair’. As it was also mentioned in the study of Leupen et al (1997) all aspects involved in design do not arise in a fixed, logical order. They further state “designing is not a linear process with a specific task leading to one and only one solution. Therefore, a summary model as a backbone, acting like a binder for the design processes, which in the meantime, is very general to include variety caused by the nature of architecture, is more applicable. This reasonable model depicts what each of the team members must know about the system, and allows them to place their work and their responsibility (Knopfel et al. 2006). The generality and openness of such a model increases its flexibility for implementation in different cases. Therefore, the present study in addition to modelling of the knowledge content, intends, to develop a process model on a similar basis that have been argued by Cross (2008). Through the establishment and validation of this model the emerging knowledge model will also become available.

In the model introduced by Cross (2008) four key stages are: (i) Exploration, (ii) Generation, (iii) Evaluation, and (iv) Communication (fig. 2.2). Of the strongest points of this concept are its potential of “generalising capability” and its comprehensive-ness. Hence, because it is flexible and open (to incorporate the artistic freedom of architects), it can be adjusted to architectural design process for a complex situation, but needs rearrangement (Shahnoori et al, 2010a).

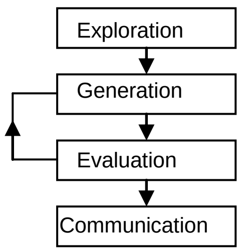


Figure 2. 2 the summary model for design process, introduced by Cross (2008)

In the procedure of developing a process model for a complex situation as in a Sustainable Reconstruction of Houses (SRH-SD) a combination of top-down and bottom-up methods assist the iteratively completing of each phase of the design processes. Hence, the potentials and advantages found in the mentioned studies are useful and adjustable with the discussed process model of Cross (2008). Furthermore, the well-known 4p’s model, after the 3p of Spreckley (1981) and Elkington (1994), introduced by Duijvestein (2004), comprising four essential items of People, Planet, Prosperity, and Project; can play the role of criteria and source of analysis for a backbone summary model inside the frame of sustainability (i.e. discussed mostly from chapter 6). Phases of the new adjusted model for the complex design are set according to the numbering in table 2.3.

Table 2.3. A backbone process model for designing in a complex situation

Phases	Actions	
1	Need	
2	Exploration	Investigation
		Analysis
		Theoretical synthesis
3	Generation, alternative concepts,	
4	Evaluation, finalising the alternatives	
5	Optimisation, communication and detailing	
6	Conclusion	Design solution
		Knowledge conclusion

2.5.2. Assessment of the phases and steps in the backbone model

"A model is an abstraction of an existing or a planned system which comprises only those aspects which are relevant to its purpose. A system model can be used for example to communicate, construct, or analyse. This abstraction heavily depends on the purpose of the model and its addressees" (Knopfel et al. 2006).

A scientific research typically starts with a problem (Bunge, 1964). Instead, an architectural (scientific) design normally starts with a need (French, 1999). In science, formulating the problem is essential, while in design recognition, awareness, and studying the need (Ertas et al., 1996). The problem formulation in an architectural design process comes after the need, but not at the very first step of the starting the design (Shahnoori et al. 2010a). The need is human desire, either the client or the artist's, which may not involve any problem at the beginning but as a consequence. The schematic order of general processes in architectural design is shown in figure 2.3. In the cases that the need is the problem, the process can still start with need. Similarly, Archer (1979), Pugh (1991), French (1999), Erden (2005), and Zeiler (2009) commence their model with the need. Pahl and Beitz (1984), Pahl et al (2007) also planned a design process model, which starts with a task instead of problem.

Therefore, the first phase of an architectural design can be generally stated as need. A similar approach was found in French's (1999) design model. French's design process, not only starts with the need, but also emphasises on the importance of the problem (which can be attributed as investigations in the architectural design) dividing it into two different stages of problem statements and analysing the problem (French, 1999). With which all the explorations, investigations, and analysis start after the need (Leupen et al., 1997).

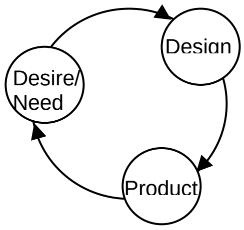


Figure 2.3. Order of general processes in architectural design

Second phase of design, Explorations

Although Cross's (2008) model starts with "Exploration", in an architectural design (apart from the rare exceptions), following the desire/need, investigations and explorations in the related fields, domains, disciplines, criteria, and aspects start. These are essential bases to organise a successful design (Shahnoori et al. 2010b). Similarly, Alexander (1964) and French (1999) emphasise on the importance of inclusive investigations and explorations prior to design. Alexander indicates that many items involved in a failure or weakness of design are due to unclear vision of the designer about the whole situation, interactions of the involved items, constrains, and conflicts. In a comparison with science, Bunge (1967) mentions the investigations and information in the first phase of research (i.e. within structuring the problem) as essential part of this process. Ferguson (1993) states that insufficient information may cause a misjudge in the selection between the alternative concepts. According to Pugh (1991) poor design specifications lead to poor design, good design specifications do not necessarily result in the best designs but they do however make that goal at least attainable. This exploration phase can be interpreted as fundamental documentation for the design. It must be considered as an evolutionary, comprehensive, written document (Pugh, 1991). For example for the dynamic evolutionary approach of the design specification, he says, "If there is a good reason for changing it then change it." The mentioned importance has been also indicated by some other studies such as Rittel et al. (1973), Mitchell (1975), Simon (1976), Schön (1985, and 1987), Pugh (1991), Kalay (1992), Roozenburg et al. (1995), Ertas (1996), Achten (1997), Leupen et al. (1997), Lawson (2006), Cross (2008). Therefore, after the need stage the exploration phase is an appropriate step for an architectural design process model for a complex situation. This exploration phase can provide a strong base for the conceptual design, which comes next.

The third phase in a complex design

In the proposed model in this research, similar to Cross (2008), the next phase after the "exploration" is "Generation". Within the generation phase, the alternative concepts are generated. For an architectural design, conceptualisation is very important; it is the core of the design (Leupen et al. 1997). Lawson (2006) calls the imagination and conceptualisation 'ability to design'. According to Lawson (2006) a good engineer requires considerable imagination and can often be unpredictable in its outcome. Ertas (1996) calls this phase 'the preliminary design'; similarly, Roozenburg et al. (1995) call this phase 'embodied' design because "it embodies decisions on the geometry and material of the new product". The talented designers are more identified at this step, in which intuitions are more involved (Ferguson, 1993). This conceptual stage of any design is concerned with synthesis (Pugh, 1991). According to Ferguson (1993), although it poses a low academic status of visual thought, it is an intrinsic and inseparable part of engineering. If we accept the process of design as a solution- finding process the design concept will be the phase of introducing the preliminary solutions. In which, "a solution principle is being worked out to the extent that important properties of the product- such as, appearance, operation and use, manufacturing and costs- can be assessed in addition to the technical- physical functioning" (Roozenburg et al. 1996). Therefore, this phase locates after the data, information, and the required knowledge have been collected and analysed, thus locates after the exploration. This third phase of the design processes requires an evaluation in the next phase.

The fourth phase in modelling a complex design processes, Evaluation

As it was shown in the scheme of figure 2.2, Cross (2008) arranged the 'evaluation' phase after the generation phase. In the process of a scientific research also after selecting the hypothesis solution for the problem its value should be tested (Bunge, 1967). Similarly, in an architectural design, after selecting the alternative design concept it should be evaluated. According to March & Smith (1995) "research in the evaluate activity develops metrics and compares the performance of constructs, models, methods, and instantiations for specific tasks. Metrics define what a research trying to accomplish". The values that a design is aimed at and the unpredicted values coming from the intuition and aesthetic aspects in the selected alternative concept are tested in the evaluation phase. In the study of Schön (1985) the evaluation phase for architectural design students is the step of critics. He further considers the requirements for norms to evaluate the design essential for an architectural design.

The necessity for evaluation phase in the general design process has been mentioned by a number of studies including Simon (1969), March et al. (1976), Schön (1985), (Kalay, 1991), Ferguson (1993), Roozenburg et al. (1995), Leupen et al. (1997), Moughtin (2003), Galavan et al. (2008). In the impression of Ferguson (1993) evaluation is the qualitative and quantitative judgment of human for a successful design states, and 'computerised illusions of certainty do not reduce the quantity or the quality of human judgment'. However, type and frequency of evaluation that differs from one case to another is another relevant issue for the design process. For example, Leupen et al. (1997) calls it testing against requirements for rejection or adjustation that at every step the designer examines the possible consequences for sequent steps and creates margins for solving whatever unforeseen problem may occur. At every step he or she also looks back to see whether the original concept holds or requires modifications. The way of evaluating depends also on the number of the involved items. Similarly, Pugh (1991) states 'depending on the complexity of the project, it is not untypical to carry out five or six evaluations and comparisons in all, before a single concept emerges, which is then carried through to final design, detailing and manufacture'. The required modification recognised during the evaluation, mentioned also by Leupen, is optimisation of the design as the next stage, after the evaluation phase.

Optimisation, the phase of communication and finalisation of the process model

The last phase of Cross's (2008) model is "communication". Although this is not stated in most architectural design, it is also an important step of the "evaluation" phase. However, some designers take it into account, although not directly with this name (e.g. Schön, 1985; Alexander, 1985; Salingaros, 1998). By mentioning 'there is no place in an ideal engineering system for unpredictable actions, either by machines or by people', Ferguson (1993) involves the importance of the evaluation while also indicating communication. In this way he included communication as a part of the evaluation phase. Siegfried Wendt (1974) identified the field of human communication as the main source of problems for software development (Knopfel et al., 2006).

However, the communication in the architectural design may differ from one to another. For example, in the 'Mexican project of Houses' Alexander (1985) involved the user from the beginning of the design to the end of the production process. In this way in the whole process, communication was included. An opposite example can be houses designed by Le Corbusier (e.g. Chandigarh), in which the user was not involved in any stage, but the governmental organisation were communicating with the designer in the last phase of the design (Cohen, 1992). Similarly Knopfel et al. (2006) state "by modelling the knowledge can be recalled, and the model can be used to communicate the information with other people". Finally, after experiencing failures, many architects evolved a final phase in their design as optimisation (Shahnoori et al. 2010a). Because optimisation is for perfection of design, it covers crucial items as communication.

The communication phase of Cross's model, can be transferred into complex architectural design process model as a part of "Optimisation" phase, located after the evaluation phase. As the language of the conceptualisation phase can be for instance drawings the language for "optimisation" (i.e. including communication) may be prototyping. This is detailing and a sampling of the product before the building is made. In either case this phase, called "optimisation" phase in the complex design process is the final step before the conclusions. Ending the process model up with the "design conclusion" is referable to the final 'solution' in the Archer's (1984) model. Similarly, Roozenburg et al (1995) include a final phase as approved design. However, the achieved conclusions are not only the design concepts and solutions but also the acquired knowledge that has been added to the basic knowledge within the iteratively completing design processes. This new knowledge may be referred to as an indirect conclusion.

Although these phases are iterative and can be completed only at the end of the design, most relevant activities of each is done or at least defined in the specified phase. The design that ended with these two conclusions entails its characteristics that even though can be used for a new design but not directly. Therefore, the new design similarly starts with its specific need and goes through the whole processes again. However, the next design will start with a different or progressed background even if this difference may not be considerable. With this it can be assumed that every new design is being built up on the bases of the conclusions of the design as well as the added knowledge emerging in the previous design project (positively or even negative). Therefore, the design processes may even be presented as a series of processes that act independently, but can greatly benefit from the previously experienced challenges.

2.6. Summary and conclusions

The problem stated in this study was defined on two different scales of case (discussed in previous chapter), and design level in an extremely complex situation. Within the discussions in this chapter, this problem on the second scale of design was segmented and analysed on theoretical level. In addition, the design constraints were examined, such as, sustainability and the case of the seismic desert. Of course, systemisation and organising the design are of general, theoretical solutions that go to the action in practical cases throughout the next chapters. Although most discussions in this chapter are project independent (at least to a large extent), the theoretical synthesises are to provide practical solutions for design on case level as well. Other important issues are:

- Circumstantial complications as design constraints can severely influence the design.

- Increase of complexity in a design due to extreme situations such as the situation, in which more than one severe constraint impacts the entire design and cause an extremely complex situation

- Modern design tools require new approaches, such as:
●Digital design approaches, modern construction techniques, and awareness/communications …
●Dynamic and change in societies
●Variations and possibilities in artefacts…

In summary:

- According to the arguments mentioned, and according to the new functions in buildings, for architectural design in complex design situation new methods are absolutely necessary.

- The key issue in this chapter was criticality of understanding of design and its crucial requirements on global level in a complex situation. This understanding is also due to the distinction between the traditional and modern design.

- Grounding modern theories and scientifically based systems do not have contradiction with architectural design, but also they are crucial for strengthening and enhancing the design in demanding areas.

- In a scientific design or generally an architectural design, knowledge base is suitable. However, being knowledge-oriented in addition to have a system approach is effective for designing in a complex situation.

- Systemisation is an appropriate way of organising a design in complex situations in order to avoid probable failure. A systematic approach does not interfere with intuitions and creativity; instead, it provides a more relaxing situation in a complex environment for novel design ideas.

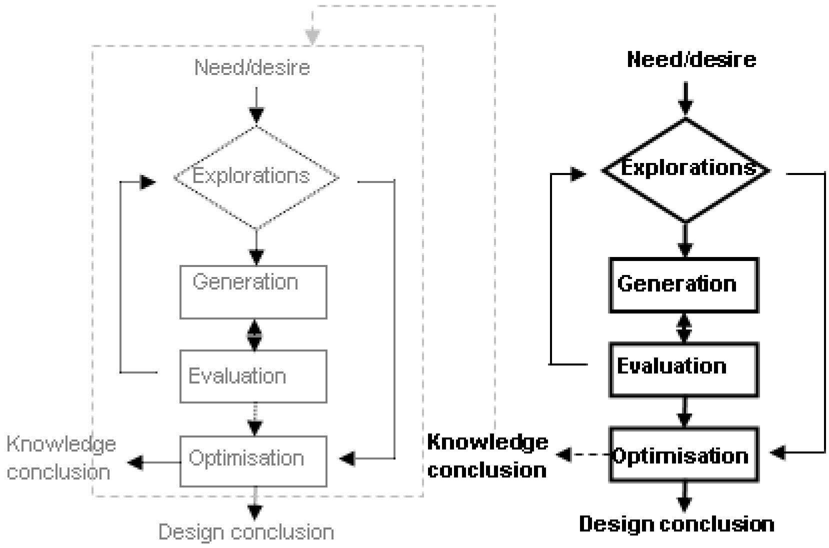
- A systematic approach for design helps the design to grow from ‘an architect centre/architect dependent’ phenomenon to value centre/ independent system; thus, it is complete on its own.

- Breaking or dividing the complex problem into sub-problems is appropriate to deal with complexity of the design situation. However, possible conflicts may appear between the solutions.

-. Although architectural design is an interactive and interconnected procedure, distinction between several phases of design, in addition to organising the complex situation, is a checking criterion.

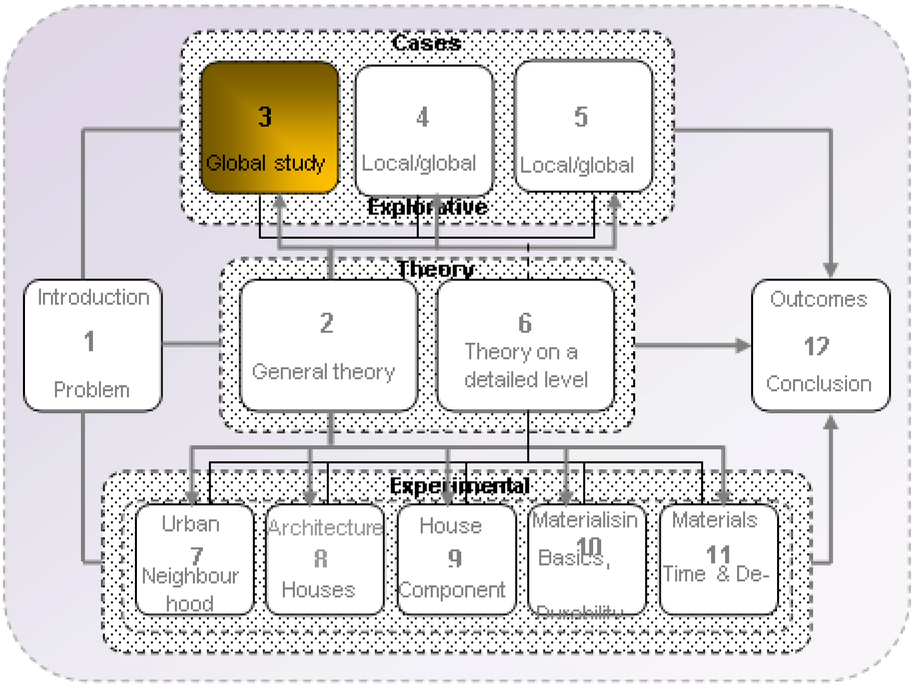
- Transferring the methodologies into the architectural design needs to be adjusted with design’s nature. The main points/issues in such adjustation include, flexibility of the design process model, freedom of the architect, importance of intuitions and aesthetics, being value-centred instead of market- or user-centred.

- With the discussed background, points, and arguments a general summarised design process model is required for application in the architectural design field for an extremely complex situation. For which we adjusted the basic steps of Cross (2008) initial design model as a backbone for modelling the architectural design processes in a SRH-SD. This is demonstrated in the scheme in figure 2.4, which shows the compositional structure of the system. In this system the approved design is one conclusion and the other conclusion is the emerging new knowledge. In these two conclusions the design concept is mostly a conclusion for local applications or case oriented. However, in the design with a scientific approach the created knowledge is the conclusion for a global application. Therefore, this model will be called Glocal Process Model for a Complex Design situation or GPM. The possible repetition of the processes in a new project based on the achieved design conclusion and the added knowledge is also indicated in the scheme of the figure 2.4. The difference between these two parts of the scheme may only be due to their different backgrounds.



Figure, 2.4. The backbone model for the complex architectural design processes

- The steps of the developed model are iterative; however most of the relevant activities will be concentrated in each phase. These phases may not be completed before the final stage of the design. This theoretical framework and grounding the overall theory of this study will be followed on a structure based on the sequences of phases of the proposed process model. Within which validity of the model and the theory will also be proven. Therefore, the next chapter discusses the phase of need in a complex design situation on two levels of the global need for human as well as on a case scale involving constraints of seismicity and a desert context for a SRH-SD.



Cases
3
Global study
4
Local/global
5
Local/global
Explorative
Theory
Introduction
1
Problem
2
General theory
6
Theory on a detailed level
Outcomes
12
Conclusion
Experimental
Urban
7
Neighbour hood
Architecture
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Houses
House
9
Component
Materialisin
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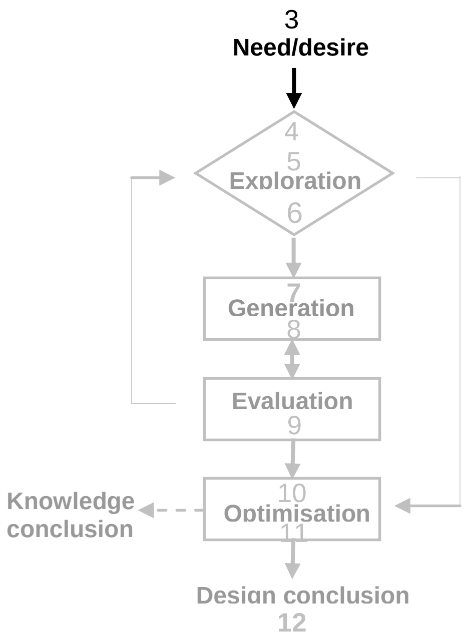
Basics,
Materials
11
Time & De-



3
Need/desire
4
5
Exploration
6
7
Generation
8
Evaluation
9
10
Optimisation
11
Knowledge conclusion
Design conclusion
12

CHAPTER 3

NEED

As it was mentioned in the previous chapter, the structure of the theses from this chapter follows the order and sequence of phases of the Glocal Process Model (GPM), proposed in chapter 2, which starts with need. Therefore, this chapter will discuss the content of the need, real meaning that it entails, and the required recognition of designer about the depth of the need. This recognition of all items including the tacit ones is critical for an architectural design in a complex situation that is loaded by severe constraints. Cases such as Reconstruction of Houses in Seismic Deserts are examples of such a situation. Therefore, in the following discussions, first the importance of a deep understanding of need for a complex situation on a global level will be realised through literature study. The second step is to go through case studies to provide both the knowledge content and a deep insight to the need that is not visible in superficial and simple observations. Therefore, the background information is provided in three main groups.

(i) Nature of earthquakes and a basic vocabulary understandable for non-seismologists/building technologists, in addition to a brief definition about deserts is collected in this group.
(ii) In this group of discussion, the problem that the constraints of earthquakes and desert circumstances entail will be brought.
(iii) The third is about the situation that the two constraint of seismicity and a desert circumstance combine, making an extremely complex situation, with potential risks for the urban habitat.

Earthquake is the most destructive natural phenomena on the planet. This phenomenon has economic, social, and environmental impacts on people. Thus, it is a big threat for the construction industry and priority for designers and engineers. Looking into the nature of earthquake and its possible impacts describes “need” for starting a design. In addition, desert cities are vulnerable areas, requiring extra attentions. Sustainability in desert cities is a crucial issue. Therefore, getting insight in a desert situation to find a global overview and to recognise the actual need in such lands requires general information that will follow the seismicity in this chapter. A conflict between the need in seismic areas and desert environment comes up. A quick discussion about this conflict will be introduced to show/prove the crucial consideration and attention that should be given to the “need” in such a situation. However, this need will be further refined in chapters 4 and 5 that discuss the exploration phase of the design processes.

3.1. Meaning and depth of need on a global/design level

The GPM developed in previous chapter is not only concerned for the technical and other similar aspects of the design but also is based on human’s desires and values. In general, architectural design is closely related to human life, having also big influences on it (Fry, 1992; Duijvestein, 2005; Lawson, 2006), requiring extra attention to specific characteristics of the individual use and the user. The basic aim in an architectural design is creating a healthy space, while a progressive aim is upgrading it to a pleasant environment for human spirit (GSA-IWA, 2003). Apparently, this is a heavy responsibility, because the product of such a design should cover the wishes of the client, suiting both the current state of the need and the future desires, hence foreseeing the consequences in future. Besides, particular circumstantial interferences can also make the design a challenging task.

According to the study of French (1999), the need should be identified and satisfied as precisely as possible. In the idea of Schön (1985) this 'need', may require particular attentions. The need in architecture is particular because the architect with the difficult tasks as functional specialist should also involve artistic and social aspects (Schön, 1985). From O'Reilly's (2000) point of view superficial recognition of need may cause heavy costs for the design.

In architectural design the need is normally, case oriented and is segmented in the Program of Requirements (PoR) with main components of functional requirements, technical and special requests, and other relevant items. However, some other requirements are not directly observable and may not even be listed in the PoR, while they can be strongly influential. Simple examples of such cases are manufacturers that need to cool done parts of their systems with water. Although this water may return to the local system, it may not be applicable in the natural environment (e.g. agricultural) anymore. Thus, satisfying the need of manufactures in this way causes catastrophe. A good example for different level of understanding the need is given by Schön (1987). About the road-building situation, he states, "where the civil engineer may see drainage, soil stability, and ease of maintenance; he may not see the differential effects of the road on the economies of the towns that lay along its route. Although we call it a deeper understanding of the need, Pugh (1991) calls it establishment of the true need and the 'Voice Of the Customer' (VOC).

It is well known that the most important needed building for human is an appropriate home. However, historically and theoretically, a house has not been a serious subject in architecture, compared with monuments (Rappaport, 1969). Therefore, this issue is also involved in the recognition of the need in architectural design that plays a major role in human's life in a broader scale (Lawson, 2004, Duijvestein, 2005). Larry (1957) also states 'Architecture does not consist in the sum of width, length, and height of the structural elements which enclose space, but in the void itself, the enclosed space in which man lives and moves. This tiny difference and quality is objective and precise, but it cannot be named' (Alexander, 1979). In a complex situation for an integrated design process to avoid failure, the most critical point on the phase of 'need' is to understand the content that the desire entails on various scales. Otherwise with a limited view, for example, on material level may cause major problems on other levels (e.g. urban level). Nevertheless, in the study of Pugh (1991) he generalises the importance of a good understanding of the need for all of the design cases (not only for complex cases). However, he also indicates that otherwise it is a strong cause for failure of many design cases (Pugh, 1991). Thus, a deep understanding and comprehensiveness of the 'need' on a multidisciplinary scale while estimating it in a long run is significant for a complex demanding design case.

3.1.1. A brief discussion about fundamentals of the need for human

As an important item concerning human's life, the phase 'need' has been deeply and thoroughly studied (e.g. Maslow, 1947; McKillip, 1987; Ebdon, 2001; Faichid, 2005; Ehrenfeld, 2008). As the most known pioneer of such studies, Maslow (1947), in his famous hierarchical pyramid predetermines the need on five levels of importance, where the fundamental desires are the basics and thus the lowest levels. Other desires are hierarchically levelled to the top, showing the stages of growth in humans as well. To illustrate the possible depth of desires in the phase of 'need' in a complex design situation, a SRH-SD or the Sustainable Reconstruction of Houses in a Seismic Desert town seems an appropriate case.

The ‘Need’ in a seismic desert situation, includes complexity, because acquiring the need on, for instance, building level may cause harmful consequences on the future of the city. Therefore, the design processes are facing not only the constraints, but also the conflicts in their requirements and solutions. By applying a top-down together with a bottom-up approach estimation of these mutual or multiple relationships, interactions and interferences will be better understood.

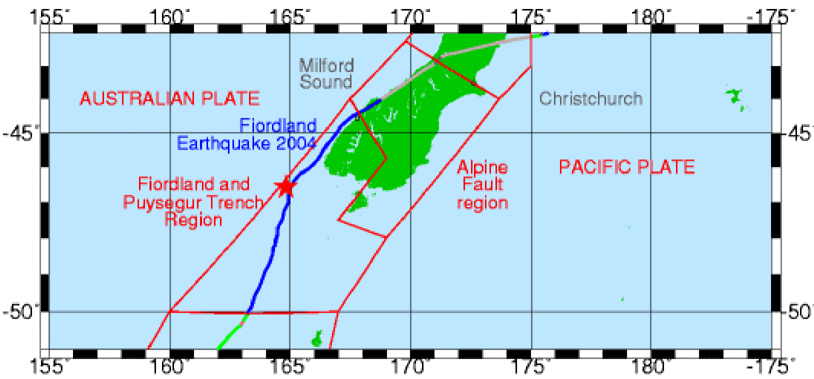
Based on the pyramid of Maslow (1970), the need for designing a house in such a situation includes three large parts. The first relates to ‘a house as a basic and the most important place for a person or a family’ to survive. This can be common and general in different situations, while the second and the third parts are particular, and case oriented for this specific situation. The second is the demand for a house to protect the person or the family from the intense desert sun. Hence, acquiring this need may also involve other domains of the design. However, the third is a demand for safety of the inhabitants of the house when earthquakes occur, that also engage other levels of design. Therefore, the design knowledge should cover all of these parts, which in this case focuses on basic knowledge about earthquakes’ nature and deserts in the following section. After this, the intensity of the relevant/driven problems and the necessity for recognition of the situation will be presented to provide a complete insight into the issues relevant to the design.

3.2. Preliminary step for understanding a demanding situation

In a case as a SRH-SD, a combination of the two constraints is the major problem. To start understanding the need in such a combination obtaining the basic knowledge of each of the two constraints will be provided. However, this model of information sometimes looks rather too deep into the subject, but it is required as the relevant knowledge about these cases in the architecture was found insufficient (discussed in chapter 1).

3.2.1. Nature of Earthquakes

Humans consider most earthquakes (relevant to the building sciences) as earth-shakings. Bruce (1999) brought it as ’Rupture has commenced; the ground begins to shake’. Although these symptoms of earthquakes may seem similar, the cause of the earthquakes can vary considerably. There are several types of earthquakes to be recognised. In the division made by Naiem (2001) typology of earthquakes include tectonic earthquakes, dilatancy in the crustal rocks, explosions, volcanic earthquakes, collapse earthquakes, large reservoir-. However, as the most occurring not only by the number but also in the variety of the places of the occurrence across the globe, the relevant earthquake type for this study is the tectonic earthquakes.



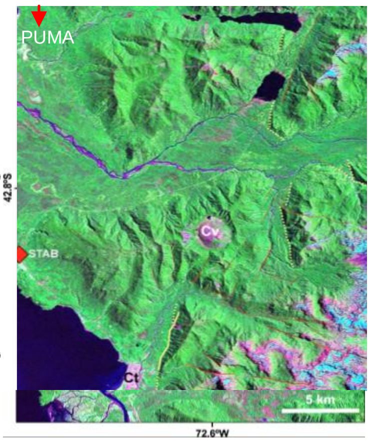


Figure 3.1. Left: tectonic earthquake Fiordland and Puysegur Trench region, New Zealand, right: Volcanic seismic activities, recorded in Pumalin and Santa Barbara, courtesy of L. E. Lara

Occurrence of Majority of earthquakes relates to the plate tectonics. The several large and unstable rock slabs of the lithosphere are called plates. The theory of plate tectonic in fact classifies earthquakes by the type of these movements and interactions of the lithospheric plates (Bruce, 1999). According to the theory, the moving of the plates of the earth's surface creates a mechanism that causes a great deal of the seismic activity of the world. When forces applied to the rocks of the earth push and pull them, the elastic properties of these rocks cause them to deform and vibrate (Naiem, 2001).

An explication of this process is that within the crustal rocks the rupture begins at the earthquake focus and then expands outward in many directions in the fault plane. The edge of the rupture forms an exception to this, as this does not spread uniformly. The occurrence on the edge has an irregular progress, because crustal rocks vary in their local physical properties. The overburden pressure at a specific point in the crust decreases towards the surface. On the surface of the fault, there are rough patches (often called asperities) and changes in fault direction and structural complexities that act as barriers to fault slip. Thus during the process the rupture front may come almost to a stop. Then, because of a rearrangement of elastic forces, it may suddenly break free and swiftly move out to catch up with the rupture on either side of it (Bruce, 1999/ 2001). A visible fault trace happens when this rupture reaches the surface (as happens in only a minority of shallow earthquakes). The waves of the released energy, from the activities in the rocks inside the Earth, in such a process, called seismic waves, make up earthquakes.

The elastic waves causing shaking and damages are classified in three basic types. First type is called surface waves and in these waves, the motion is restricted to near the ground surface. The two other types are the P and the S waves. These waves propagate within a rock. The speed of those waves depends on the density and elastic properties of rock and soil it passes (Naiem, 2001). The P (from 'Primary') is the fastest of the three types of waves. Its motion is the same as a sound wave that can travel both in solid bodies (e.g. granite mountains) and in liquids (e.g. volcanic magma). When such a wave spreads out in a solid body down in the earth it alternately compresses and dilates the rock (i.e. pushing and pulling). The nature of these waves (similar to the nature of sound waves) causes, sometimes, audible waves in the atmosphere (Bruce, et al. 1999). In such an occurrence people often mention hearing sounds during the earthquake (e.g. Bam, December 2003). In most earthquakes, the P waves are noticed first (Naiem, 2001). The S waves (from 'Secondary') cannot travel through liquids. Normally in earthquakes, S waves arrive at the surface some seconds later than the P waves. The S wave includes significant components of side-to-side motion that cause both vertical and horizontal ground shaking. Therefore, these waves provoke most of the damage on the ground surface. However, most of the energy of the P and the S waves reflect back into the crust, when they reach the surface of the ground. Thus, the surface suffers simultaneously upward and downward moving waves. These sometimes, cause significant amplification of shakings near the surface (Naiem, 2001). Due to different characteristics of the weathered layers of soil and rocks near the surface, the waves react differently when meeting these areas. In these layers the elastic moduli mismatches from one layer to another. The layers filter waves differently in a way that they amplify the waves at some frequencies and de-amplifying them at others. In which the resonance effects at certain frequencies occur (Naiem, 2001)

The plate tectonic theory is a simple and important description for earthquakes; however, it does not explain all seismic activities in details. For example, large devastating earthquakes sometimes occur within continental regions as intraplate earthquakes, away from boundaries. The Dashte-Bayaz earthquake of August 31, 1968 in Northeastern Iran and The New Madrid Missouri earthquake in Charleston in 1886 are both examples of such earthquakes (Naiem, 2001). Keeping in mind that faults' sides slip slowly during the time (i.e. tectonic creep), they may also have a sudden rupture. A fault rupture varies from less than a meter to some kilometres such as the San Andria fault, which occurred on the plate boundary, where notorious fracture runs some 1280 km along the length of California.

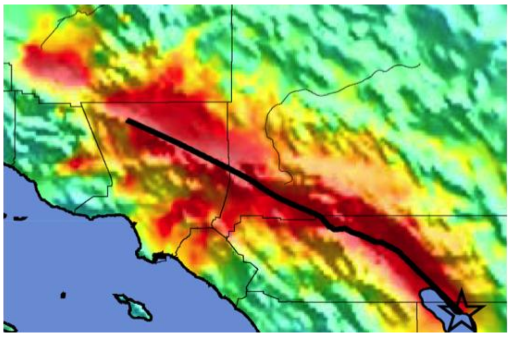


Figure 3.2. San Andreas Fault (courtesy: Daily Galaxy& The Great California)

To characterise a fault as creeping, seismic researchers are looking for signs in rocks. The slippery fault behaviour in one of the most recent researches in the Geological sciences in the University of Michigan is explored on a smaller scale. With this research, Pluijm (2007) stated that this behaviour comes from the clay. He claims that 'through a combination of chemical and mechanical processes, the grains making up the rock develop Nano-coatings of clay on their surfaces, which act something like grease on ball bearings' they form inactive creeping fault zones. This creates a dynamic environment. Although the results and consequences of this phenomenon is not proved yet, Pluijm is certain about the occurrence of these Nano-coatings (i.e. only a few hundred nanometres thick) all around broken-up, fractured grains. These occur in the places that they can affect the weakness of the fault. In fact, as these grains move past one another, the coatings facilitate the displacement.

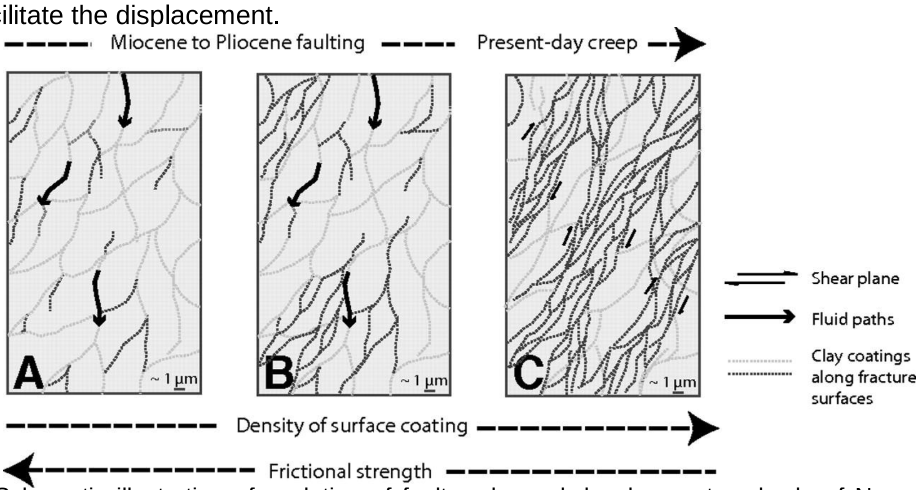


Figure 3.3. Schematic illustration of evolution of fault rocks and development and role of Nanocoatings in mechanically weak San Andreas fault (source: Schleicher et al. 2010)

Therefore, even after an occurrence of a rupture the movement may stay active, sliding slowly or slipping as results of some other activities in the nature. Although knowledge in the field is advancing, prediction of earthquakes is not entirely and accurately possible yet. Therefore, design of earthquake resistant buildings in many places stands on estimations referring to specific norms.

3.2.2. Desert as a part of earth's nature

Approximately 15% of world's population lives in desert while about one- third of the Earth's land mass is desert (Pyper, 2000), which is due to the harsh climatic and land conditions (Gradus

1985). The desert is typically understood as a land with usually spars vegetation, desolated and sparsely occupied (Webster, 2005). A definition for this word is a piece of land in which the amount of moisture is low predominantly because the precipitation level is low (Goudie, 2002). From the view of Walther (1970), “the rain in the desert does not wet, springs which yield no brooks, rivers without mouths …”.

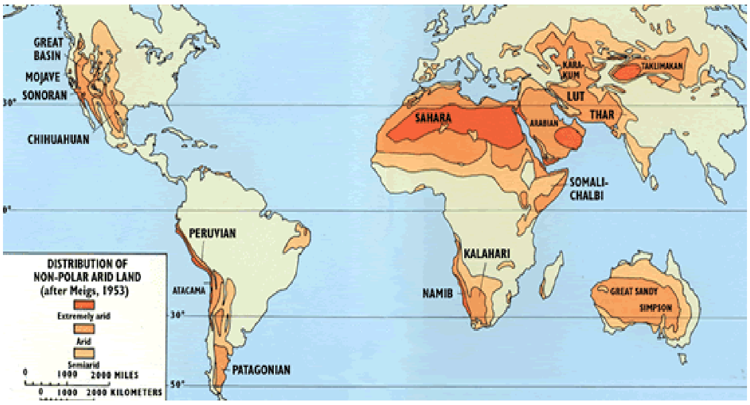


Figure 3.4. Distribution of Non-Polar deserts in the World (source: USGS)

Unlike imagination of most people, desert includes a vast variety of lands on the planet, spreading almost in every continent. In these lands, the energetic sunrays cause a high level of evaporation that ends with the lack of moisture, which is not compensated by the annual rainfall. The world’s deserts are generally dividable into polar and non-polar deserts. Polar deserts receive less than 250 mm rainfall per year, but the temperature in the warmest seasons does not exceed 10°C. The most habited deserts are non-polar deserts. Thus, this study focuses exclusively on non-polar deserts, and the references in the dissertation to ‘deserts’ always mean ‘non-polar’. Deserts are dividable into five regions separated by oceans or forests (Goudie, 2002). The major deserts in various continents are shown in table 3.1.

Table 3.1. Major deserts and their extent on continental level

deserts distributed within different continents	Asian	Arabian	2,330,000
		Gobi	1,300,000
		Syrian	520,000
		Central Asia	300,000
		Rub al Khali	647,000
		Thar	200,000
	African	Sahara	9,100,000
		Kalahari	900,000
		Namib	81,000
		Karoo	400,000
	South America	Atacama	105,000
		La Guajira	20,848
		Patagonian	673,000 (largest USA,7thW)
		Sechura	188,735
		The Monte and others	dispersed spots
	North America	Mojave	57,000
		Chihuahuan	362,600
		Sonoran	311,000
		Great Basin	520,000
	Australian desert	Great Victoria	348,750
		Great Sandy	267,250
		Tanami	184,500
		Simpson	17,650,000
		Gibson and others	156,000 and 237,950

Desert comprises some extreme situations; a number of these extremes have been collected in table 3.2.

Table 3.2., some top measures in deserts

Top measures in Desert				
Driest desert	Largest hot desert	Lowest spots	Highest temperature	Oldest desert
The Atacama	The Sahara	In the Negev Desert	In the eastern Sahara	The Namib
		This is world's lowest spot as well	The highest temperature in the World	

(Courtesy Houghton Mefflin science, 2009)

Desert landscape is mainly modified by the climatic differences. Deserts are also classified into two main branches of the mountain range and their basins and the shield deserts. Apparently, mountain ranges deserts gain more rainfall and are possibly cooler. Nevertheless, the classification of deserts is possible in some other ways as well, various examples were found in different studies (e.g. Mabbutt 1969; Rendell, 1997; Cooke et al. 1993; and USGS, 1997; Goudie, 2002).

3.3. The tacit depth of the "Need", revealing a demanding situation

Incorporation of every single relevant issue in realising a need/desire is necessary because relying only on limited technical aspects may end the understanding of need in a direction that may differ from the actual desire of the future inhabitants. Hence, it may lead to a particular solution for specific problem or group of problems that may conflict with solutions for other problems. For example regarding the case of design for a seismic desert situation, a technical view may conduct the design towards the following directions:

- The main item for the designer is that earthquakes of a certain scale will destruct the structure with an estimated level of damage. Thus, regarding the economy the designer decides how to optimise the project accordingly (i.e. normally economic efficiency and technical safety are the leading issues). However, in most countries, houses are not counted as important structures, unless they are concentrated in a high rise or residential complexes (i.e. in big cities). Yet, in reality, seismicity for houses is not a simple problem. Of course, technical aspects are important, but for a designer the life and the future of the inhabitants are more important.

- For the design of a house in a desert climate, the designer normally specifies a certain type of desert as the context and counts the climatic limitations. The stage of 'need' in such a situation includes protecting the inhabitants from the harsh desert climate. The difficulty is then mainly the severity of the climate in that particular desert. The important issues in such a design normally include designing different components of the building for climatic compatibility to make the building an integration of joint components for increased indoor comfort of the house.

. Hence, neither the certain seismic resistance nor climatic comfort is the only requirement for a comfortable house. There are not only many other relevancies that may not be recognised in a simple standard way of understanding the need, but also even in a simple way of visualising, a combination of these two limitations creates consequent problems as well. For example, lightweight materials are suitable for earthquake resistance of a building, while the heavy thermal mass moderates the harsh summer afternoon in the desert by a longer heat transfer. These procedural and consequential conflicting problems may go far beyond standards. The main objective for presenting this information is providing an insight to the severity of possible impacts and influences on a multi- disciplinary level.

3.3.1. from the seismicity

The first earthquake recorder was invented in China about 132 A.D. in a system where balls were held in dragon's mouth connected by a linkage to a vertical pendulum, in which shaking released the balls (Bruce, 1999). Because earthquake sensing and recording highly depends on the instrumental progression, available statistics about earthquakes are recent, aging about a century. To give an overview of the high rate of seismic hazards, worldwide earthquakes with magnitude more than 5 or strong earthquakes (CERCESJ, 2006), since 1900, are shown in table 3.3.

Table 3.3. Magnitude-average annually (Data from USGS and Wikipedia)

Magnitude	Date					
	1900-19	1920-39	1940-59	1960-79	1980-1999	2000-2007	Total
5	-	-	-	75	79	70	224
6≥	21	34	37	71	164	43	370
7≥	422	373	507	408	265	86(2005)	2061
8≥	5	6	9	8	8	2	38
9≥	-	-	2	1	-	1	4
Total	71	88	117	224	281	138	919

(Average: 19.4 magnitude 7 and greater earthquake per year)

Statistics also show that globally, there have been 19 major earthquakes (magnitude more than 7) per decade since 1900 (USGS, 2002). In the period after 1950, in Central Asia in this interval 2 towns and 200 villages were destroyed. Before the year 2000, towns such as Ashkhabad (1948), Agadir (1960), Skopje (1963), Managua (1972), Gemona (1976), Tangshan (1976), Mexico City (1985), Spitak (1988), Kobe(1995), Kocaeli and some other places in Turkey (1999), Taiwan (1999) and hundreds of villages were destroyed or severely damaged by ground shaking (Naiem, 2001). Due to the instrumental accuracy, recent statistics are more reliable. As an example it is shown in table 3.3 that in the period of 1990- 1999, globally 1325 earthquake of 6.0- 6.9, and 13965 of magnitude 5.0- 5.9 occurred.

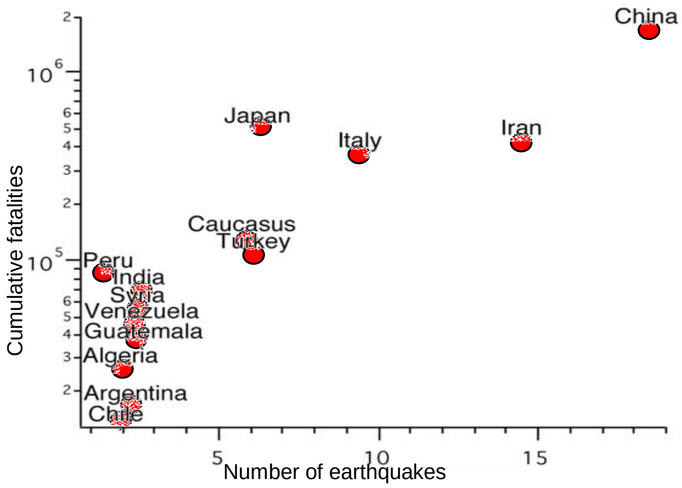


Figure 3.5. Global decadal casualties caused by earthquakes (adopted from EERI. 2003)

The graph in figure 3.5. shows the intense impact of seismicity by global decadal casualties. The excessive occurrence of earthquakes caused annually 10,000 deaths on average. For example, from 1926 to 1950 damage losses amounted to $10,000,000,000 (Naiem et al., 2001). Moreover, these big impacts still continue (e.g. Jan. 2010 Haiti; Feb.2010 Chile).

Less than 4% of the world's populations live in the mega cities (≈400 million) of which half are located on the seismic lands. However, most of the cities and areas located on the seismic zones are not mega cities. Therefore, the living style and the typology of desired houses in such areas are different from the high rises or other kind of residential complexes. In addition to the intensity and high frequency, the dispersity of the places prone to earthquakes is very important; figure 3.6., shows the map of the most recognised seismic zones.

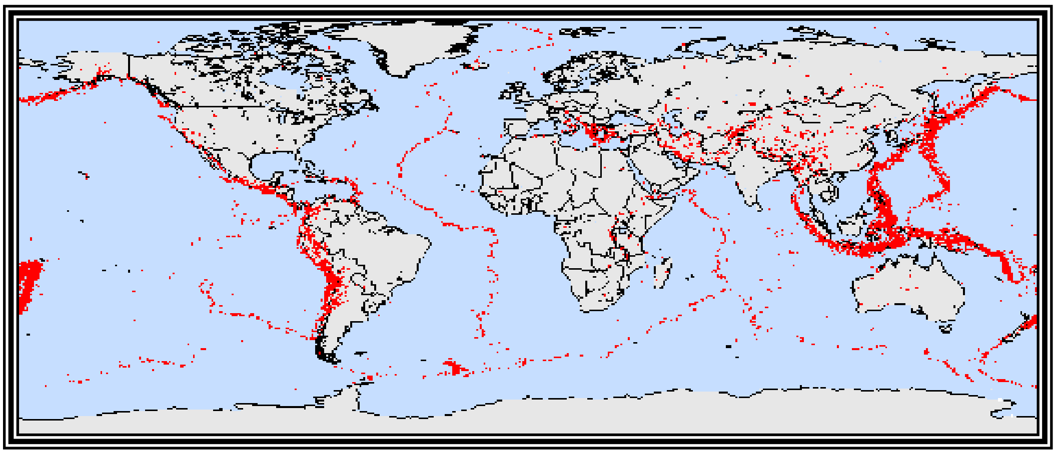


Figure 3.6. The most recognised seismic zones worldwide (source: USGS)

3.3.2. From the desert situation

Deserts are mainly sparsely populated areas; according to Gradus (1985), these ecosystems have not been especially favourable for many occupants. In addition to the extreme climate that requires extra considerations, desertification is a major threat for desert habitats. This causes social and professional sensitivity for the design, posing dependency on the local conditions. The major problem is that deserts are expanding very fast, and the marginal areas are likely for the phenomenon of desert expansion. For example, about 6000 years ago Sahara in north Africa was the Green Savannah with an area of 9 million km² (Weisman, 2007), while currently it is the largest desert on the planet.

The diminishing or destruction of the biological potential of land, which can ultimately lead to desert conditions, is termed desertification. This kind of land degradation only occurs in dry (arid, semi-arid and dry sub-humid) countries. One important factor contributing to the acceleration of desertification and is occurring in all over the world is deforestation. The rate at which rain forests are disappearing globally is at 2 acres (0.8 hectare) per second. This amounts to 10 million acres per year for temperate zone forests (Kibert, 2005). In connection with carbon diffusion into the atmosphere, that can be stored in trees mass, that fact is a worldwide environmental problem.

The above data shows that the phenomenon is happening on a large scale, causing huge carbon releases, which in turn, is contributing to accelerating climate change. Pollution is not the only consequence. Soil erosion is a consequence of deforestation, which is a key contributor to land degradation. For example in 1999, a gigantic flood washed out the Neka region, a productive green land in the north of Iran, causing death and huge losses. This area was surrounded by forest in the past; the forest disappeared on a rapid rate before the flood. Similar regions that are now depopulated are observable in various places. Due to human intervention in agricultural and forestry development, population growth has caused deforestation in the first place. On a worldwide scale more than 2 billion tons of topsoil is lost annually and now, more than 12.5 billion acres is considered to be degraded (Kibert, 2005). The problem in most hot lands is that their annual rainfall comes, in many cases, all together. Therefore, although the annual rainfall is barely considerable the level of water at once may even cause flooding.

Hence, according to vegetation data, world dry lands count for 6.45 billion hectares, or 43% of the global land area. Seventy percent of the 5,200 million hectares of dry lands used for agriculture around the world are already designated degraded areas at least moderately threatened by desertification and accounting for 3.97 billion hectares or 75.1 per cent of the total dry lands, excluding hyper-arid deserts (DTE/UNCCD, 2000). The same source reports that more than 100 countries are affected by desertification and 15% of the world's population inhabits dry lands while 78.5 million live in areas that have recently undergone severe desertification. For instance, in Mexico about 70 percent of the land is vulnerable, which is what prompts 700000 to 900000 Mexicans to leave the country annually.

The scale of the disaster (is severe for desert marginal cities) presented through the above indications are examples to show the demanding situation for the drying lands. These discussions demonstrate that not every segment of the demand is observable with a superficial observation. For example, design of a house, as the most wished building for human, in a seismic desert requires incorporating the implicit desires. By facing the mentioned constraints, the complexity of the design goes far beyond the technical aspects. Because in architectural design there are always choices of solutions, avoidance of the negative impacts of the design solution should be ensured. In order to do this, the desire should be well understood first, both explicit and implicitly. Secondly, a suitable system as a sustainable framework to cover the design on a multiple level, involving more human and environmentally concerned aspects is required. Due to the mentioned consequences that influence lives of the inhabitants, at present as well as in the future, social relevancies are significantly involved and are crucial aspects for designing houses in such areas.

3.3.3. Combination and deduction

Due to the relationship between architecture and human's life, satisfying the 'need' that is unavoidable, should be seen on a multidisciplinary scale. Maslow (1970) states 'If all the needs are unsatisfied, and the organism is then dominated by the psychological needs, all other needs may become simply non-existent or be pushed into the background'. The designer must find comprehensive insight into the need in order to foresee the threatened future of seismic prone desert's inhabitants. Although they may not seem so, these aspects of need are fundamental for their lives, thus they cannot be ignored. Maslow (1970) says, "For a man who is extremely and dangerously hungry, no other interest exists but food. … Freedom, love, community feeling, respect, philosophy, may all waved aside as fripperies that are useless, since they fail to fill the stomach. Such a man may fairly be said to live by bread alone."

In a comparison with the pyramid of Maslow (1970), as mentioned before, the need in the design of a house in such a situation includes three large components. First is the need for a house as a basic place to be protected for living, which can be common and general in different design situations. Thus this has not been particularly distinguished for the need specifically for the SRH-SD in this part. However, the second and the third components are particularly case oriented. Thus, in a seismic desert, the second is the demand for a house that protects the person from the harsh sun, and the third is a demand for being safe inside the house in terms of earthquake occurrence. Without a roof/house one cannot live in the desert, while without the roof there is not normally a real danger from the earthquake.

This emergency condition may not be so severe when the design is constrained by one of these forcing limits (e.g. either seismicity or desert circumstance). However, for instance for desert context, sustainability should be seriously engaged because these are sensitive places. Ignoring sustainability and the possible consequences of the design solution on the desert environment, is a situation in which the relevant issues are only climate compatibility and normal requirements of the house. Of course, making a moderate indoor temperature and humidity with clean air are very important for human's life, they are the second step after the desert can be habited and the house can be acquired. As without encountering the sustainability the existence of the desert habitat will be in question, sustainability is crucially needed for the reconstruction of houses in seismic deserts. This particular environmental issue would not have been a problem 300 years ago, when deforestation and desertification were not yet spread as a serious threat across the globe. Similarly, Maslow (1970) states 'Emergency conditions are, almost by definition, rare in the normally functioning peaceful society.'

However, the way that designers, executers, construction industry, and authorities treated the environment in the last century caused huge environmental problems putting present lives at risk. Underestimating the negative influences, for future of a sensitive situation as a desert city, most likely causes the inhabitants changing their lifestyles or even leaving their land, which is a global problem (e.g. many places in Africa, Latin America, Asia…). Whereas, inhabitants of desert cities are of local potentials/opportunities with global benefits. Thus, sustainability is urgently required not only because of the mentioned benefit, but also socially (and environmentally) health and lives of the inhabitants are endanger. Sustainability in a SRH-SD is not similar to a normal construction project and therefore it should not be considered as the second level of need.

Thus, analogous to the outcomes of the study of (GSA-IWA, 2003) and according to the aim in architectural design for a qualified design, design solutions must be completely suitable for a desert environment. This means that the seismic resistant house as a sustainable solution should cover both environmental and social sustainability. With this frame, desert town houses are very important buildings for resisting earthquakes. Because a reconstruction of houses after earthquake disaster in desert towns, may take place in a larger scale (than an individual house), sustainability of this reconstruction is crucial.

3.4. Summary and conclusions

- An architectural design normally starts with a need that may include design problem(s) as well. "Need" in architectural design may cover a large area of relevant issues, which require a deep recognition and understanding of the content. When the design is facing circumstantial interferences (e.g. more than one severe constraint), deeply studying the need is critical for battling the design problems, and to avoid possible failure of the design conclusion in addition to foreseeing the future consequences.

- In a complex design situation, various causes may lead to further growth of the complexity. Interactions and interferences of the requirements may appear, and may even end in conflicts. These have been overviewed by the case of a seismic desert context. In which social and environmental aspects play significant role.

Case related summarisation and conclusions include:

- The specified location as a case of design context in this study includes a non-polar moderate dry desert climate with a large difference between the night and day temperature. The difference between the highest and lowest temperature exceeds 50°C. Furthermore, there is a large temperature difference between the summer and winter. This desert is prone to strong tectonic earthquakes (specified in the range of $5 \leq X < 8$).

- The case study of designing a house for reconstruction in a seismic situation is a complex demanding design case.

- Even on a principal level and with a limited view on ‘need’ the possible conflicts of design conclusions are recognisable. The first requirement in a desert is to have a roof for avoiding the intense sun radiations. Man should be protected from desert sun with the roof, while the threat of earthquake comes after the roof is provided. Thus, the roof that protects him from the sun may endanger him in earthquakes.

- Sustainability is crucial to be incorporated in the design for a reconstruction of houses in seismic desert on a multidisciplinary scale.

- Understanding the need is not always to avoid losses; it can also provide insight into the local opportunities. These opportunities include integrated vernacular methods, sources, etc.

- The sensitive situation of the desert cities, especially seismic desert habitats urgently require more attention to the sustainability at the design level as well as at the performance level. This includes decision making on urban and construction design and performance. In this way, sustainability of a designed individual house is measured in a larger sustainable system of the desert town (i.e. integration).

The Pyramid of sustainability, hierarchies the level of need for a sustainable reconstruction of houses in a seismic desert context, which is shown in the scheme in figure 3.7., because its hierarchy started based on the GPM, it is also called Glocal pyramid.

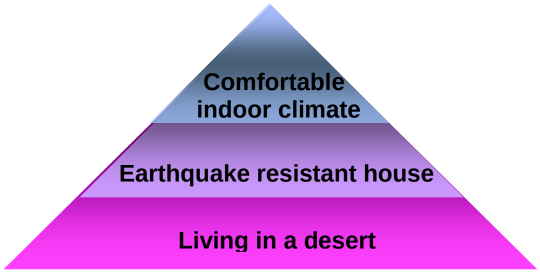
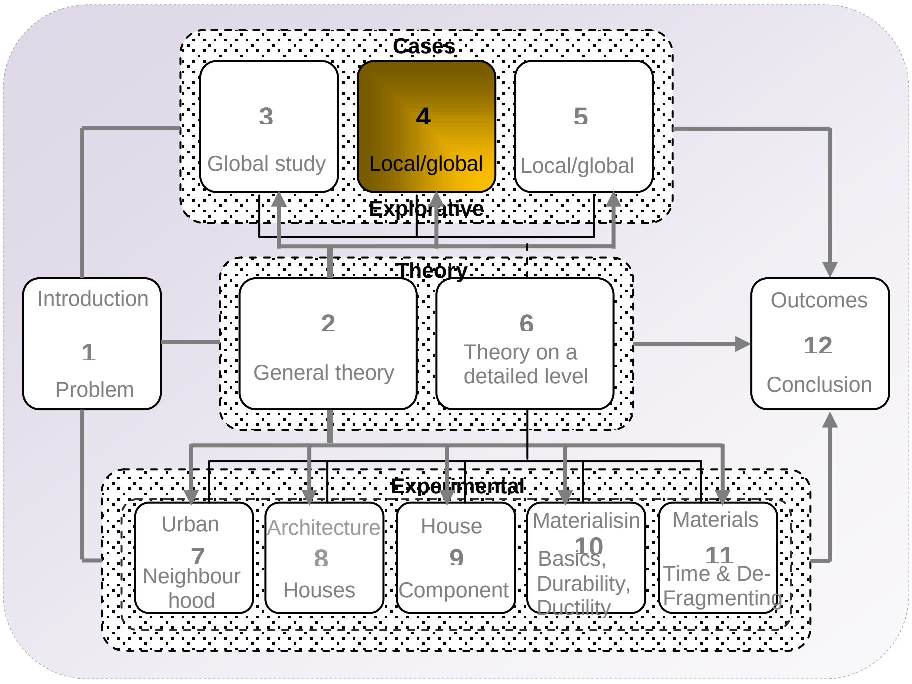


Figure 3.7., Glocal Pyramid of need for a SRH-SD

Finally, in addition to the whole emphasis on the great relevance to understanding the stage of ’need’, the refinements of the requirements inside the need can be elaborated in the next phase of the GPM, “ Exploration”, the subject of the next three chapters.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Global study
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Problem
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Outcomes
12
Conclusion
Experimental
Urban
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Basics, Durability, Ductility
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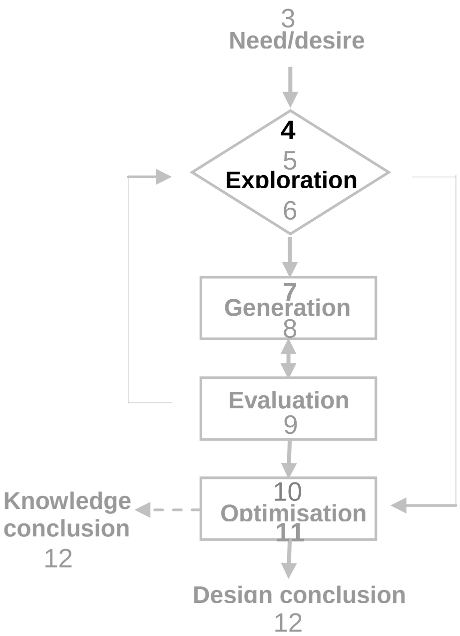
Time & De-Fragmenting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Design conclusion
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CHAPTER 4

THE EXPLORATION PHASE OF A COMPLEX DESIGN; EARTHQUAKE ENGINEERING IN A DESERT TOWN

According to the Glocal Process Model (GPM), the 'exploration' phase can be started once the 'need' has been determined (see chapter 3). The exploration phase occurs prior to the conceptual design, in which the design context needs to be comprehensively studied. It requires a broad bird's eye perspective on the one hand, and detailed preparations on the other. The involvement of coercive elements, design constraints, consequent interactions, and possible conflicts between proposed solutions results in a tremendous growth of complexity. For example, seismicity and a desert environment form major constraints to building design or redesign. Each of these two constraints is the subject of a chapter; the current chapter focuses on earthquakes while the next one discusses the desert circumstance. The entire complexity will be modelled in a 'Designerly' way in chapter 6 as the third and final step of the exploration phase of the GPM.

After briefly indicating principles of the exploration phase background knowledge will be introduced here. Firstly, a bird's eye perspective on interplaying issues can provide insight into the possible consequences of reconstruction and relevant subjects on urban life, perhaps even on the life of the inhabitants. Secondly, earthquake engineering and design will be exemplified by cases. As the most relevant case, Japanese ways of dealing with seismicity, from traditional to modern systems, demonstrate the state of the technology. Sustainability aspects of current seismicity-resistant systems will also be discussed. The final part comprises a short view on traditional systems in desert cities, which focuses on the central desert of Persia. As a case of desert cities this will be followed by the state of earthquake-resistant systems in Bam, which experienced a catastrophic earthquake in 26 December 2003.

4.1. General introduction

The majority of successful architectural designs dovetail well with their context and function perfectly (Prophyrios, 1984; Hersi et al., 1988; Lissitzky, 1970, Lawson, 2006). In most of such designs, the designer is familiar with the design environment and acquires a great deal of data, information and knowledge before the conceptualisation phase is initiated (Schön, 1984; Mitchell, 2004). However, the necessary data, information, relevant analysis, and theoretical outputs are case-related. According to the GPM and its supporting theory, these are called upon in the second phase, 'exploration' phase. The exploration phase includes all items involved from the beginning of a design to the end of prioritisation, selection, and theoretical decision-making. These are worked out iteratively; therefore, they will be finalised only when the design is completed.

Exploration phase in an architectural design

Normally at the beginning of an architectural design task, the general function and location are determined and the client provides a list of wishes or objectives (Schön, 1988; Ferguson, 1993). This first principle data may also include some extra information. In the statement of Leupen et al. (1997), the principle data include a given programme and a site. In the study of Moughtin et al. (2003), the ideal situation for the development is where design and planning guidance is already available for the given site. Apart from the division of the investigation methods, a general approach is to determine which items or groups of items require further investigation. For a complex design situation, these items can be placed in different categories. For example, they may be divided into various aspects: e.g. technical, economic and financial, social, and environmental aspects, all local or global.

Depending on the particular design task, a designer may study the local climate and environment, infrastructure, landscape and the surrounding buildings at the site with regard to their orientation, architecture, and spatial configurations. Some of the criteria then have already been set for the building, and these are refined in terms of size, form, and orientation of the building, soil condition, layout, and function. External and internal relationships, which influence the form and functional figure of a building, should be also considered at this stage. Managing the structure, contents, skin, and generally the construction system is another essential item in the whole project. Finally, based on the criteria, the designer will decide on the materialisation of the building, the internal structure, and the building system. The interactions and interferences of the different levels and different domains sometimes require redesign and rethinking. For example, the materialisation has a close relationship with the building system, reusability, and environmental load of the whole project. Thus, elementary design and materialisation are intensely interrelated.

Even if the design levels have been successively studied, the different levels may significantly influence one another in a comprehensive procedure. Again, we can refer to the example of materialisation. The aim of the analysis prior to the conceptual design phase is to determine which characteristics need to be created and which criteria need to be met in the design of the house. These scales of detailing in architecture are often recognised and indicated as macro-, meso- and micro-levels (Eekhout, 1999). The above-mentioned groups of items involved in a design are variously classified by different people or in terms of various methods. This will be further discussed in Chapter 6.

After listing all the requirements and issues relevant to a particular design situation, the second task is to look for interaction between these requirements (Alexander, 1964). The limitations involved in the design are examples of such problems. For example, the financial scope of the client very often forms a design limit. Such limitations may play a crucial role in influencing design elements and even the entire design, and may consequently cause a considerable increase in the complexity of the design. At this scale of influence, these are major problems or ‘design constraints’. Each design constraint may cause complexity for a design, and a combination of two or more of these may bring extreme complexity.

4.2. Design constraints and the possible affection

Design constraints in the GPM are the extreme circumstantial conditions. According to Roozenburg and Eekels (1995), the total of all properties describes the behaviour to be expected under certain conditions. Thus, intensive properties plus geometrical form makes up the extensive properties. The same source defined functions as: *the intended and deliberately caused ability to bring about a transformation of a part of the environment of the product.* Similarly, for a building, the circumstantial effects and affections may significantly change the configuration. These circumstances may result from various causes, their interaction, and possible conflicts.

For example, the wind load may be a limitation for a design, whereas an extremely strong wind can be interpreted as a design constraint (Shahnoori, 2006). Constraints are interpreted differently in various fields. In computer science, all coercive items whose absence causes the design to fail are called 'constraints' (Clarke, 2001; Kemper, 2006). In product development (e.g. Hutchin, 2002; Whitney, 2004; Ulwick, 2005), in architectural design (e.g. Tunstall, 2006), in civil engineering (e.g. Dion, 2002), in structural engineering (e.g. Laing, 2005; Forester et al., 2008) and in construction engineering (e.g. Pierson, 2001; Mehta et al., 2008), constraints are influential as well but they influence the details. For the research presented, every aspect of design has its own constraints that draw the designer's attention to that particular aspect. Therefore, constraints are involved in the design procedure from the earliest stages of the design, prior to setting the requirements. They affect all aspects, segments, processes and relevant items. For example, in abstraction, seismicity may seem relevant only to technical aspects; in reality, however, it influences all items involved in a designing procedure (Emmit et al., 2003). Figure 4.1 shows a schematic arrangement of the way seismicity is normally taken into the account.

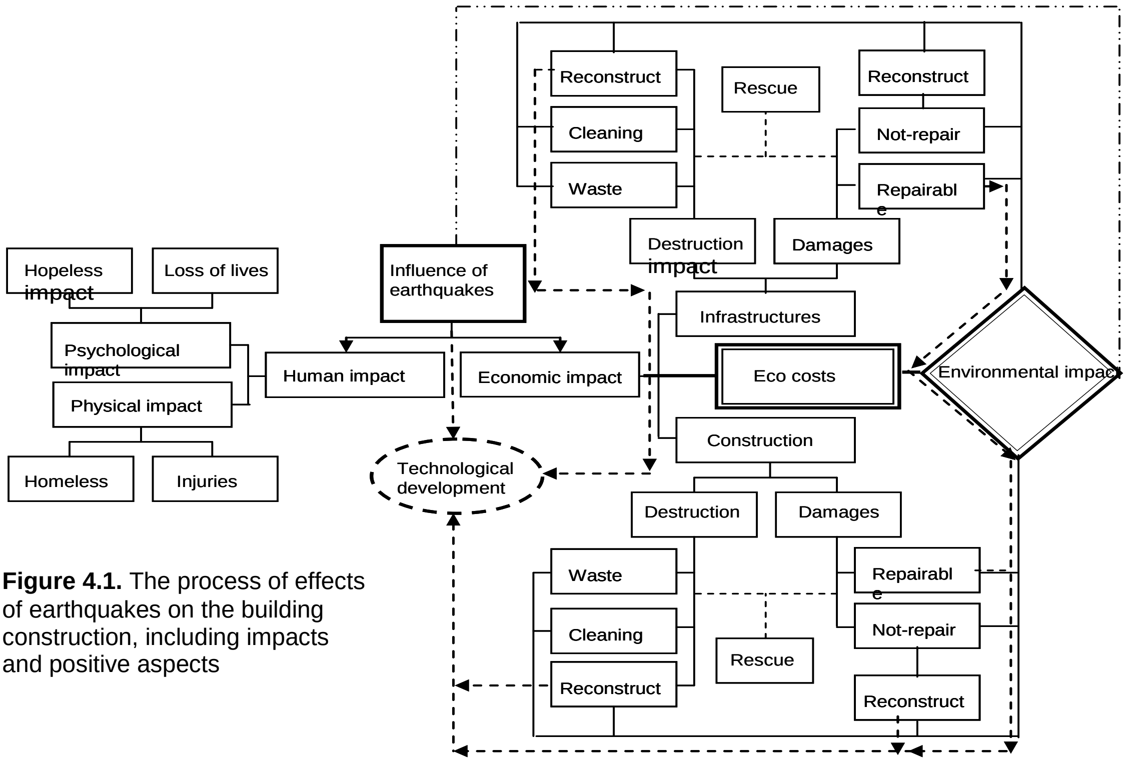


Figure 4.1. The process of effects of earthquakes on the building construction, including impacts and positive aspects

This is even more important in a reconstruction project with environmental concerns. The following sub-sections cover the issues on urban level relevant and useful to foreseeing the possible effects of planning and reconstruction of buildings.

4.2.1. Destructions by earthquakes, analytical cases for foreseeing the future

Earthquakes pose considerable problems for building industry due to their frequency of occurrence and the vast range of places situated in seismic zones. As an example figure 4.2 shows the major earthquakes that have occurred since 1990 worldwide.

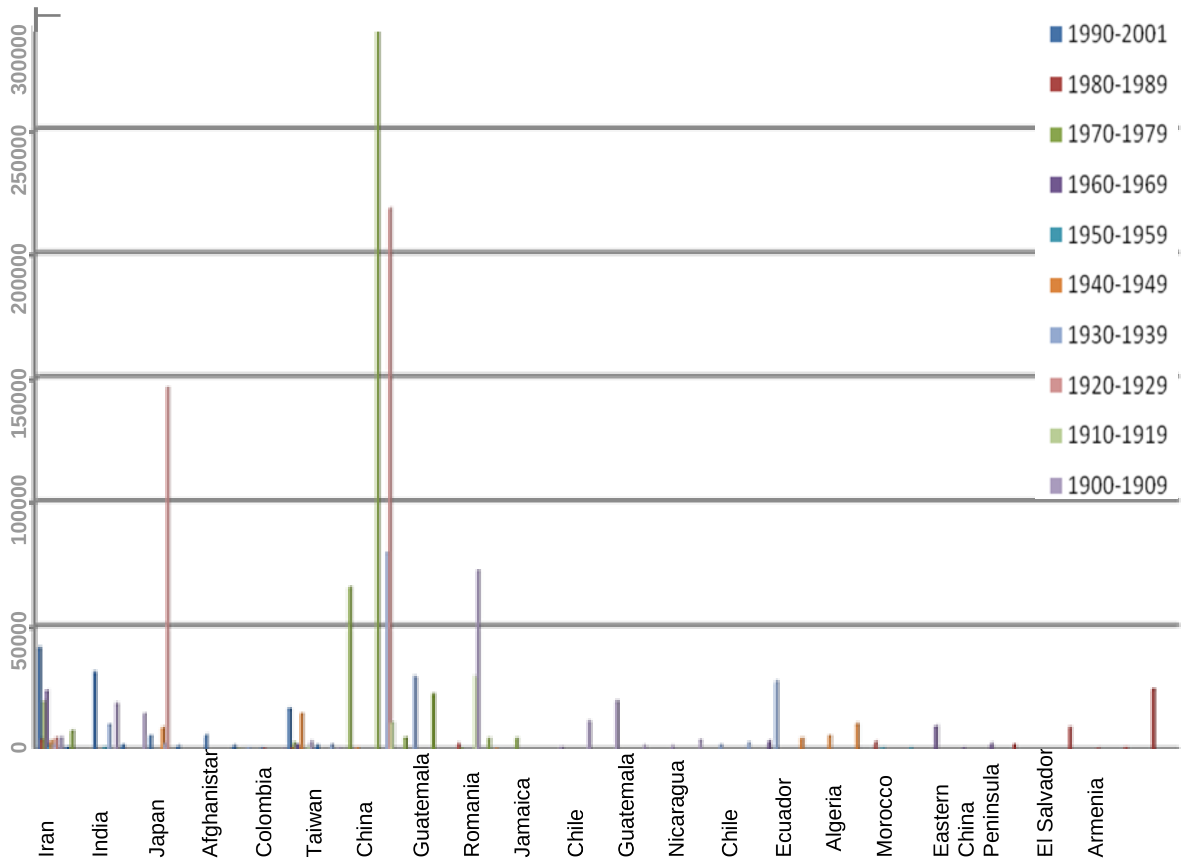


Figure 4.2. Strong earthquakes and relevant fatalities, recorded from 1900 to 2000

In Japan more than 2000 earthquakes are recorded annually, including major and infamous earthquakes, some of which are collected in Table 4.1.

Table 4.1. Statistics on sample earthquake phenomena in Japan

Earthquake	Magnitude	Date	Death toll
Mino-Owari	8	October 1891	7273
Kanto	7.9	September 1923	143000
Tango	7.6	March 7 1927	3020
Sanriku	8.4	March 2 1933	2990
Tonankai	8.1	December 7, 1944	1223
Nankaido	8.1	December 20, 1946	1330
Niigata	7.5	June 16, 1965	26
Kobe	6.9	January 17, 1995	5509
Hokkaido	8.3	September 25, 2003	0

Table 4.1 only charts a number of earthquakes in a few Japanese cities. Other seismic activities remain unmentioned. The region of Hokkaido is one example. The last tremors in this region occurred on 4 March 1952, with a magnitude of 8.1; 31 people were killed, 72 injured; 713 houses were destroyed and 5,980 damaged. Another earthquake with a magnitude of 7.9 occurred on 16 May 1968, with 48 killed and damage estimated at 25 million USD. On 15 January 1993, there was an earthquake with a magnitude of 7.6, with 2 killed, 614 injured, and substantial damage at Kushiro, Hokkaido and Hachinohe, Honshu.

The death toll in the table is a parameter to show the intense impact of earthquakes. This number depends on many factors. For example, in Niigata an earthquake with a magnitude of 7.5 killed 26 people, whereas an earthquake in Kobe (1995) with a magnitude of 6.9 caused 5509 fatalities. The extent of the damage and the intensity of an earthquake therefore only partly relate to its magnitude: it is also a function of some other important factors. These include the focal depth of the earthquake, the epicentre, the soil condition, the typology of buildings, building systems, materialisation, the mechanical properties of the structure (e.g., strength, stiffness, ductility and natural period), and other safety-related aspects. Penelis & Kappos (2005) propose a general definition for intensity "a measure of the consequences that this earthquake has on the people and the structures of a certain area." In fact, the intensity of an earthquake is not completely quantitative. It is a perceptibility measure of damage to structures, ground surface effects and human reactions to earthquake shaking (Elnashai et al., 2009). Thus, an earthquake with one magnitude may have different intensities in various places.

Because it is not possible to measure the actual damage precisely, estimations and qualitative methods using an empirical intensity scale are applied. However, discrete scales are used for quantifying the intensity of earthquakes (Richter, 1990; Kramer, 1996; Lee et al., 2003; Penelis et al., 2005; Elnashai et al., 2009). The most common macro-seismic scales are Mercalli-Cancani-Seiberg (MCS); Modified Mercalli (MM); Medvedev-Sponheuer-Karnik (MSK); European Macroseismic Scale (EMS); Japanese Meteorological Agency (JMA).

4.2.2. Urban and regional view on the intensity of earthquakes

Strong earthquakes have impacts on people not only through the destruction of houses but also by influencing their life and livelihood, neighbourhood, city, and possibly region. Reconstruction after each earthquake, even only for housing, is a complex and multidisciplinary task for designers as well as for authorities, decision-makers and the construction industry. Analysis of two cases of the early-inexperienced reconstructions are summarised as examples.

Earthquake and reconstruction of Tokyo

The reconstruction after the Tokyo earthquake started at the upper level of infrastructure, in which a reconstruction plan was formulated by Goto Shinpei. In this plan, a modern network of roads, trains, and public services was drawn up. Because the city was highly earthquake-prone, parks were placed all over the city to work as refuge spots as well. In this reconstruction, public buildings were constructed according to stricter standards and under better quality control than the private buildings that would accommodate refugees. The planning was going smoothly until the outbreak of World War II, when the subsequent destruction severely limited resources.

Conclusions from the reconstruction of Tokyo (after the Great Kanto earthquake, 1923) may be: (i) Small construction firms were more successful than the biggest ones. (ii) Even with similar building systems and construction materials, a lower quality – at least in terms of earthquake-resistance – was observed in private houses than in public buildings (EC, 2006). (iii) Crucial issues were related to disaster management. Disaster management is not only the rescuing and sheltering of people and important objects during and after an earthquake, but also includes similar intentions related to possible earthquakes in the future. With this, social vulnerability is reduced in two ways. First, by prepared sheltering, and second, by preventing or reducing the risks. Nevertheless, although the reconstruction of Tokyo was well planned, not everything was studied or estimated in adequate depth. Therefore, as is always the case for first tries, many of the unpredicted factors popped up only later. Ignorance or insufficient in-depth study of the possible consequences of reconstruction may result in serious problems. For example, in the reconstruction of Tokyo, the intention of stimulating the city resulted in an unpredicted migration to Tokyo of villagers from the countryside. This exodus from rural areas resulted in an unbalanced population. Moreover, these villages were supposed to support the city, in terms of agriculture and nutrition. Therefore, the consequent unpredicted problems were not easily solvable (see also Shahnoori et al., 2007c). Bouin Zahra is another case that experienced comparable problems, but on a different level.

Earthquake and reconstruction in Bouin Zahra

The earthquake of 1962 in Bouin Zahra, a rural area in the vicinity of Qazvin, with a magnitude of 7.2, destroyed a collection of 121 villages in this dry, cold region of Iran. The destruction level of houses reached 50% to 100% in many villages (UN, 1968), of which 21,000 were destroyed or severely damaged (Zare, 2001). The government, national and international groups, as well as individuals, paid extensive attention to this area (but only on a superficial level). Rapid planning for sheltering and reconstruction was organised, which went very well. However, after few years many villages were evacuated to the adjacent city first and later to elsewhere.

Before the earthquake life in the villages of Bouin Zahra was based on agriculture, farming and cattle rising, and the products were consumed by neighbours and people in the region. The villagers were the producers, and neighbours were the consumers. Nowadays (almost) all of them are consumers. This reconstruction caused not only a regional problem of unbalanced occupation or density and production in the long run, but also many social problems for these villages as well as for the city to which they migrated. This is to be mentioned in discussions on evaluation criteria of design in Chapter 7.

4.2.3. Deduction, urban circumstantial analysis and desert environment

The cases mentioned above are representative to illustrate development and evolution of earthquake engineering. They also show that earthquake engineering is a large subject comprising much more than only building-related knowledge. Hence, although analysing the situation and local information is crucial for a design, the design solution may be influential for the neighbourhood or even the entire region. Such problems may become far too serious for vulnerable cases such as desert areas (see also Shahnoori, 2006).

In the two cases discussed, the problem was intensified by a superficial estimation of effects in the urban areas surrounded by green land with great natural potentials. The consequences observed were problematic, especially in the case of reconstruction of Bouin Zahra. Therefore, it is foreseeable that such unpredicted consequences may severely affect a potentially vulnerable zone such as a desert area. This was the case in the reconstruction of Qir & Karzin, a collection of villages in a dry region of southern Iran, after the earthquake of 1972 as well, which will be mentioned in Chapter 7 when discussing the design evaluation on the building level.

Fields such as earthquake engineering are based on methods of learning from experiences and gradual progression. While the urban level has shown slow adoption, many examples of faster progression are available on the level of building, structure, system, and materials. Nevertheless, in addition to lacking knowledge, expensive and difficult test facilities are still quite difficult hurdles for serious progression. These facilities require large-scale samples and spaces, with great financial support. Innovative solutions such as SMETP (Slow-Motion Earthquake Testing Probes) are gradually replacing the costly laboratory experiments with a hybrid approach (Masqueda, 2009). A problem is that results of scaled experiments in the lab are different from those in the practical work on site (Shahnoori et al, 2009). Some items and aspects that may not seem directly relevant actually are and may unexpectedly involve in the design.

4.3. Earthquake engineering in summary

Studies in the field of earthquake engineering are mainly dividable into two general branches of (i) studying seismic activities, recording, registration and instruments (e.g. Knoll and Kowalle, 1996;

Monteiro, 2009) and (ii) seismicity-resistant constructions. The first group of studies is not directly related to this study. However, they provide the fundamental information on causes and effects that is required to enable designers and engineers (i.e., the second branch) to develop earthquake-resistant concepts.

The second group of studies about earthquakes is very large, and includes a vast variety of subjects. Here, many works concentrate on geo-techniques and resources (e.g. ASME-SFEN-JSME, 2000; INAWG-MNC, 2001; El-Hawary, 2001; Ansal et al., 2009) and infrastructures (Brandon, 2001; Chen et al., 2003; Pender, 2005). These mainly focus on dams (e.g. PEECD, 1990; Gosschalk, 2002; Li et al., 2005), bridges (e.g. TRBEC, 2002; Chen, 2003; Williams, 2003), and transportation (e.g. Dawson, 2009; Gupta, 2002; Tatano et al., 2007). Nevertheless, many researches have been done on buildings, building systems and building structures. Examples of these include Kawano et al. (1998), Brandon (2001), Nilson (2003), Paz and Leigh (2004), Both et al. (2006), Chopra (2007), Betbeder-Matibet et al. (2008), Elnashai et al. (2008), Dowrick (2009), Fardis (2009), Ilki (2009), Mendes et al. (2009), Papadrakakis (2009), Sen (2009), and Fernandez and Bauer (1999).

4.3.1. Response of structures in earthquake engineering

In structural design, engineers are obliged to design structures with the three main properties (see scheme in Figure 4.3) of strength, stability and serviceability (Booth, 2006).

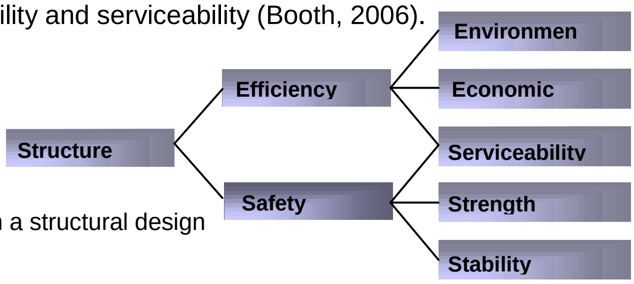


Figure 4.3. Essential aspects to begin a structural design

Even at this step and general criteria for structural design, different influences can be caused by other variables such as the level or type of seismicity. The way the load-bearing structure is conceived depends on the degree of seismicity and the design methodology that are normally based on the agreed standards (e.g. Eurocode 8 and ISO 3010, which are prepared or published by IAEE, ASDI, TIT, IASPEI, ICC, IBC, etc.). Standards such as Eurocode 8 (EC8) specify the design limitations or basics to cope with certain earthquakes in a particular situation. Therefore, in addition to the dead and live loads, the lateral loads are initials for strength, stability and serviceability, while the design and construction methods guarantee efficiency. Some other important items related to seismicity that do not directly play a role in the loading process are also involved in the structural design. The regional frequency of the earthquake is one of these items.

Table 4.2. Seismic probabilities

Event	Recurrence interval (years)	Probability of exceedance	PGA (g)
Frequent	21	90% in 50 years	0.06
Occasional	72	50% in 50 years	0.11
Rare	475	10% in 50 years	0.31
Very rare	2475	2% in 50 years	0.78

Table 4.2 shows the differences that the seismicity of a region may pose due to the annual, decadal or centennial occurrence. As this example shows, factors such as probability of earthquakes in a region are not directly considered as a design issue, but they are essential in choosing the design methodology. Hence, due to the involvement of seismicity, there is much more information similar to that in Table 4.2 that needs to be incorporated into the design. Therefore, within the design boundary, every single factor in the scheme of Figure 4.3 is influenced by

seismicity, and this is why it absolutely constrains the design. As a result, a great deal of design solutions concentrates on the requirements for mitigating the earthquake-load.

4.3.2. Structural behaviour and earthquake resistance

The most important parameters that describe the behaviour of structures when subjected to earthquakes are strength, stiffness and ductility. None of these values is constant. Strength is the capacity of a structure to resist loads in a given response situation. Strength represents both action resistance and the ability to endure deformation, or its deformation capacity (Elnashai et al., 2009). Stiffness is the ability of the structure to resist deformation. It is the ratio between action and deformation at a given level of either of the two quantities, and the corresponding value of the other. The ductility of a structure is the ability of the structure to deform beyond the elastic limit.

Design of earthquake resistant structures

Two types of essential division in the structural design for seismic resistance are more often observable, A and B.

For the A type, two general approaches are evident. The first is traditional force-based design, and the second is the more recent approach of substituting ductility, or inelastic deformation capacity, for strength (or force capacity). The first approach relies on force capacity to resist seismic effects expressed as a set of horizontal actions defined as a proportion of the weight of the structure. Nevertheless, estimation of seismic demands involves great uncertainty, and a strength-based design is significantly sensitive to unexpected increase in the force demands imposed on it. In the second approach, structures are lightweight (relatively) and use less material, but require more workmanship (ACI, 2003/2004).

Type B also includes two sub-divisions: (i) capacity design and (ii) direct design. The first is a combination of strength-based and ductility-based design, so both the strength and the ductility of components are applied. This approach covers members with a high load capacity and members of high inelastic deformation capacity for optimising the response of the structural system. The second method, direct design, is the dimensioning of individual components to resist the locally evaluated actions with no due consideration of the action redistribution effects in the system as a whole (Elnashai & Sarno, 2008), either ductility-based or strength-based. Nevertheless, many modern systems are introduced by the capacity design, such as the examples following.

4.3.3. Isolation of the structure to mitigate the seismic loads

Seismic isolation is a modern concept for seismic design, which is based on the separation of the structural system from the seismic-energy dissipation mechanism. Instead, conventional design involves the whole structure to dissipate the seismic energy through plastic deformation cycles. The disadvantage is that during high-intensity earthquakes, the structure suffers costly damage or even destruction (Penelis & Kappos, 2005).

Table 4.3. Typical range of value in basic characteristics of seismic isolation devices

Item	Effect	Range of values
Natural period		1- 4 s
Yield shear coefficient	Reduction in response acceleration and	0.04- 0.15
Damping ratio	story drift of superstructure	
Normal pressure		5- 15%
Second shape factor	Improvement in bearing capacity	20-100 kg cm^{-2}
	Improvement in bearing capacity and deformation capacity	2- 6

* Information adapted from Kitagawa and Midorikawa (1997).

In severe seismic motions, reducing the inter-storey displacement and floor acceleration of the structure helps to minimise the damage (Komodromos, 2000), where inter-storey drift or storey-shear strains cause damage to the structure (and construction). Hence, the floor acceleration causes damage to the content of the structure. Stiffness ensures a minimisation of the inter-storey drift. However, it leads to amplification in the building of the earthquake ground acceleration with high floor acceleration. Conversely, reducing the stiffness may reduce the floor acceleration, but due to the structural flexibility, the inter-storey displacement increases. Seismic isolation (Fig 4.4) can simultaneously reduce inter-storey displacement and floor acceleration (Komodromos, 2000).

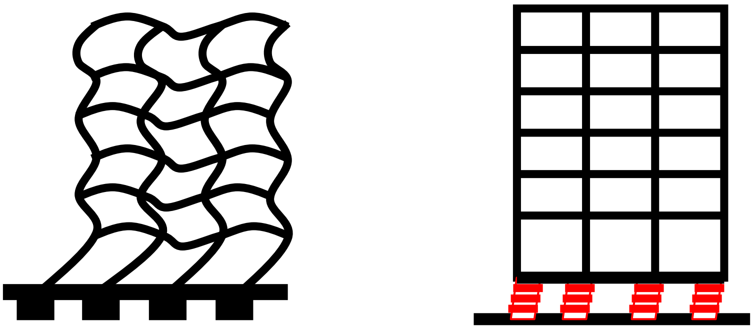


Figure 4.4. Deformation patterns of a fixed supported and a base-isolated building

The isolation mechanism defines the upper limit of the earthquake force that transfers from the foundations to the structure. Therefore, it can be concluded that the isolated structure is designed only for vertical loads and that the seismic actions are predefined according to the yield shear of the pads (Tarics, 1987). These pads absorb and dissipate the seismic energy through elastoplastic loops when subjected to cyclic loading in the plastic range (Kelly et al., 1980). A seismic gap to allow free movement and large displacement is required around the structure. This needs to be ensured for the entire lifetime of the structure (Komodromos, 2000).

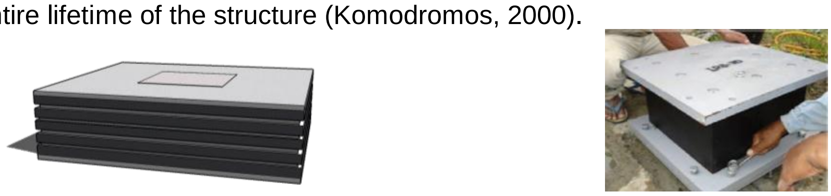


Figure 4.5. Details of pads made of reinforced Neoprene, with a lead core in earthquake isolators.

The pads must undergo cyclic elastoplastic deformations without being destroyed. Hence, due to aging effects, when the intended lifespan has exceeded, replacing them represents a problem (Penelis & Kappos, 2005). Regarding these, designers proposed several innovative solutions. For example, a new pad is made of reinforced Neoprene with a lead core acting as a dissipative mechanism (Fig. 4.5), but it is still costly.

Table 4.4. Comparison of acceleration of isolated building and ordinary buildings

			Ordinary buildinA0		**Isolated building A1**		**Acceleration ratioA1/A0**	
Eq. No.	Loc.	Dir.	Obs. (gal)	Cal. (gal)	Obs. (gal)	Cal. (gal)	Obs.	Cal.
	Roof	T	7.18	6.96	1.87	1.59	0.26	023
		L	7.29	7.16	2.46	1.94	0.33	0.27
	1st Floor	T	2.10	2.45	1.39	1.33	0.66	0.54
		L	2.79	3.58	1.90	1.70	0.68	0.47
	Roof	T	8.73	8.56	1.44	1.34	0.16	016
		L	5.43	5.27	1.09	0.86	0.20	0.16
	1st Floor	T	1.66	1.95	1.19	0.97	0.71	0.50
		L	1.43	2.05	0.93	0.76	0.65	0.37

Information adapted from Wang et al. (1993)

The isolation concept ages more than a century (Komodromos, 2000), but only in the past few decades, due to manufacturing advancements, has the technology of elastomeric bearings and dampers enabled the utilisation of this concept to mitigate earthquakes. Although the seismic isolation concept has great advantages over conventional designs, it is only used for special structures because of financial and technological limitations.

4.3.4. Damping systems for earthquake resistance

Another innovative mixed system concerns structures that use dampers to absorb the violent seismic shocks. The conventional design for damping is one of these systems. Damping systems are classified in three main branches: (i) passive damping systems, which are not controllable (ii) active damping systems, which are force generators that actively pressure the structure to counteract disturbances, and (iii) semi-active systems, which counteract motion with a controlled resistive force to reduce motion rather than push on the structure. In this way, they require little input power, while they are controllable.

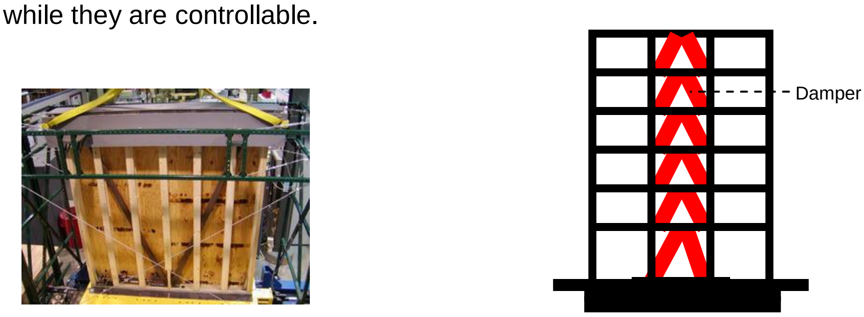


Figure 4.6 Damping system made of fluid-filled shock absorbers, installed horizontally throughout the walls to channel some of the energy into dampers (Photo: Rensselar/Symans, 2006)

This damping system inside superstructures (e.g. in Figure 4.7) can combine smart systems with other types of structural designs. The damper systems may implement different details, such as large dampers filled with magnetorheological fluid (MR, discovered by Jacob Rabinow in 1940). This MR, also called liquid-solid, is a liquid that changes to a near-solid state in milliseconds when exposed to a magnetic force. Once the magnet force is removed, it turns back to liquid. 20 to 40 per cent of the fluid is made of Carbonyl Iron Particles, which are suspended in a liquid, usually hydrocarbon oil (Carlson, 2008). This is a semi-active system, because MR fluid devices change their damping level by varying the amount of current supplied to an internal electromagnet that controls the flow of MR fluid.

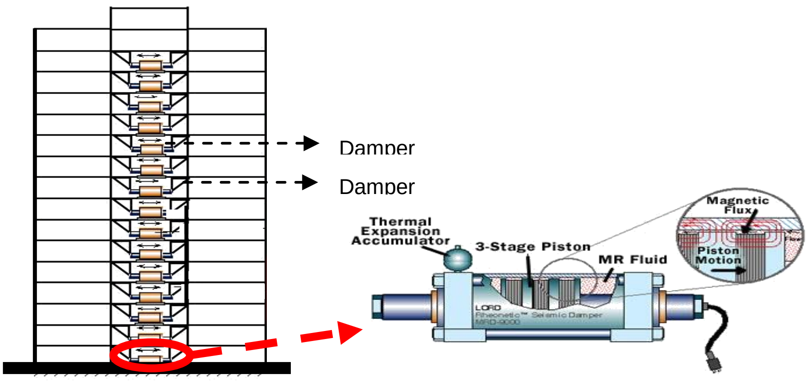


Figure 4.7. Large dampers filled with MR, stabilised in structure. (source of damper's photo's: Lord Corp).

However, similar to the seismic isolation, these also need special attention and technology that make them difficult to implement in ordinary buildings.

Finally, in a different classification Kitagawa et al. (1998) call the semi-active systems as response control. The scheme in Figure 4.8 is an example branching of response-control systems proposed by Kitagawa et al. (1998). The response control, as a mix of some introduced systems, poses similar drawbacks as indicated.

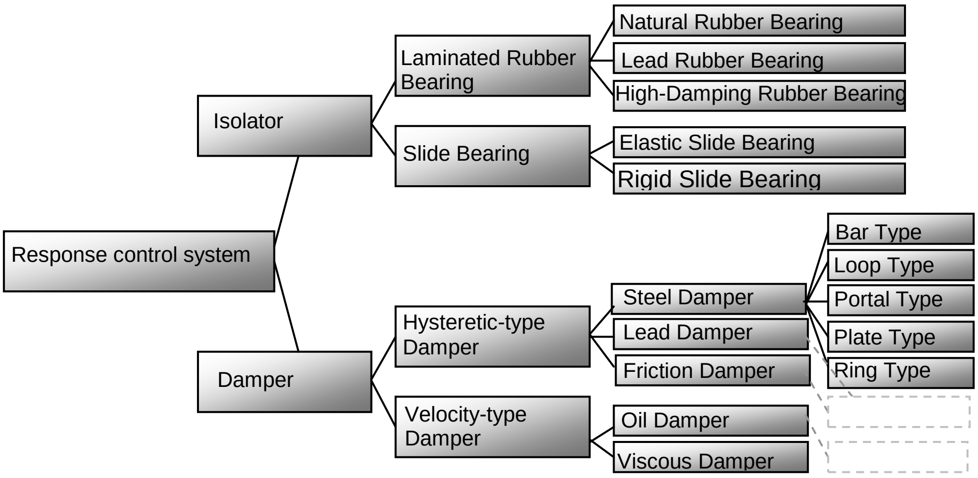


Figure 4.8. Branches of response-control system according to Kitagawa et al, 1998

4.4. A short analysis of buildings for seismic loads

As post-earthquake reconnaissance shows, ”building configuration plays a significant role in seismic performance of structures subjected to seismic loads” (Vrouwenvelder, 2006; Chopra, 2007; Elnashai et al., 2008). Due to a concentration of inelastic demand that is likely to occur in zones of geometrical discontinuity or mass and stiffness irregularities, irregular structures show poor performance. Failure begins in a situation with limited ductility; this may lead to collapse in the end. Typical structural irregularities are shown in Table 4.5 along with their sub-branches.

Table 4.5. Typical structural irregularities

Structural Irregularities			
Plan Irregularities		Elevation Irregularities	
Re-Entrant Corner/ In-plane Offsets	Non-Parallel Lateral Resisting Systems	Re-Entrant Corner/ Vertical Offsets	Non-Parallel Lateral Resisting Systems
Lateral System Horizontal Discontinuities	Diaphragm Discontinuities	Lateral System Horizontal Discontinuities	Weak and/or Soft Storeys

For seismic performance, the possible impact from inappropriate configuration, in plan and elevation, depends on:

- *Size*: an increase in size of the structure may influence both the choice of configurations and the choice of materialisation (Laogan et al., 1999; Aoyama, 2001; Elnashai et al., 2008).

- *Proportions*: The relative proportions of a building are very important for the earthquake response of a building, rather than its absolute size. A reduction in the slenderness in elevation reduces the overturning effects on buildings under later loads. Torsional effects are of possible consequence with a large aspect ratio (ratio of the height to the smallest depth) in the plan. For a seismic performance, the ratio of the height (H) to the smallest depth (B) should not exceed 4-5 (Dowrick, 2003). However, this exceeds by a ratio of 10-15 in tall modern buildings (CTBUH, 1995).

- *Distribution and concentration*: Seismic motions are multi-directional, so a proper distribution of structural systems to resist vertical and lateral loads can prevent inelastic demand concentrations. To reduce the shear force caused by ground motion, low-rises should be stiff, whereas tall buildings should be flexible to minimise lateral deformation (Elnashai et al. 2008).

- *Perimeter resistance*: the dynamic response of the system is significantly influenced by the location of the resisting system in the plan. A higher gyration radius of the plan layout of the structure increases the lever arm to resist overturning moments. In framed systems or frame-wall systems, frames employing perimeter columns possess high bending stiffness and resistance (Elnashai et al., 2008).

To prevent unwanted results two fundamental aspects of structural configuration are (i) the form of the entire structure, and (ii) the type of the lateral resistance system used. According to Elnashai et al. (2008), the basic principles to achieve adequate seismic performance are simplicity, uniformity, symmetry, redundancy, bidirectional resistance and stiffness, torsional resistance and stiffness, diaphragm behaviour at storey level, and adequate foundation.

In summary, for an adequate seismic performance, a structural system requires the following characteristics (see Dowrick, 1987; Paulay and Priestley, 1992; Priestley et al., 1996; Foliente, 1997; Bruneau et al., 1998): adequate stiffness, adequate strength, high ductility, high damping, high stability, and high redundancy. However, most earthquake-resistant systems possess only some of these characteristics. These systems may combine to provide a new resistant system, called a ‘hybrid system’.

Categories of earthquake resistant systems, cases and analysis

Earthquake-resistant systems have been classified in various ways. For example, the NEHRP defines more than 70 individual types of seismic force-resisting systems for structures. From another perspective, Chen et al. (2002) categorise them into five basic groups, as shown in Table 4.6.

Table 4.6. An example of categorising earthquake resistant systems, based on Chen et al. (2002)

Typology of the resistant systems	Resisting methods of the earthquake resistant systems
(i) Bearing wall systems	The vertical elements of the lateral force resisting system comprise either shear walls or braced frames. These walls or braces must provide support for gravity (dead and live) loads in addition to providing lateral resistance (similar to the old box systems).
(ii) Building frame systems	The vertical elements of the resisting system comprise shear walls or braces, however this shear members/ elements are not supposed to provide gravity resistance
(iii) Moment-resistant frame systems	Flexural rigidity and strength of interconnected beams and columns provide the lateral resisting. In this interconnection stress is induced in the frame by lateral displacements.
(iv) Dual systems	Either moment resisting frames+ braced frames or shear walls provide the lateral resisting. The braced frame or shear walls provide the primary lateral resisting. The moment resistant frame acts as backup or redundant system, to provide supplemental lateral resisting when earthquake response severely damages (to a functional ineffectiveness) the primary lateral force resisting elements
(v) Special systems*	Comprising unique structures (e.g. the one that uses rigidity of cantilevered columns for their lateral resistance system), are structures provided with detailing believed capable of withstanding large cyclic, inelastic demands.

The other widely used classification is dividing the resistant systems by their level of detailing that include ordinary, intermediate and special systems. The latter is common with special systems (v in Table 4.6), which are based on the quality of detailing and the resulting ability of the structure to withstand earthquake-induced inelastic, cyclic demands. However, the intermediate types are structures with limited levels of detailing and inelastic response capabilities. Thus, in contrast to the special systems, the ordinary systems with relatively little detailing, are incapable of withstanding significant inelastic demands. Nevertheless, a wide range of these systems is available, based on various combinations of different classes and diverse materials. A largely utilised basic classification divides them into:

(i) Horizontal systems: Horizontal bracing or horizontal diaphragms are provided by floor-framing systems.

(ii) Vertical systems: Inadequate stiffness and strength of the vertical components of lateral structural systems may lead to structural and non-structural damage. This damage may be due to insufficiency or absence of ductility.

According to Chen et al. (2002), the lateral load-resistant systems are composed of five sub-categories: (i) moment-resistant frames, (ii) bracing frames, (iii) structural walls, (iv) hybrid systems, and (v) tube systems (table 4.6).

In general, the earthquake-resistant systems described comprise different characteristics that allow various choices in different situations. However, they can also be compared to one another. Table 4.7 gives examples based on Elnashai et al. (2009); cost effectiveness is also an item in this comparison. Combinations of these main classes create an immense amount of choices. Furthermore, many systems are not included in this table (e.g. the base isolation).

Table 4.7. Relative measure of suitability of some earthquake resistance systems (vertical lateral)

Resisting system (vertical lateral)	Strength	Stiffness	Ductility	Appropriateness	
				Maximum storeys	Seismic application
Moment-resisting system	High	High	High	1-3	++
	High	Low	High	15-20	++
Braced frames	High	High	Low-med	20-30	+
Structural wall	High	High	Low-med	25-30	+
Hybrid (or dual) frame	High	High	Med-high	30-40	++
Outrigger-braced frame	High	High	Low-med	50-60	+
Frames tube system	High	High	Med-high	60-70	++
Tube-in-tube	High	High	Med-high	70-80	++
Trussed tube system	High	High	Med-high	80-100	++
Bundled tube system	High	High	Med-high	120-150	++

+ means ‘adequate’, and ++ = ‘very good’ (content courtesy of Elnashai et al., 2009)

A crucial point in this analysis relates to the knowledge of the deformation of the overall structure and its components during an earthquake, which still needs elaboration. However, similar to the mentioned outline of seismic isolation concepts, most of the systems are applicable specifically in special or expensive structures; they are less suited for cheap low-rise town houses.

4.5. A brief inventory and background of the applied systems

San Francisco earthquake of 1906 was the strong start of post-earthquake reconnaissance for earthquake engineering. However, most reconstruction occurred after World War II. Much of this reconstruction, either documented or not, is readily observable (for instance, the shopping mall Linda Vista, 1941; Willow Run, Willow Village, 1945; the House of Tomorrow by Buckminster Fuller, 1944; Aluminium-based housing, Consolidated Aircraft Company of California; Dymaxion and Vultee House, Dreyfuss and Bames; Douglas, 1946; London 1947-68; reconstruction of the City of Dresden, 1950). The knowledge and products used in these reconstructions were also used, either directly or analytically, for reconstruction after earthquakes.

4.5.1. Earthquake resistance systems in Japanese houses

As a highly earthquake-prone zone, Japan provides a suitable case for vast application of earthquake-resistant systems. Three general branches of the systems applied in Japan are:

(i) The old system: A. timber houses or B. the traditional system
(ii) Conventional systems
(iii) Modern systems.

(i) The old system: A. Timber houses. This system is based on using the earthquake-resistant capacity of wood, and the details of the system. ***B. Traditional systems.*** To avoid eccentric loading, a wall plays the role of resistant element, in this system; the proportion of the walls is important. In addition, a bracing system of wood or nails to anchor the wall to the ground is used. The system is based on a modulation in which walls are composed of several unites. The number of required unites in a wall has a factor of between 0.5-0.6. However, these houses are limited to two-storey buildings. In this system, the proportion of windows is small (different from the traditional wood windows), and it is locally called a two-by-four sycte.

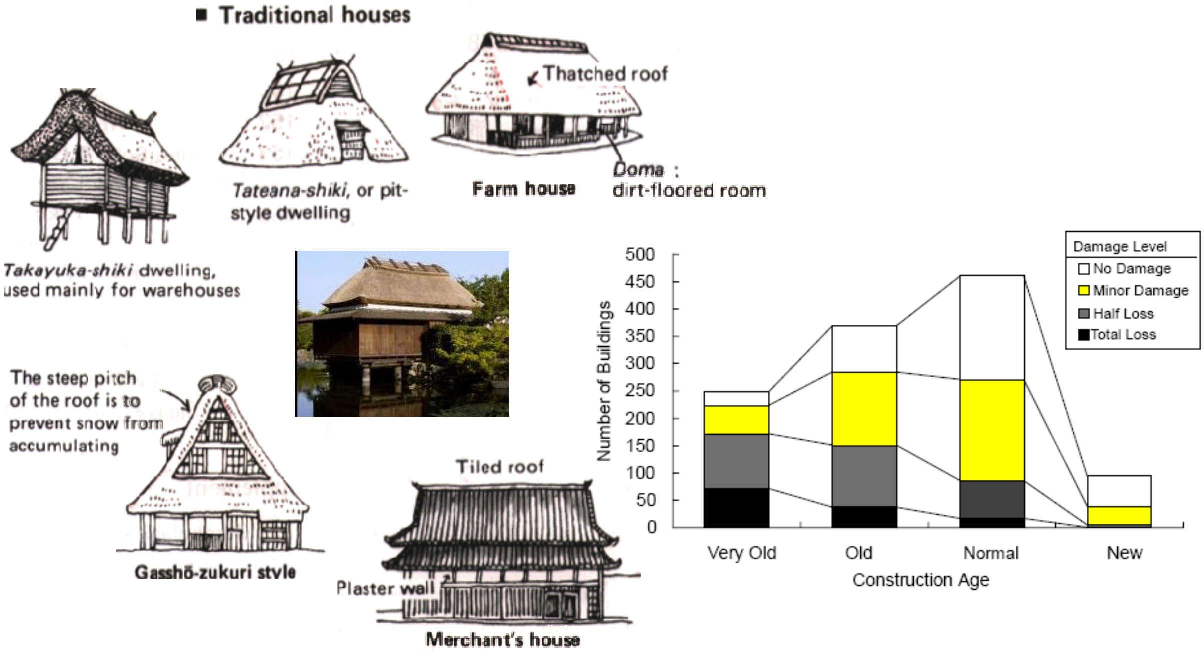


Figure 4.9. Japanese timber houses (photo courtesy: JAANUS, 2009 and Otani, 1999)

(ii) Conventional systems. Especially during the reconstruction of Tokyo after World War II, Japan's government was faced with providing housing for millions of people. Therefore, in view of the safety the houses were made of prefabricated concrete components. These houses were mostly lower than six storeys, functioning as private houses for individual families (mostly built in the 1960s and 1970s). The major companies in Japan working with this system, in conjunction with wood and steel, were Sekisui, Daiwa, Misawa, and Sumitowo.

The method used for reconstruction after WWII mostly was the 'boxed wall building system' (Shiohara, 2007). The proportions in this system were limited (mostly about 48 m² for each house), and the majority of these buildings were built in Tokyo and Tama. The other constraint for these boxes was their developability, which is only possible within a limited standard frame. However, the system worked very well and the quality of the boxes in terms of durability and strength has been proven. Unfortunately, it is no longer socially desirable. Due to the vulnerable joints and connections, prefabricated concrete elements failed in earthquakes of China, Russia, Armenia and so on. Therefore, this system does not offer much reliability in seismic areas. Nevertheless, the Japanese conventional system (after WWII) meant an evolutionary step in seismic application.

According to Shiohara (2007), prefabricated elements with special connections (called an emulating system) are used in Japan, New Zealand and the USA. Here, parts of reinforcing bars connect and overlap the elements, and the holes at the end are filled with fast-hardening high-strength concrete.

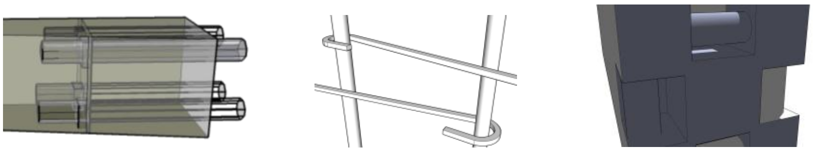


Figure 4.10. examples of the reinforcing bars as safety connectors

(iii). Modern systems. A number of more recently applied earthquake-resistant systems in Japan are similar to those used worldwide; examples will follow.

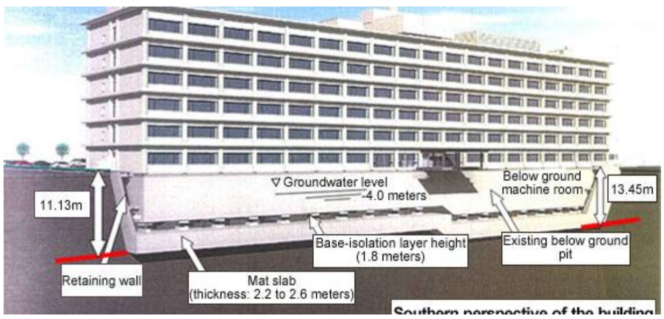
4.5.2. Examples of modern systems applied in Japan and some other countries

Modern earthquake-resistant systems applied in Japan include:

- Response-controlled earthquake-resistant structure (Seishinsei Taishin Kozo): the structure damps vibrations, thereby imparting vibration-resistant properties (Takabya)
- Damping (Seishin): the amplitude of the vibration in the structure is controlled mostly using a response-control or attenuating mechanism.
- Vibration prevention (Boshin), Menshin: seismic waves are not allowed to pass to the structure by a blocking mechanism, which cuts off seismic waves from the structure.
- Earthquake-resistant Taishin: enabling the structure to withstand seismic vibration.
- Damping, earthquake-resistant (Seishin, Taishin): the structure is rigid with respect to spatial co-ordinates of seismic motion.
- Vibration protection (Boshin), Menshin: the structure has absolute steady space coordinates.
- Damping (Seishin): structure properties control seismic vibrations.
- Rubber and other resilient materials in the building foundation as a shock absorber are mostly used in Japan and the US. …

Figure 4.11. Rubber and other resilient materials and systems in foundations (photo: Saito, T.)

- Base isolation and energy dissipation techniques applied in some existing Japanese building complexes (e.g. figure 4.12 and table 4.8). For example in buildings 1 to 4 of the 'Tokyo DIA Building', 264 rubber bearings, 28 wall-type viscous dampers over an area of about 68,000 m^2 were used (Takenaka Corporation, 2000).



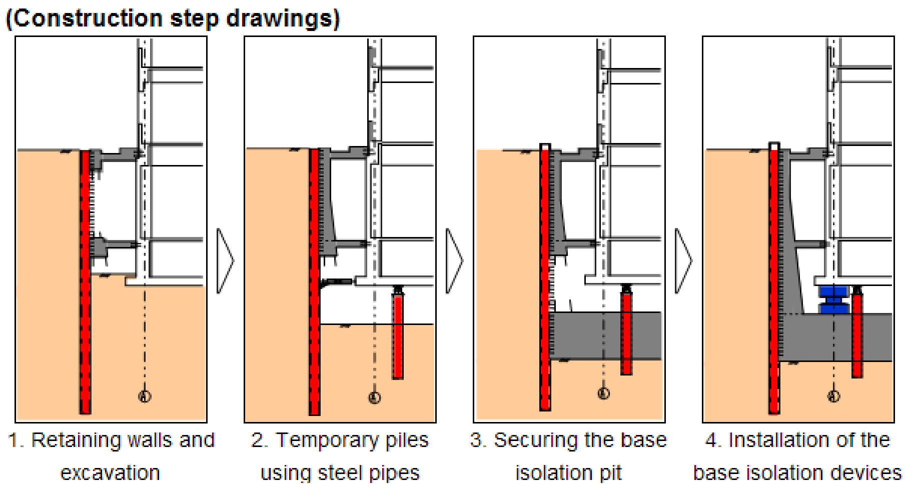


Figure 4.12. Installation of the base isolation system for the first time and its processes (TC, 2000)

Table 4.8. Examples of major (early) projects of base isolation in Japan and USA

Building's name	Total floor space (m²)	Old/New
Building1 through4, Tokyo DIA	68, 219	Retrofit
Shizuoka Cancer Centre	64,155	New
Yokohama Municipal Port Hospital	62,627	New
Geographical Survey Institute Joint Government Building (Main building)	19,797	Retrofit
Los Angeles Hall	82,000	Retrofit
San Francisco City Hall	47,800	Retrofit

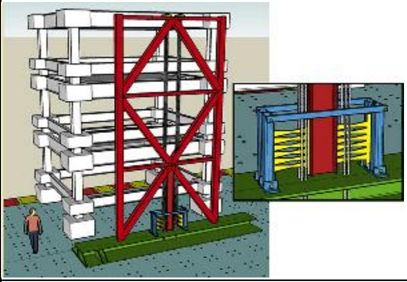
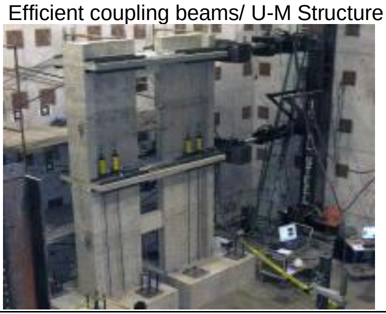
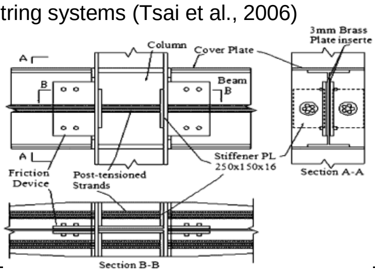
Adapted from Takenada, March & April 2000, October 2009

- Kuroda et al. (1993) developed a system applied to one of a matching pair of buildings in Sendai. Difficult steps in the construction were related to the manufacturing and testing of high-damping natural rubber-laminated earthquake isolation bearings.
- A modern system is a hybrid solution called Hi-DAM. This was used in the Pacific Tower in the Roppongi district in Tokyo, a 27-floors, 95 m high-rise residential building of the Glorio Roppongi. It contains 2 coupling beams per storey, with 54 ECC coupling beams that are designed to mitigate earthquake damage. Material properties such as high damage tolerance, high energy absorption, and ability to deform under shear force were the superior advantages of this system. The Hi-DAM system that absorbs the shake is located between the Super Beam and Connecting Column. The Super Beam is the collection of the main beams located at the top of the structure and attached to the central core, the Super Wall. In the Super Wall the reinforced high-strength concrete is used which as a core supporting the floors. The Connecting Column is connected to the Hi-DAM and Super Beam, and supports the floors and the external façade. The Hi-DAM system, this time with 4 coupling beams per floor, has also been used in the 41-storey Nabeaure Yokohama Tower designed by Kajima Corporation.

Figure 4.13. a., and **b.** Glorio Roppongi/ Pacific tower, **c.** and **d**, Nabeaure Tower, Yokohama, Japan. (Source: Structure, 2007, and the Concrete Producer, 2006)

Finally, in addition to Japan, many of other countries (e.g. the US, New Zealand and Australia) are also developing modern systems to mitigate earthquake excitation. Therefore, various systems with different design methods are globally available (examples are given in table 4.9).

Table 4.9. Examples of earthquake systems

Some on-going Seismic resistant system and designs	
Self-righting building (Deirelein, 2009) 	Efficient coupling beams/ U-M Structure (Wight, 2009) 
Tsunami proof building (Wang, 2009) 	Self-centring systems (Tsai et al., 2006) 
Of other examples on laboratory level are: - PCPW (Darama & Shiohara, 2007), - Frame Without Beam - Small Concrete Blocks - hybrid systems - Viscous Dampers - Semi-Active control systems …	

4.5.3. Systems in traditional desert houses, cases of Yazd and Bam

From a worldwide perspective, many traditional methods for mitigating seismic motions, especially in houses, are based on wood. Wood however is scarce in most desert areas. Therefore, not many seismic resistant methods were found in desert cities. Instead stability of the building by symmetrical plans and some other configuration details such as the relative walls portion and other design details (e.g. small openings or no opening in the loadbearing walls) were mainly applied. Of the few other systems, supporting arches and walls between two massive walls may be assumed as an example. However, validation of this assumption needs a thorough research. This system (e.g. figure 4.14) was found in cities as Yazd, Kerman, and Kashan in the central desert of Iran for shading purposes.



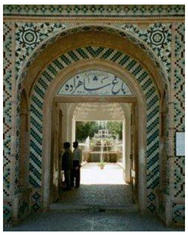



Figure 4.14. Sabats in Kashan. Mahan, and Yazd, the shading and supporting arches for the adjacent structures and houses (photo: Shafiei, Soheili, Stefano and Mohamad, 2009, Kinesiologie, 2003)

These supporting arches, which are called Sabat, provide shadow for streets and pedestrians in the harsh desert days, and they may act as support for the walls and structures of adjacent houses as well.

Figure 4.15. Some bracing system of Sabats in Yazd (photo: Emdadi, travelbicycle, Maghbooli

In cities as Bam, this system has not been generally applied, but a few cases inside the citadel of Bam (e.g. Figure 4.16).

Figure 4.16. Sabats on the alleys inside the citadel of Bam (photo: Architecture, Ismaielpour, & IDIA)

In cities as Bam an observable system is that of using thick walls on the ground level, the thickness of which was gradually moderated towards the roof. Furthermore, reinforcing the clay, as the main construction material, with straw or some other reinforcing elements was a traditional way of boosting the structures of houses to resist seismic excitation. This method was mainly used in agriculturally productive lands, as is the case with Bam. Nevertheless, in luxury houses, even in remote cities similar to Bam, wood supporting beams can be found. This is due to the scarcity of wood, which makes this material extraordinary and expensive. Finally, in some other seismic desert lands as Mongolia or Arizona traditional housing was not as permanent as that in cities as Yazd. However, the tents in the Arizona or Mongolian style are strongly adopted for earthquake resistance by their special structures and their light weight (e.g. examples in fig.4.17).

Figure 4.17. Mongolian yurt and native Arizona tents (photo: Chinablog.cc, 2009; Shutterstock, 2011)

4.6. Review and analysis

Earthquake-resistant systems for buildings were described mainly by three major types: (i) the conventional design approach, (ii) seismic isolation concepts, and (iii) energy dissipation, dampers, shock-absorbing and mixed systems. Similar to that of a number of traditional systems some hybrid and super modern systems were also exemplified in this categorisation.

In conventional design methods for earthquake-resistant systems, the aim is to avoid collapse by allowing some structural damages (Vrouwenvelder, 2006). In this way, in order to absorb the energy of the earthquake, inelastic deformations are allowed to occur (Komodromos, 2000). The Uniform Building Code concerning earthquake-resistant design, for instance states (in Section 1626, version 1967): "The purpose of the earthquake provision herein is primarily to safeguard against major structural failures and loss of life, not to limit damage or maintain function."

However, in the seismic isolation concept, the aim is to minimise the damage in order to retain the sensitive, important or expensive content of the building with a minimum of damage. Thus, the isolation system dissipates the energy of the earthquake, which is not allowed to enter the structure by providing flexibility that decouples it from the earthquake motion (Penelis & Kappos, 2005). Nevertheless, in damping resistance systems, which depend on the type of damping system and the installation of the damping mechanism, the superstructure may be or may not be involved in the load-bearing task. Thus, the structure may suffer damage or minimum damage.

4.6.1. Critical issues in exploring into the earthquake resistant design

Although the systems mentioned or other systems mostly are new systems, they still obey traditional building practice in terms of the three competitive factors of cost, quality and time. Of course these are serious values, but they are secondary to the main factors of environment, economy and social systems (CIB, 1999). In line with our definition of sustainability, this study assumes that the boundaries identified by CIB also need to change further in a seismic desert situation. The value that the methodology and theory of this study proposes is that where lives are so critically dependent on a design, the hierarchical arrangement of values needs to be (i) sustainability (for the environment and for enduring safety as well), (ii) social systems and (iii) economy.

In a detailed analysis of the systems mentioned, critical points in most of these systems involved first strengthening the main structure. The second common issue was that they prioritise economy to environmental issues. None of them considered the environment as a leading or even as an important issue. The most essential and fatal point in the current state of structural design is that every type of building has a boundary outside which it collapses. This was identified according to the importance or level/class of the building (EuroCode 8). Houses are not counted as important buildings (with a coefficient of 0.8), while buildings as hospitals do have a certain level of importance (coefficient of 1.2). With this level of importance, the structure meets the boundary of resistance with more force than a normal situation, with an increase according to the certain coefficient. At that certain level, the entire structure collapses. As design has the capacity to qualify products as well as lives, it can guide earthquake-resistance design in a sustainable direction. Where the aim is the optimisation of the structural design, this may comprise a minimisation of damages or the prioritisation of inhabitants, or any other important factors, or a combination of them.

It can be said that sustainable design of earthquake resistant systems in the field of earthquake-engineering does not yet have priority. Although some systems can be said to comprise environmentally friendly aspects as well, they are not designed and evaluated according to sustainability. With the load of constraint of seismicity, all the design's focus is on seismicity, and sustainability is lost in the solutions available. Hence, the human factor has no significant priority yet.

4.6.2. Requirements of typical solutions for seismic and desert areas, conflicts

It was mentioned that although a design constraint as seismicity severely influences the design, this design might have to deal with some other constraint too. For example, a SRH-SD (Sustainable Reconstruction of Houses in a Seismic Desert) will have to challenge both of the constraints of seismicity and desert conditions. In such a case, the intention is to provide a solution suitable to resist earthquakes, whilst offering a solution to cope with the desert climate and conditions. Possible conflicts between the design solutions were demonstrated in the scheme of Figure 4.18. Three examples of possible solutions or requirements to abate seismicity can be selected, such as:

(i) Applying high-tech solutions in high-rises
(ii) Implementing light-weight materials
(iii) Using thin walls

In contrast, in a desert town, the standard solutions typically comprise:

(i) Low-rise housing (e.g. single family houses)
(ii) Heavy materials
(iii) Thick walls

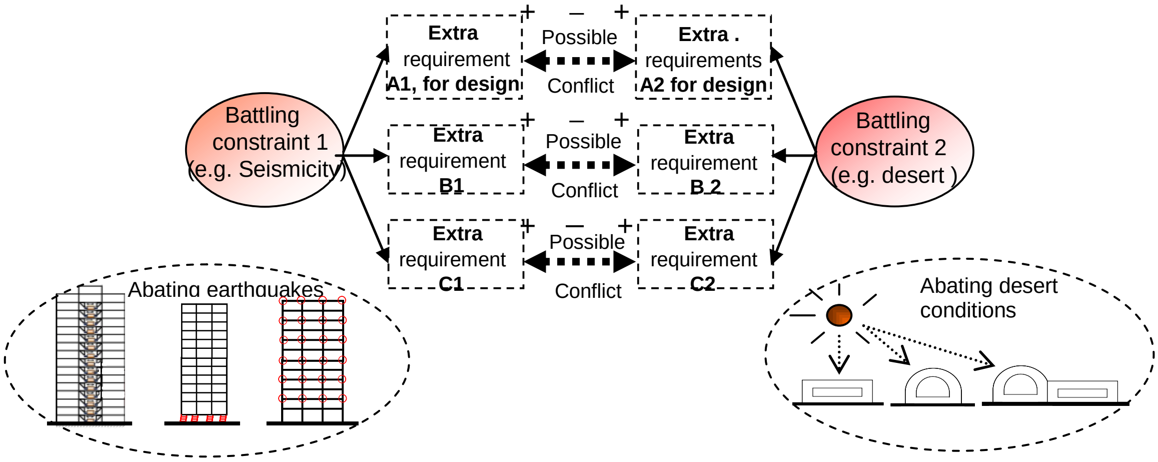


Figure 4.18. Extra requirements due to the design constraints and the possible conflict between the design constraints of seismicity and desert conditions

The following chapter will discuss the way that desert houses deal with the conditions, clarifying the conflict between the requirements to abate earthquakes and circumstantial problems in deserts.

4.7. Summary, conclusions and recommendations

The above-mentioned arguments demonstrated the severe influence of constraints as earthquakes on a design, as well as involved details. In many countries single-family houses and low-rise residential buildings are not counted as important buildings in designing for earthquake resistance, while a house is the most important building for humans. On the other hand, the previous study indicated that the importance and priority of the effect of reconstructions after a disaster on the upper level of society is much greater than that on the individual level (Shahnoori et al., 2007c). For reconstruction it states: ”re-housing is very sensitive and should be done with great social and economic care”. Social aspects are of course serious matters in any design situation. Although this matter has sometimes been neglected in designs over the past, because of its significant role, it was the focus of many studies (e.g. Park and Burgess, 1924, Miller, 1964; Burgess and Bogue, 1964; Matthews, 1977; Bulmer, 1984; Davis, 1992 and 1998). These studies mostly concentrate on urban design, but due to the sensitivity of people and situation after a disaster, and due to the importance of houses for humans, this role of social aspects in the design for reconstruction of houses is crucial.

Spending less expense on structural enhancement of houses is not always equal to less efficiency, which is a very important engineering goal (Giulio, 2008). However, in either case the whole story shows that technical aspects of the reconstruction, for instance in a seismic region, is only one branch of the involved aspects in the design. Still, the influence of seismicity even only on the technical level is very severe which attracts the design attentions. Thus, association of two or more severe constraints increase the complexity of design situation to an extreme that may turn the situation into a complicated one.

Conclusions and recommendations

Design principles are an accurate reflection of the fundamentals that guide decision-making in an enterprise (Pieterse, 2006). In a complex situation, where the complexity is caused by constraints, design principles need to be rearranged according to the new situation in following sets:

(i) The standard basic design principle and building regulations
(ii) Extra items inserted by the constraints
(iii) A new generation of principles because of interaction and interference, due to involvement of design constraints
(iv) A new phase of design must take place because of conflict in design solutions.

Nevertheless, there are also other important considerations for such a design (e.g. SRH-SD) that need to be taken into account including:

- Sustainability should be the main and general statement in the reconstruction of desert towns as Bam. Various contemplations to ensure sustainability are:
    - The houses need to be reconstructed according to the local identities, social desire, and landowners’ wishes.
    - The houses need to create additional attraction or providing social awareness to make the people feel secure to live in the city and their houses.
- Because traditional methods are not directly applicable at present, as has been argued, communication is very important for performing sustainable reconstruction. In the other words, local labourers and other members of the reconstruction team need to understand the problem and to learn how to build correctly, while they need to learn modern methods of construction as well. Educated members (e.g. engineers) also need to understand the strength of the local methods and their meaning to the society whenever it is required.

Practical conclusions are:

- Although most of the solutions for houses to withstand seismic motions focus on high-rises and residential complexes, for a desert town similar to Bam a typical building is a single-family house. Compared with the former the latter is able to survive competition in the market, because it is socially desirable. Therefore, high-rises and similar concepts are not an option and thus excluded from the alternatives for the SRH-SD. However, due to the effects of modernisation the one-floor single-family concept may also be a bit adjustable. The schematic conclusion of these arguments is shown in figure 4.19, which will be realised one step further in the next chapter, when discussing the desert houses.

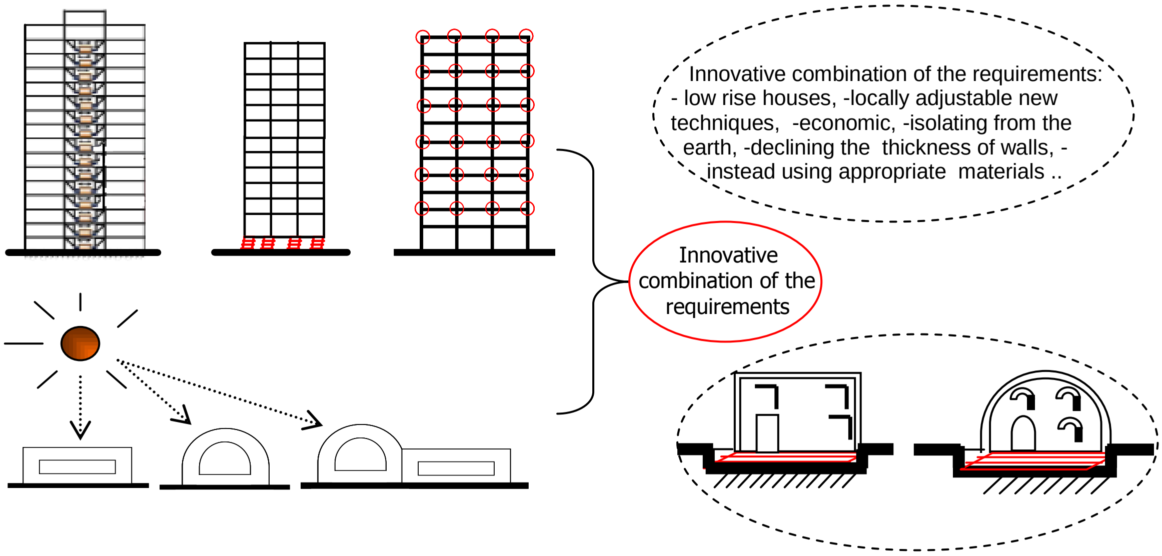
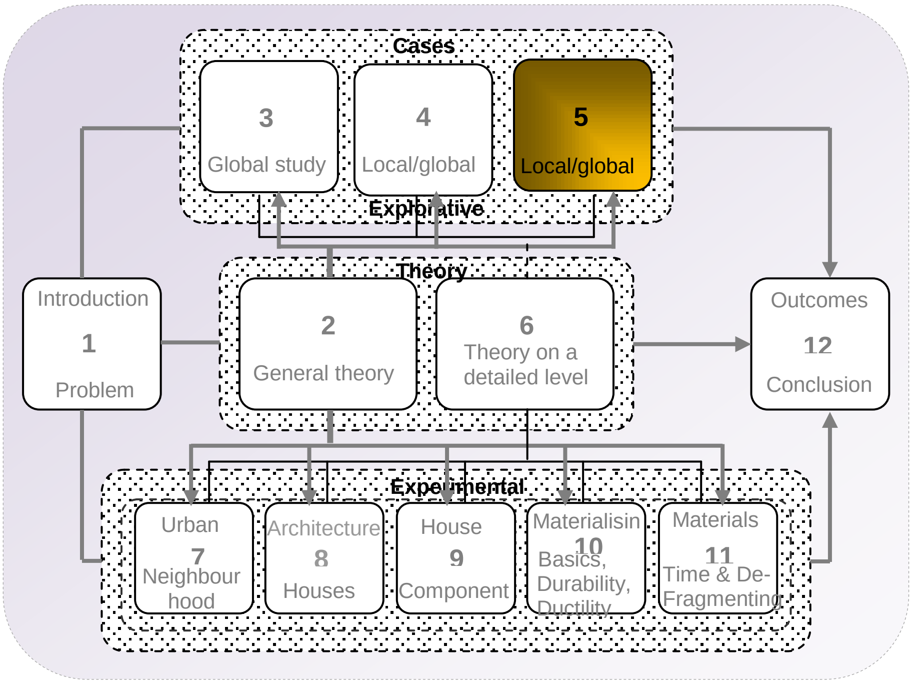


Figure 4.19. The outcome criteria enable the design to avoid conflict between the necessities for withstanding earthquakes and desert conditions which requires innovative solutions

- With a rigid structure, a simple system that separates the building from the earth allows a limited horizontal movement to the foundation or structure, which considerably damps and dissipates the seismic energy before entering the structure.
- The traditional method of thick heavy walls is conflicting with earthquake resistance; hence they are not appropriate in accordance with an efficient use of land and with sustainability. Therefore, thick walls should be avoided in the reconstruction.
- With the current state of technology adobe is not an appropriate option for the SRH-SD. Therefore, in the selection of a strong material for the structure of the houses, availability and sustainability must be compensated. For the SRH-SD a wide scale of materials should be considered, so availability on such a scale is one of the priorities in the materials selection.
- In addition to adjustability with the local technology and economic efficiency of the strong material for the SRH-SD, some properties including stiffness, damping and ductility are important criteria in the selection.



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Introduction
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Problem
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General theory
6
Theory on a detailed level
Outcomes
12
Conclusion
Experimental
Urban
7
Neighbourhood
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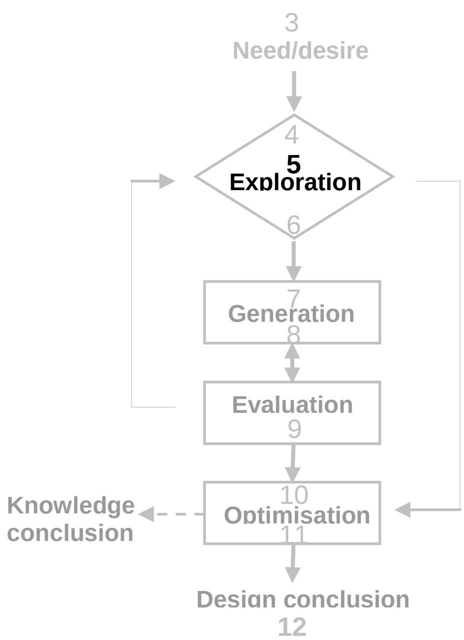

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Optimisation
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Knowledge conclusion
Design conclusion
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CHAPTER 5

DESERT HOUSES IN AN EXPLORATIVE RESEARCH;
THE SECOND STEP OF EXPLORATION PHASE OF A DESIGN PROCESS

This chapter represents the second stage of the exploration phase of the GPM (Glocal Process Model). In a complex situation for this particular design context (seismic desert), the 'exploration' branches out into the subjects of seismicity, desert architecture and sustainability. As the first part of the 'exploration' phase, Chapter 4 discussed principles of design for seismicity. The second part of the 'exploration', which is the subject of this chapter, is about the principles of design in desert circumstances. Finally, the third part of the 'exploration' phase, relates to organising and modelling complexity, led by sustainability, which follows in Chapter 6.

While presenting the relevant information we will go through the cases and a particularly demanding desert city as Bam, which can be compared with certain other desert cities. In order to achieve such a comparison this research starts by studying houses on three levels, first at the regional level, then at the global level, and thirdly returning to a local level. These will be followed by an exploration of the houses in Bam. To gain a good perspective on the region some cases in Arab areas will be briefly presented, then, for a global comparison, Phoenix Arizona will be examined. However, in the local study the architecture of the city of Yazd represents the Persian desert houses. This will be followed by an overview of houses in Bam. Nevertheless, throughout the discussions many cases of other desert locations, such as cities in India, China, Morocco, Jordan, Peru, Australia, will also be presented to provide a broader view and grant a better comparison. Finally, a sustainability analysis of the houses and city development follows the outcomes of the context exploration, as principles of the design considerations for the reconstruction of houses in a demanding situation.

5.1. General introduction

Desert cities all over the world were identified as sensitive places in Chapter 3 (also see Shahnoori, 2006; Shahnoori et al. 2010b). The particular sensitivity of desert areas subject to earthquakes was also explained. Design is an inclusive field, which means that designing, for instance of a building, is not an abstract task. It was argued that design variables, the items involved, and the relevant aspects are important parts of the design processes that are vastly incorporated in the exploration phase of design.

Designing buildings, especially designing houses is influenced by globally (or regionally) available knowledge, but it is a local task. Starting with local aspects, the desert environment and climatic situation are of first concern for building design. In addition to the unique nature of various cultures, the climate of deserts may vary. It has already shown that deserts cover a large variety of countries in which climatic conditions may vary significantly. The focus of this research will be on houses of desert inhabitants, in particular in the city of Bam (see figure 5.1).

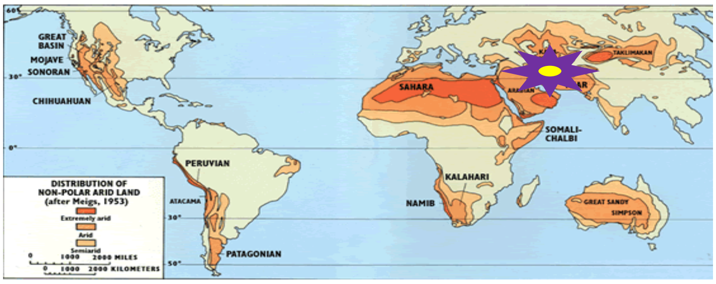


Figure 5.1. Location of Bam on the map of deserts worldwide (USGS, 2007)

Although Bam is a dry region, its average temperature is not as high as that of certain other deserts (e.g. the Sahara, Thar and Gobi). This is not the only reason for differences between the houses in Bam and in other areas. For example, Cooper Pedy is a town in northern South Australia with a climate similar to that of Bam, which also has a long history. The local traditional houses were cave houses or underground houses. Because the city was rich in opal, many mines were excavated in the early ninetieth century. Later they were abandoned and finally they became new houses where immigrants could settle in cool underground spaces. Therefore, all houses in this city provide indoor comfort without the need for air conditioners normally required for temperatures varying between (minimum) –2°C in July and (maximum) 48°C in December in a hot arid region. Cooper Pedy was a village before the mines were discovered in 1858 and excavated in 1915; it needs to be said that recently new houses are being built in a modern style, similar to those in other cities that are equipped with air conditioners. This variety of houses and styles in different areas will be further examined in the following sections.

5.2. A survey of houses in the neighbourhood, a regional study

The Middle-Eastern region includes various climates, one of which is the desert climate. Even between the desert areas of the region, different climates are observable. The presence of several seas and lakes (e.g. the Oman Sea, the Persian Gulf, the Caspian Sea, the Red Sea and the Gulf of Aden), together with different mountains (e.g. the Elburz Mountains, the Zagros Mountains, the Taurus mountains, the Caucasus and the Hindu Kush) are just some of the elements that create such variety. Examples of this variety are shown in figure 5.2 by climate charts of the Syrian capital of Damascus, and the Lebanon capital of Beirut. Accordingly, natural typologies of buildings and building materials may vary considerably. A brief overview of certain randomly selected examples as in Yemen, Syria, Lebanon and Saudi Arabia will be given. Although most of these regions are located in seismic zones, particular solutions for withstanding earthquakes were not often found.

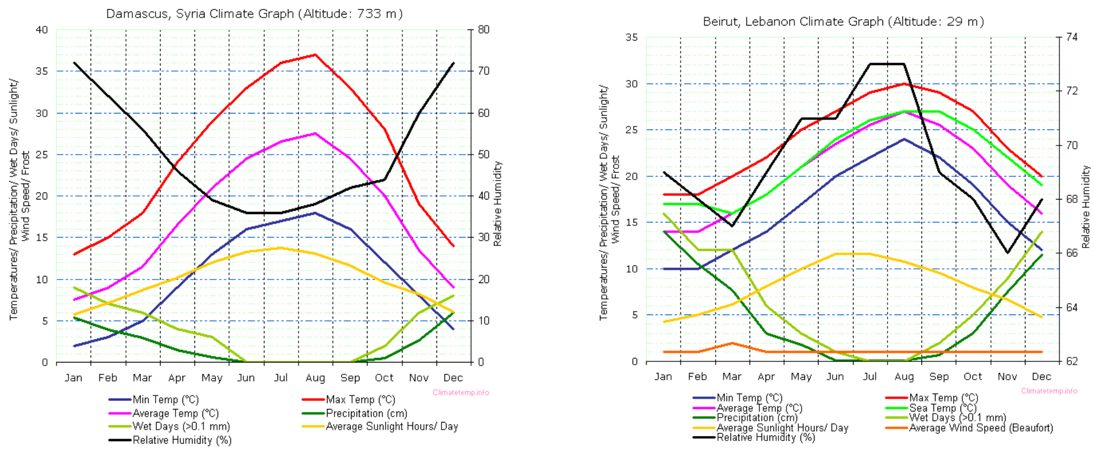


Figure 5.2. Climate charts of the capital Syria, Damascus and Beirut, capital Lebanon (Climatetemp, 2010)

Syria, Lebanon, Palestine, Yemen, Saudi Arabia, Algeria, Egypt …

The landscape of the Arab region is extraordinarily diverse. Even though rainfall is considerable in the higher parts of the southerly area, also in summertime, most of the region still faces water shortage (for instance, figure 5.3 shows the climate chart of the Yemen capital of Aden and the Saudi Arabia capital of Riyadh). Similarities can be observed with buildings in African countries. During the 400 years of the Ottoman Empire, Syria, Lebanon, Palestine, Israel and Jordan formed a single province, which was bordered on one side by the Mediterranean coast and its mountain ranges and on the other side by the Syrian Desert (KHR, 2005). Because of the extensive modernisation, only the countryside and the villages still retain some local identity.

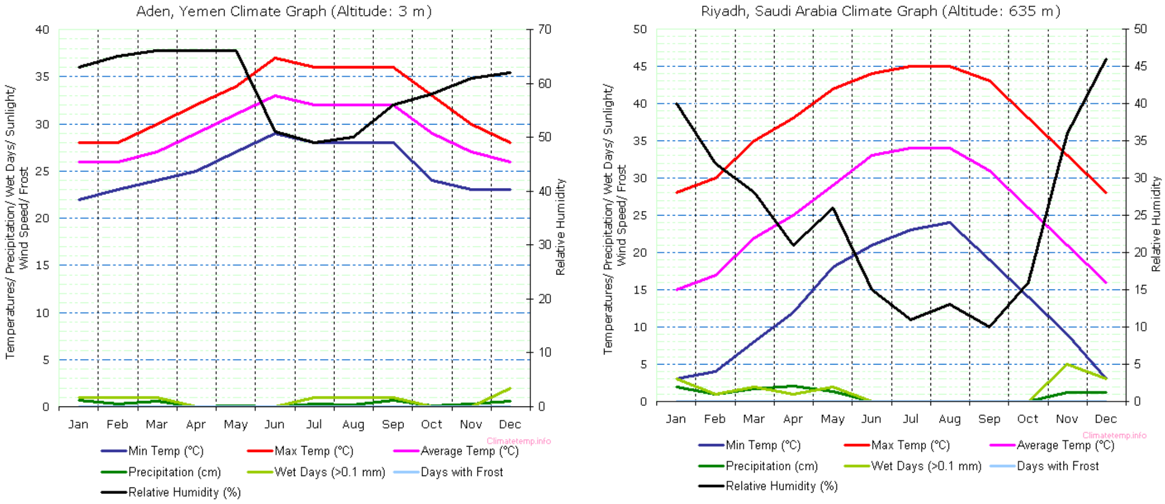


Figure 5.3. Climate charts of Aden and Riyadh (Climatetemp, 2010).

5.2.1. Syria

In a harsh and uncompromising desert environment with extremely hot summers and dry cold winters vernacular architecture have come up with a perfect solution built of locally available adobe materials (figure. 5.4). Beehive houses of Sarouj and Twalid Dabaghein in Northern Syria – west and east of the Aleppo were being constructed from 3700 B.C. (Bikash, 2010).

Figure 5.4, Beehive houses in Twalid Dabaghein, their high-dome's interior structure, and the applied adobe brick (source: first photo from Christopher 2009, second and third from Bikash, 2010)

In the last decades of the twentieth century, one of the most popular house types of rural Syria (regarding the variety and indoor climate) was the gallery house. Although local inhabitants had to endure high-level taxation during the era of the Ottoman Empire since they lived surrounded by larger cities such as Aleppo and Damascus, they were safe from nomad attacks in these styles of houses. The particular styles of dome houses proliferated as far as the Euphrates Valley.

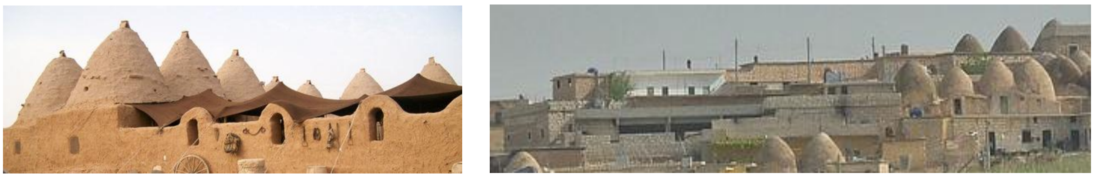


Figure 5.5. The particular style of Syrian dome houses (source: THE.ARC, 2010; Diannemurrey, 2010)

Air- or sun-dried brick made from clay found on site was the main building material. The builder would erect solidly constructed one-and-a-half-stone mud on a low rubble base to protect the house from rising damp. The curve of the dome begins directly above the base at a height of about 60 cm, thus allowing the builder to do his work without the use of timber. Today, the straight vertical walls continue up to the door lintel (KHR, 2005). At that height, short wooden rods are laid across the corners of the room, forming an octagon, which is the starting-point for the curve of the masonry dome. In central Syria, flat outward-protruding stones used to be inserted into the dome's masonry so that the dome could be scaled for its yearly coat of plaster. The corbelled dome, or 'false' dome, was achieved by overlapping concentric rows of masonry and allowing each subsequent layer to be shifted inwards about two to three centimetres towards the centre. Nowadays domed farmsteads all have at least one flat-roofed building. Inhabitants repeatedly stress the excellent indoor climate properties of their dome houses (Kris et al., 2004).

5.2.2. Lebanon

The vestibule or gallery house dating from the end of the nineteenth century was the preferred building type, as residents sought to escape the confinement of their one-room houses. The characteristics of these houses started with the Riwaq (the deep-set gallery) that provided shade on hot days while connecting the living rooms and reception rooms and creating a transitional zone between the interior and exterior located in front of the house. The mountain houses are two-stories high and cut into the steep hillside. The necessary work and housekeeping rooms are often located in the basement or in a separate part of the farmstead. The arcades with their façades of carefully worked cut stone give an impressive outer appearance to the gallery houses

Figure 5.6. Lebanese mountain house (source: Alb Lebanon, 2010; Mejourneys, 2010)

5.2.3. Palestine

The hilly landscape of Palestine, with its abundant lime, calcareous sand stone, and basalt deposits, led its inhabitants to turn to stone construction methods. The proliferation of already developed vaulting techniques alongside the older mud-brick constructions with their flat wooden ceilings was also furthered by the availability of these natural resources. Many small villages of the Palestinian hinterland had one-room dwellings based on complex methods of construction. Built according to a square or rectangular floor plan, the predominant design features a cross vault with a high central apex. The lines of the vault are also visible from the exterior (Kris et al., 2004).

Nowadays the distinct vertical layout of the interior, split into four levels (including the ground floor level, the elevated sitting area, the high gallery, and the stable below) is typical of Palestinian houses. In many urban houses of the Middle East, it is customary to have a sitting area that is raised about half a meter. Since people's shoes are taken off and stowed down, the raised sitting area remains clean and ritually pure, making it a place for gathering and sharing meals.

5.2.4. Yemen

The need for protective city walls disappeared in the mid-twentieth century due to increasing government control, defence style changes and industrial growth. Over the last few decades, individual farmsteads have sprung up between the older settlements where the original buildings still resemble castles ready to lay siege (Benthabet, 2007). Hadharamout houses were constructed on stone foundations with upper stories that are erected from unburned mud-brick masonry. A square floor plan characterises the more recent houses, which taper slightly towards the top and usually have three stories (e.g. in Shibam = 'Manhattan of the desert').

The houses that were built more recently have a small air well in the middle around which the rooms are evenly grouped. The narrow stairwells contain single flight staircases. The ground floor is reserved for goat stables and storage rooms while the first floor accommodates the reception rooms for the men and the second floor contains the family living rooms and kitchen where the women and girls habitually gather. High parapets conceal further small rooms or quadrangles on the roof terrace, which is subdivided by low walls; these areas are used in the summer as sleeping areas and places where household tasks can be carried out. These high parapets also allow girls to watch ceremonies continuing at street level without being exposed to men. Even earthen ovens and cooking facilities are occasionally constructed on the roof. The façades of the rural Hadhrami houses are strikingly symmetrical, with their centrally placed entrance doors and the uniform distribution of the numerous windows. Encircling the house, the windows do not give any hints as to the use of the rooms behind them; otherwise, the façades are very plain. In few cases, flat plaster strips decorate the exterior walls, terminating above in pinnacle-like raised roof parapets.

Figure 5.7. Houses in Abha and vicinity (flicker, 2009)

Highland Yemen is typified by construction work done in natural stone that is locally extracted and finished. In some places, stone techniques are combined with clay construction methods. From the exterior, highland Yemen houses appear large and inspiring. However, the interior rooms can be small with quite low ceilings. The room width and height, repeatedly, only reaches 2.5 m, or even less. Like in many countries, the rooms in Yemeni houses are generally positioned according to the direction of the sunlight.

The buildings in Shibam for instance are imposing multi-storey single-family houses, which tower to a height of 30 meters. The ground floor rooms, which are used as storerooms, have massive, windowless walls while the rooms situated on the higher levels are refined with fretwork (Takhrim) windows. The top floor is always a terrace, water proofed with lime, and surrounded with outer walls. The construction materials used in those traditional skyscrapers are mostly adobe or large unfired bricks made from the mud carried down from higher areas by the occasional flood.

Figure 5.8. City of Shibam in Hadramawt Yemen, (photo: War & Games 2008).

5.2.5. Saudi Arabia

The south-western Saudi highlands are the only places that display a long-standing rural sedentary tradition because the vast majority of this country consists of barren, uninhabited desert. These deserts are characterised by seasonal living situations where people shelter in various kinds of tents. One of the fascinating construction types to emerge in this region was the 'coursed clay house'. This building technique, known locally as Zabur or Midmak is also employed in the Saada region of northern Yemen. Only the foundations of the houses are built of masonry, using rubble or cut stone, while the walls above are formed from clay courses. This clay mass is manufactured in on-site mud pits in which the clay is stamped down and mashed. Water is then added together with chopped straw to form a firm, viscous paste. The master builder applies large clumps to the wall in a course that is 30 to 40 cm high. Using a wooden mallet, the clay sludge is then carefully packed down. The builder lays each course about 20 cm higher at the corners to lend stability to this vulnerable area. On the exterior, the base of each clay particle juts out a few centimetres beyond the one below, while each vertical face slopes slightly inwards as it rises to meet the next layer. A course has to dry for at least two days before the next layer can be added. The house as a whole tapers slightly towards the top. The location of the main living rooms is indicated by the lime whitewash daubed around the larger windows (KHR, 2005).

Figure 5.9. Coursed clay house with Zabur technique (source: DIRECT.rss, 2010)

Nowadays these buildings, which are virtually rectangular, typically have three floors, whereas five floors used to be the norm. Just as in the Yemeni houses, the lower windowless storey is where animal feed, provisions are stored, and where the owner’s goats are penned. The upper floors are where the family lives. The stairwell terminates in a small room mounted on the flat roof to keep rainwater from entering the stairwell. The roof is where women carry out various household activities. A bread oven is sometimes built in a shady corner of the roof. In contrast to highland Yemen, Asir kitchens are frequently located on the top floor.

The floor plan for these from the outside apparently closed buildings exhibits a clear tripartite division: a central part with a stairwell, hall and one room, together with two side areas containing the living rooms. The interiors are meticulously plastered with gypsum. In some places the whitewashed reception rooms are extensively decorated with delicate geometric and floral patterns, a task for women of the region specialised in that particular craft. These dwellings also resemble fortified houses. Even at the upper levels, the windows traditionally remain small, though this is partly due to the lack of window glazing in the area until a few decades ago. The roof parapets are surmounted with whitewashed corner pinnacles executed in various designs (Kries, 2004).

5.2.6. Algeria

Figure 5.10. The desert city of Ghardaia and the M'zab valley in Algeria, picture by J. Baxter

Ghardaia, a desert city in Algeria, lies at the traditional heart of the M'zab valley. The M'zab region is a rocky limestone plateau criss-crossed by a network of deep valleys. At night, the temperature in winter is 0°C and in summer, it is 50°C during daytime. The Mozabites adopted the Islam faith in the 10th to 11th century. The city of Ghardaia, which is located within the perimeters of the Algerian Sahara desert, features two-storied white stone houses huddled together in small clusters, each with its own private courtyard. There are also clusters of terraces, yards, and narrow streets carved into the hillside in a way that allows the city to completely blending into the landscape. Their architecture displays a form of harmony, a unique ability to take advantage of the characteristics of the site (Kries et al., 2004). The walls of the whitewashed houses stand out against the blue sky in stark contrast to the reddish brown colour of the desert soil, but at the same time, the houses blend into the landscape perfectly. Because of this unique architecture of species, the M'zab valley is classified as a World Heritage site by the UNESCO.

5.2.7. Egypt

For a comparison between the climate in Egypt and that in Algeria the climate chart of the capital of Egypt, Cairo, and Algiers, the capital of Algeria, is shown in figure 5.11.

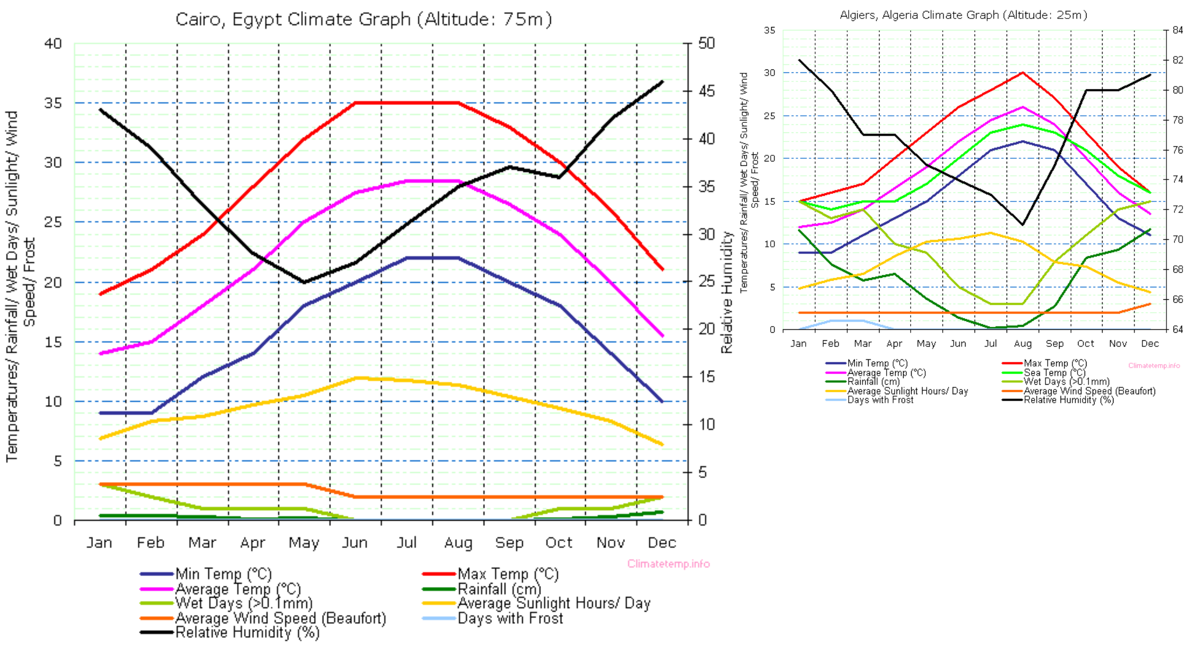


Figure 5.11. The climate chart of Cairo and Algiers (source: Climatetemp, 2010)

Much of Egypt is covered by desert, while the longest river of the World, the Nile, also flows through it. The river Nile, which flows through the Sahara, is the most influential single factor in Egyptian civilization. In the fifth century BC the Greek historian Herodotus (484 BC-425 BC), sometimes also called the father of history, described Egypt as the Nile's gift. Even with the significant developments of the past few decades along the Mediterranean and Red Sea coasts, 95% of the population of Egypt still lives within a few miles of the river. Although the amount of rainfall in the Nile valley is insignificant, and certainly not abundant in the delta, almost all of Egypt's arable land (about 34,000 km²) lies in the river valley and the Delta. Unlike most rivers, the Nile rose and crested during the summer, at precisely the hottest time of the year.

Unlike temples and tombs, most dwellings in Egyptian cities and settlements were composed of mud brick throughout Pharaonic times but changes in the course of the Nile, the build-up of the floodplain caused by the annual deposition of silt and the impact of high floods all led to their destruction, a destruction that was sometimes complete. Very old cities, such as Thebes, have been built over by newer settlements though some remains survived. Finally, the mud bricks were taken by farmers and used as fertiliser. Egyptian desert houses are predominantly made of mud-brick while the roofscape is characterised by flat roofing and copula forms.

Right in the heart of the great Sahara, where the architecture had been preserved for centuries, uninterrupted by modern influences, villages such as Gharb Aawan are located. The area has 2000-years-old houses, normally with a single vaulted room made of special mud brick and including extra straw to lighten the structure. In Luxor, Ramesseums (figure 5.12) are long vaulted storehouses, built of mud brick that have survived for some 3400 years (Fathy, 1997).


Figure 5.12. Aswan, Fatimid Cemetery (Looklex Ltd 1996), Ramesseums (Bossone, A. 2009)

Today, in New Gourma (1946), a village in Luxor, a modern vernacular architectural style, known as neo-vernacular, is being combined with the 2000-years-old traditional housing style, started by Hassan Fathy. In many Egyptian desert settlements such as in Al-Qasr and Al Dakhla, it is flat-roofed houses that prevail.

Many similarities have emerged from these examples taken from the Middle East although there are some definite differences in the house typologies and the way in which they were constructed. However, there are desert cities in other parts of the world that have a completely different background; Phoenix, Arizona, in the USA is one such city.

5.3. Phoenix Arizona desert

Phoenix, a city in the State of Arizona near the confluence of the Salt River and the Gila River, where Indian (Hohokam) tribes have their origin, was an arable area covered with irrigated desert (and canals). The valuable beaver, otter pelts, deer, and Mexican wolves were discovered by Americans in the early 19th century. At the end of the Mexican-American War, most of Mexico's northern territories, including the city that is now known as Phoenix, eventually came under US control in 1848. Phoenix was founded in 1850, first registered in the US in 1868, and turned into a city in 1881.

With an area of 1,230 km² and a population of 1.4 million, Phoenix is located in the Northeastern extremities of the Sonoran Desert and is currently the state capital. Less than 100 mm of rainfall has been registered in the Sonoran desert; most of the precipitation falls in the summer months. Block-faulted ranges, fringed by pediments and alluvial plains, characterise the Sonoran desert (Goudie, 2002). The first seismic shock registered in Phoenix was the 1887 Pitayacachi quake in northern Sonoran. Since then, three major earthquakes have been recorded (Arrowsmith, 2007). For Phoenix's possible seismic activities, Arrowsmith (2007) used the empirical relations of Wells and Coppersmith (1994) that were based on surface rupture length (SRL). He states that the maximum fault length produces maximum magnitudes of M6.3 (Carefree Fault), M6.6 (Horseshoe Fault), M6.1 (Sugarloaf Fault), M6.2 (Verde Fault), and M5.9 (Cottonwood Basin Fault).

The enormous growth of Phoenix has made it the fifth largest city in the U.S (Flaskerud, 2006). This growth has led to uncontrollable land occupation and to extensive sprawl. Exceptionally, the downtown area is occupied by multi-storey buildings and there is quite a density of high-rise buildings. However, this flat city mostly consists of one-floor single-family houses. Wide streets spread through the entire city, even into the quiet neighbourhoods with a low density of houses in the northern or southern areas of Phoenix. Sprawl, which is a general phenomenon (or pattern) throughout the US, is overstated in the development of this city. For instance, in the northern parts the sprawl has not even been stopped by the northern mountains.

Figure 5.13. Wide streets that are not appropriately used together with open and green areas and the sprawl and spread of single-family houses in Phoenix

Although Phoenix is a metropolis, its density is very low. Coincidentally, the footprint of houses measured in northern and southern Phoenix happens to be similar to the very rural low-density areas in the Netherlands (Shahnoori, 2006a). Figure 5.14 shows the land occupation in a neighbourhood in southern Phoenix as established in May 2006. The processed local information and calculations used in the Spacemate program showed a similar type of land use to that in the rural areas presented in the Netherlands. Figure 5.14 also shows that the FSI (Floor Space Index) = 0.22 and GSI (Ground Space Index) = 0.15: meaning that 85% of the ground area remains for streets, open spaces, and a small number of gardens.

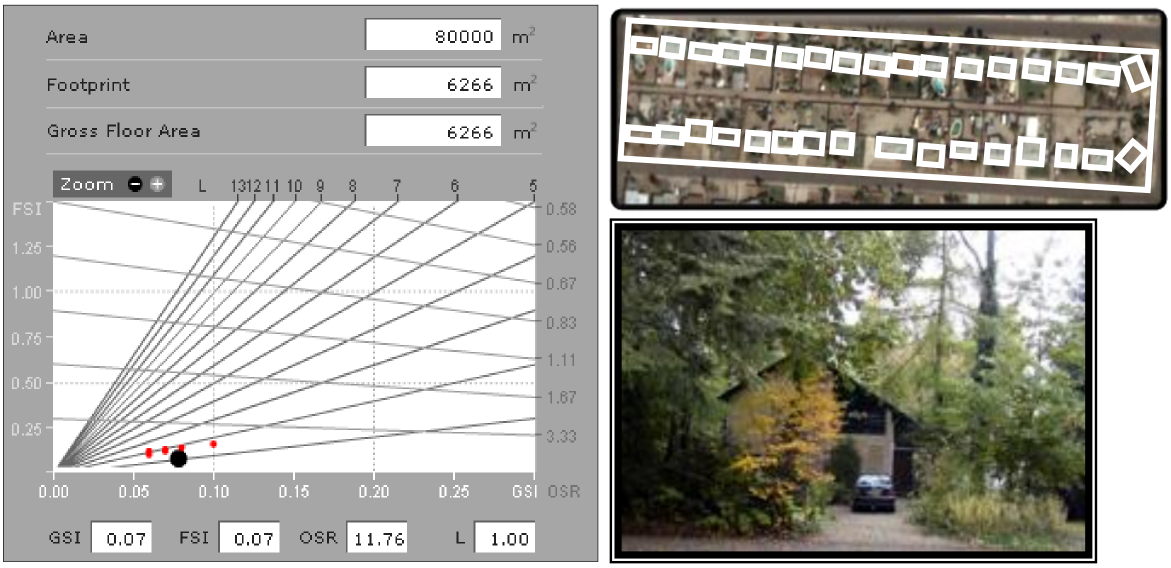


Figure 5.14. Example of the sample neighbourhood in Phoenix (a), and simulated density (b), the comparable density in a rural area of Wageningen in the Netherlands (c)

The typical American grid is the main skeleton of the city plan, which is an important reason for this type of city development. The city is dependent, for its future, on the underground water resources, which were not designed to support such a proportion of the population of the city, so they have been overused. One of the current plans for the future life of the city is to refill the water sources excavated underground with new water from the Colorado River or elsewhere. Researchers in ASU have predicted that with the present state of growth the sprawl will continue forecasting a land area of between 10,467 and 3,575 square miles. However, according to this prediction, the density will also grow to a level of 2.7 thousand per square mile, thus indicating a huge increase in the population; the chart of Figure 5.15 illustrates this.

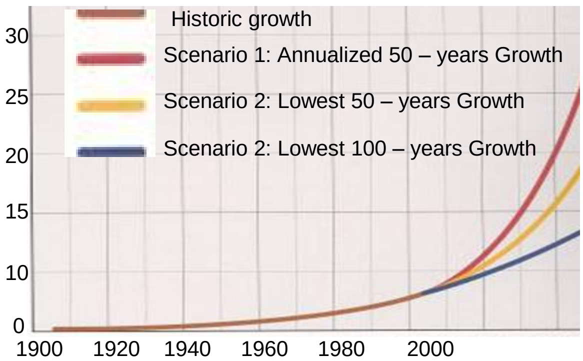


Figure 5.15. Historic sprawl and prediction of the population growth in Phoenix (source: ASU, 2008)

Since the city has expanded considerably and the only mode of public transport is the bus, transportation and access are recognisable issues. This is mainly due to geotechnical and second social factors. Due to the rigidity of the ground, underground transportation would be very tricky and costly. Furthermore, American people in general and desert inhabitants in particular are used to excessive car use.

With a top temperature of about 49° and an average temperature of about 38° (at least for three months per year) due to the influences of the Sonoran Desert, this city comprises the hottest climate of any major city in the US.

5.3.1. Residential neighbourhoods and houses in southern Phoenix

The metropolitan area of Phoenix includes various settlements such as Phoenix, Glendale, Tempe, Mesa, Scottsdale, and Gilbert. Of these, Phoenix is the largest. Although low density is a common factor in all these places (e.g. the Mesa city), they have not been studied as intensively as Phoenix. According to official statistics (i.e. 2008), 407,450 families resided in Phoenix, there were 895,832 housing units and an average density of 403/km². The average family size is about 3.5. The orientation of the majority of buildings is north south. However, building orientation does vary considerably. A sample neighbourhood comprising such variations is shown in figure 5.16.

Figure 5.16. A sample neighbourhood, various regardless orientations

The grid structure of the city and the expansion of it make car dependency reasonable, but people even use cars for very short distances. A realistic analysis of more than 100 cases (e.g. figure 5.17) shows that for an inhabitant of Phoenix being outdoors means driving in one's car. An essential part of the house and the property is the parking lot. In addition to having easy access to their cars one sees that in every single case the dimensions of parking facilities, compared to those in Europe, are invariably enormous. This is not only due to the size of American cars but also to the number of cars per family. In many cases, the number of cars is equal to or even exceeding the number of people in the household (e.g. figure 5.17). However, hardly any car is parked on the street, because of plenty of public spaces, which are partly taken up with green areas, between the street and the houses. In many neighbourhoods, the ratio of open space rises to 80% of the total area. Notably, the increasing air pollution that is a concern in Phoenix is not irrelevant to the number of cars, although the main cause is related to airplanes and the aviation industry.

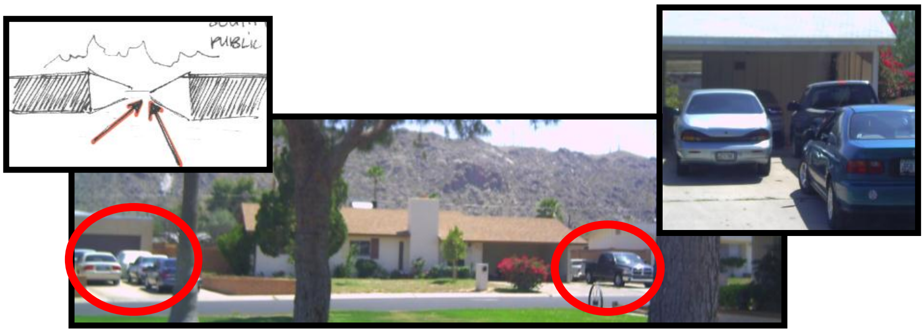


Figure 5.17. Examples of proportions, buildings, streets and the number of cars per family in Phoenix

The second major trend in the city is the extreme individuality of the people living there and their desire for large houses. Villas of 250 m² floor plans are not uncommon (figure 5.18).

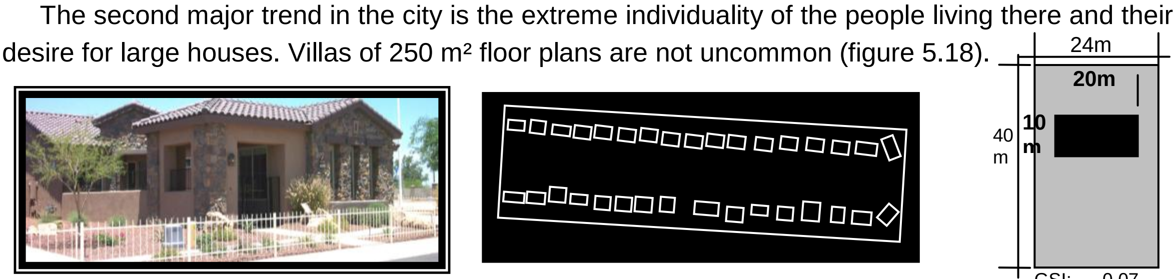


Figure 5.18. Example of comparing the footprint of houses with the empty space, large houses as the residence norm and their land occupation ratio (right)

Contemporary architecture of Phoenix is not specifically different from that seen in other states of the US or generally in present-day architecture. Although single-family houses are an old trend stemming from indigenous (i.e. from Mexican inhabitants in combination with that of the Americans of the early 1900s), the dominant large house trend is rather new.

5.3.2. Typology of houses in the studied districts of Phoenix

Although the types of houses in Phoenix are numerous, for a general categorisation, they can be classified into the six most prevalent types of:

Single-family houses belonging to Mexican people: these inhabit the low-income areas of the neighbourhood, so their houses are smaller and not well prepared. People sell their plots cheaply, which is why developers tend to be concentrated on these parts. The inhabitants of these houses are the most religious people residing in the southern Phoenix.

Single-family houses of American families on normal parcels of land: are large houses with large living rooms and, on average, four bedrooms, with more than two parking lots. Although the kitchen may not be used very often, these houses consist of big kitchens as well. These constitute the majority of houses in the neighbourhoods studied, and in the past, they were the most desirable residences. Although it is the most attractive option for the newcomers, due to the dropped security it is losing market dominance.

Single-family houses in gated communities: these are mostly either inhabited by rich people or by people with average incomes who spend seasonal periods in Phoenix (mostly between the end of winter and mid-spring). Although a gated community entails extra costs when compared to a normal residence, because of high security, they have recently become more popular. Condominiums also fall into this category.

Figure 5.19. A single family house in southern Phoenix

Villas: inhabited by the richest in the community of the city, and they are mostly for seasonal use. These houses are extremely large and tend to demonstrate the wealth of their owners. They are located either inside a private area with a large parking area for many cars, or in a gated area, which again provides adequate numbers of parking lots for the various individuals. Several large living rooms and dining rooms with a huge kitchen are just some of their usual characteristics. The normal number of bedrooms is four and usually the houses remain furnished for the entire year.

Figure 5.20. Distribution of villas before the insecurity

Residential complexes: few buildings, at least three floors (figure 5.21) are inhabited by some of the poorest families. These are young families, mostly starters. The units are very small, with one or two bedrooms, and small living rooms. Some units only have a single room, and do not contain services such as bathrooms and showers; they have to use low standard shared services.

Figure 5.21. One of the few residential complexes in southern Phoenix

Mobile/moving houses: there are people who live in containers or combinations of containers. Many of these dwellings are rigidly connected to the ground, in some cases even by concrete foundations. The number of houses of this type is significant and unusual. In a normal situation, mobile homes are signs of people going on trips or holidays, or they may be occupied by gypsies. Although individual containers have also been observed, most of these are clustered together in sizable groups (e.g. 75-120 containers in one district). These create their own particular neighbourhoods; they are repeated in certain other spots as well. A reason for the extensive presence of these container homes lies in the fact that inhabitants (known locally as strangers) pay lower tax rates. Researchers were advised to avoid interviewing the inhabitants of these settlements. It should furthermore be mentioned that the container option does not constitute the only type of mobile homes in Phoenix. There are many wooden mobile houses as well. The wooden style originates from the Indian culture that tends towards a mobile/dynamic lifestyle.

Although it is not directly identifiable as a typology in the city of Phoenix, a large number of families are living in the Indian community, remote from the city. Among these inhabitants, a community lives in tents, similar to the traditional tents of Indians. These are believed to be the true indigenous inhabitants of Phoenix. It is locally believed that the main indigenous Indians are not connected to the city, but rather located around the mountain ranges. They live in modern houses, old houses and even in tents.

5.3.3. Summarising the exploration in Phoenix and the results

As far as the housing typologies in the southern districts of Phoenix are concerned, relevant results of surveys, interviews and local observations are:

- A bird's eye view of Phoenix does not reveal any specific differences from any other moderate climate. The high temperatures and precipitation did not have any noticeable influence or effect on the district patterns and neighbourhood tissues.
- Street profiles have no relevant scale to the rate of use. People have many cars, but the streets remain much larger than required. Having several parking lots per family is a general trend.
- Details of the streets, the shoulders and even the bus stops provide no significant information for a particular climate as a desert.
- Car use is very common for long and even for very short trips.
- The mountains that border the city are national parks; this not only limits sprawl but it also creates greenery and protected natural reserves.
- Although public space and unused spaces exist excessively, green areas are lacking.
- The orientation of buildings varies greatly and in many cases takes no account of sun and wind directions (neither positively nor negatively). The house plans have opposite locations as they may face either towards the south or in a northerly direction.
- The building forms and configurations had no particular desert climate features.

- The size and location of windows in the façades is not in any way specific; both large and small windows are used in combination (regardless of the direction, orientation, and placements in relation to the sun).
- Using solar energy to power appliances in houses was not often observed.
- Every house is equipped with a mechanical cooling system.
- Although in the older houses white or brighter colours are more common, in the more recent buildings these colours are no longer dominant, however new building regulations do demand better thermal insulation systems.
- The local government has installed rainwater collection facilities and has made the water produced available for public use at a lower price. Digging water wells for individual use is encouraged by the local government.
- The building materials of the houses did not reveal any particular effects attributable to the Sonoran desert.

These points will be incorporated and further finalised in Section 5.6 by brief comparison with other houses. The following section provides an exploration into Persian desert houses.

5.4. Persian (desert) houses

Due to climate variation, Iran has a diversity of architecture. The north, on the Caspian Sea coast, with a moderate climate (mean temperature of 15°C to 20°C), has tremendously large forests that provide timber and wood for structures. Because of the cultural characteristics and customs of the people and the climate, the houses there constitute extrovert architecture. The cities are not distinguished literally, but rather politically. Traditionally, houses tend to locate inside gardens; they are dispersed over a wide area. The two main traditional styles of this region, although currently only used in villages, are houses made of wood and clay with steep roofs. In contrast, in the second type, found mostly in mountainous areas, the walls are made of stone while wood is the material used for roofing. The second type is similar to the dominant typology found in north-west Iran as well.

In north-western Persia, where the climate is cold and dry (i.e. the average maximum does not exceed 12.4°C); the dominant building material is stone with lime or clay mortar. Concentrations of houses either on the urban or individual level are a strong characteristic of this region.

In the very southern areas of Persia, because of the tropical climate (annual average of 25.6°C to 26.8°C), houses were protected from the sun and natural ventilation systems as Windcatchers were used. The dependency of lives on the sea, the urban tissue and form mainly obey the coastal lines.

Finally, a large part of central Persia is desert. Since the focus in this study is on desert houses, further indications of other typologies will be avoided.

The architecture of the central desert region of Persia/Iran has had a big influence not only on the architecture of other climates in the country but also on the architecture of certain countries in the neighbourhood (e.g. United Emirates, Qatar and Kuwait). When analysing desert morphology in central Iran, because of its magnificent species (e.g. desert houses) and its general and long-lasting sustainable urban fabric and architecture, the city of Yazd constitutes a proper case study.

Yazd is a Persian city that is located in a hot arid desert where the temperature ranges between -16 and +48 degrees Celsius (Hung, 2002) and the average annual rainfall in the area is 60 mm (Monshizadeh, 2008). Inscriptions have been found on some mountain stones in districts of Yazd that date from 6000-7000 BC (Vaez, 1996). The survival of the city of Yazd is helped by its location in a wide dry valley between the two mountains of Shirkooh, which is the highest mountain in the area with an altitude of 4,075 meter, and Khannagh Mountain (Mostoufiolmamalek, 1997).

Although the people respected nature to a great extent, they had to deal with it by means of smart methods and details. In fact, many cities or towns in the desert or desert peripheries are not alive anymore. The latter are sometimes buried under tons of desert sands: only the top edge of the houses is visible whilst the rest is buried. Vaez (1996) explains his experience in a sand storm: “Suddenly, the sky would turn dark red or yellow and all you see is sand. By the time that it was over, every open area was covered with about 1 to 5 or more inches of sand.”

The smartness of Yazdies is famous, especially among architects. The city is not only famous for surviving in such a harsh desert conditions yet also because it has survived different foreign invasions such as various Arab or Mongolian invasions. Because of the clever geometry in both the urban layout and architecture (e.g. with the complex narrow alleys, the tall thick walls of the houses, and the internal openings), attackers could not defeat the local people during battles (Ale Ahmad, 1961).

As is shown in the first picture of figure 5.22, the urban fabric and patterns of Yazd are compact so that penetration of the intense desert solar radiation and sandstorms is decreased. This further aids security in the long term. Narrow alleys with high walls are linked by arches that may also serve to support the system regarding the structures of walls on both sides. These constructions known as Sabat (the second and third picture in figure 5.22) provide further shading and accelerate the wind velocity for the passer-by.

Figure 5.22. A historic zone and two Sabats in Yazd (Vaez, 1996; Dar1385, 2006; Ghoolabad, 2008)

Water resources backed up the city during its long history; they were used for either daily life or irrigation. This provided the city with the opportunity to cultivate many agricultural products such as pomegranate. The system of using and preserving such water supplies, scarce in desert regions, was again a clever method. Water was kept deep underground in a canal that encircled the city. From there it was transported to the surrounding villages. These supplies were accessed through 3300 wells. These narrow, deep water-wells, called Qanat, were situated in specific strategic places (see also chapter 7).

5.4.1. Persian desert houses represented by houses in Yazd

In addition to various preserved old structures (e.g. Qanats, Caravansaries, temple / Atashkadeh, Khanghah, and Abanbar), a number of residential neighbourhoods have survived in Yazd. These represent Persian desert houses.

Generally, two important elements, identical to all desert houses, are the courtyard and the Windcatcher. This shows the significant role and the necessity of shading and breezing in desert houses. Although the position of the yard was enhanced by religion or traditions, the most significant value in a desert house is climate related. The harsh desert climate affects the comfort of a house through the two major forces of sun and wind (negatively and positively). Because the role of the desert wind is important but not as important as the sun, courtyards attracted the first attention. The history of excavating a courtyard as a connecting element between spaces in ancient houses (e.g. in Tappeh Zagheh and Tappeh Ozbaki) dates back to the 6^{th} millennium B.C. (Salimi, 2006). Figure 5.23 shows a cross-section of a residential building with a courtyard in Yazd.

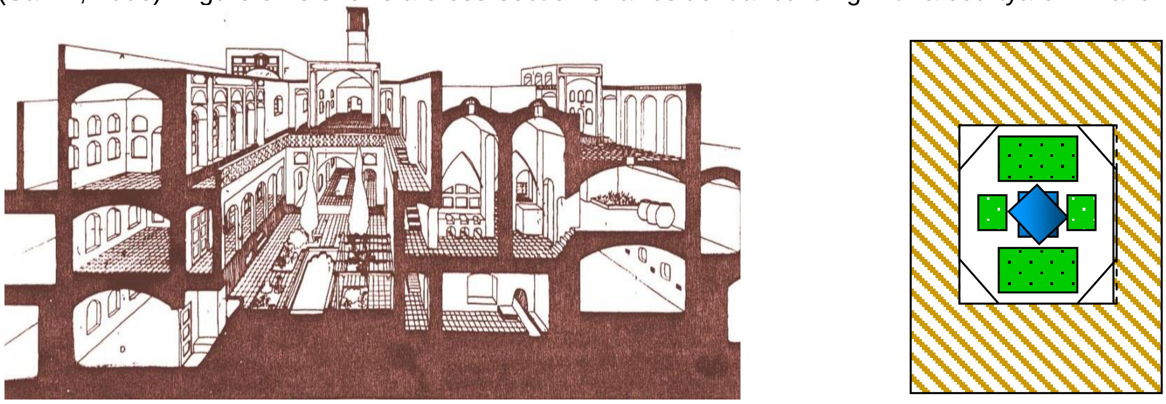


Figure 5.23. Cross-section of a house with a multi-storey courtyard (Tavasoli, 1989) with courtyards' scheme

Courtyards, including basin(s), trees and bushes, were mostly symmetrical, providing shaded corridors (on opposite sides) for connecting and accessing different spaces at various times of the day. Regarding its orientation, it thus provided a hygienic environment. Less important rooms benefited from the turning sun and sunshine. Inevitably, the majority of the rooms faced southwest and southeast, as that was the optimal orientation for the climate. Although the courtyards were always said to have a rectangular shape, the rectangles sometimes embedded other rectangles to make hexagonal shapes, but with shorter tendons (the second picture in figure 5.23). This form prevented problems (e.g. from desert sand storms, from the blowing of harmful winds) arising from inadequate orientation. With maximised passive potential, the courtyard warms the house in winter when the sun angles have maximum penetration into the winter rooms. The design thus comprises several functions such as:

- Reducing the effects of the energetic sunrays on the inhabitants
- Optimising the lighting by indirect light
- Cleaning the dusty desert air
- Creating a natural environment and greenery suitable for sleeping at night
- Humidifying the house, by means of the water basin in the middle
- Creating a boundary between seasonal divisions of spaces
- Separating or connecting some spaces/sub-functions
- Unifying some elements
- Integrating the spaces; spaces form around or according to the centre (it may not be geometrically the centre but it still performs a central role for the spaces of the house)
- Providing a private covered shaded corridor for internal accesses
- Playing a crucial role in the microclimate

This is also because the design satisfies the function of the Windcatcher that transfers the refined humidified wind from one side of the house to the other into its internal spaces. Thanks to the almost symmetrical plan, the appropriate arrangement concerning the location of the rooms towards each other and the yard, the purposeful locations and the proportions of the openings (e.g. the windows), maximum integration for efficiency and optimisation of the microclimate is provided.

5.4.2. Special configuration regarding the yard

Although the roles of the courtyard are significant for the comfort of the city's inhabitants, the way in which these roles are incorporated into the spatial configuration of the house varies. Examples of some spatial configurations regarding the courtyard are shown in figure 5.24.

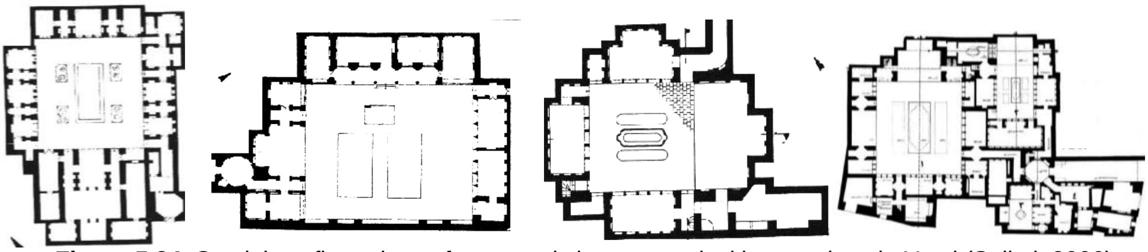


Figure 5.24. Spatial configurations of courtyards in some typical house plans in Yazd (Salimi, 2006)

In addition to the specific local conditions, this discrepancy also depended on the location of the house within the city and the district, the building orientation and people's wishes. The latter includes such matters as finances, specifications and characteristics of the neighbourhood. Hence, the local beliefs such as the dominant religion, together with the religious persuasion of the owner may be involved in the location, form, size, and configuration of the courtyard.

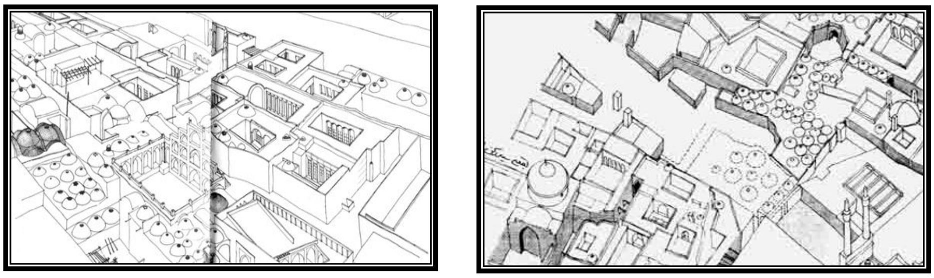
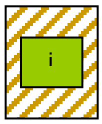
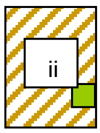
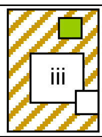
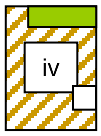
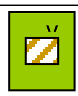


Figure 5.25. Houses, courtyards and roof lighting in a historical zone of Yazd (Vaez, 2006)

Desert courtyards in Persian desert houses have been divided into five main groups as shown in table 5.1. When it comes to providing more shaded areas and cooler microclimates, multi-storey courtyards are not uncommon (e.g. as shown above, in figure 5.25).

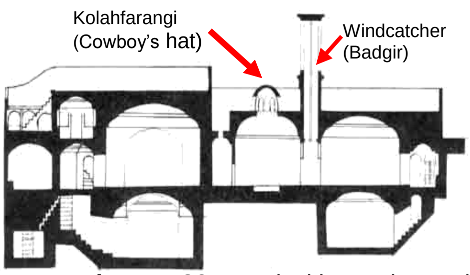
Table 5.1 Groups of courtyards with their schematic situations

Group	Characteristics	Scheme
(i) Internal central yard or Cortile:	The common courtyard that was explained above, is counted to be more private than public. It means it is provided for the family and the closer relatives.	
(ii) Front/ outer yard:	This rather small space isolates the house from the public area and undertakes entertaining guests.	
(iii) Cool garden:	A small space that provides access to water reservoir, lower than most of covered spaces, it provides extra lighting the dark spaces, functioning as patio, too.	
(iv) Backyard:	In two forms, the first is a very small open space adjacent to the kitchen, which serves an open storage for the kitchen. The second type is a small open space that functions in special occasions (e.g. ceremonies).	
(v) Garden:	These large yards are exceptional in cities, but normal in the countryside (called Kooshk). Two major types of its users include rich people and farmers.	

When studying these configurations of spaces and yards, a significant issue, known as spatial hierarchy, becomes apparent. On the upper level of the scale, the hierarchy starts with the public amenities, the semi-public neighbourhood leading to a private space inside the wall and going from the upper to the lower level. However, in the normal hierarchy of building and use level, the centre of focus remains the house, from the lower to the upper level. This hierarchy starts with the private space, which includes family rooms and private services. The second level is the semi-private space, which includes the courtyard, kitchen, corridors and so on. The third level of the spatial hierarchy includes semi-public spaces, including guest rooms, the entrance yard, and external corridors. Finally, public space is outdoor space, which may be a street or an alley. Such hierarchical levelling is cultural and possibly even ritual, something that is restricted to some religious or traditional families. Examples of such distinctions and hierarchies appear even in the details, for instance in the door-nock system. In this system, door-nocks provide distinct voices for men and for women. The longer door-nocks are for men and the shorter and round ones, which are also higher-toned, are for women.

Within this hierarchy and inside the house, the guest room normally included two or more doors, one was the entrance from (and connected) public spaces and the other one was an opening leading to the semi-private space for the purpose of serving food and so on. A public bathroom was also a service provided for guests or visitors. The guest room was a decorated space with ornaments and tapestries, plaster ornaments (e.g. gypsum and mirror works) on walls and/or on the roofs. Guests were not allowed to enter the other parts of the house. The private space was self-sufficient so that it would not require services from the public area.

Halls (Talar), where all the family members gathered together, were almost always located in the middle of the private space. Normally, rooms did not have specific functions. A room was a flexible space, which could be used as living, dining or sleeping room as required. Because the residents did not normally use fixed furnishing components such as wooden beds, tables and chairs inside the rooms, these spaces could easily be made multi-functional. Despite these divisions, each house was composed of two main parts as the winter section and the summer section. The former generally belonged to the north of the yard and the latter was usually located on the south side of the yard (because sunlight was only allowed in from the yard). Less important spaces such as storage areas and hayricks, which included openings from the ceiling (and hardly any opening into the yard), were located on the eastern side of the yard (facing the harsh sunrays of the west). Except for when storing hay for winter, this side was almost completely abandoned in summer. In the middle of the ceiling of the central space, a wind-directing system was built that made the space comfortable for use in the afternoons of the desert summer. This was called Kolahfarangi (a cowboy's hat). It sucked in winds in a multidirectional way (Vaez, 1996). If there were several openings (on at least four sides) on the appropriate sides and locations of the Kolahfarangi, the wind blowing for indoor comfort was possible from various directions. These structures are different from the Windcatchers; they only create comfort for the specific hall while the entire house benefits from a Windcatcher.



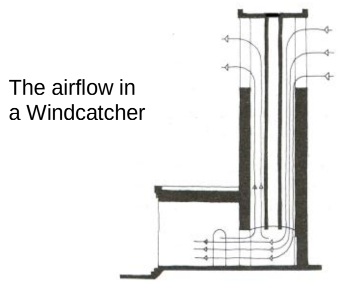


Figure 5.26. A typical house in Yazd with Kolahfarangi hall and a Windcatcher (MHUD, 2006).

5.4.3. The Windcatcher as the second identifying feature for desert houses

The Windcatchers in Yazd constitute some of the most beautiful ones in the entire central Persia, figuratively and functionally. Their height (e.g. 33 m in the Dowlat Abad garden, built in 1750) and their qualitative and quantitative wind blowing are well kno

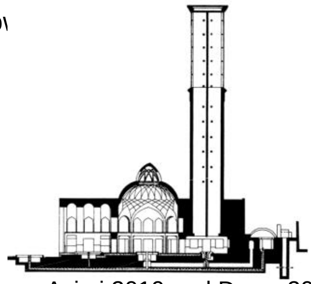
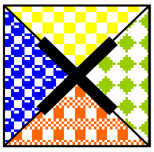
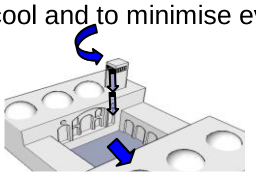


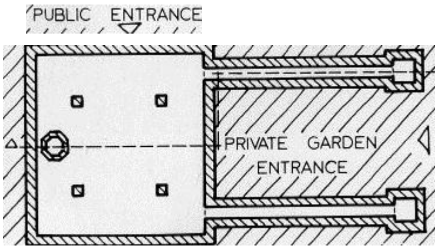
Figure 5.27. A cross-section and view of the Dowlat Abad Windcatcher (source: Azimi 2010 and Dany, 2005)

Depending on the local directions of the desirable winds, Windcatchers incorporated different sections. Four ducts were usual in Yazd (the cross section shown in the diagram). These could be closed on special occasions such as during sand storm periods or Sistan wind periods. This is a strong wind that comes from Sistan province and may continue for 120 days, although once it reaches Yazd from such a distance its energy and effect has dissipated considerably.



The pleasure wind is sucked through the Windcatcher and conducted down into the yard. In the process, desert sand is filtered through bushes and trees, while the clean wind transfers the moisture from the surface of the basin. Because the basins were large but not deep, harmonised moisture was provided, while the trees and bushes provided different filtration sizes for the sand and dust that came with the cool wind (e.g. a scheme is presented in figure 5.28). In some cases, the wind was conducted from the Windcatcher through a canal/duct to the water reservoir (Abanbar) of to the family or the relatives (in a small neighbourhood). These reservoirs were located below the street and house levels to keep the water cool and to minimise evaporation.





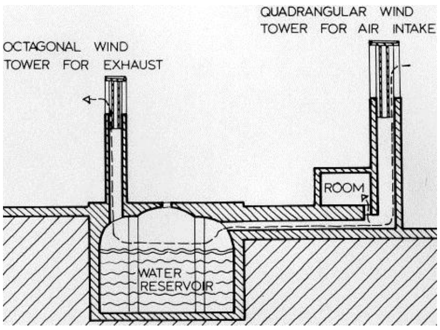


Figure 5.28. Scheme of air moving through a Windcatcher and going into the internal spaces, Windcatchers, and Ab Anbar (the latter pictures are from Vaez, 2006, and Holod et al, 1982)

The water storage kept drinking water cool, by first placing the storage deep under the surface, accessible via a long staircase. Secondly, the roof of the reservoir sometimes was a copula, equipped with one or more Windcatchers. On hot summer afternoons when the cool wind was not present, the Windcatcher heated up, thus turning itself into a solar chimney. The solar heat would then increase the temperature of the air at the top of the Windcatcher, thus forcing cooler air from the basement to be drawn into the house, cooling rooms and eventually leaving it through the chimney. Figure 5.29 shows a unidirectional Windcatcher that lets in cool breezes from the north, while excluding the hot wind from the south. The vacuum created at the mouth of the Windcatcher draws cool air into the rooms from the patio. All ducts of the Windcatcher were closed during the cold season.

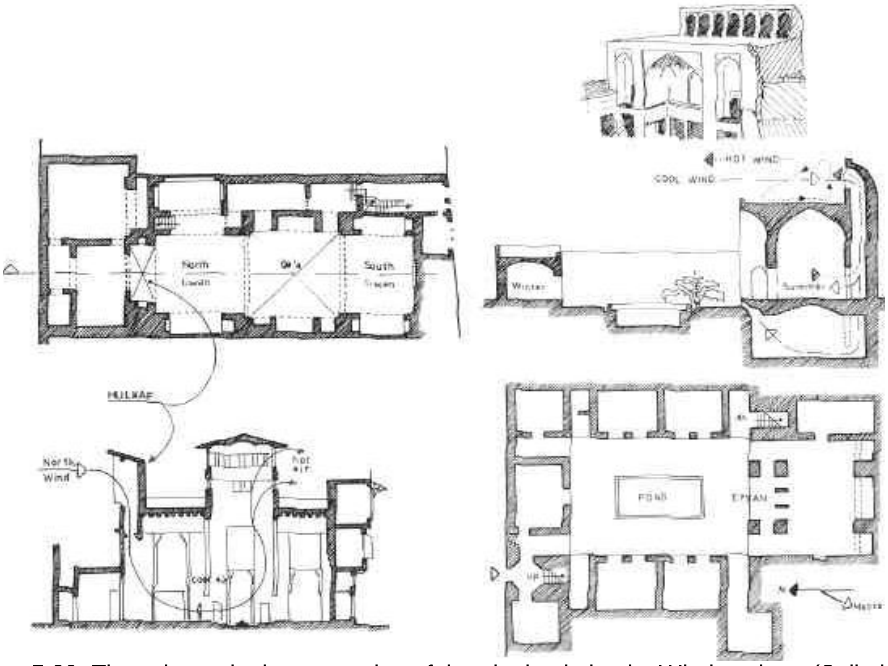


Figure 5.29. The schematic demonstration of the air circulation by Windcatchers (Salimi 2006).

Because the spatial configuration of private spaces tended to be symmetrical, a hall (called Talar) was generally located in the middle of them. Summer halls normally attracted more attention, had more ornaments, special rugs, and glazed tiling. The special configuration of rooms around the Talar created typologies for Persian desert houses (e.g. figure 5.30). In front of the main hall there was a semi-covered space (roof and columns) called Eyvan. Arches rose between the columns that had latticed fretwork windows (called Orsi) with coloured glazing. For the Eyvan and for the internal spaces beautiful lighting and shading was created.

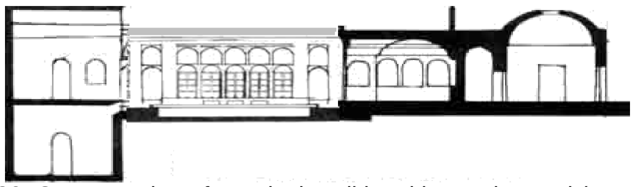


Figure 5.30. Cross-section of a typical traditional house in Yazd (MHUD, 2006)

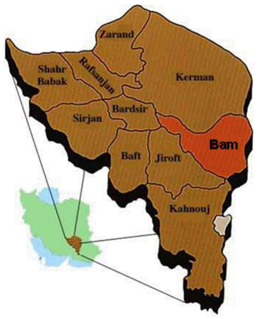
An important way of cooling was provided by the underground spaces. These were places for resting in the afternoons during very hot days, whilst having different functions at other times. Temperature differences in the underground (cellar) are considerably smaller than variations in the open air. For example, at 12:00 o'clock on August 12th, when the outside temperature was 41 degrees (in the alley), the temperature inside the yard was 35 degrees and 26 degrees in the cellar.

Another important climatic compatibility specification in Persian desert houses is material usage, not only the type of materials used but also the details and methods of construction employed with those materials. The most commonly used traditional material in the desert (like in Yazd city) was bricks made of clay and reinforced with straw in various specific sizes (e.g. 25 x 25 x 5 cm; 20 x 10 x 5 cm; 21 x 11 x 5.5 cm). These bricks provided good thermal insulation and they stabilised the climate in hot summers and cold winters. They were baked in a furnace or they were sun-dried; normally they were constructed with clay mortar.

Regarding this whole discussion dealing with people's ways of shading and humidifying their dwellings, in Yazd most modern houses in the area are not proper for such a climate. At the heart of traditional houses was the courtyard, equipped with the Windcatcher. In contrast, the focus in modern houses is on systems of mechanical cooling and heating. Modern houses are constructed and configured without accounting for the climate and they make use of inappropriate materials. Therefore, little concern is shown for energy, resources and the environment. This attitude towards design is not only becoming prevalent over Persia yet also throughout the world. Extravagant architecture throughout the countries in the region is displaying this modern trend, some of which is becoming widespread. The traditional system of houses that carried many advantages in old times needs a boost but now in a sustainable direction.

5.5. An explorative research in Bam, an old desert city

The city of Bam is 1,283 km away from Tehran, the capital of Iran, located southeast of Kerman province, in the east of Iran. Bam, which has a smooth topography and morphology, originates from the old city of Bam, which is now enclosed to the northeast of the present city. Old Bam or the citadel had been abandoned for about 150 years; prior to that, it had been occupied by military organisations and soldiers for some years. Before the earthquake, it was a tourist attraction.



5.5.1. Geography, climate and demography of Bam

Bam is located on a vast plain between the two mountain ranges of Barez and Kabudi. The altitude of the city is approximately 1,067 meters above sea level (WHO, 2004), at a longitude of 57 degrees 42 minutes east and a latitude of 59 degrees and 34 minutes north (Mohajeri, 2005). Bam includes more than 75 per cent of the urban population in the region.

The main topographical feature of the city is the volcanic hills located to the north and south-west of Bam. Five different lithologies can be observed in the main geological formations of the area including recent Quaternary alluvium, late Quaternary sandstone and siltstone, Paleogene sedimentary rocks, Eocene volcanic rocks, and intrusive igneous rocks (Granodiorite). Quaternary fine sands and silts form the alluvium around the old town of Bam and its vicinity (Ghafoori, 2006). One seasonal river, the Poshte Rood, is virtually dry for most of the year. It flows through the Northern boundary of the city. Due to the small amount of rainfall and surface water, the main source of agricultural water for Bam and its periphery is underground resources in the Qanat.

The average annual temperature is 23°C (average maximum: 44°C, average minimum: −2°C). The absolute highest temperature recorded in the past 30 years is 48°C whilst the absolute lowest temperature recorded in the past 30 years is -9 °C. The temperature usually starts to rise in February and temperatures between 38-44°C are not uncommon in summer.

The city experiences an average of 298 days of dry and eight days of rainy weather annually (minimum: 3 days); the average annual rainfall is 62.5 mm (Ghafory-Ashtiany et al. 2007); some years 10-20 mm was recorded; the maximum recorded is 147 mm (WHO, 2004).

Wind directions vary during the year, but most often, they blow from the northwest to the southeast. Throughout the year small windstorms occur, the recorded exceptional speed being 133 km/h. less severe storms are common towards the end of the winter period and the beginning of spring and the humidity is very low. Examples of the prevailing winds in the area are:

- The Shah Bad is the most important, local wind in the region, which blows from the south to the north. It is cool and humid. Although it does not greatly affect the weather, it does have more impact than other local winds.

- The Lovar wind or Tash Bad blows in summer and comes from the South-east. It is a hot, dry wind that carries dust particles.

Although Bam is a desert city, farming and gardening form the primary sources of income for its inhabitants, and the city has large orchards of citrus fruits and palm groves. Bam's dates are well known worldwide, with 100,000 tons of the finest quality dates being exported each year. A new major industrial complex accommodating various factories, including a major automobile assembly line has been built during the last decades. According to statistics, in 1996 52% of the 142,376 city population lived in the urban area of Bam. The number of people living in the urban and rural areas of Bam is detailed in Table 5.2.

Table 5.2. Number and percentages of population distribution

Bam	**Relevant number**	
Area	21381km²	
Population	242,438 person Urban area 109,487 (45.1%)	 Rural 116639 (48.1%)
Regular + part time civil servant	7645	

Despite its 2500 years of history, Bam has been virtually neglected for a considerable period of time during the latest centuries. Therefore, much of its development is very recent. For example, the municipality installed a piped water system for the first time in 1963 and it was not until 1992 that the city's Water and Sewage Company was established (Parsizade et al. 2006). Prior to this date, all requirements were met by the underground water supplies, which are still drawn for irrigation purposes.

Table 5.3. Under ground in-used water wells

	Nr. of deep wells	**Nr. of semi-deep wells**	**Number of Qanats**
Bam-Narmashir plain	723 with 408 mcm capacity	222 with 12.5 mcm capacity	348 with 414 mcm Capacity
Rahmatabad plain	118 with 45 mcm capacity	59 with 4 mcm Capacity	74 with 43 mcm Capacity

Prior to the 2003 earthquake, residential utility coverage in Bam was 93% for electricity, 86% for clean water and 32% for telephones. About 51% of the homes were air-conditioned. Liquefied natural gas is used by 88.7% of families for cooking and kerosene by 93.4% for heating. The source of drinking water for 14% of all families is fountains and Qanats. The transportation network in Bam consisted of 10 km of highway, 327 km of main roads, 369 km of paved (asphalt) roads and 57 km of unpaved rural roads. There were 6 gas stations and 18 fuel tanks in Bam, with a total capacity of 720 m^3. In 2002, about 398,000 people made use of the out-of-town (inter-city) bus services and 150,000 tons of goods were transported on an annual basis (Ghafoori, 2006).

Apart from all the attractions, 104,446 of all foreign tourists visited the city's historic citadel (Arg-e Bam) in 2002. The citadel (figure 5.31) is a five-story structure located on top of a giant rock to the northeast of the ancient Bam. It has a height of 60 m, is 300 meters long and 200 meters wide, and consists of two main sections.

Figure 5.31. Bam Citadel, the central part with the houses outside the wall, (UNESCO, 2004 & shivai, 2003)

5.5.2. Buildings in Bam

The city of Bam displays one of the most outstanding fortified settlements built of mud bricks by means of the mud-layer construction technique. According to UNESCO (2005), Bam was developed at the crossroads of important trade routes (on the silk-road). In a desert environment, it represented glorious artisanship and soon became a recognisable testimony to the development of a trading settlement in the region.

Three main styles of buildings found in the Bam area are shown in Table 5.4. Because the newly built types of buildings (i.e. not ancient and non-traditional) seen in the city comprise three sub-sections, the relevant values are separately recoded in Table 5.5.

Table 5.4. Classification and relevant values of buildings in Bam

Typology of buildings	Ancient buildings	Normal buildings		
		Traditional	Traditional new	Newly built
Age	+ 2500	+100	20-60	-20
Materialisation	Mud bricks, bricks, straw, animal hairs, clay and exceptionally wood	Mud bricks, straw, goat and animal hair and clay	Clay, bricks, lime, gypsum, cement mortar	See table 5.5.
Morphology	Copula and cradle roof	-Copula or cradle-like roof -Simple, with limited sizes	Cubes , flat roof	Cubes & Boxes, flat roof
Location	Mainly inside the citadel	Villages, around the city, few luxury houses in the city	Outside the citadel, eastern part of the new city	Inside the city concentration: western parts
Climatic compatible	Perfect	Location dependent (perfect-good)	Very poor – Poor	Poor
Seismic resistance	Poor	Poor	Very Poor	System + materials Dependant
Qualification	Good form and system (time related issue)	Good- poor (in the city –out of the city)	Very poor	Normal-Poor
Note	Controlled by ICHO	e.g. Helikhani, Asadpoor, Behzadi, Naghibzade, Naderi houses measured		

The citadel and houses

Obviously not all findings about buildings in Bam can be given in Table 5.5. This includes exceptional data, such as the differences between the buildings in the centre of the citadel and the buildings around the fortification. The citadel, with an area of 20 hectares, forms the largest collection of buildings built of clay and adobe materials in the world (UNESCO, 2004). This collection comprises two main parts separated by a fortification wall. The 1800-meter long wall was 15-18 meters high, with 38 watchtowers. The governor, his family and relatives, in addition to other important people lived within the city wall. The structures contained a castle (where the governor resided), arsenals, and the main stables and so on. The area around the citadel and outside the city wall included 528 houses for the ordinary people and farmers. Later the whole complex was equipped with certain services such as public baths, a temple (which was later converted into a mosque), caravansaries, a reselling hall (Zoorkhaneh), a bazaar, ritual buildings (Tekyeh) and a particular religious quarter for the Jews (Etemad, 2004).

In the centre of the citadel, the buildings are large, beautiful, and made of high quality and luxury materials, even including wood. There is no forest in the region which is why wood was definitely a luxury, an expensive material. Hence, protecting the wood from desert termite was another major task. Good quality wood, which was well oiled to prevent termite damages, can also be found in the buildings situated at the heart of the citadel. The domed and copula roofing of most buildings decreases the desert heat influence. One side of the dome always remains in the shadow, while its combined flat parts make it possible to walk on them and provide cool space to sleep overnight in summer.

The architecture of this settlement is yet another example of rich Persian desert architecture, harmonic use of material, colour, texture, and roofscape. The cooling systems are similar to the ones seen in Yazd (sometimes with minor differences in the details). An example is the cooling system in one of the buildings in the citadel: its Windcatcher is located 50 meters away from the building, and it is connected to an underground canal (Zaimi, 2010). There is a garden on the top of the canal, which is regularly irrigated, allowing the water to penetrate the walls of the canal. Furthermore, the wind that enters the building from the Windcatcher cools and humidifies the building. In contrast, buildings that are located beyond the fortification walls include plenty of small houses unornamented with ordinary materials and construction. Still, the symmetry of the plan with its vaulted and domed or arched roofs with repeated arches in the walls and entrances is common in houses inside and outside the fortification wall. However, in houses located outside the wall vaulted and dome-shaped roofs were more common than inside the wall. The outside houses were connected and even interconnected but had separate individual spaces. Some of the houses in the entire complex included private baths as well.

An obvious difference between the internal settlements (of the citadel, inside the wall) and the architecture of Yazd concerns the position of the citadel in relation to its surroundings. The citadel is located on the top of a hill at the highest spot of the whole area (60 meters higher than the rest). This meant that the guards on the 18-meter-high fortification walls and the watchtowers (which are even taller) were able to watch every single movement around the citadel. This was necessary due to the insecurity of the region: Bam is closer to the country borders with Afghanistan and Pakistan, which have been insecure regions for a long history. Besides, it was a solitary isolated and distant city when compared with Yazd. Multi-storey buildings were erected after the gate and fortifications limited the growth of the inner city.

Nevertheless, similar to Yazd the system of narrow alleys with tall walls gives a better airflow in the citadel of Bam, because of the complex's hilly situation. Covered air-ducts, connected to the walls by arches over the alleys, further boost the dynamics. Four ramparts were constructed on the southern side of the structure in addition to another one in the north-eastern section. The main connection between the central citadel and the houses outside the wall was the huge entrance gateway. Much of the whole collection was destroyed by the recent earthquake and subsequently some infections such as termite penetration into the walls were also revealed (Langenbach, 2004). The repair and rehabilitation of the citadel is still continuing alongside reconstruction of buildings in the present-day city. Although progress is slow, compared with the citadel the reconstruction of houses seems to be going faster. This does not include the reconstruction of the ancient, traditionally built houses. Traditional houses are not being repaired or reconstructed in the same style, but rather in a modern style. An example of traditional houses in the surroundings of the present city of Bam is shown in figure 5.32.

Figure 5.32. Ordinary traditional houses in the vicinity of Bam

A certain number of architecturally rich houses that are owned either by wealthier families or by government organisations are being restored to the original style (figure 5.33.).

Figure 5.33. Aspects of the traditionally rich house architecture, Bam after the earthquake

Newer building typology in the present city

As was already mentioned, the city of Bam also had many houses newly built. They are classified into three sub-categories, which are addressed in table 5.5.

Table 5.5. **Typology and characteristics of newly-built houses in Bam**

Typology of buildings	Masonry	Steel structures	Reinforced concrete structures
Age	+ 45-10	-20	-20
Materialisation	bricks, lime, gypsum, cement mortar, steel	bricks, cement mortar, steel	Concrete, steel rebar, bricks,
Morphology	Flat roof, + exceptional copulas and cradles	Flat roof cubs	Flat roof cubes
Location	City centre towards the eastern part	City centre towards the western parts	Western parts
Climatic compatible	Very poor	Very poor	Poor
Seismic resistance	Very poor	Poor	Poor- acceptable
Qualification	Very poor	Poor connections and welding	Poor- acceptable

In the classes of houses mentioned in Table 5.5 various building typologies can be observed. Although the size of any house is closely allied with the wealth of the family, large houses are most sought for in Bam. The size range in Bam varies, as is summarised in table 5.6.

Table 5.6**. Distribution of residential units in Bam and their households/the size of the house**

Size of residence	Percentage of residential unites	Percentage of households
One room	5%	12%
Two rooms	20%	31%
Three rooms	26%	33%
Four or more rooms	49%	24%

Except for the houses belonging to people in the lowest income bracket, houses are normally provided with public services and facilities for drinking water, gas, telephone etc. In the past, relatives used to live together, but now the modern life style dominates. Therefore, relatives tend to live close to each other but normally in separate houses. Although before the earthquake the majority of buildings, especially in the eastern and central parts of the town, could be described as adobe constructions, in the reconstruction process they are being rebuilt with the help of new systems and materials. In modern Bam, before the earthquake, the typology of houses regardless of their material facet comprised:

- *Town houses*: single family houses, being the recent major trend.

- *Neighbourhood houses*: based on ancient Persian architecture these are communal houses in which relatives live close together and where each neighbourhood is a known and trusted territory for its inhabitants. In the past, close relatives lived together in separate spaces of big houses and other relatives lived in the neighbourhood. The hierarchy from the most public to the most private areas, starting from the street and leading to the entrance of a house was an important criterion.

- *District houses*: the heterogeneous houses in this group accommodate inhabitants from various segments of society; these people are more flexible about accepting others so they reinforce the modern fabric. In such a small city, there is still a sense of social connection between inhabitants.

- *Multi-functional houses (or mixed function houses):* these are an emerging type as far as modernisation and modern life style is concerned. These are street-dependent houses. Normally the ground floor includes different functions such as shops, but the first and the second (if there is a second floor) are residential with separate entrances. These are compact houses and because of their economic benefits they are being more popular.

- *Garden houses*: these vary from very large traditional houses located mostly in the middle of the garden to the normally sized houses located in various spots of the garden.

- *Village houses*: these vicinity houses are not located in the city centre but prevalent in the villages. They mostly are low-quality small houses with a small or no yard. The size of the site or garden may be larger in rural areas. Therefore, the density of these houses varies quite considerably.

Although Bam's traditional methods are not preserved very often, urban patterns even in the newest neighbourhoods are rather concentrated and dense. Surprisingly, such compact units are sometimes green units because of the agricultural background and because parks and public spaces still provide scenery.

Figure 5.34. One of the main streets of Bam, a paradise inside the surrounding dry desert

5.6. Cultural integration in Bam in relation to the reconstruction

Next to the numerous interviews and questionnaires about building design and materialisation, four periods of interviews and four series of questionnaires concentrated on socio-cultural aspects were locally carried out in Bam. A team of five members including a teacher, a journalist, two research assistants and the researcher, assisted by local organisations and institutions, worked on the project in the summers of 2005 (10 through 12 July), 2006 (29 through 31 July), 2007 (11 through 13 August) and 2008 (12 through 14 August). Prior to this, a team of students from Hormozgan University explored the site in December 2003, right after the earthquake. Furthermore, in April 2004, a few months after the earthquake, another team of 24 students, accompanied by a teacher from the Department of Civil Engineering and led by the researcher, investigated the collapsed buildings in Bam. The latter was completed later in 2005, 2006 and 2007, while other parts of the local research were still going on. The local research, still going on today, served other purposes within the entire study presented, which was carried out in 2008, 2009 and 2010.

The sets of questions were based on the three main divisions of age, educational background and level of suffered (social and economic) impact, as shown in Table 5.7.

Table 5.7. Type of classification for interviews and research for social cultural aspects in Bam

Classification of the interviews		
Age	i	15-25
	ii	25-35
	iii	35-45
	iv	45-55
	v	55-65
	vi	+65
Level of Educations	i	Until high school
	ii	Diploma
	iii	Technician
	iv	Bachelor, master and above
Impacts (social & economic losses)	i	Suffered minor damages on their home
	ii	Suffered major damages on their home
	ii	Suffered major injury
	iv	Lost relatives
	v	Lost their close relatives and suffered severe injuries

In view of the fact that so many aspects are involved when it comes to reconstructing houses in a desert location, social and cultural research was also required. Interviewees were selected on a random basis. However, these random interviews were organised in three parts of the city, the eastern part, rather close to the citadel, the central part, and the western periphery of Bam. The first part contains traditional old houses; the middle is also mostly composed of traditional houses with masonry and other possible mixes. The last area, the western part, is the location for newly built houses. The arrangement was that 100 families would receive the questionnaires with various sections. It was assumed that the results would also be used for other purposes within the larger research framework. However, the results did not show significant connections between the answers and the location of houses in relation to specific questions.

Not all of the respondents completed the sections or all questions in each section. In total, 75 responses were collectable. The results were processed and finalised for different parts of the research, and relevant results of the on-site research for this chapter are incorporated in the statistics shown in Table 5.8, 5.9 and 5.10. In these tables the collected results are put into three main categories of age, education and loss. The building-related questions and answers are exempted here.

Table 5.8. Age-related results of local research in the three categories

Age related classifications, numbers and percentages								
Classes of ages			Connected to city/citadel		Re-building on former		Facilities, supports & progression	
Period	Nr.	%	Nr.	Percent	Nr.	percent	Nr.	Percent
15-25	11	15.1	+4	+5.5%	+3	+4.1%	+1	+1.4%
			-7	-9.6%	-8	-11%	-10	-13.7%
25-35	13	17.8	+7	+9.6%	+5	+6.9%	+0	+0%
			-6	-8.2%	-8	-11%	-13	-17.8%
35-45	14	19.2	+12	+16.4%	+10	+13.7%	+0	+0%
			-2	-2.7%	-4	-5.5%	-14	-19.2%
45-55	14	19.2	+14	+19.2%	+13	+17.8%	+1	+1.4%
			-0	-0%	-1	-1.4%	-13	-17.8%
55-65	11	15.1	+10	+13.7%	+10	+13.7%	+2	+2.7%
			-1	-1.4%	-1	-1.4%	-9	-12.3%
+65	10	13.7	+10	+13.7%	+10	+13.7%	+1	+1.4%
			-0	-0%	-0	-0%	-9	-12.3%
Sum	**73**	**100**	**+57**	**+78.1%**	**+51**	**+70%**	**+5**	**+6.9%**
			-16	**-21.9%**	**-22**	**-30%**	**-68**	**-93.1%**

Table 5.9. Education-related results of the local research in the three categories

Education related classifications, numbers and percentages								
Classes of educations			Connected to city/citadel		Re-building on former		Facilities, supports & progression	
Groups	Nr.	%	Nr.	percent	Nr.	percent	Nr.	Percent
High school	17	25	+14	+20.6%	+14	+20.6%	+2	+2.9%
			-3	_4.4%	-3	-4.4%	-15	-22.1%
Diploma	24	35.3	+16	+23.5%	+15	+22.1%	+2	+ 2.9%
			-8	-11.8%	-9	-13.2%	-22	-32.4%
Technicians	12	17.6	+10	+14.7%	+9	+13.2%	+1	+1.5 %
			-2	-2.9%	-3	-4.4%	-11	-16.2%
Bachelor master …	15	22.1	+14	+20.6%	+10	+14.7%	+3	+4.4%
			-1	- 1.5%	-5	-7.4%	-12	-17.6%
Sum	**68**	**100**	**+54**	**+79.4%**	**+48**	**+70.6%**	**+8**	**+11.8%**
			-14	-20.4%	-20	-29.4%	-60	-88.2%

Table 5.10. The result of the local research based on the amount of impact suffered by the respondents

Impact related classifications, numbers and percentages								
Type of impacts			Connected to city/citadel		Re-building on former site		Facilities, supports & progression	
Impact	Nr.	%	Nr.	Percent	Nr.	percent	Nr.	Percent
Minor damage	10	13.3	+9	+12%	+9	+12%	+4	+5.3%
			-1	-1.3%	-1	-1.3%	-6	-8%
Major dam., home	18	24	+13	+17.3%	+12	+16%	+4	+ 5.3%
			-5	-6.7%	-6	-8%	-14	-18.7%
Major injuries	15	20	+13	+17.3%	+13	+17.3%	+5	+6.7%
			-2	- 2.7%	-2	-2.7%	-10	-13.3%
Loss of relatives	17	22.7	+11	+14.7%	+10	+13.3%	+4	+5.3%
			-6	-8%	-7	-9.3%	-13	-17.3%
Major injury, Loss relative	15	20	+8	+10.7%	+8	+10.7%	+1	+1.3%
			-7	- 9.3%	-7	- 9.3%	-14	-18.7%
Sum	**75**	**100**	**+54**	**+72%**	**+52**	**+69.3%**	**+18**	**+24%**
			-21	**-28%**	**-23**	**-30.7%**	**-57**	**-76%**

From the interviewees the houses of 15 people had been entirely ruined, so these people were entirely dependent on external supports, literally and mentally. Some of them believed that they, like some of their neighbours, should have left the city and gone to relatives in other cities earlier.

According to Table 5.8 younger people do not feel very connected to their city; however, according to the details in questionnaires, they like the citadel. Therefore, this group is not positive about reconstruction on the same site, where their former house was located. Besides, they are very negative about the support that the government provided for them, claiming that they hardly ever received any support. However, according to the statistics given in Table 5.9, the more educated people are, the more they tend to like the citadel and feel connected with the city. Nevertheless, due to job opportunities and the decline in public hope, people with an average education, who possess diplomas, tend to look for jobs in other cities and regions. Otherwise, the level of education does not seem to be very influential. Furthermore, according to Table 5.10, the people who suffered severe damage to their homes are more negative about the facilities and support received after the earthquake and also about the progress of getting the city organised by the government. An overview of all these statistics is summarised in Table 5.11.

Table 5.11. The sum of the results of the local research

Categories / Impressions	Connected to city/citadel		Re-building on former site		Facilities, supports and progression	
	Nr.	Percent	Nr.	Percent	Nr.	Percent
Positive	55	76.4%	50.6	70.3%	10.3	14.3%
Negative	17	23.6%	21.6	30%	61,6	85.6%

Finally, these studies were performed because the first assumption was to move the city from the old location to a safer site in the neighbourhood, but the results showed that according to the social trend rebuilding Bam should take place in the previous location.

5.7. Analysis

The general approach to the research comprising two methods of global and local investigation was applied to the study of desert cities as well. For the global approach cities were studied that are remotely related to each other (e.g. Phoenix and Bam). Studying major traditional architecture in countries as Syria, Yemen and Saudi Arabia is regional in a worldwide perspective and global from the viewpoint of a city such as Bam. The cases studied may therefore be divided by (i) A selection of counties from the Middle East; (ii) Housing conventions in Phoenix, Arizona; (iii) Persian desert houses; and (iv) Houses in the particular case of Bam. Comparisons between these four facets was possible not only from the viewpoint of climate, settlement organisms, urban patterns, fabric and characteristics but also with regard to building form, orientation, configuration, sustainability and adaptation to climate, etc.

If one considers the mentioned cases, together with many of the other cases exempted in this chapter (e.g. Texas, USA; Changsha, China; Lima, Peru), Phoenix may be considered a modern type of urbanism, also in its buildings. The remaining cases are, however, connected to original and traditionally built dwellings with a long history. As the presented information already shows, particular points can be stated about Phoenix but no particular lessons concerning sustainable original architecture in a metropolitan desert area. However, as metropolises are rather new domains for designers, much can be learnt even from inadequacy or inappropriateness. This comparative information may therefore provide some criteria and guidelines when it comes to sustainable design methods for deserts.

In the following sub-sections, results of different are briefly discussed.

5.7.1. Ultimate items of section 5.2 about houses in the Arab region

Since the Arab region is most influenced by religion, many cultural and social issues relevant to architecture are similar. The most obvious differences between the housing typology in these areas can be characterised by: (i) the agricultural background and potential of the land; (ii) the security aspect; (iii) the combination of farming and security factors.

i. In this group, life is combined with work in various ways. There is less ground floor occupation to leave plenty of arable land for agriculture. Some characteristics of this type of dwelling are: different products are stored for annual use in a place that provides heat isolation for the house as well; room is provided for sheep, goats etc., at least during the coldest winter nights (in some houses).

ii. This group contains a variety of solutions for security and the differences relate to the diverse levels of security in that particular country. Openings are minimal and carefully placed in the outside wall; animals and food are kept indoors. In addition, the group lifestyle is a manifestation of insecurity in these countries.

iii. In some arable desert countries security could also be threatened by desert raiders, so the houses were multi-floored to monitor the distance, either for the farm or for the family (like private watchtowers), little ground floor area and minimum openings to the outside world are typical features of such houses.

5.7.2. Closing points deduced from section 5.3 about Phoenix, Arizona

The great potential offered by Phoenix (mainly in the past) included:

- An attractive landscape by desert ending against mountains, and a variety of public gardens and vegetation resulting from a combination of these two factors.
- Possibilities for a high-quality standard of life for inhabitants.

- A unique situation in autumn and spring when compared to so many cold regions in the country and abroad.
- An open society that accepts different cultures.
- A relatively great number of job opportunities.
- Affordable plots of land available for people with different levels of income.
- A central position in the neighbourhood.

It was already explained that Phoenix is facing problems such as urban sprawl; therefore, related points will only briefly be indicated below:

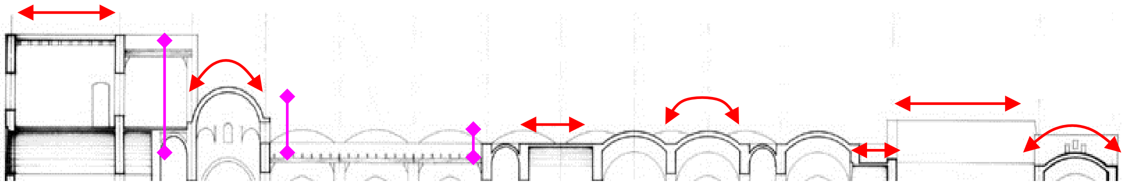
- Limited water resources are a critical threat to the future of the city.
- The current level of waste produced is still harming the natural environment, both on an industrial and public level or on a residential level.
- The presence and position of the airport and its contribution to air pollution is seen as a growing problem.
- Increasing difference between the rich and poor in various neighbourhoods or districts has given rise to increased aggression.
- This is also a reason for increasing insecurity, especially in the marginal neighbourhoods, and a cause for depression, leading to a rise in mental health problems.
- Growing individuality together with growing societal differences diminishes the friendliness of the environment (which attracted people in the past), leading to increased loneliness.
- Developers and similar organisations are taking advantage of the situation and ignoring the consequent problems, which are economically 'ghettoised'.
- Unlimited expansion causes an increase in the use of cars and also:
  - Traffic breeds, pollution and accidents.
  - A sedentary life leading to obesity, diabetes and heart disease.
  - Direct and indirect consequences as asthma increasingly threatening the lives of children.
  - Increased time and distance to access the city.
  - Uneasy access in the lives of elderly people.

Because Phoenix grew unsustainably, regardless of the climate, not much is left to discuss about its houses with regard to these items. In situations where no local potentials and clean energy have been integrated into the design of houses, the main onus from the climate is upon mechanical equipment.

5.7.3. Summary of section 5.4 about desert houses in Persia, Yazd

Yazd comprises valuable cases of indoor comfort and sustainability of desert houses. The urban fabric is well adapted to a region with a dry and hot climate, while still being a relatively good example of a living and dynamic area. This can be stressed in the following items.

- The urban patterns are compact; in a closely packed neighbourhood the surface exposed to direct sunrays may be reduced to 50% (Hung, 2002).
- One may consider the incredible aesthetics of the city regarding the skyline, which is dominated by the artistic engineering seen in the Windcatchers, in addition to the city's dynamic roofscape (e.g. a combination of copulas, Kolahfarangi and flat roofs).



- Yazd reflects a heterogeneous urban tissue and pattern with breathing organs such as Sabat, courtyard, Windcatcher and Kolahfarangi, which are integrated in a sustainable system.

- Access within the neighbourhoods is provided by narrow alleys of 2-3 meters, shaded by the high walls of the surrounding houses, which also accelerate the air movement.
- Interlinked arches (between two walls of the alleys), Sabat, which may act as a supporting system for structures (see chapter 4), make the high temperature of the city tolerable.
- The integrity of the Sabats with the general slopes and the underground water (canals, tunnels and water wells) boosts their functions.
- The introverted typology of the houses protects the inhabitants from wind, sand and sun (and, in the old days, from strangers outside).
- Thick walls structurally support the adobe houses and facilitate indoor comfort day and night (reflection and heat transfer). Construction materials and details delay the heat transfer during both summer and winter.
- Minimum external openings prevent penetration of desert sand and dust and provide more privacy (and also security in the past).
- A courtyard not only creates a natural internal environment but also acts as a significant element of natural cooling and heating.
- Windcatchers provide indoor comfort and give rise to a cooler microclimate while refining the dusty air. The height of the Windcatchers allows for a wind velocity of 1.5 to 3 times the velocity of that at 1 m above ground level (Hung, 2002). Thus a solar chimney is created by the Windcatcher, which draws cool air from the basement into the rooms whilst simultaneously extracting smells, smoke and heat from the house.
- Kolahfarangi is another important element of the integrated natural ventilation and cooling system, specifically in the worst hours during a summer’s day.
- Recyclable materials are used, with little or zero embodied fossil energy.

5.7.4. Finalising the section 5.5 about Bam

Important assets to the traditional houses of Bam are the use of clean energy and creation of microclimates for internal comfort, in addition to maintaining sustainable construction and materials. Integration of social, environmental, urban, economic and building aspects in the architecture essentially led to the city’s duration for 2,500 years without harming the surrounding environment and the planet.

Although minor differences are observable between various regions in the central desert of Iran, the principles of desert architecture are common. Climatic adaptation and the integration of the environment and nature into construction and lives are crucial points leading to both similarities and differences in their appearance. The essential belief of Persian people in olden days lied in the sanctity of the four elements of nature (i.e. water, air/wind, soil, and light/fire). This is not only a reason for the nature manifested in vernacular architecture, but also links up with sustainability as defined in modern terms.

Some passive design methods related to indoor comfort were illustrated by traditional Persian houses in Yazd or Bam. These were obtained, for instance:

(i) in the urban settlement

(ii) by using trees for the filtering of desert sand (desert-stop trees are locally called Gaz), shading and filtration inside individual sites

(iii) through spatial configuration

(iv) by combining nature and building in a smart way (e.g. courtyard + basin + greenery + Windcatcher)

(v) by focusing in detail on building components and elements (e.g. isolation spaces, arches, covered semi-open spaces of Colonnades and Eyvans).

Integration of all of these details and the other methods is the most important element to create harmless simple solutions. However, the most common characteristic of these houses and one that can be justified within the framework of sustainability is the fact that they are culturally interplaying roles, making use of, but never overuse, the local materials, technology etc.

5.8. Discussion

There are other desert cities in the World that were not categorised in this chapter. These include for instance cities in the Gobi desert where houses have evolved fantastically over a long period of time. Another example is Cueba Andulucia, in southern Spain, where underground housing helps keeping the house cool in the hot summer and warm in the cold winter. Another interesting but different example is the defensive housing in Hakka Tulou in Fujian province in China. These complexes of connected houses of close relatives, immigrants from the Gobi desert, have only one entrance and windows opening inwards. Similarly, in some insecure regions in Africa access to defensive houses is indirect and is not easy, and the window proportions are all strictly adapted to the climate. Therefore, houses are not only adapted to the climate but also to security and the social environment.

Because of their rich architecture, in combination with their more relevance to the case of Bam, some other Persian desert houses are further discussed.

Pirnia (2005) summarises the principles underlying Persian architecture by five main categories: (1) Structural rigidity, (2) Self-sufficiency, (3) Modular unity, (4) Introversion, (5) Avoidance of futility/un-necessities. An example of a simple solution in Yazd is sleeping on the roofs of the houses when inside it is relatively warm. This not only reduces the required cooling energy but also optimises the use of the available space whilst making the houses multi-functional.

The initiatives and principles discussed in this research can be categorised, for instance by considering the following sustainability issues:

- The unity of the urban fabric, the heterogeneity of a homogenous integrated urban settlement
- Connectivity and social integrity
- Climate compatibility
- Adaptation to (climate and social) context, integration with the lives of people in a mutual way (social desires require particular architectural solutions; particular architectural solutions encourage life-style optimisation or the reverse)
- Use optimisation as by:
    - having flexible spaces
    - having mentally and physically comfortable spaces
    - multi-functional natural elements (e.g. using green for filtration, cooling and heating)
    - minimising waste water by introducing smart systems on all levels
    - using clean energy
    - integrating cooling and heating into one system
    - utilising local materials
    - implementation of entirely recyclable materials with low energy costs
- Environmental friendliness: minimise damage, maximise preservation and respect to nature while optimising use
- Celebrating a rich culture by preserving historic elements.

Although terms as eco-architecture, ecological cities and sustainability are rather new paradigms, all of which are emerging as the fragility of the environment becomes increasingly apparent, they are simultaneously revealed as principles that have always been present in historic houses in some old desert cities (e.g. the Persian desert regions).

There are many instances of modern sustainable buildings in the USA, such as the new adobe buildings that can be seen in Pueblo and the traditional houses of various styles in Santa Fe. These are individual buildings designed for particular purposes, which, in many cases, are being built for the very rich or for those seeking luxurious circumstances. Designers such as Nader Khalili, who is affiliated to the California Institute of Earth Art and Architecture, are concerned about nature and the lives of those domiciled in desert regions. The solutions that they have found display climatic compatibility, affordable and environmentally friendly housing but their solutions cannot be described as entirely sustainable. This is because not many people are willing to have such houses as permanent dwellings. If a concept cannot fulfil the wishes of inhabitants, it cannot be publicly used and so it remains at the conceptual level.

5.8.1. A brief argument about the current state of sustainable desert houses

Different styles, such as the Santa Fe homes, originate from true adobe structures that have been around for centuries among the Anasazi people who are native to the southwest of the USA. The area's original inhabitants took refuge from the hot summers and from the cold winters by making their houses three or even four stories high and constructing them from stone and mud adobe bricks fabricated in the area. Nevertheless, only a few of the houses of these original Santa Fe inhabitants still remain; today most of the houses in the region are imitation adobes made of stuccoed concrete (Richardson, 2009). They thus continue the development methods as seen in Phoenix. Obviously, Phoenix is not a good example of a wise solution for a desert city. For instance, the wide streets in Phoenix not only increase the temperature level in the microclimate of the surrounding area but have a mental impact on the people as well. Apart from anything else, it occupies a considerable area of land that could be used in more appropriate ways. For example, in Madrid, Spain, 1 million square metres of green space was gained by simply allowing the M30 motorway to go underground (Figure 5.35).

Figure 5.35. Increasing the greenery in Madrid by submerging the M30 motorway (Faust, 2010)

The beautiful work of Frank Lloyd Wright in Taliesin West is not far from the city of Phoenix (located inside the Phoenix area), but such architecture is not affordable for the average Phoenix city family. Nevertheless, these days many people travel to Taliesin West to understand the green architecture and sustainable quality, and to learn how to respect nature, to connect and combine with it, and to benefit from it without destroying it. The other example of such perfection in a desert area takes us back to Arizona, to the works and designs of Paolo Soleri.

5.8.2. Paolo Soleri and desert friendly construction

Soleri, the Turin-born Italian-American designer, lived in his own designed and constructed small desert house in Cave Greek, Arizona. The principles of his building philosophy were very much based on respecting nature, as is often evidenced in his works, not least as witnessed in Ceramica Artistica Solimene, in Vietry on the Amalfi coast. By closely studying the Indian culture and traditions and by adopting an innovative approach he managed to transfer the earth-casting technique from ceramics to building construction. His well-known Wind-bells (Figure 5.36) also originate from this indigenous culture.

Figure 5.36. A combination of Wind-bells and the dome concept, Arcosanti complex, Spring 2006

In Arcosanti Paradise Valley, Arizona (Figure 5.37), Soleri has developed his studio into a complex of green architecture that introduces innovative solutions for the desert climate (e.g. various domed and vaulted roofs).

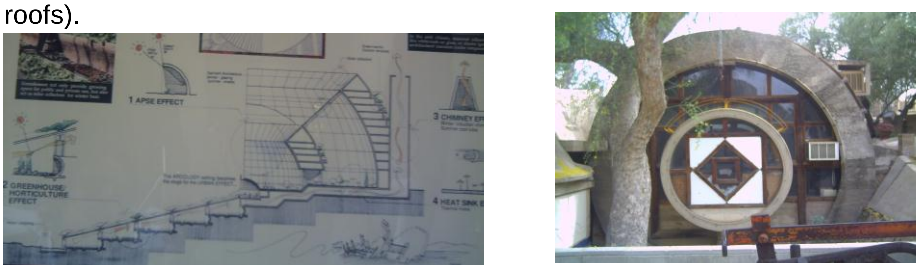


Figure 5.37. Some views of details in the Arcosanti complex, spring 2006

Arcosanti embodies Soleri's urban ideas and his aim to minimise the interactive accessibility associated with the urban environment as well as the use of energy, raw materials and land. Thus, he achieved to reduce waste and environmental pollution and allow interaction with the sounding natural environment. Soleri's designs provide solutions for future desert region populations and are, as such, outstanding examples of how modern environmentally friendly construction can be realised (Figure 5.38).

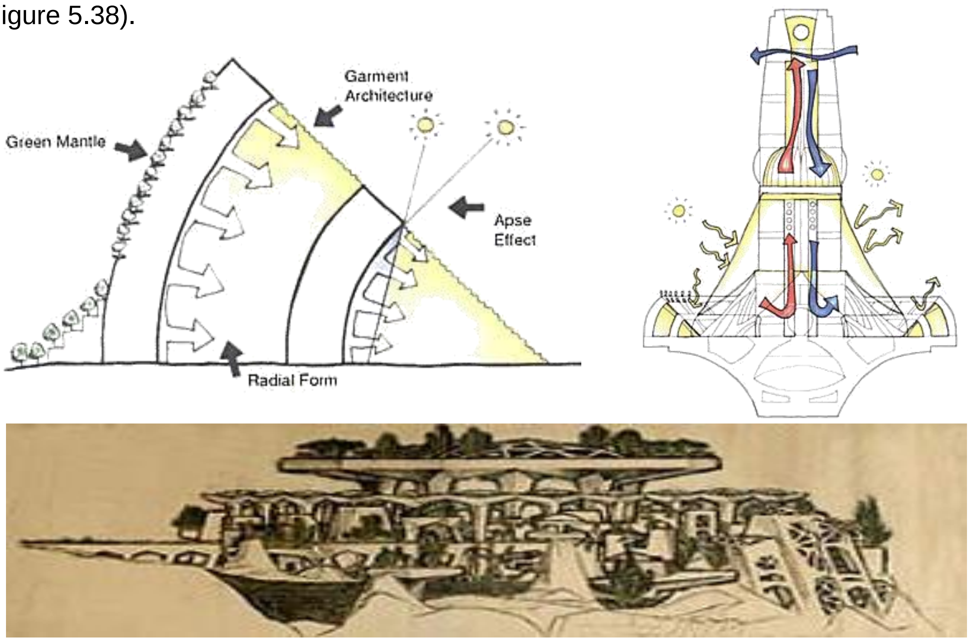


Figure 5.38. Climate design and desert habitat concept by Soleri

About using cosmic energy and its derivations, he asserts: "The use and consumption of the income of the earth, and not of its capital, is essential if we want to keep open our options on the future." The main roots of his philosophy can be attributed to three individuals: Friedrich Nietzsche, Pierre Teilhard de Chardin and Frank Lloyd Wright. From Nietzsche he seems to take the notion that one should strive for perfection in whatever one does. From Teilhard he took the idea that the omega points ‘steers’ all evolution, thus indirectly justifying all our impulses to strive. From Wright he got the idea of organic architecture and thinking in terms of built forms belonging to and being part of natural environments. Moreover, based on these strong theories and philosophies he then went on to realise his constructions in concrete composites.

5.8.3. Recapitulation and collective discussion

One may compare the design principles of Soleri with traditional desert houses to admit that the strength of both emphasise the need for such approaches (i.e. sustainability) in current and future desert area development. However, at present neither of these is popular nor implemented on a public scale. The causes for absence of such architecture should be examined. The architecture of thousands of years with great qualities were abandoned (e.g. in the citadel of Bam), and substituted by weak inadequate inappropriate systems. Therefore, methods are required that do not contradict the principles of environmentally friendly desert architecture but respond to current tastes. One of the findings that emerged from studying the central desert region of Iran revealed that there was a lack of skilled craftsmen to meet the requirements within the expected timeframe. That was a reason for the loss of traditional methods. The number of skilled craftsmen was limited when population growth, and simultaneously the need for houses, became huge. Besides, there was a disconnection in the evolution of traditional materials, such as mud bricks, in the current era and the lack of a modern metaphor has also critically triggered the mentioned methods. Marketing is always important for products, but it is also crucial to construction firms and this is a major issue surrounding traditional methods. Either they can be lost or they have to evolve to acquire the current desires and standards for marketing.

Due to the increasing wish for privacy and individuality among desert inhabitants, the concept of grouping together several families, as was the custom in old times, is no longer an option. However, the compact urban fabric, which was inevitable in the old urban situation, can still be realised in various ways today and needs to be revived. Like Soleri (and many of others), the use of clean natural energy needs to be incorporated both at the individual and public level. Although the solar radiation in hot seasons needs to be avoided the sun can provide an enormous amount of clean energy that can be collected, converted and used. In addition, implementing passive or semi-passive systems can decrease the cooling and heating loads, and hence the energy use.

Population growth may be detrimental in two contradictory ways: more people require more food (i.e. more arable land) and more dwellings, so more clay for construction, leading to more destruction of arable land. This example illustrates how traditional methods need to be refined in modern ways before they can be applied to sustainable houses. This also applies to urban and building design and that is where, for instance, eco-concepts are required.

As here (see also Shahnoori et al. 2009), Bouma (2008) and various others have also observed that solutions that work in the lab may not always work in reality. The social aspects are especially important in design performance. Local issues are not only climate related.

5. 9. Summary and conclusion

The discussions and the cases provided have made the exploration phase more understandable. Especially in a case as a Sustainable Reconstruction of Houses in a Seismic Desert (SRH-SD) area, the complexity increases by two forcing constraints of seismicity (discussed in the previous chapter) and desert conditions (discussed in this chapter). For the exploration phase of the GPM these tacitly proved the required inclusiveness and comprehensiveness of every single item that may influence the design, or it threatens the design conclusion in the future.

The arguments in this research showed:

- Vernacular and traditional architecture of desert houses responded to the desire of the inhabitants even in those severe conditions in a natural and biological way. The routine needs of dwellers of such an environment and climate have been acquired with minimum expenses. Their methods of construction and urbanisation were incorporated with their lives and culture to qualify it. Therefore, it survived for millennia with minor harm to the environment.
- Modern life style destroyed the connection between the traditions and lives of the inhabitants. The old architecture was not applicable or in most cases was not even wished, whereas this transition did not offer adequate substitutes for it. Instead, the replacing methods directly or indirectly resemble damages to the environment. The significance of traditional desert architecture lays in its awareness of the need of the user, respecting nature, integrating all solutions on different levels, and simplicity.
- Due to the huge increase of population and change of life styles, a direct use of the old methods is not possible, or it may not be harmless to nature anymore. However, supporting new designs by principles as simplicity, applicability, desirability, and sustainability helps to experience the unknown solutions.
- A perfect solution that may work in the laboratory and even in society may not be applicable everywhere. Thus, perfection of a solution or method is not only a technical term but it may strongly depend on social aspects.
- People with a refined culture from a long civilisation, which own the known required skills and settled proper life styles, are more probable to stay in their land and collaborate in disaster prevention. However, they are also more difficult to convince to accept unoriginal sudden changes.

Case-related summary and findings

- Although the core of the society in Bam and its culture is a result of an evolution of at least 2,500 years the life style has greatly changed. The people are losing their old evolutionary habits with no worthy substitute, so that they are losing their identity. Thus, today social awareness of the consequences of over-using resources and over-scaling waste production, as well as social involvement of inhabitants for sustainability in a desert environment, is conditional.
- Although the earthquake in Bam was a disaster, it provided some opportunities for the city as well. These positive aspects include: (i) the great sustainable architecture of Bam (e.g. urbanism, architecture, water system) became revealed worldwide. (ii) The recent un-sustainable inappropriate city development was stopped; instead, an opportunity for new programming and design was provided. (iii) The city could be a model for a sustainable town and architecture for desert cities worldwide. This can be rearranged in a new style for modern cities as well. (iv) Inappropriately built buildings, which were destructed in the earthquake, are cases for a proper reconfiguration. (v) It can be a great laboratory for sustainable seismic resistant desert houses with an optimal energy use and waste dispersion. (vi) The old infrastructures (that are destroyed by the earthquake) in Bam could not serve the current population, which can be rebuilt accordingly. Hence, town planning could also boost the economy of the city so that people do not emigrate from the city that needs to battle desertification. This can be done not only by enhancing the date production (as the main business) but also by conducting the potentials for tourism, provided by the citadel in a suitable planning and design.
- In the last earthquake in Bam, the scale of destruction was generally high. However, the level of demolition between the newly built houses and the traditional houses is not that significant. The main differences relate to the location and the distance of the houses from the focal centre and the location of the main fault. The oldest part of the city was close to the citadel that locates on the north-eastern side of the city where the destructive fault also lays from northwest to the southeast. Therefore, around the fault, including the districts of the old nucleus of the city

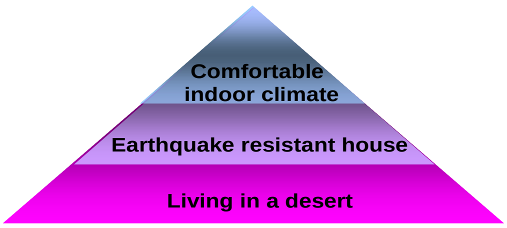
(where the current Bam began to form), the risk of destruction was naturally higher. In these districts, the oldest houses were built of adobe, in the traditional style. On the other hand, the masonry and newly built houses either near the fault or at a farther location are also vastly demolished. Only some domed roof houses, if they were not very close to the fault, experienced fewer damages. Therefore, the adobe houses, survivors of millennia, were not the only weak buildings. Nevertheless, the only concern is not material, but construction methods and details are also of important items. Therefore, strong appropriate buildings and materials with a sustainable approach for desert houses are required.


Figure 5.39. Undamaged adobe dome construction, demolition of modern materialised

- Unlike Phoenix, Bam has a great potential of underground water that supported the inhabitants throughout millennia. The old system of preserving the desert water worked perfectly and only needs some repairs and boosting. For town planning and future development, as can be learnt from what happened in Phoenix, the design should be correctly conducted. This is possible under the coverage of sustainable development.
- Local research, interviews and questionnaires have indicated that the Bami people are proud of the citadel and they would like to live close to it. This is a great potential for the social interactions and involvement in the rehabilitation of the city, as well as for integrity in a desert environment. However, five times of local interviews and questionnaires in the field (of more than 75 families each time), in different periods after the disaster, showed that ignoring such refined culture can turn down their connectivity to their city. This is more probable for the younger generations.
- Due to migration of a wave of newcomers to the city after the earthquake, social disconnections occur and urban tissues are losing their connectivity. The feelings and emotions of the indigenous towards their neighbourhoods are changing because they do not know their neighbours anymore. For a desert habitat, this is particularly serious and needs attention from the designers as well as the decision makers and authorities.
- Concentrated dense urban tissues are the best solution for climate compatibility in deserts on the urban level in both the past and present. However, for cases like Bam, due to the probability of earthquakes in the future, providing some specific places for sheltering and relief should also be taken into account.
- Three main bases for lives of Bami people were (i) agriculture; (ii) inter-city, inter-province, and other services; (iii) tourism. Reforming the incorrect styles by boosting the potentials in an appropriate programming, planning and design will deliver liveable, desired houses.
- Extra attention to modern agriculture is needed to stop deforestation in a desert circumstance and so, desertification.
- Creating additional attractions make the people feeling secure to live in the city and their houses. The people attracted to their lands continue the agriculture not only for food and economic reasons but also for greenery and the environment.
- Although multi-functional rooms are being replaced by fixed furniture in cities, in desert towns and villages a mix of both is still abundant.

Practical recommendations applicable in the reconstruction of cities as Bam

For optimisation of the energy use in hot desert days and cold nights, thermal mass has a particular priority in the materialisation of houses. However, according to the Glocal Pyramid (GP) in chapter 3, the first need for man is a shelter to avoid solar irradiation. In the second stage of need he should be protected



from earthquakes in that shelter. Therefore, isolation, thermal transfer and indoor comfort are stages of need that locate after the seismic resistance of the house in the GP. This is due to the severity of seismicity that directly threatens the life of the man who lives under a weak shelter. Therefore, earthquake resistance is conditional for the sustainable materialisation of the houses in a seismic desert.

In many cases as in Istanbul 1999 and Bam 2003, people prefer to rebuild their houses on their old sites. Although in a case as Bam the basic requirements for life were available in the villages rather far from the location of fault, social dependency to their 'own' city and the Citadel, are strong forces for reconstructing Bam on its old site.

Although individual single-family houses are preferable in many desert towns, because of the sensitivity of arable lands, two- to three-floor houses inhabited by two families are more feasible for the SRH-SD. The latter is not hugely different from the former while in addition to saving the energy (figure 5.40), it preserves more land. Hence, similar to Bam, where relatives used to live close to each other, parents can still live close to at least one of their children.

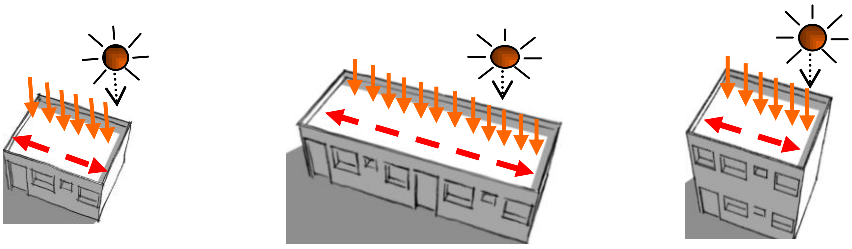


Figure 5.40. Comparison on one storey house with the three storey house in desert climate

The public trend towards hierarchy from public to private spaces is still strong in many desert cities. For example in Bam, this hierarchy is shown in the scheme of figure 5.41.

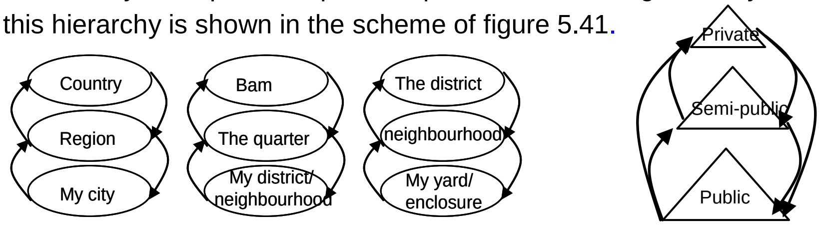
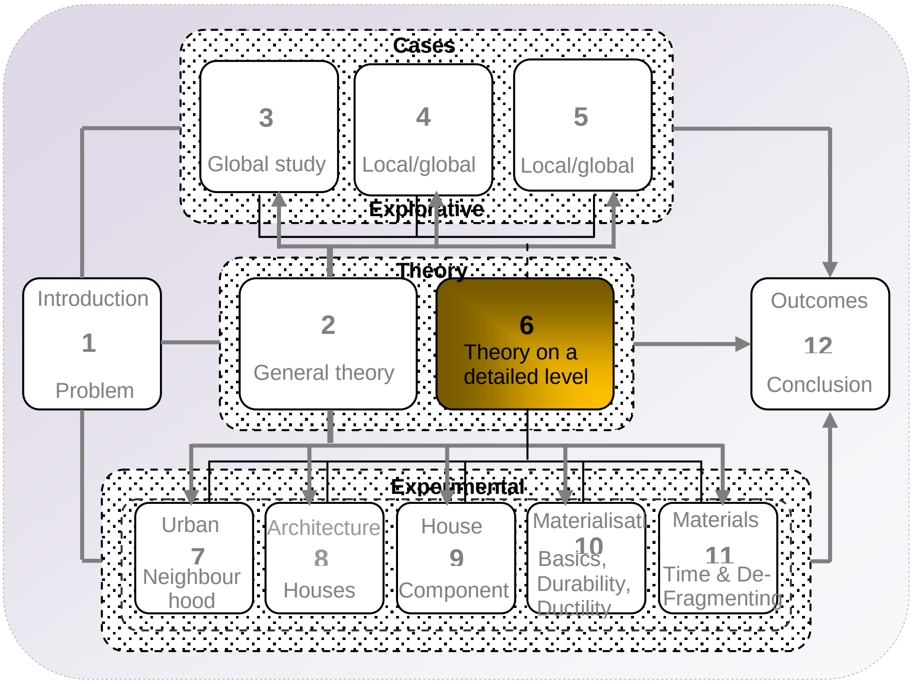


Figure 5.41. The schematic demonstration of a type of spatial hierarchy for Bami people

Although courtyards and Windcatchers are not desired anymore, principles as the incorporation of passive systems in desert climates are very well applicable. For example, on an urban level the concentration of houses is very useful to use (without wasting) water to improve the urban comfort. Integration of nature into the energy systems includes also greenery and wind. This is possible in sustainable modern styles as well. Preserving top soil as much as possible, providing private yards for every house and greenery in the public areas are examples of these facilities. The trees and bushes refine the dusty desert air before entering the houses while helping to stop desertification.

Individual parcels for houses (either the one- or two-storey houses) should be separated from each other as well as from the street by visible elements as walls.

Finally, as the discussions provided in the previous and this chapter showed, a combination of the two constraints of seismicity and desert circumstance causes an extremely complex situation for the design. This may lead the design into complications and thereby chaos. In order to avoid this, the design and particularly the exploration phase require structure, which will be discussed in the next chapter.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Outcomes
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Conclusion
Experimental
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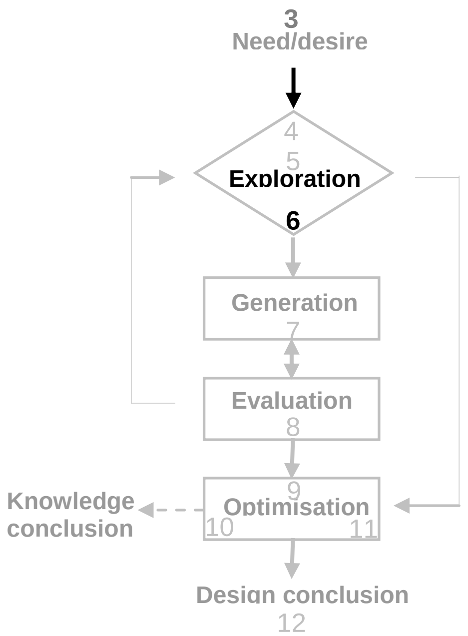
Time & De-Fragmenting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Knowledge conclusion
Design conclusion
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CHAPTER 6

MODELLING THE EXPLORATIONS OF A COMPLEX DESIGN SITUATION; SUBSYSTEMISATION INSIDE THE GPM SYSTEM

Due to the nature of the exploration phase of GPM in a complex design situation, this phase has been divided over three chapters in this study (Chapters 4, 5, and 6). In this way, chapter 4 has discussed the principles of the exploration phase and the effects of the design constraints. Chapter 5 demonstrated the necessity to have abundant information for the exploration phase, particularly in relation to possible discoveries within case-related research (i.e. SRH-SD, the Sustainable Reconstruction of House in a Seismic Desert area). Whereas the first (chapter 4) concentrated on seismic resistant systems, the later (Chapter 5), focuses on desert houses. Thus, many items have been added to a normal design case; these are illustrated through the cases in those two chapters. Such large quantity of involved items in a design could lead it to chaos and inadequate conclusions. Whereas, these involved items in the exploration phase play critical role for achieving the appropriate conclusions. Therefore, this chapter discusses systems and methods, useful to arrange the entire items, aspects, and disciplines. With this, all the information, collectable and analysable in the exploration, are organised towards the goal, within a general flexible and open frame (the GPM system) of the SRH-SD. The flexibility allows more applicability of the system for various cases, while also giving more freedom to the designers.

6.1. Theoretical overview

Venturi (1966): *(The) context is what gives a building its meaning*.

The organisation of a system makes a complex subject understandable and discussable between several individuals, rather than haphazard and chaotic. Similarly, organisation is required in a complex design situation. Besides, particular organisation, methods, and techniques are required for the exploration phase of a design, in which an abundance of items creates a busy environment that may become too vague.

Obviously great designs demand great intuition (Alexander, 1971; Simon, 1977; Johnes, 1992; Hertzberger, 2002; Lawson, 2006), but using intuition, as the sole support for a complex design, is not reliable (see chapter 2). Data, information, and knowledge are the other significant requirements. Heavy (2005) states: 'The completion of a science requires that all things relevant to our project be reviewed, one by one, in a continuous uninterrupted well-ordered enumeration.' Adequate enumeration or induction is essential when the knowledge of something cannot be reduced to simple intuition, because if we do not infer something immediately from something else, but rather from other disparate propositions, our intellect does not have the capacity to include them in a single intuition, nor can we distinguish all the links in a single chain. This is even more important for a design, as it needs greater elucidation of some issues in the later stages'.

The exploration phase of any SRH-SD project comprises the theoretical and rational/factual aspects of the design that are not completed until the end of the design process, although the majority of them are achieved prior to the conceptual design phase (the subject of the next chapter). Therefore, the exploration phase of a complex design process is also an important part of setting the design theory. Based on these theoretical outcomes, the conceptual design starts out as a practical solution. Thus, conceptualisation can also be expressed as a practical result of what has previously happened in the exploration. Therefore, it is a very important phase of the design and plays a critical role in it; this role will be realised in the following discussion.

6.1.1. Complexity and the role of 'exploration' in a design

Because of involvement of so many variables in a complex situation, the designer or the design team needs to compare values in order to prioritise and select items based on the available criteria. However, the criteria may not always be exact with regard to some particular items. This is also due to the nature of architectural design, which deals with art, technology and sciences (Achten et al., 2001; Sariyildiz et al., 2003; Lawson 2006), including the social sciences. In this type of multidisciplinary environment, the interaction between disciplines further increases the complexity (Alexander, 1964). Separate requirements may cause conflict with respect to the relevant solutions; thus, it may result in greater complications. The sensitivity and importance of the exploration phase is due to such factors. This phase is not only a major knowledge area within the design processes but also this knowledge should be collaborated and applicable for various parties. The entire area of the exploration phase can be called 'collaborative knowledge' (Hubers, 2008). According to Hubers, there are five reasons for this collaborative approach:

- Decisions at the beginning of the design process have a major influence on the cost-quality ratio
- At the beginning, there is potential contribution through knowledge and experience of all stakeholders
- The growing complexity of building projects
- the client's demand for guarantees and the claims that different parties may receive because of building failures lead to these parties wishing to have an influence on the design
- Because the advice of experts often comes too late, when other developments have already altered the design, there is a waste of time and money in the actual design process

A large body of knowledge is required to come to a scientifically based design (Carrara et al., 1994; De Jong et al., 2002) and a systematic approach to the design (Goldschmidt, 1991). This knowledge may contribute in several stages, even in the decision-making (Chen et al., 2006), or to the different disciplines. For example, De Jong et al. (2002) refer to the variety of the required collaborative knowledge for design. This is required from different aspects, based on particular goals, with various directions in architecture. From Zeisel's (1984) point of view, designers need knowledge that helps them decide how things might be. They also use knowledge that informs them of how well things might work (Lawson, 2004). According to Lawson (2004), the application of such knowledge is a highly selective process, which inevitably results in designers making their own unique interpretation of design problems. He emphasises the requirement for knowledge, which generally forms a theoretical background and a tacit structural organisation.

Pugh (1991) also mentions the exploration phase as being essential for the success of the design conclusion, and refers to this stage as 'front-end'. In Pugh's study (1991), a genuine understanding of the 'Need' of the user depends on this stage. He states 'The more thoroughly you deal with this area, the more professional you will become.' In current standard architectural designs, architects mostly focus on setting the requirements before undertaking the conceptualisation. For example, from a detailed view, O'Reilly (2000) states: 'Defining requirements, and their communication to others is the root of good briefing. Deciding on a final design or other solution before making a full assessment of the client and user's needs and problems may prove very costly.' Of course, setting the requirements is very important for a design, but it covers only a part of the exploration phase defined in this study. Based on these the scientific approach of Moughtin (2003) is similar to the current research in more than one way. These include not only the scientific design processes modelling but also the strong emphasise on the investigation and survey prior to the conceptualisation

In the exploration phase, the relevant data, information, and knowledge of all the pertinent factors form the basis for decision-making and design conclusions. Therefore, the role of the exploration phase for the rest of the complex design processes is similar to the role of foundation for the structure of a building (the scheme in fig.6.1). Although a bad superstructure may always collapse, an important condition for the survival of good superstructures is a strong foundation. The stronger and safer this theoretical information foundation is, the better the practical design will be.

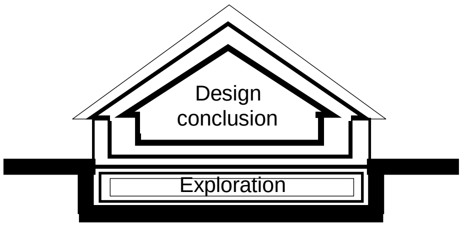


Figure 6.1. Schematic illustration of the role of exploration (e.g. of the GPM) in a complex design.

6.1.2. How to organise the design foundation, introducing a subsystem

According to Cross (2008), modern design is generally complex. Hubers (2008) indicates that the organisation and classification of subsystems or sub-processes help to organise such complexity and the potential complications. These administrations do not necessarily guarantee an appropriate design solution. However, these are supports to help avoiding obvious failure in complex situations. It should be reminded that there is no fixed limited detailed plan or classification (e.g., model) for sorting out an architectural design. Jones (2002) states: 'It's only the existence of existence that is fixed.' Leupen et al. (1997) also state that the involved aspects do not arise in a fixed, logical order: 'Designing is not a linear process, with a specific task leading to one and only one possible solution.' With these, a sub-arrangement and sub-processes in a large frame (i.e., the flexible structure of the entire design process/the GPM) form an effective way of making the method applicable to various cases. Therefore, the design information presented in two previous chapters and the principal knowledge can be better arranged within the sub-system of the 'exploration' phase covered in this chapter. This method is similar to what Pancake et al. (1990) point at in the way researchers in the field of computer science work on parallel programs, suggesting that existing single languages may not support scientific works. Another similar approach has been found in the study of Williams (1973). He states 'when a theory deals with entities that are physically part of another entity, one of those entities is the fundamental entity of the theory, and all results of the theory can, and should, be expressed in terms of that fundamental entity'. With a similar attitude, but on a design theory level, we propose the exploration phase as a subsystem of the GPM system.

Towards a solution finding

Regarding the significant influence of the exploration on the design conclusion in a SRH-SD, relying only on a simple (sub) systemisation is still risky. Therefore, based on the theory and the general approach of this study (i.e. "using systems and methods", see also Shahnoori et al. 2010a), similar to the parallel language (Pancake et al., 1990) three interrelated levels/types of organising have been proposed. The subject of each of these three solutions will be discussed in a separate section (i.e. shown in the scheme of figure 6. 2).

In the first one, the exploration phase is assumed as a sub-system. The second relates to the methodical preparation of the exploration phase, especially for the critical final stages (as well as for the entire design). The latter also provides fluent communications between various experts that involve in the design. Finally, the third proposal solution narrates the goal finding by establishing a suitable general strategy, which may also embrace sub-strategies in practice. This means that in order to ensure a proper design conclusion and to avoid the undesirable consequences in future, the ample elements in the Subsystem of Exploration Phase (SEP) need to be properly conducted.

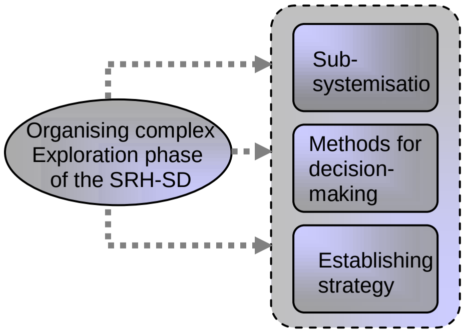
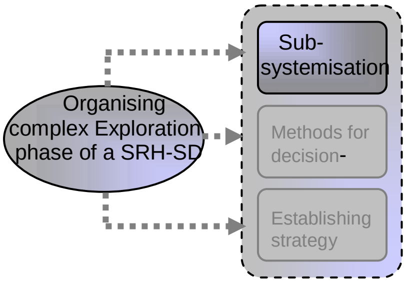


Figure 6.2, scheme representing the main subjects of this chapter, and ways to organise the exploration phase

6.2. Systemisation



Before modern design can be realised, modern methods and systems first have to be invented (Kalay, 1992; Lawson, 2004; Van Aken, 2005; Cross, 2008; Freivalds, 2009). The methods and systematic approaches adopted in engineering design (e.g., system-engineering and computer science) are more specific than those adhered to in architecture. Even though such methods are applied more in engineering fields than in architectural design, the application of modern materials, design and construction systems makes modern architecture more eligible for adaptation to new methods and systemisations. A good example of this is the involvement of the computer in this field of design. Digital design requires the adjustment of the design procedure and relevant aspects to the computer's ways of understanding, recognising and using language.

6.2.1. Systems and the SEP

System is derived from the Greek *σύστημα* (systēma) meaning an integrated group of interaction, interrelated, and interdependent entities (AHD, 2000). Generally, a system contains an environment in which elements of the system have particular relationship with one another. This system is distinguished from its surrounding by a boundary (the scheme in figure 6.3).

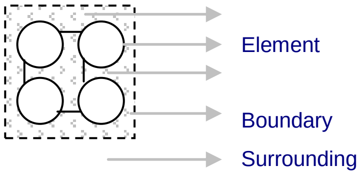


Figure 6.3. A schematic representation of a system and the related items

An element of a system is identifiable only inside that specific system (Roozenburg et al., 1991). This is because all the characteristics and roles of the element are meaningful as long as it belongs to the system, and may become meaningless out of the system.

Klassen (2003) translates this into a verbal statement: 'A system exists of:

• a set of elements with certain variable characteristics (attributes), plus

• a set of relations between these element-attributes (structure), plus

• a set of relations between these element-attributes and the environment of the distinguished system (Harvey 1973).

According to Klassen (2003), if the elements do not possess attributes then the system is termed 'formal', 'the dimensionless entity, the mathematical point'. There is a mutual relationship between a system and its element, element is a main term to define a system, while the positional value of the element is defined by the system, and the position it occupies in the system. Involvement of the element and its constituent nature in a system is not dependent on its inherent quality, but on its role according to the arrangement and instruction of the system, the positional values and relationships within the system (Angyal, 1969). A set of element-attributes is termed a 'class' (Klassen 2003). For example, four-storey residential complexes can be placed in a class. Within systems, various complex relations, causal or conditional in nature, are possible. Hence, systems, their elements, and their environment as distinguished from the surrounding by their boundaries, may become context-dependent, meaning that the arrangement inside a system may occur due to particular situation and local conditions. Thus, a system that functions very well in a particular environment may not function at all in other surroundings. For example, a perfect heating and cooling system for houses in London may not be appropriate for a house in Bam. The system of concentrated urban fabrics in Fez or Marrakech (fig. 6.4) does not apply to urban tissues in some Mediterranean coastal regions that have to deal with the problem of sprawl (Antipolis, 2001) or even with the urban fabric in the warm region of Millbrae in Nevada (fig. 6.5).

Figure 6.4. A bird's-eye view of the urban fabric in Marrakech

Figure 6.5. Urban tissue of a part of Millbrae, Nevada, USA

However, according to the law of assimilation-contrast (Vroon, 1995; Krech and Crutchfield, 1961; Klassen, 2003) many designers, engineers, and technologists tend not to perceive either this context-dependent functioning or distinction between the system, its environment, and its internal coherence. According to Klassen's study (2003), the environment of a system is understood as:

1. System and system environment are similar and hierarchical

2. System and system environment are similar and equivalent

3. System and system environment are dissimilar and equivalent (e.g. natural system, economic system, cultural system), that occupy the same space (and time).

Using these definitions and positions for organising the exploration phase of the design in a complex situation, we first assume the system of GPM as (a larger system or) the environment for (the smaller system or) the Subsystem of the Exploratory Phase (SEP). Therefore, in a complex design situation such as a SRH-SD, the SEP or exploration plays a specific role in GPM, and functions as an element of that system while it includes its own particular internal arrangement, environment and elements (scheme in fig. 6.6). With these distinctions and according to the former definitions, the system of SEP and its environment, which is the GPM, are similar and hierarchical.

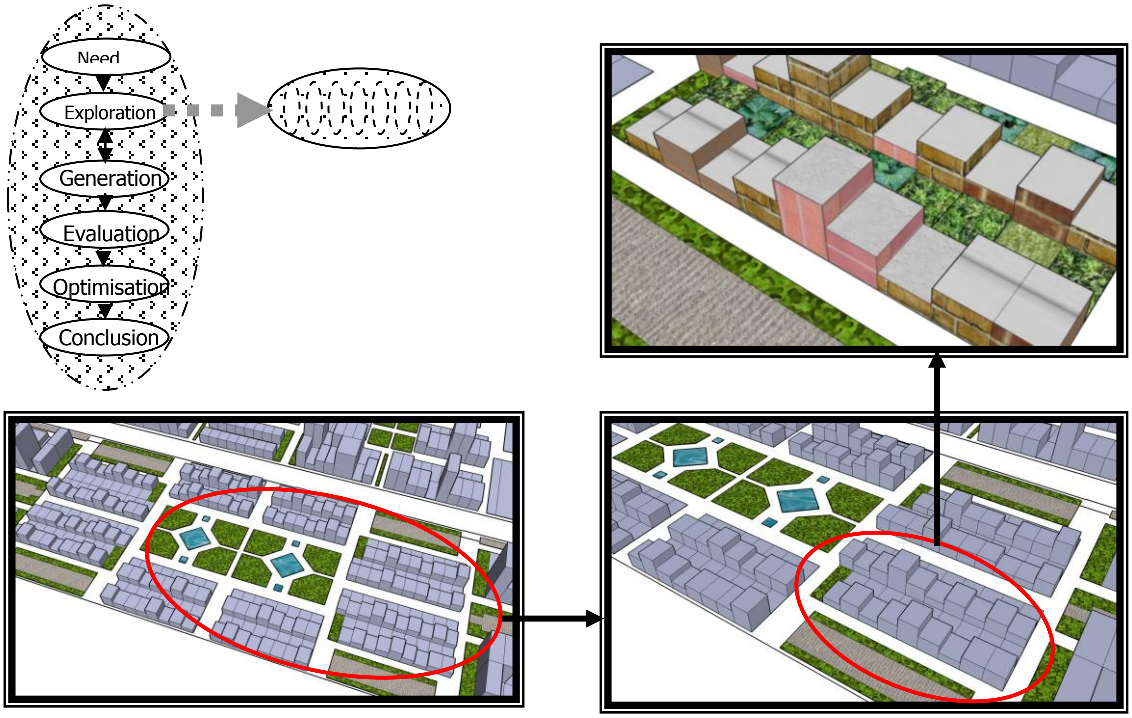


Figure 6.6. Schematic demonstration of the relationship between a larger system (environment for the subsystem) and the smaller system in the GPM (with the SEP), and in the system of a city

As the SEP also includes various types of elements, first a general division and classification of actions is followed. However, a more detailed particular internal arrangement and specifications of the elements of the SEP are applicable. Therefore, at the end of this section this will be provided and finalised as a suitable process model, which is neither fixed nor limited.

6.2.2. A general classification of actions in the subsystem

The process of problem statement, analysis and synthesis in science (Bunge, 1967), albeit with slight changes, is adjustable in the second stage of a design process (the exploration) as well. However, to designers, it seems that the analysis or understanding of the problem is largely bound up with the synthesis or the generation of a solution (DAYTU, 2004). From Ritchey's (1996) point of view, this is the case for scientific method too. He states that analysis and synthesis, as scientific methods, go hand in hand: they complement one another. According to Ritchey (1996), analysis is the procedure by means of which we break down an intellectual or substantial whole into parts or components. Synthesis means combining separate elements or components in order to form a coherent whole. Every synthesis is built upon the results of a preceding analysis, and every analysis requires a subsequent synthesis in order to verify and correct its results.

The subsystem of the exploration phase includes the design principles. Design principles are accurate reflection of the fundamentals that guide decision-making in an enterprise (Pieterse, 2006). Therefore, this essential phase also requires internal systemisation. Alexander's approach (1964) in breaking a problem down into smaller problems to make it soluble is also found in Krauss's study (1996). He states 'One must break down the problem into smaller pieces and build it back up into a final solution.' However, as mentioned in Chapter 2, this study tends to use this method for the solutions as well. In this approach, a general solution includes many sub-solutions that may also contain smaller-scale solutions. Aiming at these, and applying a scientific approach to the design discipline, based on the philosophy of Bunge (1967) and similar to the approach of DAYTU (2004) and Ritchey (1996), a general classification of the exploration phase containing three main parts can be arranged. These are (i) investigation and exploration, (ii) analysis, and (iii) theoretical prioritisation, synthesis and decision-making. A similar approach can be found in the study of Markus and Maver (1967). In a general classification for elaborating the design, they also use the scientific process as the main basis. Their proposed scheme is shown in Fig. 6.7.

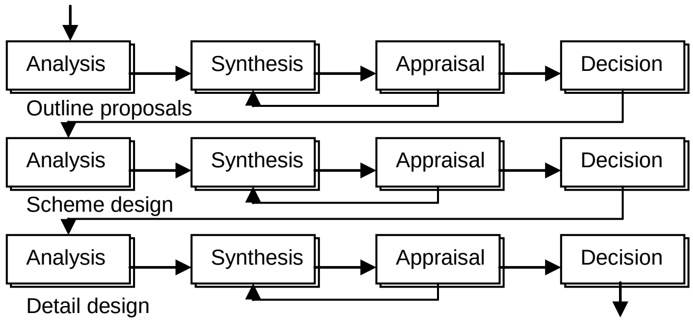


Figure 6.7. The map of the design process according to Markus and Maver

In this map, the searching for relationships, looking for patterns in the information available and the classification of objectives are the analytic components. They order and structure the problem (Lawson, 2006). The synthesis is characterised by an attempt to move forward and create a response to the problem. Lawson (2006) calls it the 'generation of solutions'. According to Lawson (2006), 'appraisal involves the critical evaluation of suggested solutions against the objectives identified in the analysis phase'.

Finally, although the elaborated model of Markus and Maver has not been directly used, it is an efficient map for showing the effectiveness of the proposed typology within the subsystem of the exploration phase (SEP). The proposed general classification of the type of details within the SEP, as also indicated in the previous section, includes data, investigation and information, and the problem statement. The second type of actions involves analysing these. It is followed by prioritisation and partitioning, decision-making and synthesis. This categorisation of the main activities and sequences form the basis for the conceptual design (shown by the scheme in fig. 6.8.).

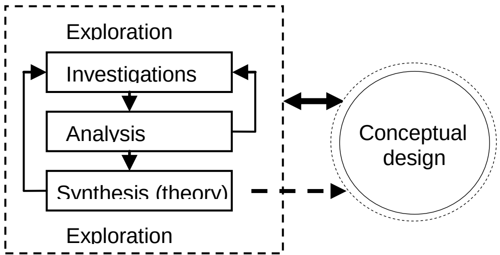


Figure 6.8. General classification of actions inside the exploration phase

However, in view of the above-mentioned arguments, a further division on a detailed scale is helpful for designing within a complex and demanding situation as a SRH-SD. This further detailing is modelled in the next section.

6. 2. 3. Modelling the processes inside the subsystem, a sub-process model

The methodology for organising the SEP is similar to the approach discussed in Chapter 6.2 when developing the GPM (see also Shahnoori et al. 2010). Therefore, for the sub-process, similarly, Cross's model (2008) will still form the basis. However, adjustment is again required to transfer his proposed processes into an architectural design. The detailed processes proposed by Cross (2008) contains stages that are shown in Table 6.1.

Table 6.1 a detailed process for design, introduced by Cross (2008)

Stage of the process	The relevant method, characteristics and the aim
Identifying opportunities	User scenarios Aim: to identify and define an opportunity for a new or improved product
Clarifying objectives	Objectives tree Aim: to clarify design objectives and sub-objectives, and the relationships between them
Establishing functions	Function analysis Aim: to establish the functions required and the system boundary, of a new design
Setting requirements	Performance specification Aim: to make an accurate specification of the performance required of a design solution
Determining characteristics	Quality function development Aim: to set target to be achieved for the engineering characteristics of a product such that they satisfy customer requirements
Generating alternatives	Morphological chart Aim: to generate the complete range of alternative design solutions for a product, and hence to widen the search for potential new solutions
Evaluating alternatives	Weighed objectives Aim: to compare the utility values of alternative design proposals on the basis of performance against differentially weight objectives
Improving details	Value engineering Aim: to increase or maintain the value of a product to its purchaser whilst reducing its costs to its producer.

As mentioned, the "Exploration" itself consists of a multiple task in which different steps should be proceeded one by one. In an architectural design process, a list of pre-defined objectives and information, including the site and location, is normally prepared by the client - i.e., person, developer, organisation, etc. (Simon, 1969; Schön, 1986; Cohn, 1992; Ferguson, 1993; Leupen et al., 1997) as the core of the design task. These initial objectives need to be clarified after receiving the first data. Generally, in such a procedure, the outcome of the process cannot be deduced from its initial goal (Ferguson, 1993). Thus, designing in the field of architecture, the function is mostly defined prior to the design. This pre-defined function may require further investigation and may sometimes require further elaboration during the processes after the designers become familiar with the context and the relevant information. In other words, in the table above, architectural design typically begins at the stage of 'setting requirements'. The previous stages are largely set by the client.

Many cases of architectural design do not have individual clients, but organisational clients, developers, or even governmental clients (see for example Cohn, 1999; Carmona et al., 2000; Lawson 2006). In such cases, the client may ask for a comprehensive investigation of and estimation for the production of the specified actual need, reintroducing the earlier phases of Cross's model. Otherwise, the developer, for example, may ask the architect or the design group to perform the preparatory work. However, on the larger scales of design, such as urban design and even in landscape design, the sub-functions may not be recognised by the user or by the client in advance, although the general function is known prior to the design. These are defined through investigation and analysis in the SEP.

After the refinement of the function, identifying the design boundaries and limitations is required. Now, recognition of the sources and opportunities are other important items to be investigated and explored in the SEP. Cross's detailed model (2008) is relevant here. In fact, the design is directly influenced by these sources and opportunities, especially in the generation phase (Bonenberger, 2005). This step, in conjunction with the limitations and constraints, is of critical importance (Kalay, 1991; Cross, 2008) when the design situation is seriously complex.

Constraints, regarding the terminology of this study, may affect several elements directly and others indirectly. For example, technical aspects may be directly influenced by the constraints (Bonenberger, 2005; Shahnoori 2008) which also indirectly influence the social aspects (Shahnoori et al., 2007) of a design. Hence, a severe constraint plays a major role in decision-making and prioritisation (French, 1999). Therefore, in developing a process model for the complex design, the sources and opportunities stage, in addition to the factor of limitations and constraints, requires special consideration.

In a normal design process, not all the objectives are known in advance (Lawson, 2006). 'The designer first defines the boundaries of the system (often involving highly arbitrary judgments). Then the permissible inputs to the system and the permissible output from the system are carefully determined. Nothing may cross the boundaries unobserved. Analysing the gathered information and completing the site observation and other complementary activities will be prior to synthesising and proposing ideas as the basis for conceptualisation in the next phase.'

Procedural steps; developing the processes model for the SEP in a SRH-SD

In an architectural design, on-site observations or *in situ* investigations are followed by the identification of resources and limitations, and refinement of the functions. Further objectives can be identified at the stage in which information and documentation for the design are more or less collected. In the philosophy of science, new scientific efforts may start up whenever available knowledge is insufficient (Bunge, 1967). Similarly, in a 'Designerly approach' (Cross, 2003), when existing solutions do not fulfil the needs of a design; a new design process will be initiated. In science, the relevant data and information are essential to the scientific approach. However, extraordinary knowledge is required to analyse this collected information (Bunge, 1967). Analysis is necessary to come up with a hypothesis in which synthesising is the best rational approach (Ritchey, 1997). In a design process, visionaries are capable of comprehensiveness (Shahnoori, 2008). Visionaries have a panoramic overview and can envisage the result (Mintzberg et al., 2006). They can analyse the available information in the light of existing knowledge and come up with suitable solutions in an appropriate way (Porter, 1998). With regard to this last factor, an appropriate supervision of the entire stages and the steps in the exploration phase should be also emphasised. This activity has been called 'design strategy' in this study, and will be thoroughly discussed in section 6.4.1.

This classification enables the designer to reduce the risk of chaos in a complex design situation, and facilitates further ramification in the design processes in a systemised way. In this classification and ramification, which is analogous to science (see French, 1999; Roozenburg, 1988; March and Smith, 1995; Ferguson, 1993; Archer, 1999), the exploration phase of the process model forms a strong foundation. Accordingly, almost everything is known at the end of the investigation. At that point, the investigation can be finalised and moved on into the analytical phase. The result of this finalisation and analysis is 'set of the requirements' for the design, as specified in Cross (2008) as well. After this, the characteristics can be determined.

The design environment at this stage has been recognised, the fundamentals are solidly grounded, and the documentation is almost complete. In fact, the analytical step consists of identifying the degree to which the specifications need to be satisfied as precisely and desirably as possible (French, 1999). According to French (1999), the output of this step is the statement of the problem. This step includes all the involved aspects along with the relevant criteria. Based on the output of the analytical step, the exploration phase can come up with the theoretical outcome (French, 1999) and synthesis. The above discussed stages of the processes of the SEP for a complex situation as a SRH-SD are modelled in the table 6.2. The accuracy of the finalisation and outcomes of the SEP are governed by the general strategy and lead to action and the tangible output of the conceptualisation (Ferguson, 1993) in the next phase. The overall strategy guides the whole process in a clear direction.

Table 6.2. A model of stages of the processes in the SEP within the frame of the GPM in a SRH-SD

<table>
<tr><th colspan="2">Subsystem of Exploration phase (SEP) in a SRH-SD</th></tr>
<tr><td rowspan="8">Investigation/ data

Analysis

Synthesis (on a theory level)</td><td>Initial objectives</td></tr>
<tr><td>Sources and opportunities</td></tr>
<tr><td>Limitations and constraints</td></tr>
<tr><td>Functions refinement</td></tr>
<tr><td>Clarifying objectives</td></tr>
<tr><td>Setting requirements</td></tr>
<tr><td>Determining characteristics</td></tr>
<tr><td>Establishing strategies & final decisions</td></tr>
</table>

However, it must be restated that, although this step-by-step structure and organising is helpful, it does not guarantee a successful solution, but it does reduce the risk of failure. The design problem, as a part of the entire ‘need’, does not resemble a puzzle to be solved by scientists or mathematicians (Cross, 2003). According to Lawson (2006), some information on design problems may not or may never be available. Besides, the steps of SEP do not terminate the relevant activities, because these activities may be iterative and need to be completed in various ways and phases. Therefore, indications of connections and relationships of these steps and in general the SEP with some other phases of the GPM will be briefly mentioned in the next section when finalising the sub-systemisation and modelling of the exploration phase.

6.2.4. Analysis and finalisation of the stages of processes in the SEP

The conclusions achieved in the SEP are directly implemented in the next phase of the GPM, the “Generation” phase (see the scheme in figure 6.9). The concepts produced in the “Generation” phase will be assessed in the “Evaluation” phase. This application of information, the production of alternative concepts and assessment in three phases is discussed in Cross (2008), Pahl and Bitz (1984), and French (1999). However, the evaluation phase is again sensitive, as the value of the selected concept needs to be tested and evaluated according to the criteria (Roozenburg et al., 1995). Objectivity, resources and opportunities, limitations and constraints, the set of requirements (French, 1999) and the characteristics (Cross, 2008) should all be checked in evaluation phase. Therefore, although evaluation comes after the generation phase, its strong and linear relationship with some particular steps of the exploration phase needs to be emphasised (e.g., by drawing loops or extra connections in GPM, as shown in the scheme in figure 6.9). Within the frame of the GPM, the optimisation and communication is situated after evaluation and prior to design conclusion. According to GPM, further detailing and rationalisation (e.g., prototyping) is required in the optimisation phase. The required connections between the optimisation phase and exploration, similar to the previous phase, must also be stressed (fig. 6.9).

Nevertheless, because of the increase in the number of internal steps within SEP, it is difficult to control all the involved items, their interactions and interferences. This requires integration, which is crucial in order to avoid chaos. Because most of the influence of chaos is on decision-making, and because the decision taken is applied in the conceptual phase of the design, the decision-making step of the exploration phase needs extra attention. It is often stated that the integration of a design, in addition to requiring a broad comprehensive view of the designer (to take all the relevant aspects, domains, criteria and segments into account), is of the utmost importance. According to Rittel (1968), the design process is an activity aimed at the production of a plan (i.e. either schematic or course of actions) that, if executed, leads to no undesired or unanticipated consequences. The most important point deduced from this statement, which has also been claimed by Garcia-Diaz and Smith (2007) is 'Thus, design is intended to be a logical, rational, and systematic activity.' This conclusion may not be favourable to many architects, but is required for the successful conclusion of a Complex Design Situation.

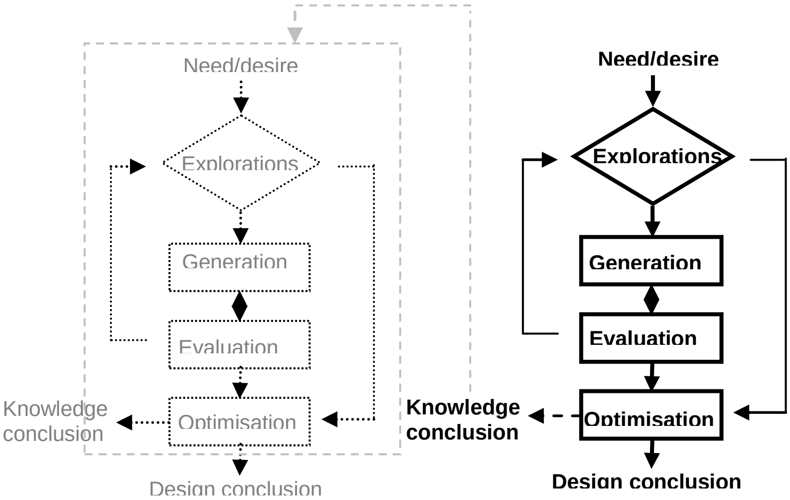
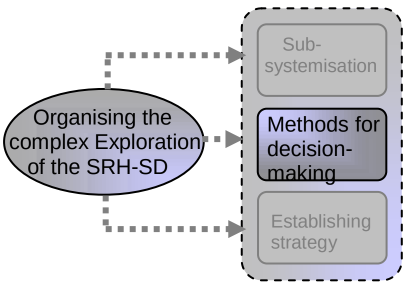


Figure 6.9. GPM, the backbone model for architectural design processes in a complex situation

Therefore, the following sections after discussions about the final stages of the SEP such as decision-making, introduces a reassuring approach to this type of controlling and unidirectional behaviour, mostly concentrated on decision-making. These are some other transformation and adaptation of existing terms for rather new applications, aiming at further organisation of the SEP.

6.3. Critical stages in SEP and the relevant problems in a complex situation



Some generic design skills can be applied to all forms of design practice, but there are also skills specific to certain types of design (Lawson, 2006). However, currently most design-related skills correlate to either the conceptualisation or the presentation of the conclusion, while a few skills are relevant to the organisation of the exploration.

The dynamic methodology of the present study, which is similar to that of Markus and Maver (1970), is context-based, process-oriented, descriptive and explanatory on the one hand (see Martin and Turner, 1986) and includes an open, flexible (general but organised) process model on the other (e.g. Ertas, 1996). Besides, controlling the possible chaos by means of a leader, especially at the decision-making step, will give a further boost to the systemisation.

In architecture, a design process is a consultation project, because several forms of expertise are involved in delivering suitable and desirable design conclusions (Alexander, 1964, Leupen et al., 1997). As the types of expertise increase so difficulties tend to arise (Van Loon, 1998), especially in the decision-making phase. On the other hand, taking into consideration more details related to the several coherent aspects of architecture normally increases accuracy (Hulsbergen et al., 2005), validity, and reliability (Shahnoori, 2008). In line with the range of aspects and domains involved, several forms of expertise are required to validate the investigations. In a normal process, each expert makes several choices and has different alternatives. Therefore, on the one hand, the involvement of expertise qualifies the design (Shieh, 2000), whereas, on the other hand, it complicates the decision-making (Van Loon, 1998). If all the experts have the same shared right in the decision-making, the most critical step will then be prioritisation

The decision sequence starts at the beginning of the design process and focuses on two main branches. The first of these is the theoretical decision sequence (which is located in the exploration phase), and the second is the application of these facets in the conceptual design. Decision-making continues throughout, but basic essential decisions constitute one of the last activities in the exploration phase, thus making them directly effective in the design conclusion. Thus, prioritisation and decision-making (at least on a theoretical level) are significant steps in the exploratory phase (De Vries, 1984). Nevertheless, in the step of conceptualisation not only theoretical decisions are applied, but some unwritten decision sequences may also be found to underlie the design concepts.

These unnamed, hidden decisions may incorporate great potential for integrating all the detailed decisions. Because of their leading position in decision-making, they can even be interpreted as tacit aims. As they form a very effective factor, creating a position and arranging a role for them in the system is an important pursuit. Using the potential of this comprehensive unnamed aim, this criterion or guiding item, in order to direct the whole subsystem of exploration is a persuasive way of realising a dynamic organisation. In this way (the subject of section 6.4.), the decision sequences are unified and integrated (Hubers, 2008) as well. In the approach advanced by Mintzberg (2000), general planning is an integrated decision-making: 'Planning is a formalised procedure to produce an articulated result in the form of an integrated system of decisions.'

This integrated system of decisions is crucial for a complex and risky design situation. For example, in a SRH-SD, seismicity and desert location creating a sensitive situation influence the design. Hence, the decisions made in the exploration and subsequently the design conclusions may influence a large number of houses (e.g. more than 40000 houses in Bam, 2003, about 190,000 in Haiti, 2010, etc.). Because of the risky situation and the role of the decision making, the following discussions, focus on decision-making, prior to providing the basis for the mentioned planning and integration

6.3.1. Prioritisation and decision-making, application of risk analysis

As it has already been indicated, the final decision is one of the most important outcomes of the exploration phase, although it is not wholly terminated in this phase. The success of the conceptualisation, as well as the design conclusion, is dependent on the decision-making step. Freivalds (2009) calls this step the 'core' aspect of information processing. This stage has been emphasised as important because it includes theoretical evaluation, prioritisation and selection.

Because of the sensitivity of decision-making, especially in a complex situation or when faced with risk, it has sometimes even been termed the 'basis for the engineering perspective' (Gehner, 2008). Operations research that is based on mathematics has resulted in the development of quantitative methods and techniques for risk analysis (Ackoff and Sasieni, 1968). According to Gehner (2008), decision-making linked to risk is based upon the idea of rationality. Applying quantitative methods, the objective being to develop and employ mathematical models, theories and hypotheses, is therefore the proper way of facing risky situations (Gephart, 1988). Although applying such techniques to the entire process and the whole exploration segments, especially in a complex situation may not be possible, some of them, which can be combined, are applicable for risk analysis in decision-making steps when applied uni-directionally with qualitative methods.

'The process of numerically analysing the probability of each risk, its consequences for project objectives, and the overall project risk, is a quantitative risk analysis' (PMI, 2000). However, the process of assessing the probability and impact of identified risks in order to prioritise the effects on project objectives is qualitative. Therefore, qualitative and quantitative methods may combine for a complete "risk avoidance" procedure. In the risk response, a risk plan is required; monitoring the risks and executing the risk plan are the final steps. This process has its own internal steps such as identification and analysis, for which various techniques have been developed. For example, common techniques adopted for risk identification (e.g. in Figure 6.2) include Brainstorming (e.g., Delphi brainstorming SME techniques), using Nominal group techniques, adopting the Decision Conference technique, carrying out Interviews, making Checklists, filling in Forms and Templates, doing a Stakeholders' analysis, creating Cause-and-effect diagrams, and making a SWOT analysis (Vargas, 2009) …

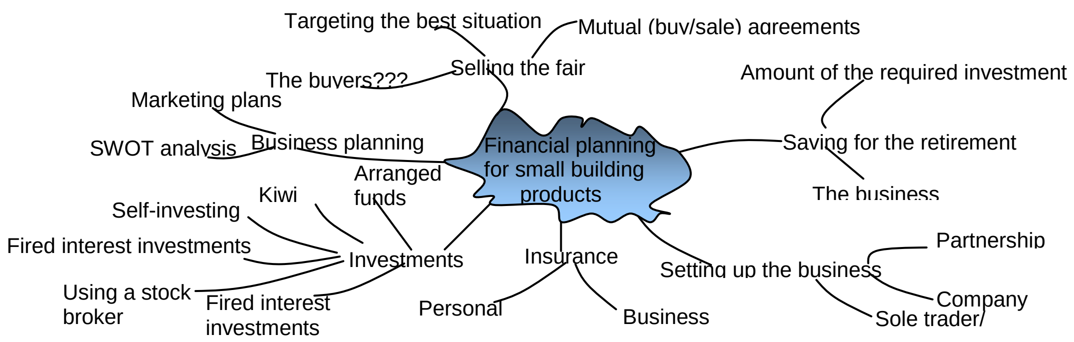


Figure 6.10. Representative sample of a method (e.g. Brainstorming)

Decision-making is dependent on information and information processes. Organised information provides a better environment for the final decision. Several information processing and modelling methods have also been developed (e.g. Melvin et al., 1982; Wickens et al., 1988; Gordon, 1997; Switzer et al., 1999; Wallace et al., 2003). However, these models have sometimes been denounced as immature, which may be partly due to the relatively incomplete information provided (Man Hui et al., 2009; Freivalds et al., 2009). For example, Freivalds et al. (2009) state: 'These models consist of black boxes.' He claims that these black boxes may cover the entire model or be included in a model (models including black boxes). From his point of view, these black boxes represent various processing stages. He gives the example of the generic model developed by Wickens (1984), which consists of four major stages or components (Wickens and Liu, 1997). Although many of these models need to be improved, they can still be very useful for preparing processed information that is crucial for decision-makers, especially in risky situations.

According to Von Newmann and Morgenson (1947), decision-makers select the course of action that maximises expected utility. Gehner (2008) states that 'being able to make a fully rational decision assumes that the completeness of information – the impact and probability of a risk can be assessed objectively – and having the ability to compute with perfect accuracy.' Halman (1994) puts decision-making into four categories. As shown in Table 6.3, these categories are distinguished by frequent versus non-frequent risk events, and the risk taken in a static context versus a dynamic decision-making context.

Table 6.3. A typology of decision-making under risk, adapted from Halman, 1994-2008 (Gehner, 2008)

	Frequent	Non frequent
Static ('gamble view') The results can be influenced	Objective estimates Example casino games, non-workable days in contractor's planning	**Subjective estimates Example: the buying a share**
Dynamic ('management view') The result can be influencing a dynamic process	Objective estimates Example: quality procedures in process (serial) industry	**Subjective estimates Example: architectural/ construction/real estate development project**

Due to the nature of architectural design, many risks occur non-frequently; this means that probabilities cannot be calculated (e.g., tossing coins, throwing dice or drawing cards). Neither can they be assessed by the recurrence of risk (e.g., the frequency of failure in serial industry) (Gehner, 2008). According to Gehner, decision-makers in the field of architecture have to rely on subjective estimates for both the assessment of probability and the impact, which is hard to do in a complex situation (Beach & Connolly, 2005). According to Freivalds (2009), in classical decision-making theory a rational approach would involve calculating an expected value based on the sum of the products of each outcome multiplied by its expected probability. This approach does not, for example, interfere with making decisions for some parts of the SEP in an SRH-SD.

Therefore, for a SRH-SD, a rational approach is first organising the segments within a suitable frame as a system. Second is applying an appropriate method such as checklist for the exploration phase of the GPM. This not only helps for a rational decision-making but also acts as criteria for the next stages of the design. In this approach, qualitative measuring is adaptable to the design. Besides, similar to the approach of Freivalds (2008) calculation of some quantitative values is also possible, which is very useful for prioritisation and decision-making in a SEP.

6.3.2. Some principles of decision-making

The assessing of relative preferences for decision sequences starts with hierarchical goal analysis or value-tree analysis (Borcherding et al., 1984). Pitz and Riedel (1983) suggest that the practical importance of value trees in decision analysis should be considered separately from their descriptive accuracy. However, some researchers such as Wickens et al. (1997) or Freivalds (2009) criticise the typical approach in which people use a variety of heuristics to make decisions. He argues that a variety of biases may influence the way these people seek information, attach values to outcomes, and make overall decisions. Wickens et al. (1997) provided a typology of these biases:

- A limited number of cues or pieces of information are used
- Undue weight is given to early cues
- Inattention is given to later cues
- Prominent cues are given greater weight
- All information is weighted equally, regardless of true weight
- A limited number of hypotheses are generated
- Once a hypothesis has been selected, later cues are omitted
- Only confirmatory information is sought for the chosen hypothesis
- Only a small number of responses are chosen
- Potential losses are weighted more heavily

Recognising these biases helps to present the information better while also leading to a better set-up for the overall process to improve the quality of decision-making and to minimise errors. In

Freivalds’ theory, he emphasises ‘situation awareness’ as the central element in decision-making. This is an evaluation of all the cues received from the surroundings. This is similar to emphasises of this study on the context for the design, in which local limitations and opportunities are seriously regarded. Freivalds et al. (2009) also emphasise integration, which, within the step of decision-making, focuses on the integration of cues or information into mental representations, ranging from simple schemata to complex mental models. This can be stressed as similar to the integration under the covering umbrella of the leading strategy in this study (i.e. section 6.4.). Due to the excessive information and cues, to comprehensively finalising the exploration phase, and specially the decision making stage of the exploration of the GPM for a SRH-SD, a purposeful integration is necessary. However, because this integrator organiser is open, the integration will be assured by detailed (sub)arrangement as well.

This detail organisation includes not only the discussed stages and modelling of them, but also appropriately gathering, arranging, processing and coordinating the information as well. This includes the application of quantitative and qualitative techniques within these procedures. Some of the methods applied need to be adjusted accordingly while yet others are directly applicable. The latter may apply to the design processes as well as to the performance throughout the construction. Nevertheless, the problem seems to stem not so much from the availability of these methods, but rather from their use in decision making in the field. The next section shows an exploration in the level of these applications.

6.3.3. Application of decision supporting techniques in the field

In the field of architecture, construction work has a more rational, quantitative basis when compared to design work. However, the application of the mentioned techniques is still insufficient, even in the construction phase. Generally, observation and investigation have shown relatively little progress in this type of application. Two relevant study cases have been conducted and analysed and are presented here. The first one is a comparative study concerning the application of the quantitative techniques in the construction industry (Table 6.4). The second, however, covers research into application in the field of architectural design (i.e., urbanism, architecture, real estate & housing, and building technology) in a complex situation (see Table 6.5). Gehner (2008) also studied the application of risk management and decision-analysis techniques in the construction industry in some detail. Most of these studies have been incorporated and classified in Table 6.4.

Figure 6.11. Two large firms applying risk analysis on various scales (e.g. design & construction)

Table 6.4. Investigations in recognition and application of probability techniques & decision analysis

Studies / Options	Akintoye et al. 1997	Uhner et al., 1999	Baker et al., 1999	Lyons et al., 2004	Gehner et al., 2006	Shahnoori 2009
Country	UK	Australia	UK	Queensland	Netherlands	Iran
Samples	100	713	100	200	31	75
Response	30 general contractors & c313 Project Management	200 comp. (include. 37 developers)	40 construct 12 oil companies	17 contract 11 consult 10 owners 6 developer	15 developers	11 consultant 15 contractors 17 developers 5 individuals
Using probability techniques	3%	Construct. sufficiently using checklists, brainstorming and flow charts	Expected monetary value method, break-even analysis and scenario analysis	Developers make least use	0 developer	Least use in Individuals and developers
Being familiar with techniques	44% (20% respectively)	Construction sector is Very good in relevant knowledge	Oil comp. very familiar, construction Not	Acceptable	Only partly for investment in financial, qualitative description…	Consultants (more) and contractors of Infrastructure very familiar
Using decision analysis	13%	Poor knowledge & use	Least use in construction, most use oil	Developers make least use	Some risk identifying techniques	Individuals & developers are not very familiar
Note	-	Inadequate application, skill, and knowledge, about risk management and lack of: understand its potential benefits	a lack of: -familiarity, -seeing the benefits, -reliable data, -expertise, & believing that fairly subject risks are better dealt	Intuitions, risk premium & quantitative analysis are used	Scenario or sensitivity analysis are the most used techniques	Except large projects, in most cases decisions are mainly relied on intuitions; probability analysis are relatively known

According to Table 6.4, the implementation of qualitative and quantitative techniques is not popular, even in the construction industry. However, quantitative techniques are applied to a significantly lesser extent than qualitative techniques. Nevertheless, in the construction firms employed in the structures for marine or oil industry, these applications have been seen relatively more often. Elsewhere the main reasons appear to be a lack of expertise, a lack of reliable data, a lack of understanding of the potential benefits, and the notion that subjective judgement is more suited to the decision problem (Gehner, 2008).

Similar studies, but with different details, show how these approaches have evolved differently in various countries. For example, Shen and Kwok (1999) state that due to the financial crisis of 1997, Value Management and Decision Analysis have gained increasing acceptance in the building and construction industry in Hong Kong. Examples provided by them include the 'Architectural Services Department, the Civil Engineering Department, the Mass Transport Railway Corporation, and the Kowloon Canton Railway Corporation'. From the study carried out by Shen and Chung (2002) the users had encountered problems pertaining to lack of active participation, insufficient time and lack of decision analysis information. Shen and Chung (2002) suggest that the application of information technologies such as the Decision Support System (GDSS also known as Group Decision Support System) has the potential to promote active participation, to encourage interaction and to facilitate decision analysis. According to DeSanctis et al. (1987), Thierauf (1989), and Aiken et al. (1995), this technique provides a better environment for decision-making by a group of people. The internal division of the GDSS technique is shown in Fig. 6.12.

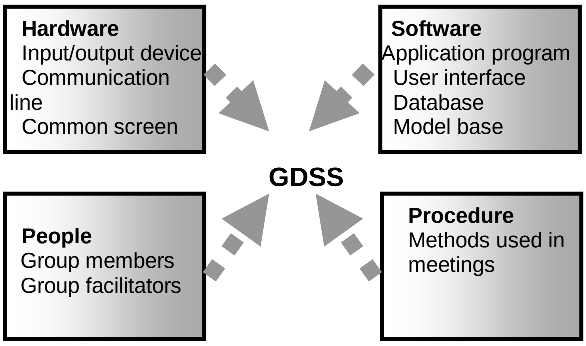


Figure 6.12. Internal organism of a GDSS (adapted from DeSanctis et al., 1987)

Shen et al. (2002) admit that technology, calculations, and cost analysis can translate ideas into proposed alternatives, improve decision analysis productivity, and reduce the time required for all of this. Besides, they can eliminate human error while improving the quality of decision analysis by improving information processing and management. They also noted that only big firms and international corporations use these techniques on a public scale, an observation, which corresponds with one of the findings in the current study.

More specifically about the design field, table 6.5 gives al summary of the outcomes of the survey carried out on the implementation of decision-making techniques in architectural design. The conclusion was that generally these techniques are not very often applied to design, even in complex situations. They tend not to be applied by individual designers, while at university level certain individuals may be aware of them but are not very familiar with the techniques. What emerges from the relevant interviews and questionnaires seems to be the lack of awareness and understanding of the qualities and effectiveness for decision-making and therefore for the design. A further factor may be the fear of being fenced in and of thus losing their design freedom at academic level; this group of interviewees is also inclined to find these applications contrary to art.

Table 6.5. Application of risk analysis in complex design

Groups / Divisions	Individual designers	Design corporations	Academic individuals (in the relevant design fields)
Nr. Samples	100	15	145(+20)
Nr. Responses	58	11	61
Being familiar with techniques	Poor	Poor	Acceptable
Using techniques	Poor	Poor	Poor
Notes	Older designers are mostly better qualified in the design field but they are zero or minimum familiar with techniques	In the field of civil engineering, they are rather familiar, while in architecture very few people know these	Civil engineers relatively know these, architect don't, few people in Urban planning In real estate and housing techniques are at least heard

Although systemisation was commonly recognised as being required in complex design situations, its application in practice was not stressed. It is still, however, applied more frequently than decision supporting techniques in complex design situations. However, compared with the dated literature (e.g. Felsen, 1975; Wideman, 1992; Grant, 1995; Roberts, 1999; Hamaker, 2006), a growing trend has been sensed, although the current application level is not significant. It can be concluded that at least at academic level, the value is tacitly appreciated, although such techniques have not been properly mastered and implemented. In higher education, a greater need to use modern methods was felt; this seems significant in participants engaged in practical and performance-related projects at the university. Thus implementing methods, which is critical to ensuring failure avoidance in the decision making stage of the SEP in a complex situation such as a SRH-SD, does not basically cause problems. However, the method ought to be suitable and it may also need to be reviewed and adjusted for particular cases.

Regarding the whole discussion, three main points, related to the phase of exploration, can be derived from this section. These are:

(i) there should be more emphasis on the importance of comprehensive information (required for decision-making),

(ii) modelling the information and processes is an appropriate approach prior and for decision-making in a SRH-SD,

(iii) the implementation of methods for decision-making and analysis techniques is very useful in a SRH-SD as a case of a complex situation

6.3.4. A case related application of techniques in decision making of the SEP

According to the outcomes of this research, to reduce the risk of SRH-SD failure, tools such as decision trees, influence diagrams, checklists and so on can easily be applied. The schemes shown in Fig. 6.13. provide examples of decision analysis techniques for a case of SRH-SD.

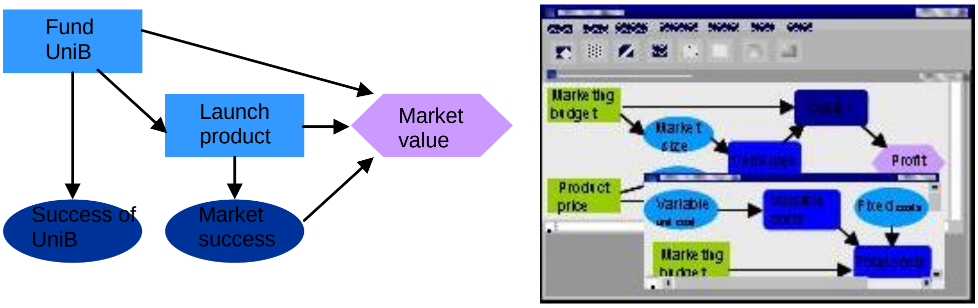


Figure 6.13 examples of influence diagram (individual & hierarchical) manual & digital (e.g. for SRH-SD in Bam on a product development level)

In order to draw accurate conclusions in a complex situation involving a new application such as the SRH-SD, methods such as the checklist method are now being directly used. Making use of flowcharts, decision trees, and the ensuing influence diagrams, are just some of the uncomplicated methods that can be adjusted to the SEP of a SRH-SD. Although with some methods, like the influence diagram, the complete sharing of information is not possible, they do provide a proper teamwork environment so that decisions can be made and optimum solutions found. However, due to the range of categories of information and the required related decisions in a SEP, methods such as flowcharts that are inherently sequential may not work with some categories of information. In such situations, influence diagrams may be suitable, as they can be created with many chance nodes pointing to primary decision nodes. Besides, the influence diagrams include cycles and circular paths between nodes.

In the case of the SEP in the SRH-SD, due to the influence of the two severe constraints that seismicity and desert conditions place on the entire design environment; the methods should be capable of more clearly demonstrating the variable dependencies. This is referred to as kinetic modelling (see e.g. Figure 6.14a, b, c, and d).

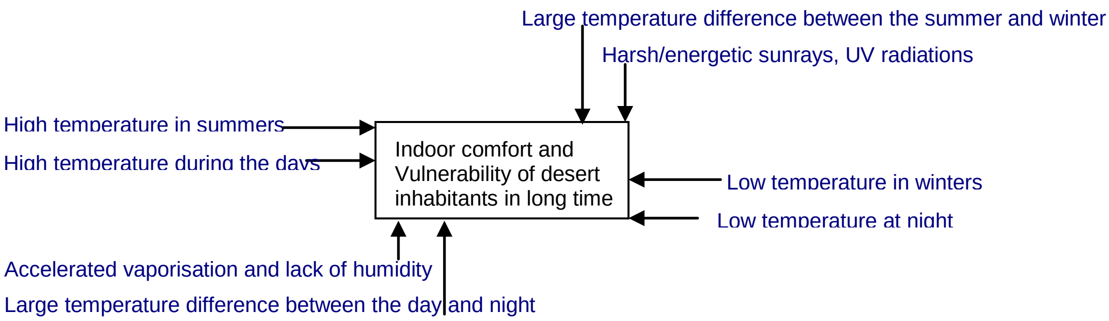


Figure 6.14a. Example of basic analysis of situation/information (influences of desert constraint) in a SRH-SD

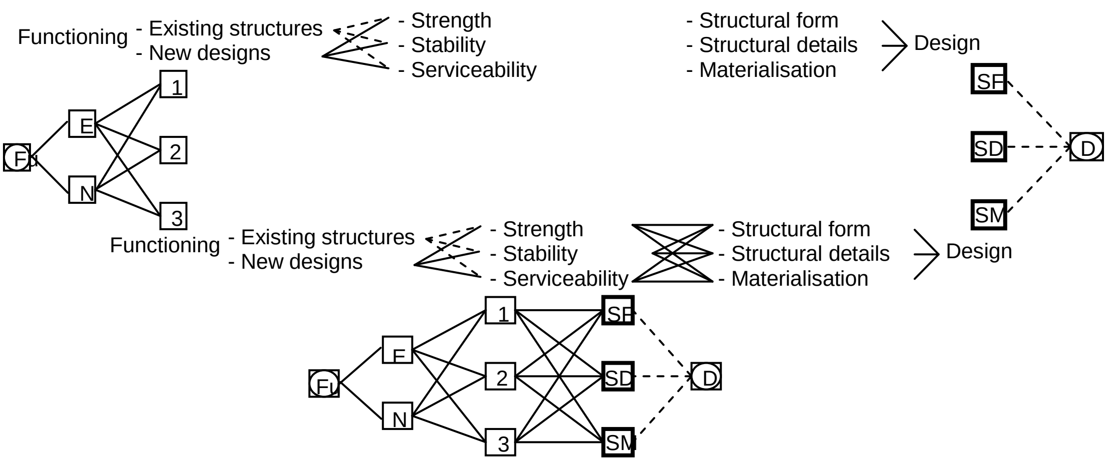


Figure 6.14b. Example of the steps in the analysing diagram (e.g. the first structural analysis stage before the influences of the second constraints of SRH-SD seismicity are inserted)

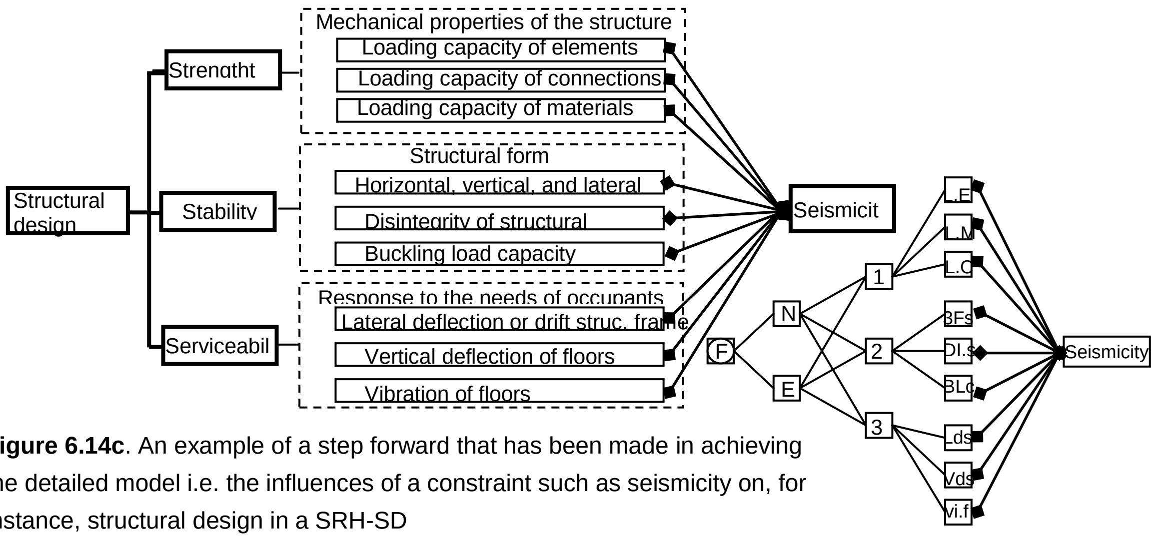
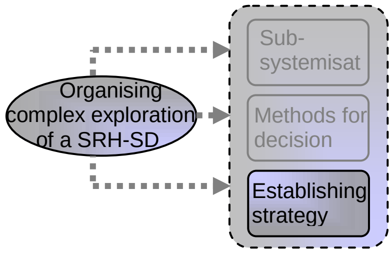


Figure 6.14c. An example of a step forward that has been made in achieving the detailed model i.e. the influences of a constraint such as seismicity on, for instance, structural design in a SRH-SD

Finally, the section 6.2 mentioned that every minor progress toward organising and systemisation within the SEP is a step forward. However, it may still be controversial when applied to reduce the risk of inappropriate decisions or unwanted design conclusion due to increased complexity in a SRH-SD.

6.4. Complexity and chaos



In a complex situation, the probability of chaos increases as the number of items involved and their interaction increase (Bakker, 2007). In order to avoid chaos in architectural design, integration remains a major issue (Shahnoori et al. 2010a). Manipulated systems are normally established to avoid chaos or to control the chaos (Ott, et al., 1990), either in the function or in the relationship, which again may end in functional disability (Grebogi et al., 1997). According to Bakker (2007), in order to control chaos, it is necessary to construct models that represent the complete behaviour of a system. Thus, when using a systematic approach to avoid chaos in a complex design situation, it is also helpful to arrange the subsystems (Kalay et al., 2003) inside the process model system. Nevertheless, the complexity that grows to an extreme extent in an SRH-SD may be more describable or controllable, but not through the mere application of one simple method.

Integration, especially at the stage of prioritisation and selection, is significant (De Vries, 1993). Directional leadership is very effective for creating an overall homogenous atmosphere to cover the multiple but organised segments of SEP of the SRH-SD. Similarly, in the definition provided by Carrara et al. (1991), we are told that when designing a new building the designer needs to begin with a general definition of the objectives he wishes to achieve, and to find a suitable design solution for the realisation of these objectives. In terms of the design task, these objectives should be formulated as testable, compatible, precise and analytically verifiable goals, although in practice this may seem impossible (Carrara et al., 1991). Hubers (2008) calls it a ‘leading strong idea’.

In conventional architectural design, designers often rely upon prototypical sets of objectives adapted from building codes, common practices, experience, and the ubiquitous ‘average occupant’ label (Carrara et al., 1991). All these points can be confirmed by referring to the study done by Gero (2000). From his point of view, design is generally ‘a goal-oriented, constrained, decision-making, exploration and learning activity that operates within a situation that depends on the designer’s perception of the situation, and results in the description of a future engineering system’. The greater the rational and scientific basis of this process is, the less likely it will be that any incorrect personal interpretations will influence it. The main point here is to lay down a general formula for this approach, making it less prone to personal misguidance, which is crucial in any SRH-SD situation. The target is to have a leading item/general goal that integrates all the elements and segments in the SRH-SD on a systematic basis

In a similar discussion on the requirement for this leading feature, Mintzberg (1991) shows a larger realisation of the complexity involved. He states that, in this complex world, organisation and a range of concepts are needed to cut through and illuminate particular aspects of that complexity. Of course, the starting point of these objectives is normally the pure goal of the client, which may change after the refinement and processing. However, these objectives can be conducted and directed by the designer in a larger frame of efficiency. It has been similarly stated in many other studies that the core of a technical design is reconstructed as a systematic transition from the client’s goal to a detailed description of a given artefact. Examples include Asimov (1962); French, (1999); Gero, (1990); Roozenburg et al., (1995); Pahl et al.,(1996); Porter (1998); De Ridder (2007); Lawson (2004); Eggert (2005), Cross (2006); Lawson (2006); Cross (2008). One way of applying this theory, in a SRH-SD, is by determining a leading issue, or general umbrella term: in this study that has been labelled the ‘main strategy’. This broad strategy supports all processes in the GPM system as well as in the subsystems, and creates a common inclusive direction (Porter, 1998). Therefore, the next section provides a short background about strategy.

6.4.1. Strategy as a sub-solution for the subsystem

The effectiveness and power currently offered by strategy has spread its applications throughout various domains, even in design. Strategy, as one of the supporting theories, guides design which is based on knowledge and rational practical implementation (Geschka et al., 1992). Clausewitz (1780-1831), one of the earliest major theorists and strategists, and the father of modern strategy (Ghyczy et al., 2001), says: 'Theory does not mean a "scaffold" supporting man in action or a "positive direction" for action. Theory rather means "an analytical investigation of the subject that leads to an exact knowledge"; and if brought to bear on the results of experiences, to a thorough familiarity with it' (Earle, 1973). Lample (2005) states that 'a strategy that is created by conscious design is deliberate, purposeful, and controlling'.

According to Lawson (2006), not all design objectives can be inserted into the decision-making, they need prioritisation. This prioritisation requires criteria. Although all objectives may seem logical and relevant, the selection between them differs from case to case. This selection is accordingly an 'unknown' measurement that is interpreted as the designer's goal (Porter, 1998; Mintzberg, 2000; Lawson, 2004) or the invisible goal. Roozenburg et al. (1995) call it 'the light of the aims' (that were set). However, a tiny sensitive issue makes it different from the known goal. The item known as 'goal' may differ from one project to another, whereas the general criteria for selection and prioritisation seem to be repeated in, or common to, several projects. Therefore, this virtual leader is slightly different from the known goal. According to the definition mentioned by Earle (1973) and Mintzberg (2005), these criteria of prioritisation and selection can similarly be referred to as 'strategy'. However, in some contemporary architectural design projects where the presence of this hidden general goal is sensed, it may not be acknowledged as 'strategy' as such.

In current conventional projects, strategy has been applied internally and to details, but not as the virtual umbrella and the purposeful sphere to lead the entire processes and segments in a single direction for a complex situation as the SRH-SD. The applied strategies normally relate to a particular part of the design, or a particular goal of the design. Whereas, the proposed position for the general strategy for this study is that it ought to guide the entire project in the required direction, but in an open field; thus its presence is invisible. Hence, this advantage makes it suitable to many fields and cases. However, it must be mentioned that so many gradual and historical changes in design could not have been expected in the past. Therefore, it is foreseeable that, in line with the rapidity of digitalisation of design on the one hand, and the involvement of humans in computerisation and systemisation on the other, 'omnipresent flexibility and freedom' in the design on the current scale may not be required in future.

6.4.2. Nature and implementation of strategy

A strategy is a set or plan of actions and activities to be carried out to reach a particular goal (Mintzberg et al., 2005). According to Steiner et al., (1977), strategy involves having an awareness of where you are going and how you intend to get there. The purpose is to ensure that activities remain realistic with respect to the constraints of time, budget, etc. within which the design team has to work. Similar to the history of design theories and new methodologies, the concern about modern strategy formulation and application emerged from the active decade of the 1960s (Mintzberg, 1991).

The mathematical or analytical reasoning of strategy is the logic for selecting (prioritising) the particular path (Porter, 1996). Therefore, a strategy is a well-considered plan of action for achieving a goal by means of an organised and facilitated method, which will – in turn – reduce the risk of failure (Ahlstrant et al., 2005). Thus, important matters when conceiving a strategy are to define the goal, sources, environment, and possibilities and so on (Badaracco, 1991). In this set of actions (details of a strategy), in addition to prioritisation, the settlement or arrangement of the segments is critical. Morgan (1989) refers to the differences in settlements as the differences in viewpoints between several people. For example, every single person who gets on in life is a strategist (Byrne, 2005; Steiner et al., 1997). Strategy is a product of the brain (Mintzberg et al., 2005). Therefore, advanced creative brains (Cooper, 1984) with appropriate scientific levels of knowledge (Collen et al., 1995), will probably invent better strategies (Cole, 1989). However, the main strength of a strategy is its capability to analyse (Mintzberg et al., 2005). Although a rational prioritisation is based on an appropriate analysis, which depends on comprehensive information (Porter, 1998), an initial idea is always required (Mintzberg, 2000).

The establishment of strategy in the field of architecture shows a major difference between the sectors of construction and design. In construction and management, strategy is discussed at quite some length (Langford et al., 2001; Bower, 2003; Phua, 2004; Morledge et al., 2006), while it is not very often properly applied in design.

As has already been seen in business applications (e.g., the marketing base, the customer base), architectural design needs to adjust its principles in a new way to cope with the complexity of modern enterprises (Beim et al., 2005). Technology transfer from other advanced technologies to the construction, although slowly applied, is greatly appreciated (Poelman, 2005). Similarly, this transfer needs to occur in design. Facilitating the design (i.e., also in practical cases) by means of modern developments in computer science and manufacturing provides evident advantages (Nonako et al. 1995). However, theoretical support is not yet being transferred on the same scale.

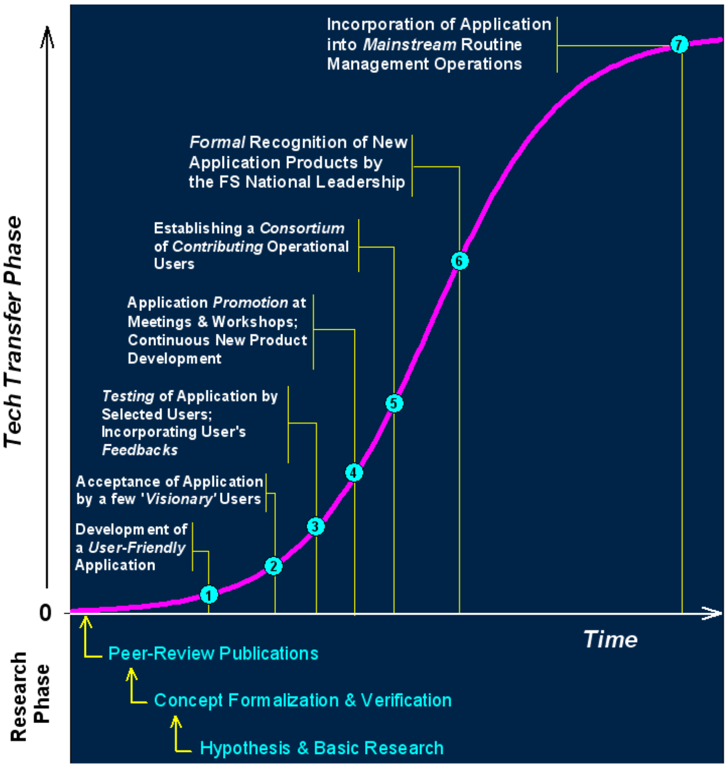


Figure 6.15. The relationship of the science technology transfer process to research (source: RMC, 2010)

Similarly, establishing strategy in architecture is not self-evident. Other fields, although different, also display some difficulties. For example, up to half of the strategy projects in trade and industry struggle with implementation issues (ZHW, 2005). According to Laporte (2001), ‘a grave flaw in current strategy implementation and formulation is the neglect of emotion’. However, Dalgic and

Leeuw (1994) state that although there is abundant literature on the definition of the topic, little academic research is available.

6. 4. 4. Establishing the strategy for a complex situation

According to Morgan (1989), the way a designer sees (i.e., understands, assumes, interprets the patterns, boundaries and constraints) the procedure and the design and planning segments in depth remains an individual strategy. Although this can cover a strategic planning which is a clearly structured and organised plan (Badaracco, 1991), it is nevertheless different from this. Thus, there is no contradiction between strategy and architectural design, which requires flexibility and freedom for creativity. The totality that Bandini (1997) generalises in order to show that 'design cannot be perceived as an organisable set of notions to be taught within recognisable patterns and hierarchies of complexity' is debatable. The reason is that being organised does not necessarily mean restrained and limited. First, strategy as it is introduced in this study is not a restrictive organised set or a restrained structure, especially with the insertion of artistic aspects and an appreciation of inspiration in the proposed design process (i.e. the GPM). Besides, modelling the relevant knowledge and using an appropriate method to organise a complex design (sub-)procedure provides opportunities as well as security for innovation (Lynn, 1998). De Vries (1993) also recommends this structuring for the integration of various disciplines into a multidisciplinary approach to complex design.

Successful strategies require a comprehensive analysis of the current and future situation of the subject (Porter, 1998). Visionaries have the great quality to be able to analyse the object while nurturing views on further steps. The visionary sees beyond the designs, plans, and positions of ordinary views. Therefore, a strategist is an analyst who has a wider frame around his capacity to foresee the future (Porter, 1998). However, prescriptive systematic planning and careful calculation, which may work in the military version of strategy, may reduce inspiration, insight and the creativity of the designer or leader (Leupen, 1997) in an architectural design.

Strategy may change over the course of time with regard to its arrangement, positioning, and the use of resources; it does not necessarily need to be replaced by a new strategy. This is in contrast to the view of Mintzberg et al. (2005), who mention the occasional need for an absence of strategy, such as, for example, when making a transition from an outdated strategy to a new and more viable one. Of course, this is the case with the current state of strategy application, which differs from the proposed large strategy and its definition in here. This is because currently applied strategies in designs cover only specific items of the design or particular directions for it. However, a strong inclusive structure with a high degree of flexibility ensures the adjustability of the strategy for the future and the changes that may occur. However, it remains independent because of the role of segments in the structure of a strategy.

Therefore, the strategy may change in either the structures or segments. For example, there is a strong probability that this change may occur when the goal changes, because the goal is crucial. In this case, a specific strategy with a particular structure may not fit other goals. This may also occur when the same goal needs to be reached when resources differ. Hence, analogous to what Mintzberg (2000) says, this misfit can be due to the nature of a strategic mindset.

The principle concept of strategy is based on stability (Mintzberg, 2005). Although a large part of strategy studies focus on change, some studies (e.g., Mintzberg et al., 2005; Porter; 1998; Hines, 1980) indicate contingency. For example, Mintzberg et al. (2005) state: 'Eventually every advantage of an established strategy becomes a liability.' Like theories, old strategies that are unused (due to their outdated settlements) could not survive the changes that have occurred in society and the entire environment (Badaracco, 1991). This is because, as it was previously indicated, strategy is not reality itself. When matching a theory with reality, there are always distortions of reality (Mintzberg et al., 2000). The more the basis of a strategy corresponds with reality, the greater the chance of success (Geschka et al., 1992), in addition, the theory or the strategy will endure longer.

With these, it may be said that strategy comprises adequate potential for application for leading the design in a demanding situation but on a larger and higher level. Therefore, the current study has set strategy as the main and the general leader to integrate all the design segments and processes in a complex situation as with a SRH-SD, especially for the SEP.

6.5. Towards practical solutions for avoiding chaos

Laporte (2001): *Energy is a key input in all human activities and its role in strategy-making should not be taken lightly.*

The general aim of this research is to focus on sustainability. This general goal has occasionally been implicitly indicated and has entered into the discussion. However, the present section explicitly discusses sustainability, which has been explored as an alternative strategy and as a leading factor in the entire design of sustainable housing in complex design situations in general. The aim is to conduct complex design on the basis of clearer vision in order to reduce the risk of chaos and the accompanying ultimate failure so as to prevent harmful consequences in the future (near or distant).

In the current case, as outlined previously, because of the scale of earthquakes and their consequences, plus the danger of desertification and the harsh circumstances in desert habitats the development of sustainability is significantly effective as a guiding principle. Every segment and move in the design and design processes, especially in the controversial phase of exploration, ought to lead to sustainability. Not all consequences of a design conclusion are known or predictable. While a conclusion may work in the short term, it may not work in the long term or it may cause environmental, social or economic losses or even disasters. To avoid this, selecting sustainability as a general leading strategy to cover all the sub-strategies in one main direction would be an appropriate approach. Because the design throughout the entire study concentrates on houses, repeating the ‘design of houses’ notion has been avoided and simplified to ‘design’.

6.5.1. Introduction to sustainability, SOS (Sustainability Otherwise Sacrifices)

The surface area of the Arctic Sea ice is 70% the size it was in 1870, which means it is shrinking rapidly (Durmisevic, 2006). Forestation is being lost at a rate of 10 million hectares a year (EPA, 2003) and official estimates in China show that ‘900 square miles (2,330 square kilometres) of land is turning into desert annually (Brown, 2001). Due to pollution, 17% of all living creatures in the seas, including millions of fish, are dying each year (Richard 2006). Between 1950 and 2000, the sea rose by 1.8 mm/year, while over the course of the current century a rate of 90 to 880 mm has been predicted (Tinto, 2009). Between 2003 and 2006, the number of dead zones (hypoxic or oxygen-deficient areas) increased from 149 to 200 (Nellmann et al., 2008).

These and many other similar phenomena are sensitive concerns that warn us about the future of our planet. Particularly, the construction industry, which is a very important contributor and actor, demands extra attention. According to the WCED book (1983) and the Brundtland Report (UN, 1987), the construction industry is an important contributor to environmental harm but it considerably contributes to the world’s economy. It contributes, on average, 10% to the GNP and accounts for about 50% of the capital investment in most countries (Durmisevic, 2006), while supporting 111 million employees worldwide (CICA, 2002). Nearly 50% of the earth's land has been transformed for human activities (SSD, 2002). The noticeable negative impacts include supply-chain issues and the effects of post-construction activities concerning the operating, maintenance, and reuse of buildings (CRISP, 1999). These show that the impact of the building construction sector is directly related to other major sectors such as mining, manufacturing, agriculture and transport.

According to the study carried out by Durmisevic (2006), apart from all the above-mentioned activities, this sector accounts for 50% of all global greenhouse-gas emissions (UNEP-IETC, 2002). Globally this makes it the largest single contributor to greenhouse-gas emissions (CIB, 1999). This brief overview is an urgent reminder of how damaged nature has become and a plea to speedily search for sustainable solutions. Although these notions started a long time ago, the process of finding appropriate solutions has been slow to catch on in the construction industry. The concerns about sustainability started with *Silent Spring* in 1962, and the Brundtland report (1987), which later attracted much attention within the construction industry. Progress is slow because 'sustainable development competes with many deeply entrenched values'. Buildings are taken down and promptly replaced by new ones, and building sites are subjected to continuous transformation (Durmisevic, 2006), all of which has environmental consequences. Furthermore, the dynamics and change that the building sector and especially the housing sector suffer (Habraken, 1998) creates a critical situation both for design and designers.

Figure 6.16. Demolition of the old building of the faculty of architecture, TU Delft, and the new campus

Much of the environmental damage caused by the construction industry also relates to design, either on a general level or on a detailed level during execution. From all these and the other relevant issues, it is obvious that sustainability needs to be recognised as an essential factor. It is much more than an imagined issue and a fashionable subject of discussion. In order to ensure the sustainability of a project it should be introduced right from the outset of any design process, and maintained until the end of the lifecycle of the targeted building or project.

Therefore, sustainability is a significant and appropriate overarching strategy (i.e., previously proposed solution), for conducting whole segments of the SEP, as well as the entire design in a complex situation such as a SRH-SD. This will be established through the following discussions.

6.5.2. Setting sustainability as an appropriate overall strategy

Two main issues relevant to the environment have been addressed in the discussion concerning the background. First, the environment is harmed by the negative impact of human activities. Secondly, the environment is also damaged by the inappropriate use or overuse of our natural resources. Each of these includes a large range of branches. Although the impact of human activity on the environment is a controversial subject, there is no doubt that natural resources have been overused. The huge technological advancements mainly derived from the industrial revolution were covered in a previous study (see also Shahnoori et al., 2007c). However, these advancements also have a dark side: mass production has resulted in mass consumption and mass disposal. Compared with the distant past, damage to the environment considerably increased during the industrial revolution. There was also a major increase following World War II, while the peak occurred in 1970 (Branvall et al., 2005). According to Cocks (2009), 'the world's average annual energy consumption per person is about 100 times higher than it was 2000 years ago, when there were only 200 million people in the world. Presently, there are more than 6 billion souls on the face of the earth.'


Figure 6.17. New York City 1936, by Albok, Tamiment library New York; Long Island (Andrew Cusack 2010)

Although sustainability as a global concern has only been an issue in the last three decades, the matter of the environment and human health has long been a topic of discussion (Benjamin Franklin, 1706-90). Nevertheless, the current wave of environmentally friendly activities, originates from Rachel Carson's previously mentioned book, the *Silent Spring* (1962). Worldwide public interest was aroused in 1972 with the UN conference on the Human Environment. In 1987, the WCED published the Brundtland Report. In 1992 there was the Earth Summit conference in Rio de Janeiro, and in 1997 the Kyoto Protocol was formulated followed by the World Summit for Sustainable Development that was held in Johannesburg in 2002 together with the slideshow presentation given by Al Gore in 2006 and his film "An Inconvenient Truth" . Of all of these, it is the Brundtland Report that has had the most significant, long-lasting effect.

According to the Brundtland Report (1987), sustainability means meeting the needs of the present without compromising the ability of future generations to meet their own requirements (Dobbelsteen, 2004). It was claimed in the Brundtland report that sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change become consistent with future as well as present needs. However, GSA-IWP (2003) claims that 'a guiding principle of sustainable design is to create places that are not only healthy and productive, but which also lift the human spirit. The premise is a simple one: healthy, happy people will be more productive and more engaged with their work and their organisation' and thus, obviously, with their home. Another point to emerge from the GSA-IWP study (2003) is that 'at the present time, we know much more about the environment and energy impacts of building design and operation than we do about the consequences for the building's inhabitants. We also know more about what causes illnesses and discomfort than we do about what lifts the spirits and morale', so that solutions are required.

The definition of sustainability in the Brundtland report encompasses the economic and social aspects of development. This large, inclusive definition can be translated into design. Although the potential of design is that it can greatly upgrade sustainability on a public level through art, as has been discussed, more criteria are required if chaos is to be avoided in a complex situation. On the other hand, architectural design, in its current state, is not an organised system but rather 'a creative chaos' (Patijn, 2010). The application and supervision of sustainability requires a rather concrete and descriptive position. This will not only involve securing sustainability on a larger scale and in a better way, but it will also prevent complex design from being lost in the chaos, thus assuring environmental concern in the present as well as in the future.

Evidence for the effectiveness and applicability of sustainability, as a general leading strategy, is provided by similar but lower-level applications. The strategy of energy saving in design has led, for example, to using passive systems and thus to lower energy consumption, consequently saving natural resources, while diminishing pollution. This approach (taking care of natural resources) is observable in various ways, for instance in the designing of affordable houses for rural India and using local technology for desert houses in Egypt. Most such strategies cover specific aspects of the design and guide them towards overall sustainability. In an extremely complex situation such as with the SRH-SD, the design requires more integrity, so that a general leader such as a strategy can bind all the segments in a general direction. If this general direction proves to be sustainability, then the design will already have prevented probable negative consequences. Nevertheless, it should be mentioned that although these solutions (i.e., establishing a general wide strategy for integrity, and establishing sustainability as the overarching strategy) are highly effective, they cannot guarantee the success of the ultimate design.

Therefore, the whole discussion on sustainability strategy can be concluded by referring to two groups of separate studies and integrating them to form an appropriate solution. In the first part, analogous to the study of Sioros (2000), Carmona (2001), Falconer et al. (2001), Gleiniger et al. (2008), this research proposes strategy but as a general leader for a complex design situation at a higher level. This is similar to a second group of studies such as those carried out by Sioros (2000), Sarkis (2001), Dobbelsteen (2004), Kibert (2005), Harvey et al. (2006), Eicker (2009), which incorporate sustainability in their design but only partially and on a lower level of scale. Instead, the current study proposes the involvement of sustainability at the design stage, again at a higher level (the wide perspective and in the long run). This includes environmental and social sustainability, which are essential for architectural design.

Arguably in the world of strategies sustainability has a broader frame of reference and may include many sub-systems and sub-strategies as well. This is analogous to the thinking of Mintzberg (2000) who writes of the: 'decomposition of the process of strategy turning it into a series of articulated steps, each to be carried out as specified and in sequence, will produce integrated strategies'. The sustainability strategy makes people look in an efficient way into the distant and long term future as well as at daily use and applications. Prioritisation in such a strategy means that not only the environment is a beneficiary at any one time, but also human society and the planet stand to benefit in the long run. It corresponds with Earle's (1971) general war strategy to battle with constraints, but in a way that future perspective, which is a highly serious factor in the analysis, is ensured. Unlike the technology strategy, the sustainability strategy does not have to contend with the conflict between globality and locality (if it is accepted that it can be applied to architectural design in a complex design situation).

Deduction and Confirmation; a case originated guideline

In the Sustainability Strategy, eco-efficiency, which was formerly the main aim of sustainability (Vale & Vale, 1991; Blaauw 1997; UN, 2002 ;…), is one of the key concerns. In this new approach, sustainability not only covers the basic needs but it also closely involves social and human well-being. Therefore, the SRH ought to envelop the relevant items of the major components of sustainability. Three general components of sustainability, the environment, society, and the economy can be divided into several items, an example of this division is shown in Fig. 6.18., and Table 6.6.

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Table 6.6. Major segments of each component of sustainability for The SRH-SD (e.g. for Bam)

	Sustainability	
Environment	**Society**	**Economy**
Air pollution	Local politics	Social desire
Water pollution	Global politics	Basic needs
Climate	Raw materials	Societal connectivity
Natural resources	Jobs	Life style
Energy	Market & profits	Nature
Waste		landscape

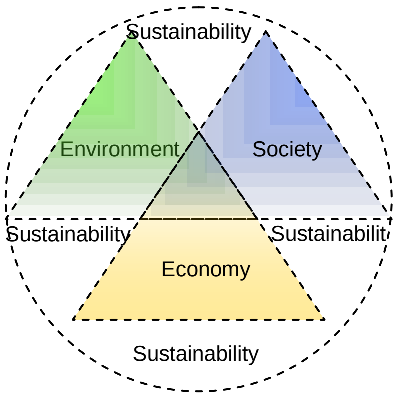


Figure 6.18. Elements of three components of sustainability

In this scheme and in the table, the item of each component may interact with the items of the other components, which should be taken into account in the SRH-SD. These interactions may therefore encompass various meanings; for instance in the scheme given in Fig 6.19. the extraction of raw material in its current state causes air pollution. The consequent negative influence of this pollution is that it affects health (i.e. a basic human requisite). Such an example of the interaction loops is also observable in the natural resources that provide raw materials. Regardless of how these resources are extracted, this may cause problems for the landscape (e.g. the brick industry near Istanbul, Bombay, and Mashhad …).

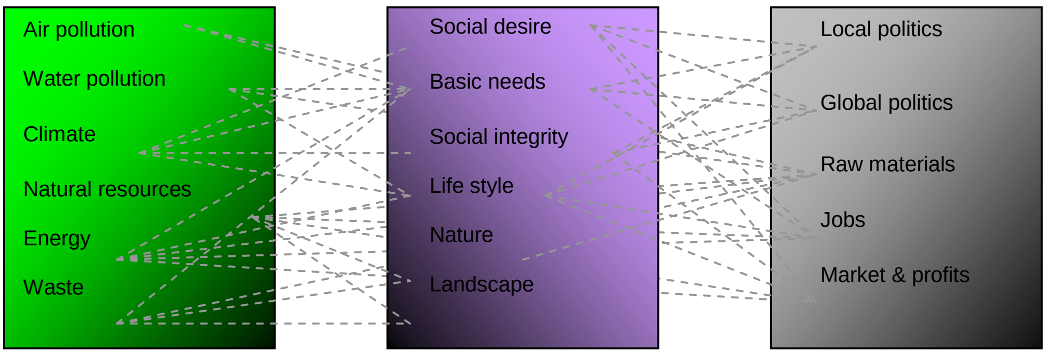


Figure 6.19. Interactions of elements in the three components of sustainability

6.6. Summary and Conclusions

- Classification and organising the exploration phase of a design is an appropriate approach for further systemisation in order to achieve a successful conclusion in a complex situation. However, the whole data, information, prioritisation, selection, and decision making for an architectural design complete/progress not only sequential but also parallel. It means that some parts related to the "exploration" will be achieved and corrected in conceptualisation phase or even in the later stages.

- The exploration phase is a vital design phase and one that is sensitive when arriving at successful design in complex situations. This importance is not only linked to its design role but also to critical steps such as prioritisation, selection, and decision-making. The outcomes of this phase are the theoretical outcomes of the design, which then become the bases for the conceptual design.

- To organise the exploration phase, the information can be categorised in three main groups of (i) investigation, (ii) analysis, (iii) theoretical hypothesis and synthesis. However, according to the major role of the exploration phase in the conclusion of a complex design, extra emphasises and connections to other phases of the design are required. These relationships and connections, similar to the GPM, are shown by iterative feedback loops (see the scheme in fig 6.20).

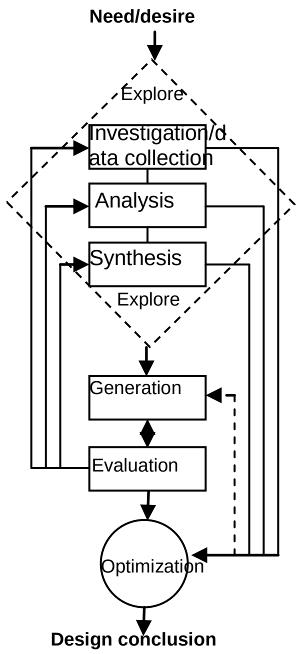


Figure 6.20. The basic model for modelling the architectural design processes in a SRH-SD

- The GPM can be one step further detailed to decline the risk of failure on the stage of exploration. For organising the actions and steps of the sub-system, every phase of a design process of a GPM is assumed and modelled as a subsystem. In such modelling the process inside the SEP, as a controversial phase of a GPM, are classifiable in a more detailed organisations. For which the main relationships are shown in the diagram of fig 6. 21.

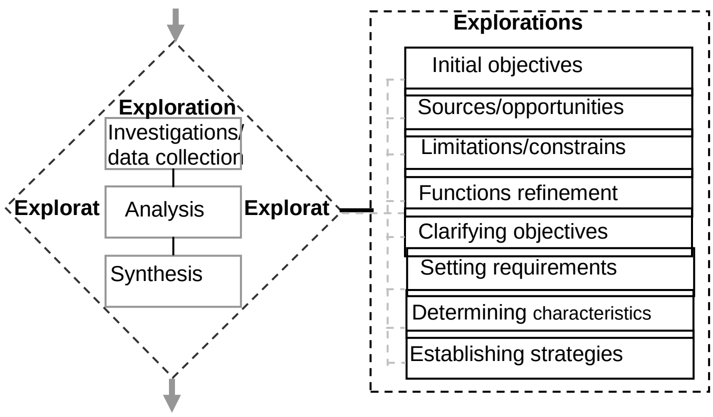


Figure 6.21. Detailed stages of the exploration phase of the GPM

- Although methods are not very often applied before the conceptual design stage, a growing trend towards modern techniques is being recognised by most experts. It is more apparent in the performance side than in relation to design; in design it can be seen that higher educated experts seem open to admitting and accepting the efficiency of these techniques, or to transferring techniques from other domains.

- Decision trees, probability analysis, and therefore also, the matrix or flowcharts, influence diagrams, checklists, and many of other decision-making techniques are useful for transferring and adjusting architectural design. These techniques are significantly effective in a complex situation such as a SRH-SD where they can help in the avoidance of chaos and failure.

- Have a conducting flag such as a general organization acting as an umbrella organization to control the whole design environment, segments, domains, disciplines, and criteria with a common goal so that the matter of dealing with the complexity can be eased.

- Economic, energy saving, and technology are strong strategies for a complex design situation (e.g. the reconstruction of desert houses after an earthquake). However, the consequences of the design solution may have a broader impact (i.e. global) and a longer term effect (e.g. application in a desert environment). Sustainability as an open strategy and the umbrella solution would be a modern solution to the present situation in which complex design has to be guided, also in the long run, and its efficiency could be time-independently significant. In this way the possible unpredicted harmful consequences of a design will be considerably reduced.

- The reconstruction of houses is multi-disciplinary; therefore, the effects and consequences of this may cover a larger domain than only an individual house. Thus, sustainability in such reconstruction depends on the sustainability of the design conclusion at different levels of urban, building and materials use over a period of about 50 years. Therefore, sustainability will be considered/measured for such a period. The idea is to count it for every 5 years until the end of the expected 50 years. These are ingredients of the sustainability strategy, which can be expressed in the following equation (e.g. Su= Su0+ Su5+ Su10+…+Su50). Thus:

$$Su = \sum_{i=0}^{10} S_{5i}$$

Thus:

$$Ss = \sum_{i=0}^{10} S_{5i} + Sb + Sm$$

Ss = Sustainability of the design for reconstruction of houses (=sustainable strategy)
Su = Sustainability of the design conclusion on urban level
Sb = Sustainability of the building, designed for the reconstruction
Sm = Sustainability of the main materials, designed for the reconstruction.

- Because of the openness, coverage, and comprehensiveness of the strategy described it is called an Inclusive Sustainability Strategy or ISS. The practical outcomes of these strategies are transferable in a system as a criterion for sustainability in the reconstruction of houses. Regarding the global study, which is also locally applicable, this system can be called a Glocal Sustainable System or GSS.

- If the design processes and segments in a complex situation are formulated as a system, the main interrelationship factor between the design elements for the SRH-SD will be sustainability.

- From the discussion put forward in this paper that is based on the sustainability strategy, the most directly relevant groups of items to the Sustainable Reconstruction of Houses in a Seismic Desert have been given. As an example of a possible checklist, these items have been summarised in Table 6.7. This can act as a basic and general checklist to achieve detailed checklists for either the design or the performance of the SRH-SD.

Table 6.7. Emphasised objectives for a sustainable reconstruction of houses in a seismic desert

Target	Possible Effects	Aim
Air	Co2 per tonne Other toxics	Reduction of co2 pollution Reduction of other toxics
Water	Water required /tonne Sewage per tonne Water pollution Desertification	Reduction of usage Reduction of pollution Avoiding desertification (protecting available resources)
Surrounding	Hazardous waste/ tonne Non-hazardous waste/tonne Noise pollution Land degradation & floating Heat islands &Desertification	Avoiding noisy uncomfortable surround Avoiding land degradation Reduction of waste dispersion Avoiding toxic waste on arable lands Greening, locally adoptable items
Energy	Various environmental harms	Enlarging use of Clean energy Societal adaptation, saving energy Prioritising passive systems
Natural resources	Misuse or overuse Depletion of resources	Optimising use scale Optimising extraction & production Recycling and reuse of materials Durable buildings & materials
Climatic comfort	Missing Indoor comfort Distraction of outdoor Un-satisfaction=Desertification	Relief from hot summer days Avoiding cold winter days Avoiding dry in &outdoor environment Boosting agriculture
Social comfort	Undesirability/economic loss Societal miss-match Leaving the desert=desertification	Healthy houses Boosting durability safety & security Boosting agriculture
Market and profit	Economic losses Financial disability Crises for jobs Leaving desert=desertification	Flexibility of houses (components…) Healthy community/urban area Avoiding crime Job opportunities Boosting agriculture

- An example of a decision analysis method, similar to an influence diagram from the decision tree (specifically applied at the step of decision making) for a SRH-SD is demonstrated in fig 6.22. The original decision tree and this influence diagram are case oriented, and may differ from case to case. The scheme in the figure is a model for the final phase of materialisation of the structure of the house in a SRH-SD for the city of Bam.

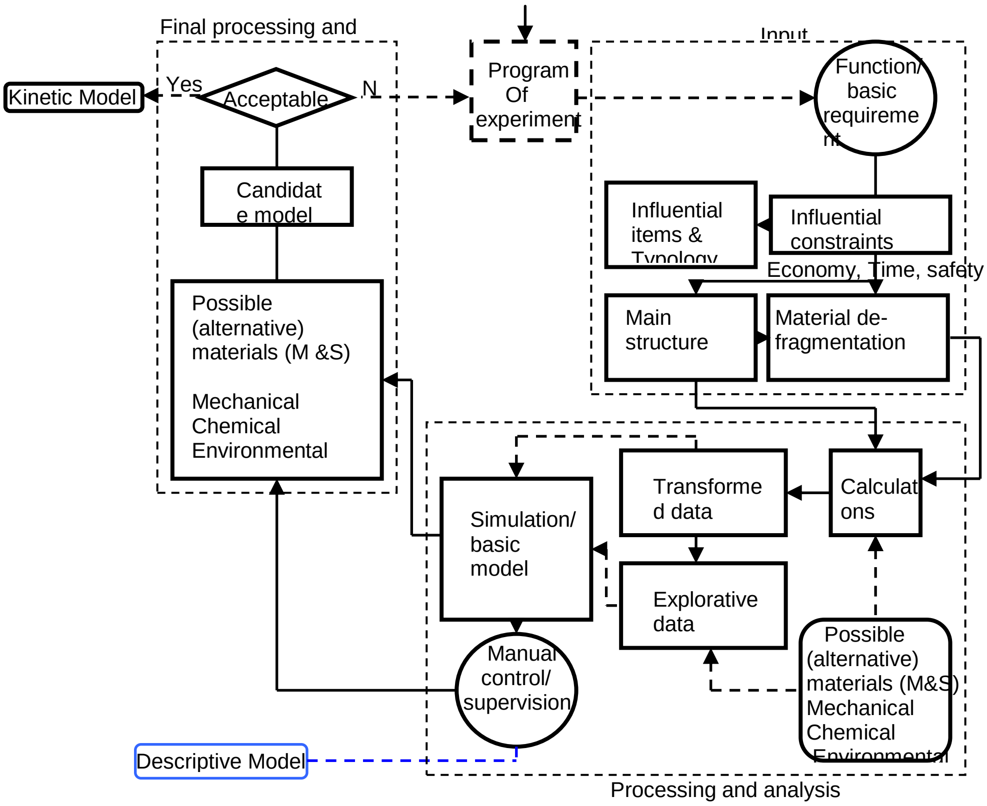


Figure 6.22. Samples of a diagram of decision analysis on the second scale of materialisation of a SRH-SD

Hence, an example of a decision tree on the product level, only for realising the selected type of products for the structural elements of the SRH-SD in Bam, is shown in the scheme of fig. 6.23

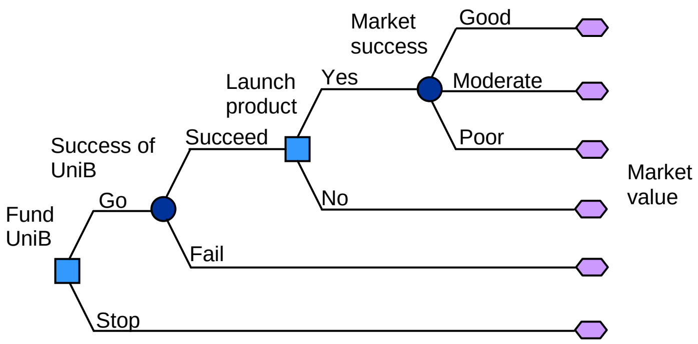


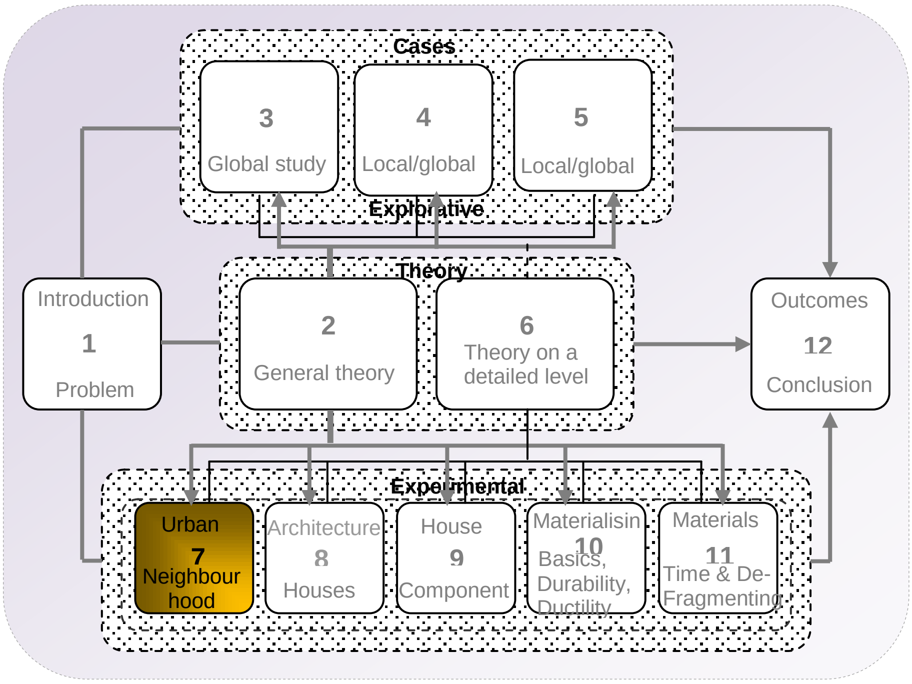
Figure 6.23. Example of a decision tree for a product development scale for a SRH-SD in Bam

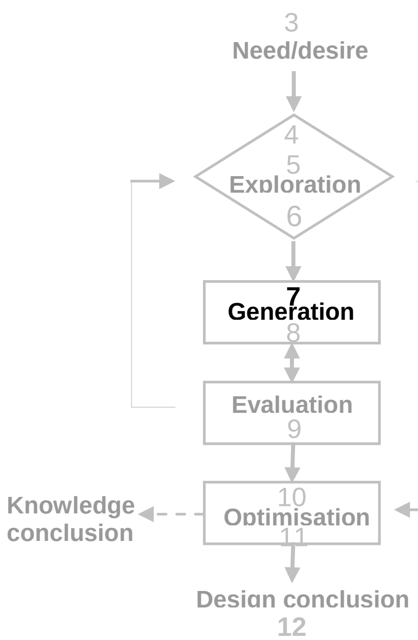
The decision analysis diagrams provided in this research are called SRH-SD diagrams, examples of which are shown throughout the current chapter. Of course, these diagrams are provided on three levels of Urban, Building, and materials, as three main categories of the groups of the diagrams (see also Shahnoori et al. 2011).

Finally, a case of how the SWOT technique can be used to make decisions in complex situations, such as with a SRH-SD, is shown in Table 6.8, which shows the SWOT analysis that was used for house reconstruction for the case of Bam. .

Table 6.8. Example of a SWOT analysis for a SRH-SD (e.g. the industrialisation of the SRH in Bam)

	SWOT analysis for industrialisation of buildings in a SRH-SD (e.g. in Bam)
Strength	- Quality control on material, construction components, structural element… - Design revaluation before insitu performance - Long un economic benefits - Energy saving/controlling - Optimisation of depletion of natural resources - Controlling and conducting waste dispersion - Profitable - Growing - Servicing and Repairing the products instead of (demolition of) the entire buildings - Transportation related costs and environmental aspects
Weakness	Short time economic loss Labour adaptation is required Technology adjustment is required Costly prototyping Short time competitive vulnerability Sales channels
Opportunity	- Mass construction - New markets - Regulations and modernisation regarding the environmental aspects - Technology development - Professionalisation of construction - Introduction of building elements as products - New complementary market - Sales - New investing positions
Threat	Loosing market Economic loss Political issues Short time job market Education of labour Localisation versus globalisation


Cases
3
Global study
4
Local/global
5
Local/global
Explorative
Theory
Introduction
1
Problem
2
General theory
6
Theory on a detailed level
Outcomes
12
Conclusion
Experimental
Urban
7
Neighbour hood
Architecture
8
Houses
House
9
Component
Materialisin
10
Basics, Durability,
Materials
11
Time & De-Fragmenting


3
Need/desire
4
5
Exploration
6
7
Generation
8
Evaluation
9
Knowledge conclusion
10
Optimisation
11
Design conclusion
12

CHAPTER 7

GENERATION: INTEGRATION AS A STRATEGIC SOLUTION, DESIGN IN ACTION ON THE URBAN LEVEL

The subject of this chapter is the generation phase of the GPM (Glocal Process Model) or its conceptualisation phase in a complex design. The result of the generation phase on the one hand is providing the basic concept for the design conclusion and on the other an enhancement, or even a rectification of the theoretical outcomes of the design. Apart from acting properly in the design process, an internal organisation and taxonomy is also provided for each phase of the GPM. For the generation phase, this organisation is in line with the hierarchy in the field of architecture for design integration. This is often classified as a macro-, meso-, and micro-level of design. Acting in architectural design is normally in one of the two general ways, i.e. top-down or bottom-up. In either of these, the macro-level is always the larger view, which here includes urban planning and neighbourhood design. The meso-level will then include building design. Finally, the micro-level comprises detailed design and materialisation (i.e. chapter 9, 10, and 11). These are applied to the Sustainable Reconstruction of Houses in a Seismic Desert (SRH-SD) town.

According to the theory developed in the previous chapter, the strategy for sustainability is the leading element, which integrally binds the design domains and segments. Due to the variety of the subjects and the argumentations, the generation phase was divided into two chapters. Urban, district, and neighbourhood planning and design are dealt with in this chapter, while building design is the subject of the next. The reconstruction on urban level will be discussed by means of cases in the desert, after a short background, which also reviews the main items of sustainability for the SRH-SD. After this, the type of influences on the urban level will be discussed with reference to the cases. Secondly, these will be analysed; outcomes will be incorporated as background knowledge for an action in the practical planning and design. Proposals will be shown through examples within the cases that also include sample criteria and a checklist for the urban level of the SRH-SD.

7.1. Introduction

Schumpeter: Innovation is a creative destruction (Hugill, 2003)

According to the GPM, after a successful exploration, the design procedure can propose appropriate alternative solutions. Based on the arguments from Chapter 2, for a SRH-SD 'generation' refers to the phase of creating design concepts. Therefore, it is called the core of design (Schön, 1983; Simon, 1996; French, 1999; Cross, 2007). The conceptual design is the practical phase for a design process using case studies. This chapter concentrates mainly on conceptualising the Sustainable Reconstruction of Houses in a Seismic Desert (SRH-SD) context on the urban, district and neighbourhood scale. The reasons for taking sustainability as a general leader for design were outlined in the previous chapter.

Sustainability is not achievable unless by it occurs on the basis of acting locally for global impact, meaning that the involvement of all individuals, institutions, politicians, and governments is required (Dobbelsteen, 2004). On a public level, although with different names, it has been a controversial subject for some three decades (e.g. Munro et al., 1987; Breheny, 1992; Rotmans, 1994; Yeang, 1999; Duijvestein et al, 2002; Dobbelsteen, 2004; Frey et al., 2007), starting with the introduction of sustainable development. In theory, the background of sustainable development relates to the former theories for development. According to Stephen (2003), “the 1950s and 1960s were the days of grand development theories all applied at the macro-scale (country, region). For example, based on the modernisation theory, the green revolution occurred in Asia. Starting from 1970s, theories were transferred into the age of ‘micro-intervention’ in developments of the 1980s and 1990s. However, in the 1980s, the concept of ‘sustainable development’ (Brundtland et al., 1987) succeeded in combining both macro- and micro-perspectives.”

The concept of sustainable development is based on a comprehensive theory that involves not only organisations, groups and governments but also individuals. Stephen (2003) notes ”… it’s not difficult to see how the all-encompassing nature of Sustainable Development – multi-scale, multi-disciplinary, multi-perspective, multi-definition – has ensured that it is perhaps the ultimate culmination to development theories”. Garcia et al. (2000) also indicate that Sustainable Development is much more than ‘development’ and ‘sustainability’. This is similar to the approach of the current study in developing the sustainability strategy as an overarching guide, which comprises sub-strategies on smaller scales of the design and planning. Because of its multi-scale perspective, the theory of sustainable development is adjustable in architectural design, which starts with the higher level of urbanism (i.e., macro-level), and goes down into a smaller scale of buildings (meso-level), and materials (micro-level). Based on the latter statement and taking a similar approach to the study of Stephen (2003) and Elkington (1994), the SRH-SD can be demonstrated for the field of architectural design according to the scheme in Figure 7.1.

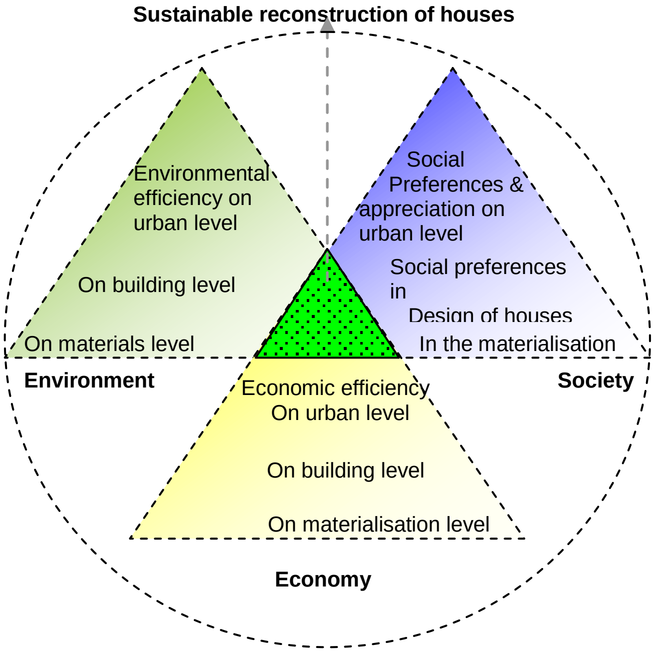


Figure 7.1. Sustainability framework for a complex situation as a SRH-SD

Walsh (2001) also defines sustainability as an integration of economic, social, and environmental policies ‘to ensure a better quality of life for everybody now and for generations to come’. One of the key objectives is the prudent and effective use of resources. For example, the UK currently uses approximately 10 tonnes of raw material to make 1 tonne of product. Although it is not sustainable to continue at this rate, it is not the only issue. It is not simply a matter of resource depletion, as alternatives can often be found. It also concerns the cumulative impact of waste products on the environment, as polluting emissions or as materials going to landfills (Walsh, 2001; Hillary 2001). These issues are critical in a demanding and complex situation; therefore, in such situations designing within the frame of sustainability is crucial.

In order to enlarge the implementation of design solutions for a complex situation to a public scale, the provision of simple solutions may be helpful (Shahnoori et al., 2007; Langenbach, 2008). It was previously stated that, in a design that is potentially complex, design constraints increase the complexity, and the potential for complications. This situation may even encompass a tacit failure in the future, or at least inadequacy. A relevant case of such a risky situation is a SRH-SD, which is forced by seismicity and a desert circumstance.

With the involvement of two constraints, a SRH-SD is a highly demanding task. Some seismic desert areas may pose particular local conditions as well, which make such design tasks extremely complex. As it was mentioned in Chapters 2, 3 and 4, the method that has always been used in this study is a combination of top-down and bottom-up. In this way, preparation for the multidisciplinary design starts on the urban level of design. However, it does not mean that everything about the urbanism or any other relevant item is finished at this stage. The process includes iterative loops, because all levels are completed gradually and in accordance with the others. To complete the work at one level of design, the designer may have to look back several times (Schön, 1967; Leupen et al., 2005/1997; Lawson, 2006; Shahnoori et al., 2010a) and occasionally even complete parallel levels. The integration and efficiency of the design solutions on various levels can be achieved by the Inclusive Sustainability Strategy (ISS), which was discussed in previous chapter.

7.2. Problems in generating solutions for urban habitats in a SRH-SD

It was already indicated that alternative systems for houses cannot be entirely separated from the context or the higher level of urbanism. Since a city is large enough to cover many relevant items and sufficiently limited to enable a direct link of issues to houses, it is an appropriate context to start the analysis of reconstruction on the urban level.

The word 'city' is the origin of the word 'civilisation' (Morris, 1976), so that originally civilisation was the first impression of an urban habitat. In addition to Durant (1997) and Bertoline et al. (2002), Van Aken (2005) also claims that design is as old as modern humankind is. Both Morris (1974) and Broadbent (1990/2005) distinguish two different types of cities. Firstly, there are the organic or informal cities that have developed naturally (e.g. figure 7.2). This growth was directed by natural boundaries, such as rivers, mountains, or fortifications.

Figure 7.2. Bushehr limited by the Persian Gulf, and Zanzibar Stone (source: IMO, and Zanzibarquest, 2009)

Secondly, the authors mention the artificial or formal cities. For these cities, the structure of the city was planned before the houses, so they are built according to a master plan. The history known of informal or organic cities goes back to the time the first colonies of humankind were created (Morris 1996). Morris refers to Chatal Huyuk (indicating also Harappa in the Sindh Valley and Mohenjo-Daro at the River Indus), while Broadbent refers to Jericho near the river Jordan (7000 BC) as the earliest known city. For the origin of formal cities, Broadbent mentions the straight streets and crossings of Babylon. Nebuchadnezzar created this city between 1126 and 1105 BC (Nemat-Nejad, 1998), but according to Broadbent, it was planned earlier. Morris, along with Strauss (1958), refers to the era of Hippodamus, between 498-408 BC. Even though older cities are known that have some planning and organisation on other levels, such as irrigation and centralisation as applied in central Mesopotamia (between Tigris and Euphrates) in 6000 BC, there are no scientific sources that view these as the first formal cities (Broadbent, 2005).

Figure 7.3. Mari in upper Mesopotamia, and Ur, the capital of Mesopotamia (Balugh, and Crystalink 2010)

The current state of cities and the consequences of solutions

Twenty-five centuries ago, Aristotle referred to the city as 'built politics'. As a result of the Industrial Revolution, "in 1990 cities emerge as the most complicated dynamic ecosystems, the only human ones, open, dependent, and vulnerable" (Mega et al., 1998). In the transition of the old traditional city, "with its physical, institutional and sociological entities", to the new world city, it changed into the metropolis of the mid-20th century "dominated by a centre-periphery morphology". Referring to Aristotle's definition, politics is faced with dynamic, shifting challenges (EC, 1996a; EF, 1997a, b). In the 21st century, the creation and distribution of urban wealth and inequality became a source of unsustainable lifestyle and an obstacle to cultural change (Mega et al., 1998). One of the most important consequences is the modern form of poverty, including fuel poverty. Of other consequences, indicated also by EF (1997b) and EC (1997b), is the 'Martyr City', a symbol of a distressed habitat, or 'Urban Genocide' (Mega et al., 1998). Hence, globalisation as a more recently emerging issue has initiated new challenges (Harvey, 1990; Sassen, 1994; Bogess, 2000; Marcus Miller et al., 2000; Sassen, 2002; Taylor, 2004).

The suggestion by Heavy (1991) to meet these challenges is "to strengthen the social places". In this situation, one of the most important potentials for cities is to act as a 'political institution' able to create democratic spaces between the worldly economic macro-regulations and the micro-regulations of the local community (EF, 1997). As a positive reaction, the concerns of sustainability seem to indicate a way to avoid the unwanted consequences of modern lifestyle and technology (Shahnoori et al., 2010b). Mega et al. (1998) define sustainability as "equity and harmony extended into the future, a careful journey without an end-point, a continuous striving for the harmonious co-evolution of environmental, economic, and socio-cultural goals". Similarly, a very important outline in this study (i.e. in the Glocal system) changes the current set up and hierarchy of the components of sustainability for the SRH-SD, which was discussed in chapter 4.

Houses are not independent individual buildings. They are members of the neighbourhood system that is a part of the district system and an element of the larger system of the city. The larger system, or the city, is an organic system in the sense that a city is a composition of humans, natural and manmade environment, and the relationship between the human and these environments (Shieh, 2000). Therefore, the optimisation of one of these interdependent systems and sub-systems is not independently achievable. Thus, the local conditions of a city are very important to the design for reconstruction of houses (Shahnoori et al., 2010b). Hence, the city, its districts, neighbourhoods, and the streets are of important components of sustainability of a house (Shahnoori et al. 2007d). Especially in old desert towns, the context of the house is very important for the lives of the inhabitants (Shahnoori, 2005; Shahnoori et al. 2010a).

To explore the local conditions, seismic desert areas are the subject, either in planning and design or in the construction and performance. Therefore, significant items concerning sustainability and seismicity in a desert city will be discussed. In this regard, water is a crucial element in deserts, which will be followed by discussions about earthquakes in urban areas.

7.3. Generation for dealing with seismicity in a desert habitat

An urban habitat involves a mutual relationship with the lives of the inhabitants. On the one hand, a city as a system is responsible for providing an appropriate structure and environment for its internal elements. On the other hand, it needs to function properly within the structure and environment of the greater system of the region or country. Therefore, it is not an independent closed system, but is open and dependent on internal elements and the external environment and structure. A city is a dynamic and living system. Therefore, understanding its situation and the local conditions is crucial. For a SRH in a seismic desert context, such aspects are critically influential.

7.3.1. Neighbourhoods and urban elements in a seismic desert environment

According to Pyper (2000), the term 'desert' evokes images of an inhospitable wilderness, hot, dry, and dusty. Because of the harsh climate in a desert environment, buildings, neighbourhoods, streets etc., as elements of the city system, have to be well adjusted. However, in most of the old cities, this adjustment traditionally occurred in a sustainable way, whereas many of newly developed habitats rely on extra energy. This point was thoroughly discussed in Chapter 5, where the similarities and differences of urban structures were discussed as well. Due to different cultural and social backgrounds, urban patterns may vary quite extensively in similar situations, while the same impulse may cause a similar pattern in two distant habitats. For example, in the desert cities of Yazd and Bam, the urban tissue is dense, and buildings have been similarly materialised. However, the urban patterns and details differ. For instance, to cope with seismicity in the city of Yazd there are strong structures for buildings of houses. In Bam, in addition to the plan configuration, heavy supports and reinforcement of construction materials form the method of individually dealing with seismicity. Studying Bam reveals a surprising point, which is that seismicity was barely addressed in this ancient city, where details at the building and urban level indicate the sophisticated skills possessed by the local craftsmen or artisans. The reason found was that no strong earthquakes had been recorded, although the region had always been seismically active (Zare, 2004). The 2500-year-old citadel also illustrates this. Furthermore, the period between any recorded earthquakes spanned centuries (ICHO, 2004), which can again be seen in the destruction patterns of the citadel (Mohajery, 2005), as the oldest artefact in the area. The third reason is a societal one, and relates to the lifestyle of Bami people, which hugely differs from that in Yazd. Yazd has grown and developed gradually, with a harmonic natural growth, while Bam is a remote city that has lost its original population. This makes the former more protective towards its assets, and less amenable to change. Nevertheless, due to governmental pressure in the past and the significant trend of younger generations, changes have taken place everywhere, even in Yazd (Vaez, 2004).

These examples show the crucial dependence of the system of a city on local conditions, both natural and societal.

7.3.2. An overview of the reconstruction of the desert city of Bam

A reconstruction option (for the site plan) after severe destruction, at the urban level, is to move the entire city to the best possible alternative place. Economically it will be the best option if the remaining properties are not worth much and if safer places for future use are available. For the city of Bam, latitude 29°6'38''; longitude 58°21'42'', an appropriate alternative could be to move further westward, where plenty of water resources are available, while being reasonably nearby. Hence, the organic growth of the city was also towards the west before the earthquake. The destruction of houses, determined by their distance to the fault located on the eastern boundary of the city, further boosts this alternative. However, *in-situ* research by means of questionnaires and interviews has indicated that this is not an option for Bam. As shown in Chapter 5, people like their hometown; they call the citadel 'our citadel', and most preferred to rebuild their homes on their own sites (see also Shahnoori et al., 2007e).

Therefore, a better alternative will be a gradual evacuation of the houses from the east to the west. Although houses need to be seismically resistant, according to the local regulations they are not counted as important buildings, so no substantial investment in earthquake-resistant measures can be expected. Instead, to use the entire local potential, the east side is a good location for industries that are financially capable to boost the buildings' structure to withstand earthquakes. An example of alternative development of Bam can be sketched as is shown in the Figure 7.4.

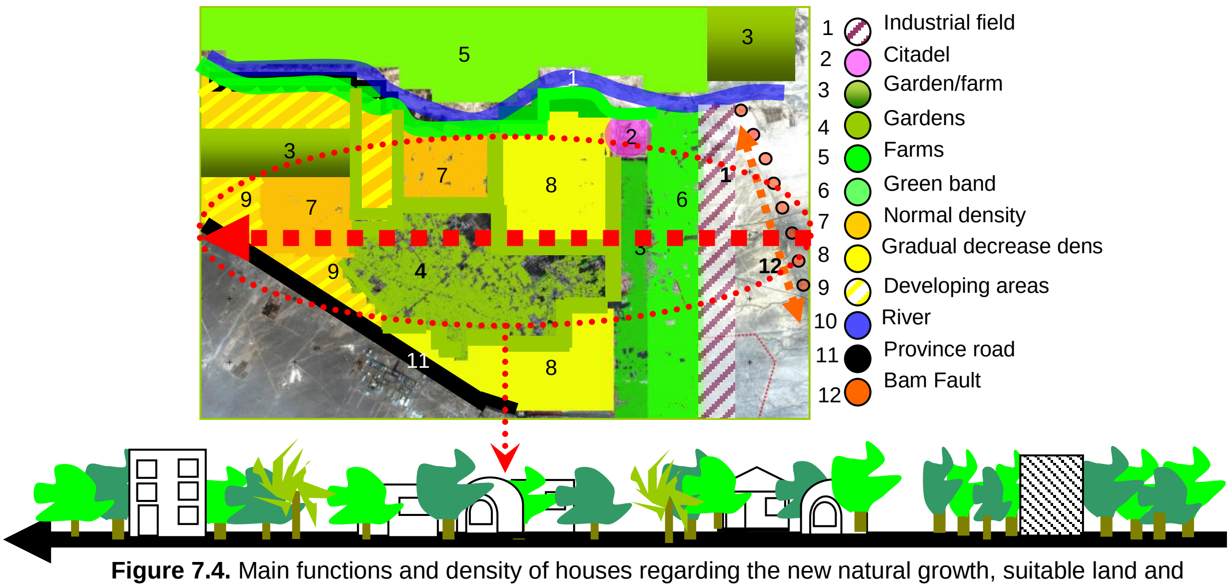


Figure 7.4. Main functions and density of houses regarding the new natural growth, suitable land and water availability, plus the level of seismicity

For both the future development and distance from the fault, it is very important to enhance the urban structure, safety and shelter to cope with the next predicted earthquake (Eshghi et al., 2003; Zare, 2004). Therefore, public places need to be adequately and appropriately dispersed throughout the city as well, and they need to be particularly equipped for emergency shelter. A conflict between solutions for seismicity and the desert situation also occurs in the sheltering. In designing a neighbourhood prepared for earthquakes, the general assumption is that streets need to be wide. This is either for rescuing the injured people and supplying emergency aid, or for clearing the rubble from the area. However, by tradition this is not appropriate for a desert district.

Because a desert environment has deep particular effects on urban fabrics, the environment of the desert city of Bam as a case discussed in the next section.

7.3.3. Desert climate and urban patterns

Streets are important infrastructures of cities in general. Sustainable reconstruction involves sustainability of the surroundings and the streets. The greater the importance of the car in a society, the more significant is the role of these infrastructures. In the old days, the streets were narrow and paved by earthen materials, which were compatible with a desert climate. This was primarily due to insecurity in desert cities. The narrow streets, which were shaded by two tall adjacent walls, also offered shelter to the passers-by from the intense sunrays. Nowadays streets are mostly covered with black asphalt because of its economic and technical advantages for transportation, but this is not advantageous for balancing the climate in the neighbourhood. Especially during the hot days of the desert summer, the streets should not contribute extra heat to the environment. The additional heat absorbed and radiated from asphalt in wide streets currently is a considerable problem (ASU, 2006). In some desert cities, such as in downtown Phoenix, Arizona, where several wide asphalt streets intersect nearby public spaces, this has also been problematic. It was already mentioned that the energy balance of a building is not an individual subject, because it can be significantly influenced by the surroundings (Jansson, 2006). Therefore, in addition to requiring natural shading (e.g. by trees), reducing the street width will provide more shaded area.

Diverse but internally connected active processes within the urban canopy and the ambience above are important to outdoor thermal comfort. The geometric characteristics of the urban surface influence these processes in various ways (Pearlmutter et al., 1999). With a detailed survey in the urban area of Bam, various microclimates are observable (e.g. figure 7.5). Based on the study and conclusions of Jansson (2006), this can be addressed by direct and indirect effects of the abundant underground water networks.

Figure 7.5. Dense garden, a shaded green street, and a combination of adobe houses and greenery

The traditional water network, the Qanat, is composed of deep wells, underground streams and a near-surface or surface stream in some areas. The direct effect of this system on the variety of microclimates in different parts of the city is reflected by the plantation and the opportunity to cover the surface with trees. The indirect effect is reflected by the cooling effects that this system has on surface or near-surface area. According to the study of Jansson (2006), the ground temperature (including various components) has a direct effect on at least 2.5 metres (vertically) of air at the surface. Of course, the green patterns that are most often provided by agriculture are very effective in making a more comfortable microclimate within the desert city, which is also a result of the availability of water in Bam.

Buildings are replacing gardens, destroying the green surface of the land. During the construction process of these buildings parts of the Qanat network were also destroyed. When added to the absence of green surface, this accelerates the negative effects of desert sun radiation on this type of neighbourhood. Physical features with different scales (e.g. from upper-level attributes of the urbanised landscape to the micro-scale detail of building level and the immediate surroundings) influence thermal comfort in an urban environment. However, it is essential to recognise and understand the effects of the urban structure on the link between these scale levels and the possible interactions between the surface canopy and upper layer. Density (i.e. spatial compactness) of the urban surface as determined by the geometry of its constituent streets, affects this link as well. These multiple influences may be simplified when the physical properties of the urban fabric are aggregated at distinct scale levels, using the familiar conceptual frameworks of the urban canyon and surface energy balance. Whereas the distinction between climatic processes within and above the urban canopy is well documented, improved linkage between these levels of scale is also fundamental for understanding the effects of urban structure. Among the factors that affect this linkage is the density, or 'spatial compactness', of the urban surface as determined by the geometry of its constituent streets. These effects and variations in a desert climate are shown in the following through measurements of the surface temperature of some different locations.

7.3.4. Urban environment & microclimates (heat islands, density and geometry)

Similar to most old cities in the world, the change of style for energy use, from a 'passive system' to a (mechanical/electrical) 'dependent system' also occurred in Bam before the earthquake. Because of this, uncomfortable heat islands are repeatedly generated across the city, especially in the western districts. In such a situation, the microclimate is determined by actions and interactions of elements on the surface. These include buildings that add heat to the outdoor space by cooling the interior, and the solar energy that penetrates the building's façade and the ground surface. According to Pearlmutter (2007), the effect of these phenomena on the urban canopy "extends into a Roughness Sub-Layer (RSL) above roof level" (Fig 7.6). Therefore, these become distinguished from the other surroundings, so that individual neighbourhoods comprise small heat islands, although exact identification of the boundaries is often difficult (Schmidt et al., 1991). Based on the study of Masson (2002), in such a situation (in the residential areas), the daytime surface energy balance may be a share of the net radiation (Q*) input and a net heat storage (DQS) increase within the urban fabric plus the turbulent sensible heat flux (QH). Thus it will be:

$$Q^* = QH + DQS$$

This is where the net radiation is a function of the short-wave absorption, and long-wave emission characteristics of the surface. Geometry modifies both of these, and 'aerodynamic roughness, as determined by the geometry of roughness elements which characterises the urban surface' (Pearlmutter, 2007), influences the HQ.

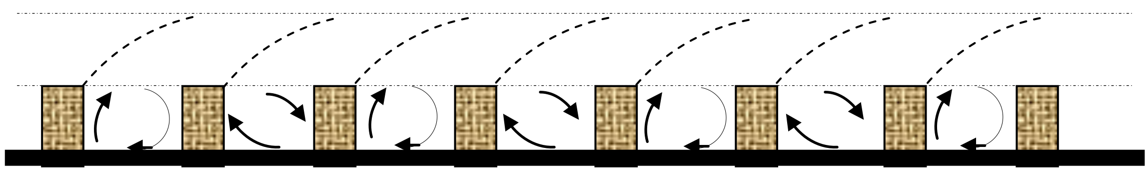


Figure 7.6. Buildings and Roughness Sub-Layer in an urban canopy (after Pearlmutter et al., 2004)

Urban geometry influences not only the Roughness Sub-Layer but also the heat storage (Grimmond et al., 2002). On a more detailed level, the conclusion can be drawn that the reasons for temperature flux and for heat islands in general in the urban area of Bam can be realised on a detailed level. According to McPherson (1994), this is highly influenced by the following:

“In the newly built areas of Bam, a cooler/air-conditioner is felt as an unavoidable element of each building. Thus, the observable variability of microclimates in the urban canopy is not always desired. Three major classes are recognisable: (i) dense traditional neighbourhood, composed of adobe built constructions, on a surface that covers plenty of water sources underneath, narrow alleys with walls on two sides with trees providing adequate shading. (ii) Dispersed traditional neighbourhoods, composed of large and small gardens, most of which include at least one house. Water is streaming even on the surface of the gardens sometimes. In some of these districts in the past, the street or the pathway was not recognisable to outsiders, although ownership was restricted and hierarchical. These paths were acknowledged by permitted neighbours, after the boundaries of the neighbourhood had been by clay and stone short walls. (iii) In the newly built or developed neighbourhoods and new construction sites, buildings appear in the place of trees.

Local and *in-situ* observations may reveal the most influential item in the urban area of Bam, which is also the main cause of the stated variety of microclimates. Parallel experiments have been conducted in Phoenix Arizona as well.

Table 7.1. **Surface temperature in Phoenix and Bam**

Areas Cities	Longitude	Latitude	Surface of Wide streets	Surface of narrow alleys	Surface, under trees	Under shadow
Phoenix, Arizona	33° 26' N	112° 1' W	37	--	18	23
			41	--	22	26
			41	--	22	27
			44	--	23	28.5
Bam	29° 6' 38"	58° 21' 42"	41	22	23	28
			42	22	23	28
			41	20	22	28
			40	19	20	26

* The time was around 13:00 on 24, 25, 26, 27 April 2006, in southern Phoenix and an old districts of Bam

The figures in Table 7.1 provide the opportunity to compare the two different desert cities. For most of the streets in southern Phoenix, trees are either rare or very young and newly planted, so little shadow is cast. However, a few old trees were found and this provided the possibility to measure the difference between sunlit and shaded areas. On these specific days (i.e., 24, 25, 26, and 27 April 2006), there was little wind in southern Phoenix, with the exception of a few parts of the National Park. However, in Bam, in the same period, the last day was relatively windy. These measurements have been repeated in detail in Bam in 2007, and twice in 2008 (June and August) to show the differences between several periods of a day (shown in Table 7.2.).

Table 7.2. **Surface temperature in different times of the day in Bam, 2008**

Surface temperature in areas of Bam	Surface of Wide streets		Surface of narrow alleys		Surface of under trees		Under the built shadow		Note
	June	August	June	Aug	June	Aug	June	Aug	
Morning	31	27	29	24	29	24	30	25	At 7:00
	29	27	25	24	25	24	27	26	
	29	27	25	25	25	25	26	26	
Midday	53	52	33	30	33	31	39	37	At 13:0
	53	50	32	30	33	30	39	36	
	54	51	33	31	34	31	40	37	
Afternoon	49	45	30	27	31	28	35	31	At 18:0
	49	45	30	27	31	28	35	30	
	49	46	31	27	32	28	35	31	

* The measurement are dated for 2-4 June and 12–14 August 2008, in the old districts of Bam
** the experiments have been performed in open spaces; they are comparative the temperatures are not absolute but relative; and the thermometers were stuck on 14 mm thick wood base.

In Phoenix and in Bam, the sky was mostly clear, with a visibility of about 10 km, with an average humidity of 6-9%, where the wind speed (if any) was less than 10 km/h. The streets and alleys were chosen with regard to their various directions (e.g. perpendicular, parallel, etc.). Adobe walls mostly shade the selected alleys in Bam (either as the wall of houses on both sides or independent walls). Five measurements were performed at each location, from which the averages are shown in the Tables. Furthermore, the temperature was measured in a park at different times of the day over three days twice a year, and compared to the adjacent open (land) surfaces. On average, a difference of at least 6°C was observed between the surface of the densely planted parts of the park and the open surfaces, especially in critical periods (e.g. 12:00-13:00).

7.3.5. Principles for the coming proposals on urban planning and design

Although measuring in open air involves several factors that may influence the results, the test environment is similar to the actual situation of cities. The materialisation of roofs and façades in desert cities in both the body of the construction and their surface have significant effects on creating heat islands. As also discussed by Tso et al. (1990), a representative building mass involves an energy balance, as the energy storage effect could then participate explicitly in the energy balance. For a desert city, for instance, the surface energy flux can be balanced by a combination of greenery (mostly agriculture), water, and shading. On the one hand, car-oriented urbanism, which is now the case in many desert cities, is positive for the design of streets and alleys with regard to the sheltering after earthquakes. On the other hand, as discussed, it may cause negative influences regarding the desert climate, which requires a compact urban tissue. In general, Bam comprises an urban microclimate, different from the rural areas in the vicinity. This difference has been observed over several years after the earthquake of 2003. There has been not much change in the surface temperature in the city of Bam throughout these years. However, inside the city, greater climate differences between some districts have been observed. Therefore, such districts have been classified within three smaller systems, sub-systems, or microclimates.

Buildings in the first nucleus of the city show a traditional orientation based on the local climate, northeast-southwest. However, various orientations have been found in the districts developed second and third (districts of masonry and modern constructions), especially in the districts developed in the second historical period of growth of the city (see also chapter 5). Problems resulting from spontaneous urban development, which have already been experienced in other cities such as Phoenix, Arizona, were discussed in Chapter 5. Compared to the cases mentioned, Bam can be placed at the beginning of this process, meaning that reconstruction can influence the historical/gradual development procedure of Bam. This has been stated as a positive point derived from a negative phenomenon (i.e. the earthquake). For example, appropriate urban planning can modify car dependency, which was also indicated as auto-orientation for inhabitants of desert cities including Bam. This is not only advantageous in reducing the impact of air pollution, but also results in less fuel consumption. Hence, because of robust physical fitness that can be provided by the habit of walking instead of driving, this kind of planning will also result in a healthier society.

Due to problems such as “loss of habitat, wetlands, prime agricultural land, and the beauty of open spaces” (Levine, 2006), the car-reliant lifestyle is regarded as a problem worldwide. Due to the critical situation in desert habitats, mainly caused by desertification, these problems can have an accelerated effect. Therefore, enhancing public spaces to increasing face-to-face interaction in a lively environment is also helpful, and encourages walking and bicycling for short trips.

Although the distances between cities in deserts may not be changeable, internal journeys inside each city can be significantly reduced. Besides, car dependency has been addressed to conform with cities such as Phoenix, whereas Bam is only a desert town.

Although the low density in some desert cities such as Phoenix is due to the urban sprawl, a low density of population is actually required in some parts of the city of Bam. This is because a great deal of gardens and farms that supply the products are situated in Bam, inside and even in the middle of the current city. In such a situation, houses are low-density garden houses.

Linking the theories and principles for going into actions in planning and design
To apply the obtained theoretical results in proposals for urban developments, a specific neighbourhood in one of the western districts of the city was an appropriate case for realisation. Principles / assumptions for this type of development include:

- Every house comprises a private yard, a small garden, and possibly a basin.
- First- and second-degree alleys/streets (collective areas from the first access alleyways) are wider than required in a normal (i.e. non-seismic) situation.
- Derived from the previous specification, crossroads at the neighbourhood level are wider than when they are meant only for transportation.
- To compensate for these specifications (i.e. the two previous statements), which are advantageous for a seismic design but hold climatic drawbacks, trees are the perfect alternative links. As such, the absence of building mass is substituted by natural mass. Because wide streets have less scale reference, which may create a sense of being lost or of incomprehension of the lack of boundaries, green details (trees) will reduce these effects.
- A courtyard, which functions perfectly for traditional desert houses, may no longer be desired in new houses. However, it is applicable at the urban level for a seismic desert city, meaning that shaded, semi-public open spaces in the neighbourhoods can be designated to play the role of courtyard.
- Green public spaces not only provide a cooler climate but also a mentally and psychologically comfortable environment
- Based on the courtyard concept (in desert houses), which was discussed in Chapter 5, the greenery of the courtyard combines with the water basin and the ventilation system to create oases in a desert. Water, utilised in a systematic way (similar to the traditional water systems), can keep the urban surface green as well as cool, while it creates a more comfortable public environment. However, because of the high level of evaporation, surface water is a loss and thus costly, and may not be sustainable, unless it plays a multifunctional role (e.g. psychological comfort, cooling, greenery, agriculture at once).
- Affordable solar panels and collectors, as well as utilities in public spaces can be installed on top of sun-breakers (shady roofs) as well as on the ground in other appropriate spaces.
- Special public spaces should be provided, dispersed throughout the city, to shelter people in the case of future earthquakes.
- Considering adequate accessibility for cars, which is a strong social requirement in Bam, increases the socially adjustability of the design. However, to ensure a more sustainable future, the current social trend can be gradually moderated by means of design. For instance, the specification of pedestrian areas, where car entrance is forbidden, encourages people to walk as much as possible. However, this type of change and regenerating such a habit, from transport by car to walking, may take a long time in the current state of the city.
- Developing a proper basic module for the parcels in a neighbourhood can increase the flexibility and thus the applications. Hence, it adds a harmonic heterogeneity to the homogeneous urban fabric, not only physical and proportional, yet also societal. People

with low incomes will not be housed in separate places, so that ought to reduce aggression and crime.

- Although sewage is one of the fundamental services of a city, public recognition and awareness can improve the environmental efficiency of sewages.
- Bam's underground resources provide plenty of water for desert inhabitants; a sustainable habitat may use this but it should be done in a way that future generations will also be able to use it (as it was the case in a long history).
- The green environment, in the form of citrus or palm trees for instance, can give shade to the streets or other public spaces.
- Every multi-storey building needs to be constructed at a certain distance to the adjacent building, based on their height and function. However, a distance of 10 cm (5 cm on each side) between adjacent houses is adequate as a base. This can be increased whenever the height on either side is raised.
- Because the integrated proposal solutions in this study mostly relate to town houses (see also chapter 5), a properly settled dense neighbourhood, which is crucial for a desert climate, will not conflict with seismicity; however, it should be more than a composition of only buildings.

Above mentioned principles are going to be taken into action in the following sections. .

7.4. Proposals for a seismic desert neighbourhood

For local utilisation of the previous results and for ensuring the integration, the design must be adapted to conform to local regulations. Therefore, an appropriate location needs to be specified first of all. For example, in Bam, the direction of natural growth is towards the west. The newer western districts are built according to the regulations, on a type of urban grid. These grids are being globally applied in large variations, examples of which are shown in Figure 7.7.

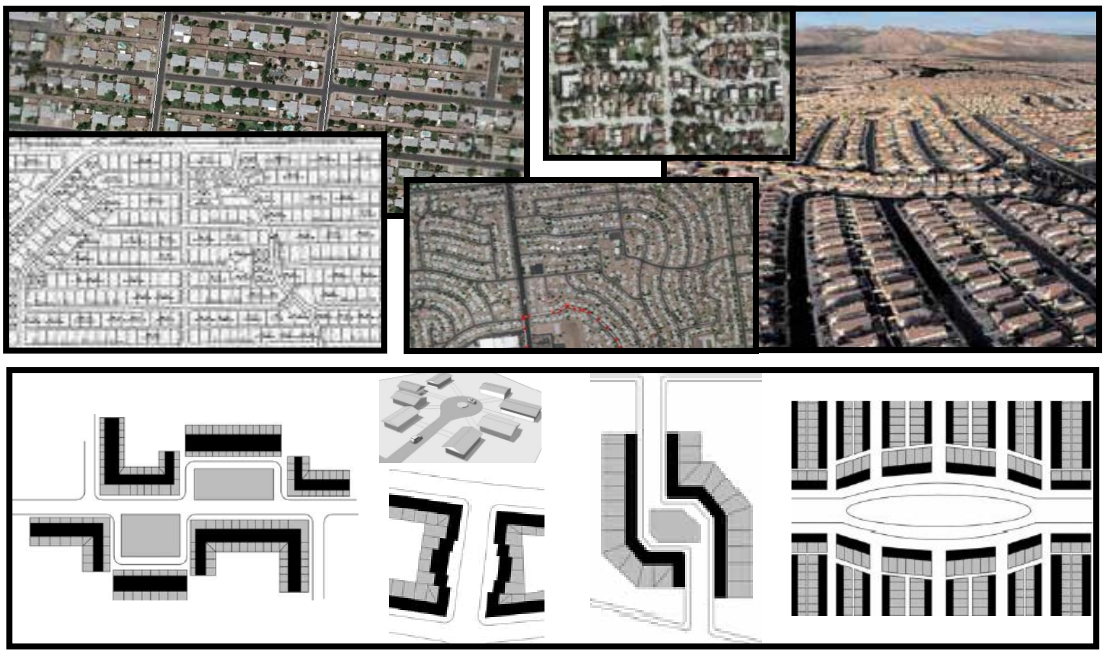


Figure 7.7. Variety of grids in Phoenix and Manhattan (top); Details of nodes and ends (source Google image)

7.4.1. Pattern analysis and site selection for the reconstruction of houses

Regarding its potentials and in order to adapt to the local regulations in Bam, the grid is a good solution for the urban pattern. The spaces required between houses that help to reduce the influence of seismicity (i.e. by avoiding the problem of pounding against each other, which may occur with two connected adjacent buildings) also interfere with the aim of protecting them against the desert sun (schemes in Figure 7.8).

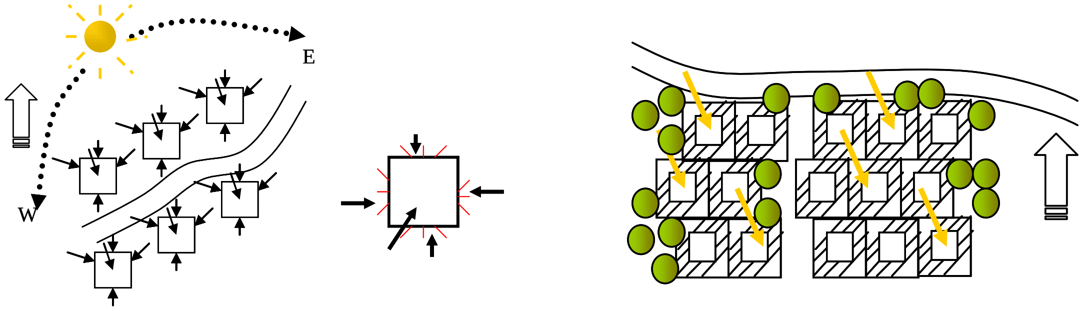


Figure 7.8. Seismicity requires separation of different structures, while protection against the intense desert sun requires a compact tissue and indirect light

As shown in Figure 7.8 the physical form and the spatial figure of the house on each individual plot, as well as its location within the plot, have great influence on receiving, storing and radiating the energy. Since lighting and ventilation were traditionally programmed internally (e.g. via courtyards) the orientation in the past was not as important as it is in the current situation.

In an integrated approach, the building level is also incorporated in the neighbourhood design. Thus, each plot of land is formulated as a module for neighbourhood planning and design. According to the local regulations, the width of houses may vary (e.g. 7, 10, 12, or 14 m), but their length (north-south orientation) may not. Basically, for individual single, double, or other similar houses, 60% of the length can be built. While building less than this is possible, going further than this length is not allowed in a normal situation. Regarding the car-orientation issue, the relevant local regulations can be modified, as shown in Figure 9. As displayed in this figure, the module plot of land is proposed to be 14 m by 24 m (a quarter of which is a plot measuring 7 m by 12 m), so that plots with various proportions are provided for different people (as shown in Figure 7.9).

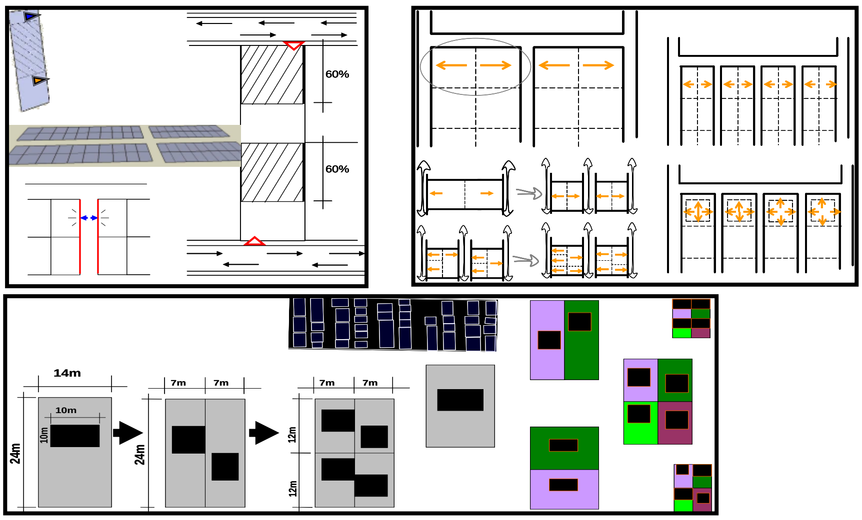


Figure 7.9. The flexible proportion of parcels as a modulation for neighbourhood design

The flexibility provided by this module parcel provides physical and spatial variety that improves the view, creates positive social diversity, and gives identity to the spot in a homogeneous neighbourhood. Besides, different sizes of houses can be provided to improve the market and the value of the neighbourhood for a longer time. Hence, the future growth will not have a huge impact on the settled urban fabric. This module can be used for applications other than just as a site for houses. For example, the module can be used for green space in-between houses within rows of houses. The samples of urban tissues in Figure 10 were developed on this basis. In the resulting neighbourhood, buildings are mostly linked to each other on two sides, thus they are protected from the sun on these critical sides while they are not necessarily connected to each other. Figure 7.10 shows some examples of the possible arrays in an urban tissue, which is developed by the same principles.

Figure7.10. Examples of possible patterns satisfying the local regulations, seismicity requirements, and the desert climate

Two locations in one of the western districts were selected for modification according to the principles mentioned (as shown in picture group b of Figure 7.11). These are situated in the relative new neighbourhoods developed before the earthquake (both the northern and southern side of the square). In the last piece of Figure 7.11 the concept developed in chapter 8 was applied to a sample neighbourhood.

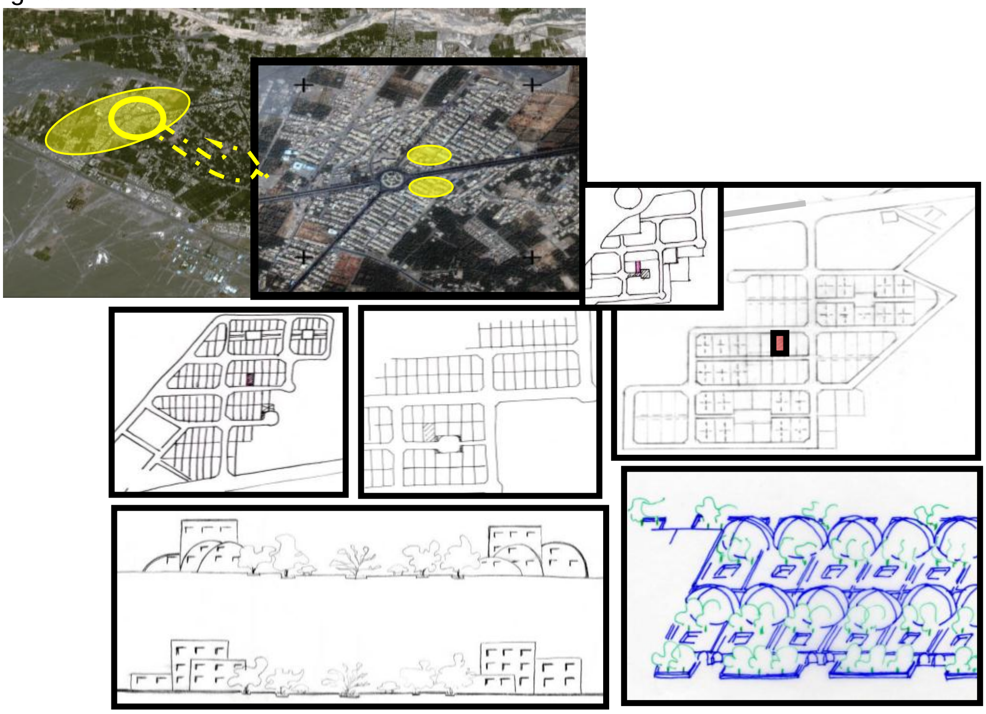


Figure 7.11. Sketches for the modification of existing parcels, based on local regulations and appropriate orientation of northeast southwest, according to the prevailing winds and sun.

Other spots of the city in the western districts are also possible locations for proposing a sample neighbourhood for the reconstruction of houses in Bam (e.g., Figure 7.12).

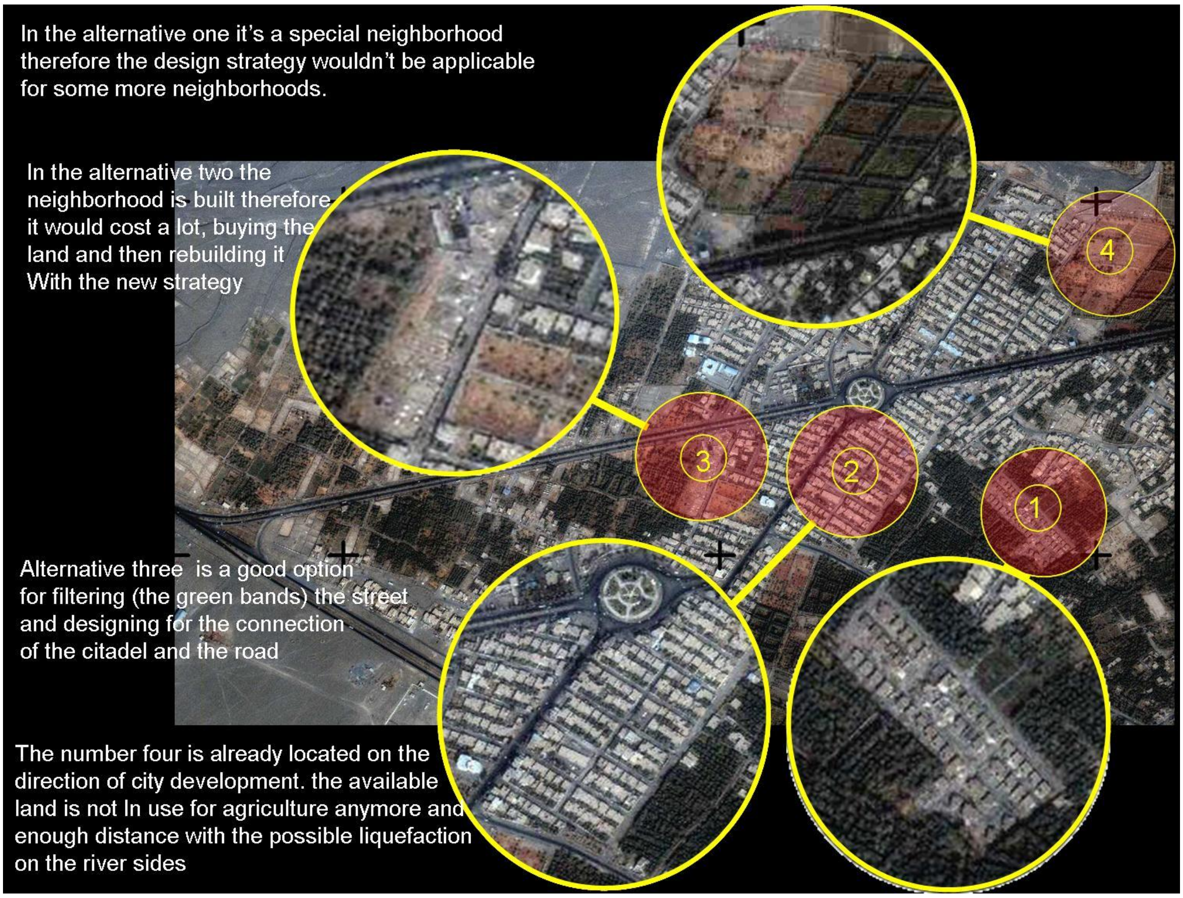
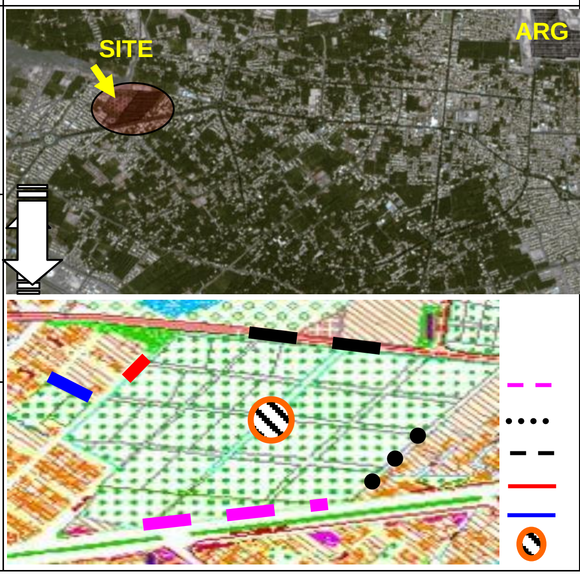


Figure 7.12 Options for the sample neighbourhood in various locations in the west

Based on the surveys and site observation that is also briefly analysed in figure 7.12, number 4 (emphasised in the figure) is the most appropriate option. Photos of the different views of the selected site are shown in table 7.3.

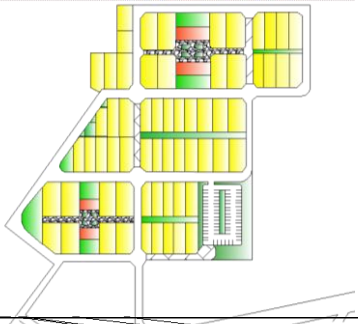
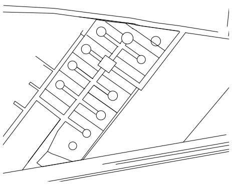
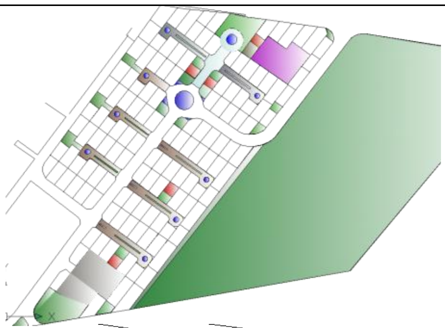
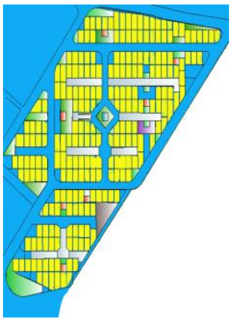
Table 7.3. **Surveys and site observations of different views around the selected**

Legend & pictures	**Locations on the map**	Pictures, various views
		
		
		

7.4.2. Case-oriented proposals in a sample neighbourhood of a SRH-SD in Bam

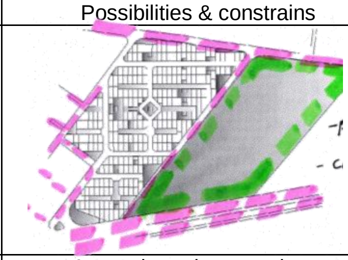
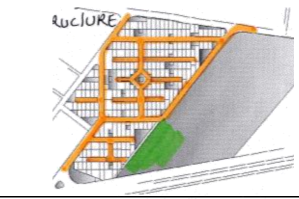
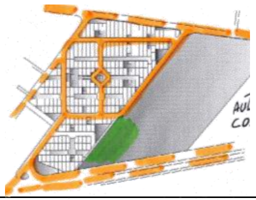
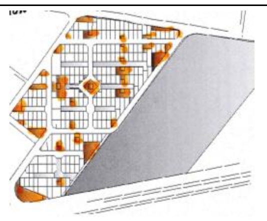
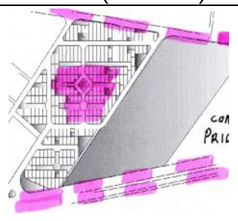
For the selected location as a neighbourhood in Bam and the context for the houses, several alternative proposals were developed, samples of which are shown in table 7.4.

Table 7.4. Some proposals neighbourhood planning for the selected site

Nr	Sketches	Examples of Alternative Proposals	Analysis
1			Parts of the neighbourhood are planned with large parcels, private and public parking lots.
2			The most possible numbers of the parcels are proposed, the neighbourhood comprises a green heart, and green details at the end of each section, while neighbouring a very large garden, as an incredible opportunity for a sustainable desert neighbourhood.
3			Priorities for accesses by car and transportation as they are wished, because of neighbouring a very large garden, water was placed in the heart of the neighbourhood, instead of green.
4			A combination of easy accesses for cars and improved pedestrians, by mixing the environment with water and green details, the riding society may become a walking society in the future. Services, greenery, parcels of various proportions, private and public parking are available.

Based on the local research, brief analysis and the mentioned principles, from the sketches of table 7.4 the fourth proposal offers the most advantages. Therefore, proposal number four, which is analysed by sketches in table7. 5 will be the context of reconstruction of the targeted desert house as the sample neighbourhood.

Table 7.5. Analysis of the chosen alternative

Indications/points	Physical patterns	Possibilities & constrains
Analytical Sketches		
Indications/points	Urban structure	Auto oriented connections
Analytical Sketches		
Indications/points	Functional distribution	Hierarchical net disturbance & accesse
Analytical Sketches		
Indications/points	De-concentration	Concentration, priority of human (distances)
Analytical Sketches		

Although keeping the urban surface green in a desert environment is a difficult task that may also become expensive, it is socially desirable and also practically possible, as Bam has always been a green city throughout its long history. Thus, details of the proposed neighbourhood consistently aim at a sustainable habitat. The location of services (e.g. shopping centres), and mixing these with a pleasant ambience created by a combination of green, water and urban details, encourages walking instead of driving. Gaining energy from sunshine on the top and having shadow under the panel is one of the urban details for a self-supporting sustainable district. Bringing the irrigation water to the surface in some particular locations enhances efficiency and boosts the effects on humans (e.g. physically and psychologically). Local and indigenous trees are the most suited for planting on the surface, not only because of their ability to survive in the desert climate, but also because of their advantages for the public (e.g. full-leaf in the summer, without leaves in the winter), so that they create seasonal shadow. The green heart of the urban fabric, in addition to its physical and mental effectiveness, emphasises the greenness of the neighbourhood. The centralisation of communication boosts social connectivity while the required services are decentralised by being distributed throughout the neighbourhood. Figure 7.13 shows general composition of these services with houses within the example neighbourhood.

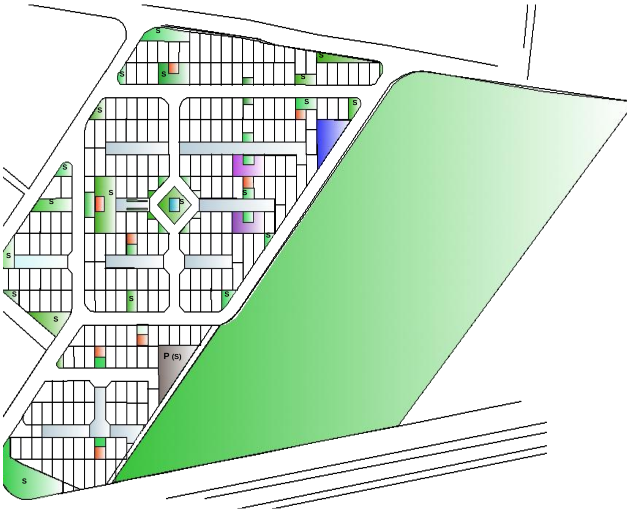


Figure 7.13 composition and distribution of the services within the neighbourhood

Encouraging walking instead of driving is a gradual process, so that cars still need special services (e.g. public and private parking lots), which are adequately provided (Figure 7.14 shows the individual parking lots).

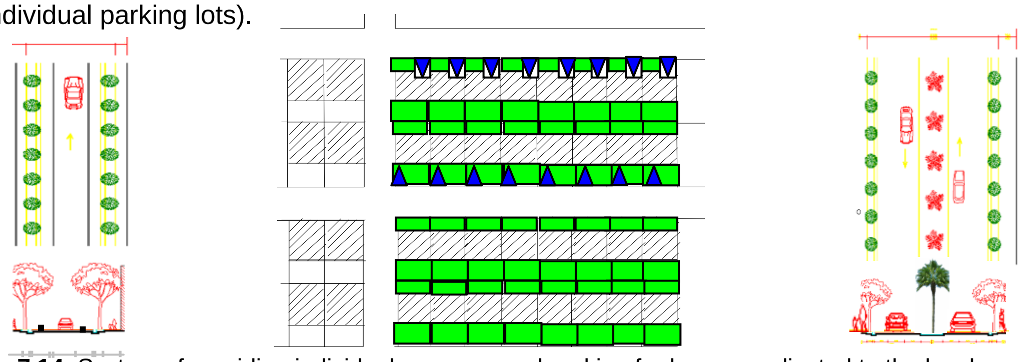


Figure 7.14. System of providing individual greenery and parking for houses, adjusted to the local regulations

The hierarchy of the traffic and access network is not only scaled accordingly between the car and human life, but is also reflected in the urban details such as the urban nodes. Example for such details is the difference between the level of streets and the pedestrian and buildings in addition to the green boundary that separates the streets from the pedestrians (e.g. figure 15). This way, integrating simple items to create significant comfort is also reflected in the selection of a particular type of tree, bush and other vegetation, with the suitable height, and leaf density.

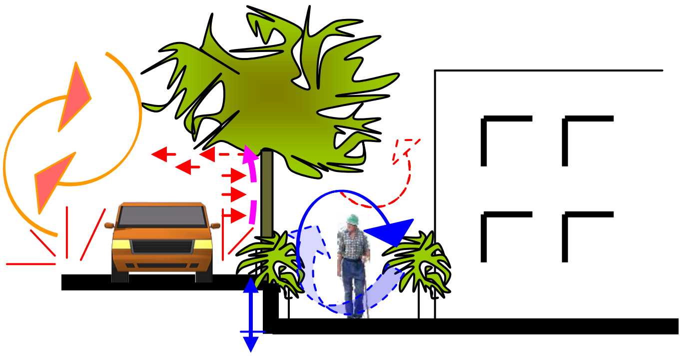


Figure 7.15. The level, height and density difference between the street, pedestrian, trees, bushes, etc.

Residential plots are connected and thus protected on the two weakest (climatic) faces of houses, the west and east side. Finally, the location of the site between the two important squares in the western districts of Bam is shown in Figure 7.16.

Figure 7.16. Location and composition of the proposal neighbourhood in the district and the vicinity

7.5. Reconstruction in a seismic desert, an analytical discussion

With the current level of knowledge and due to the nature of the world, in general we can know the entire world only by approximation (AAAS, 1991). Although the main focus in earthquake engineering for housing is placed on high-rises and residential complexes, most of world's population live in low-rise single family or similar houses (see also chapter 1). For example, about 50% of the population in developing countries live only in low-rise single family adobe constructions (Blondet, 2003, Khalili, 2004).

A study of housing in developing countries shows that a dynamic transfer from adobe constructions to masonry is still taking place. Most of this transfer involves migrant villagers who cannot afford an appropriate house inside the city. These migrants prefer to settle in affordable urban areas in order to be able to build a non-standard cheap house. More than 50% of people on the planet live in cities; this exodus from villages and subsequent settlement in cities is continuing at a rapid rate in developing countries. The more the world's rural population (especially in less developed countries) migrate to the cities, the more the percentage of masonry construction increases. However, these masonry constructions are not always appropriate homes (Zho, 2005; Bentinck, 2000; Soleymani, 2005). Two main threats to sustainability in this growth are, first, the fact that low-quality masonry buildings are not sustainable homes. The second concern is that the manufacturing and production of most of these low-quality masonry constructions also have a negative impact on the environment (e.g. cases in China, Iran, and India). Although these types of construction are more likely to be built in developing countries, the standards and regulations in many of these countries have not been improved to envelop sustainability. The developing world's share of construction worldwide was only 10% in 1965, which increased by almost threefold to 29% in 1988, and is still growing (UNEP/CIB/CSIR/CIDB, 2002). The graph in Figure 7.17 is based on this information.

Figure 7.17. Percentage of share of nominal gross domestic product by region

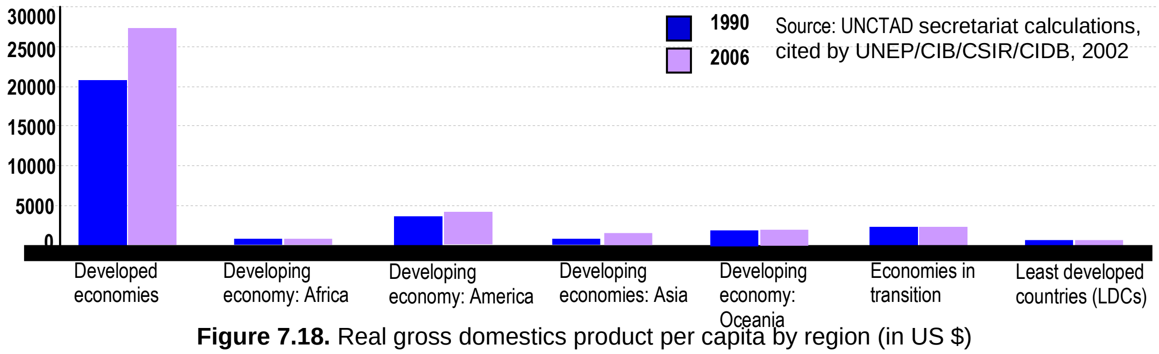


Figure 7.18. Real gross domestics product per capita by region (in US $)

The planet is a common concern for humans on five continents. The air does not discern between poor and rich, black and white, developed and undeveloped. This is a significant item and an urgent issue of the human life. Regarding the migration from villages to cities we should also carefully consider the following:

- Migration from villages to cities may turn green farms and gardens into brown fields. This is not only an issue of green or brown but it also reduces the numbers of food producers of the society, while the number of users increases.
- Former villagers in the new locations (in the cities' vicinity) will suffer and will also create major problems for themselves and other citizens, environmentally, socially and economically.
- The dwellings of these migrants mostly comprise low-quality construction and materials that may cause losses in disasters such as earthquakes.

One such case, as explained in this study, is Bam, which has suffered from both newcomers from villages and a major earthquake. Although the masonry houses and inadequate building construction and materials suffered most from the earthquake, almost all houses were involved in the disaster, practically, physically and socially.

An extensive survey in literature (e.g. Razani, 1984; Parsa 1985; Rafyie et al., 1986; Zargar 1988; Rodriguez et al., 2002; Loaiza et al., 2003; Choudhary et al., 2003; Hankins, 2005; Whyte, 2007; Al-Harithy, 2010) and local investigation (e.g. in Iran, Turkey, Peru, Argentina, Mexico, Armenia) has shown that technical aspects are the main concern in reconstruction. However, examples of consequences (e.g. in the USA, Canada, Iran and Japan) prove that these aspects are not the only concerns (Shahnoori et al., 2007d). Considerable progress has thus been achieved, but little effort has been invested in the content and lives of the inhabitants or in the real housing issues. Nonetheless, the social aspects of shelter and reconstruction after earthquakes play a significant role in public health (Kates et al., 1973; Mileti et al., 1975; Kronenburg, 2002, Shahnoori et al., 2006; Fallahi, 2007) and the sustainability of the habitat (Shahnoori et al., 2007b). The various points mentioned concerning houses and urban planning, plus many items that need to be discussed separately, all concern the SRH-SD. Many of these mentioned (as well as the ones not mentioned) are local, but nevertheless influence the interconnected global subject of sustainability.

Finally, the old argument about agriculture and economy of a city, between the doctrine of Adam Smith and the statements introduced by Jane Jacob, is valid when looking at the case of Bam. This city is an exceptional case, in which these two can actually be combined, because agriculture is crucially important to the city (Smith's point) and it is interwoven with every other single item of social and economic life of the inhabitants (Jacob's point). It can be concluded that agriculture in cities such as Bam is much more than a matter of providing food. It includes first-aid needs while comprising a higher level of need for humans as well (see also Shahnoori et al., 2010b). A good example is looking at the long way that a machine such as a computer has to take to produce a design. This can be compared, to the simple and quick way that humans take to process the information, to use the design knowledge, and to go into the conceptualisation. With this example, the comparison between local indigenous or desert inhabitations performing agricultural activities on their own land, and other ways of doing it, may become clearer. Similarly, Spray (2001) states that it is often best to use ecological consultancy of the local Wildlife Trust to carry this out, thus building relationships and tapping into local expertise. Part of the local potentials is indigenous people; therefore, to ensure the succession of a SRH-SD considering their wishes is crucial. This aspect will be further discussed in chapter 9.

7.6. Summary and Conclusions

Sustainability is the main or the general point in proposing integrated solutions and plans for reconstruction. Regarding the sensitivity of the SRH-SD, guidelines are significant, also in the practical design and conceptualisation. Criteria as checklists are applicable to measure or evaluate the sustainability of the proposal solutions for the SRH-SD as well, on the urban, construction and materialisation level. This was discussed in chapter 6. However, as an application to practice, examples of these checking criteria are useful. Because the ‘generation phase’ was divided into two chapters, the checking criteria that include many items related to the construction and materials are included in the second part of the generation, in chapter 8 and 9.

Case-related remarks, summary, and conclusions:

Three main expressions/terms are used when referring to Bam. These are:

(i) The ancient city, which refers to the mud brick and clay collection of Bam Citadel (outside and inside the wall)

(ii) The old city, the first nucleus of the current city, which is situated around the ancient city, to the south and west of the citadel

(iii) The current city, which includes the first nucleus of Bam and the newly developed area (i.e., includes also item ii)

One of the critical points revealed by the in-situ research is that just before the earthquake (also today), developers bought large pieces of land at a very low price. They divided them into numerous parcels for individual buildings or for construction sites. This was not only an uncontrolled way of construction, but also an imbalanced use of land. Gardens and farms disappeared at a rapid rate, with buildings simply popping up everywhere in their places. First of all, social awareness is crucial with such occurrences. Secondly, supportive local regulations should be provided, adjusted, and detailed for application in practice. Indeed, the political authorities and local government play a critical role in controlling this phenomenon. Patterns of land use that determine the origins and destinations of journeys have the most significant effect on understanding the traffic flows and thus transportation. Therefore, this needs radical reconsideration and supportive enforcement regarding performance and use. The significant spatial differences at the edge of the city, emphasised by dense gardens and farms, were already disappearing before the earthquake.

It should be noted that basic services and infrastructure in Bam also need a rearrangement. For example, the electricity network can simply be placed into the ground instead of complex wire lines in the skyline of the city. Countries such as the Netherlands have already experienced so-called infra-ducts under the ground (Dobbelsteen, 2010). Due to the underground water level in Holland, this method is even better manageable in a desert town as Bam.

Although solutions such as high-rises and multi-storey apartments are not socially desirable in Bam, dense and compact housing is a wise alternative for this type of desert cities. However, this needs to be adjusted for a seismic neighbourhood.

The main cause of the high level of destruction in the city of Bam was an urban catastrophe, which was also related to the migrants and the low-quality construction of their houses.

There was a question five years ago, when this PhD research started, how constructions (i.e. the citadel and the old adobe residential constructions) that had survived a history of 2500 years could be destroyed on such a large scale at the end of 2003. Many people also came up with similar questions later on. Intensive research into the destroyed as well as the surviving parts of the above-mentioned constructions revealed that most of damages were in the newer parts and were even caused by rather recent (i.e. about a century ago) repairs. It was not because the repair was always inappropriate, but also because there was inadequate connectivity between the patterns of the old and the new parts (both in appropriate repairs as well as in inappropriate ones).

Although it is not evident at a quick glance, social patterns can also suffer from this absence of connectivity. Chapter 5 discussed that ancient cities such as Yazd and Bam comprised a well-connected society and culture. This is true within the population of the ancient city, whereas the newcomers and migrants, whose numbers were recently growing, eroded this pattern. Hence, the urban modernisation also ruled this problem. In cases that the indigenous people have a strong community throughout a long history (e.g. in Bam), social disconnectivity that does not affect the group of indigenous people could give rise to discrimination. This is another type of disconnectivity, between two (or more) groups of former inhabitants and newcomers. In Bam, people in the first group call themselves ‘the owners’ of the city. Nevertheless, this phenomenon was not disastrous in Bam yet, because a common issue lubricated the process of combining these two groups. In the old days, Bam was located on the ‘Silk Road’ between east and west, making it a marvellous place. Nowadays it is near the route of illegal drug transportation from Afghanistan to the rest of the world, gradually creating an insecure situation. This was a common issue for both two groups of people.

In Chapter 5, the sustainability of some traditional indigenous urban patterns and tissues, as well as the construction methods and materialisation in the old days, could be applied to illustrate good desert examples. However, this refers particularly to the old days and ancient constructions. Local surveys, research and analysis have now revealed that this attitude has changed and a new contradictory approach is becoming dominant in some cities, as was the case in Bam just before the earthquake. In that situation, sustainability was no longer addressed on the same scale in urban land use, in social aspects, and in the construction and materialisation. The basis of change of the old sustainable attitude in Bam started with the beginning of the modernisation more than half a century ago. This happened in most desert cities in central desert of Iran.

The three basic activities in Bam are agriculture, tourism and services (e.g. on the provincial road). These are not only important for the economy of the region but are also crucial for the lifestyle and survival of the inhabitants of the Bam area.

Bam comprised a rapidly growing community before the earthquake. This element was not adequately considered and dealt with by the authorities. Therefore, apart from the terrible destruction, the earthquake has provided a new opportunity for redirecting the growth and development at the urban and building level, in accordance with sustainability.

The rapid expansion of the city before the earthquake relates to two main factors: (i) cultural and local reasons and (ii) the promising economy and income. For the first, since the indigenous population were dependent on the land and proud of their long history, they did not want to emigrate from it. Much because of the same reason, many other people from the villages in the vicinity preferred to migrate to this city. For the second reason, because of the financial scope and the relative wealth, people hoped for a rather good life in the city. The economy of the city provided jobs for the migrants and a means of support in Bam. Of course, these were mostly based on agriculture and the relevant industries. This rapid growth was not entirely healthy, because of the above-mentioned lack of supervision, so that societal problems also appeared. These were not evident before the earthquake, but combining them with other problems caused by the earthquake, they will become the subject of extensive study in the future.

The most disastrous aspect of the rapid growth relates to the functional changes or land use in the urban tissue, mainly turning farms and gardens into construction sites, supermarkets, trade centres, as well as other offices.

The high number of people attracted to the city indicates two contradictory views: (i) there is potential for this type of growth, and the residences, supermarkets, offices, etc. are (generally) needed; and (ii) this immigration requires a large area of land. In this case, it was mainly agricultural land, which, in a desert city of this type, also fulfils the role of greenery and forestation. Both of these views need arguments, planning and conducting approach in order to result in an appropriate healthy use and development of the land.

General remarks and conclusions

- Once again, a mutual dependency was illustrated between the global outcomes for sustainability and local actions through the case studies. This fact is regardless of situations, it is not dependent on the wealth or poverty of the inhabitants. The sustainability on both global and local level is dependent on both local and global activities.

- The reason for designing the house for SRH-SD to be a two-floor building was the use and social desirability (see also chapter 5). However, during the research the other significant point of the design emerged as well. This means that the influence of a building on a microclimate varies with the size of the building together with the system applied in the design for thermal comfort.

- Trees, which are indigenous in many deserts, provide shading in the hot dry seasons, while they permit sunrays in the cold seasons and they also add moisture to the air. Although the temperature under the shadow of trees is significantly less than the surface of a street or even the open air, the difference between the temperature break provided by trees and the ones under the shading of the built environment in the hot seasons is not that significant.

- Regarding the results obtained from measurements, and in accordance with the design cases, it is possible to provide the pleasant urban neighbourhood in the deserts like the vernacular ones (discussed in chapter 5) with modern design. The term ‘pleasant’ here relates to the sun, heat, moisture, and earthquakes, which can be provided by compatible details in design. In this design, the microclimate is moderated mainly by using indigenous trees, two-floor houses, combining streets with pedestrians for access, combining gardens with daily lives (as it was the case in the past, but with slight changes), multi-purpose water streams, collecting solar energy to share in the public services while providing shading underneath.

The mentioned points can be used in practice. Examples that have also been applied in the proposal solutions for the SRH-SD in the current study are summarised as:

- using clean energy sources such as desert sun on a high scale, public as well as private (e.g. on the roof of parking, covered public spaces, as well as on housing level)
- renewing resources that serve particular purposes, such as reusing water from the sustainable neighbourhood in agriculture.
- preserving usable (but remaining) energy source
- providing delightful pedestrian ways instead of stimulating car use (as a habit in desert cities)
- revitalising sewages for purposes of replacing it by natural resources and declining the environmental pollutions
- developing adaptable green surface for desert ground as much as possible
- providing a compact urban tissue of a combination of houses and trees

As the original problem of the entire study was domain related, the issues that help to define a domain for the SRH-SD are fundamental. As an example the scheme in fig 7.19, helps researchers in the future with the starting points of dealing with the two constraints in a SRH-SD. Most of the items have been already separately addressed too.

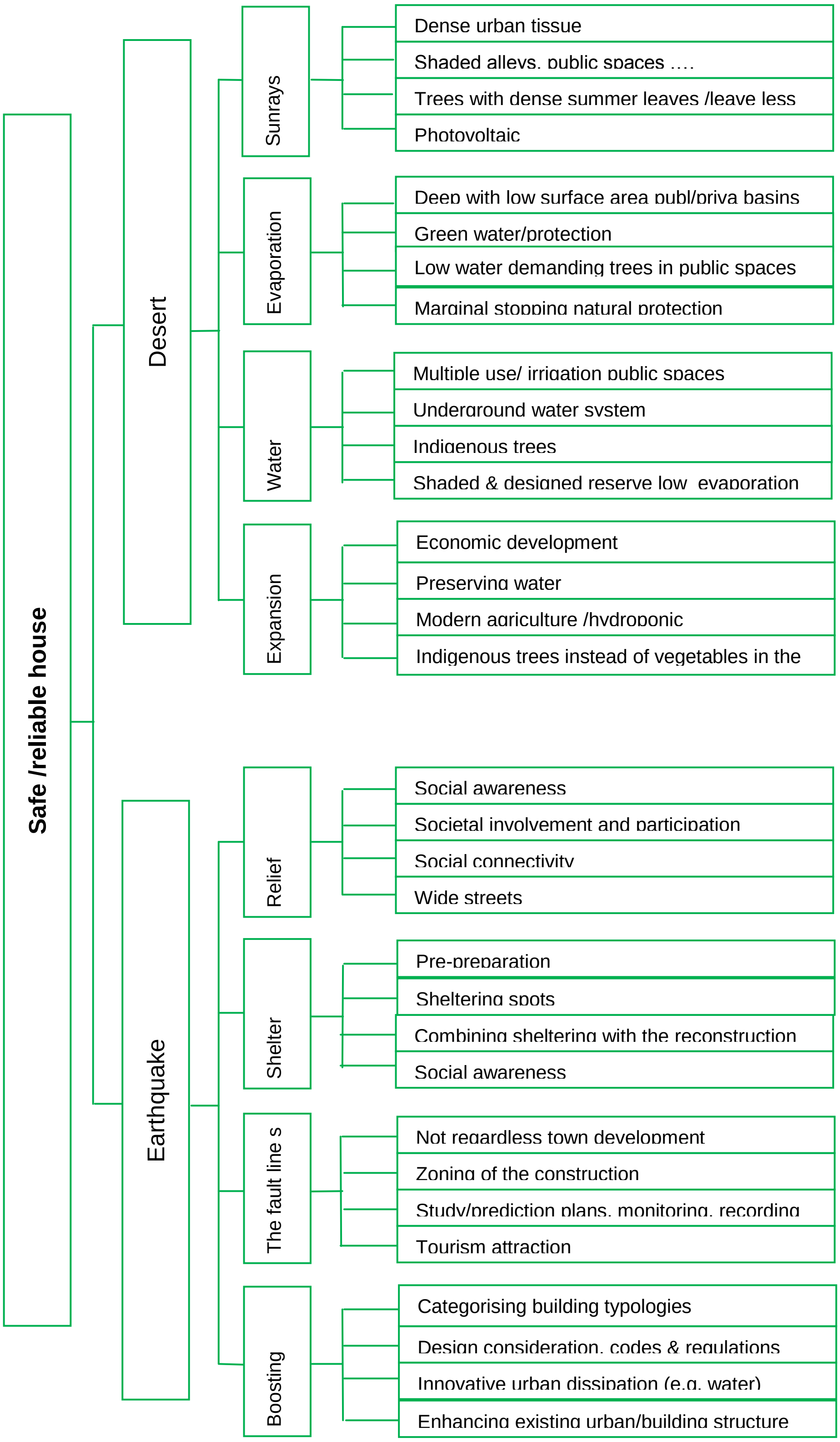


Figure 7.19. Collective items with a sample branching (for researchers) to deal with problems in a SRH-SD

Because reconstruction after an earthquake is different from a normal construction, social aspects need to be much more incorporated. This was already indicated in chapter 4. Therefore, once more it needs to be restated that the prioritisation of CIB (1991) as ‘economy, social systems, and environment’ is highly appreciated and may work for a normal construction. However, in a SRH-SD, with the required scales of new construction that were mentioned through the cases in various chapters, the three major components for sustainability are rearranged as ‘environment, social systems, and economy’. Based on this, and regarding the outcome of the previous chapter the table 7.6, is an example of providing major items for SDH-SD.

Table 7.6. Criteria for a SRH-SD on the urban level

Target	Possible Effects	Criteria
Air	Producing CO_2 Other toxic/harmful gases	Produced and released CO_2 Releasing other toxics gases Number of air pollution complaints
Water	Overuse of water Producing sewage Water pollution Desertification	Water required per tonne System and amount of use of underground water System and amount of use of other sources Sewage produced per tonne Level of pollutant agent Access of households to water
Surrounding	Unsustainable land-use Unpleasant/ dangerous surrounding Release of hazardous waste Release of non-hazardous waste Noise pollution Land degradation & floating Heat islands &Desertification	Land usage (functions, percentages, future view) Transportation Agriculture Sheltering spots Number of complaints about effects on scenery Hazardous waste per tonne Non-hazardous waste per tonne Recyclable waste per tone Number of air pollution complaints Land deformation system Land deformation level (+ future view) System of climate compatibility Heat produced (+ future view) Heat exchange with the surrounding (construction and materials capacity, insulation…) (+future view) Percentage of green items added to surroundings Type and number of plantation (+ future view)
Energy	Various environmental harms	Required energy for manufacture/product processes Amount of solar energy use Use of other clean sources of energy Ratio of passive/ active system for cooling, … Courage for conducting energy use of household Estimation for near future, future, and far future Energy source required for transportation
Natural resources	Misuse or overuse Depletion of resources	Use of various natural resources Scale of use from each resource Extraction system Scale of recycling and reuse of materials Durability of building construction and materials Recycling and reuse of building elements, material
Climatic comfort	Missing Indoor comfort Distraction of outdoor Un-satisfaction=Desertification	Level of indoor comfort in hot summer days Level of indoor comfort in cold winter nights System and level of moisture added to the dry air Air circulation and ventilation system and level System for outdoor comfort (private/semi-private) Incorporation of local traditional solution in practice
Social comfort	Undesirability/economic loss Societal miss-match Aggression and crime Leaving the desert=desertification	Scenery, combining water and greenery in desert Health of the houses (mentally & physically) Social desirability Societal involvement in changes on urban areas Courage for efficiency in agriculture Durability, safety, and security of the building Boosts for agriculture, accesses, combining it with life, protecting its area from construction…
Market and profit	Economic losses, financial disability Crime, aggression and drug addiction Crises for jobs Leaving desert = desertification	Flexibility of components and elements of houses Community oriented market **Job opportunities** **Side activities for agriculture …**

As an example, a checklist deducted from this table is shown in table 7.7, for the theme of water, because water is an important item in the desert.

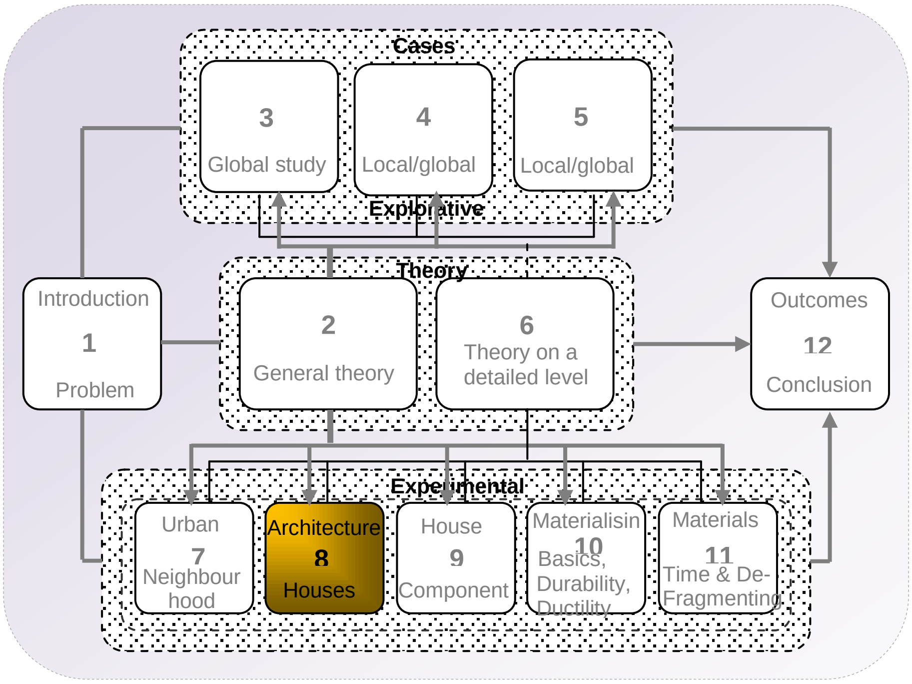
Table 7.7. Item of water, example of a checklist deducted from table 7.6

Item	Domain	Checking the use		S	U
Water	Urban (access for every family)	Water required per land use			
		Required quality per land use			
		System/technology of water use per land use			
		Renewing technologies for the used water per land use			
		Use of renewed water from other sources (than natural)			
		Upgrading standards of use, methods for declining water use			
		Waste water per land use	H		
			Nh		
		Sewage per land use	R		
			Nr		
		Water pollution per land use	H		
			Nh		
		Percentage and type of pollution	H		
			Nh		
	House/building	Quality of the water provided for family use/households			
		Encouraging methods for saving and optimising the use			
		Water system/technology in the houses			
		Renewing & recycling the used water			
		Reuse of the used water			
		Waste water produced per family	H		
			Nh		
		Sewage	R		
			Nr		
	Materialisation	Water/tone for extraction of raw materials			
		Required water/tone for processing raw materials			
		For others (between extract & production of raw material			
		Required for production processes, target materials			
		Water/tone for the target material itself (e.g. concrete			
		Renewing the entire used water			
		Use of renewed water for materials			

S= surface water, and U= Underground water
H= Hazardous, and Nh= Non-hazardous
R= Reusable, and Nr= Non-reusable

More information about Bam, especially about availability of water in Bam, is available in the appendix.

With this chapter, a clear vision on the context and the urban scale was presented for reconstruction of houses. The scale of houses will be continued in the next chapter.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Conclusion
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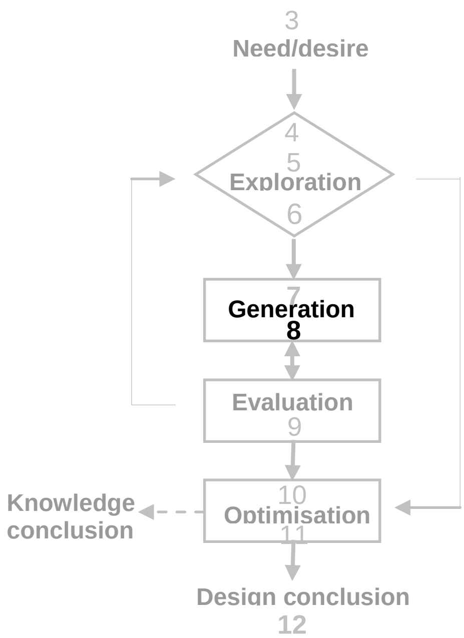
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CHAPTER 8

THE SUBSYSTEM IN ACTION ON THE HOUSING LEVEL; THE SECOND STAGE OF THE MULTIDISCIPLINARY PHASE OF 'GENERATION'

The main subject in this chapter relates to the second stage of the generation phase of the Glocal (Global/local) Process Model (GPM). In a Sustainable Reconstruction of Houses in a Seismic Desert (SRH-SD) area, the generation phase is generally the phase of conceptualisation. However, due to the variety of the discussions required on various levels of design, it covers the subjects of two chapters. The generation or conceptualising for urban habitats as the macro-scale of design has been discussed in previous chapter. Therefore, the meso-level or conceptualisation on the building/housing level is the subject of this chapter. The proposed concept will be validated in the following chapter, where the final concept will be technically elaborated.

Since sustainability is the leading issue in the generation phase as well as the entire design, the aim of the current chapter is to ensure sustainability of the design on the meso-level. After a short introduction, cases will provide the proposed concepts or the design into action on the housing level. This will be followed by a background on the type of influences on the building/housing level (i.e. a problem statement). Finally, an example of a practical case will be presented to apply the main sustainability items for the SRH-SD.

8.1. Introduction

Similar to the phases of the Glocal Process Model (GPM), the Sustainable Reconstruction of Houses in a Seismic Desert (SRH-SD) area represents a complex design case. The first stage of the generation phase of a complex design situation, about urbanism, was discussed in chapter 7. The second stage of this phase focuses on houses and is the main subject of this chapter. However, before the design of houses goes into action in this practical stage, every major issue involved in the complex situation should be considered. Due to the environmental impacts and the harm that human activities (Faye, 2001) and, more specifically, the building industry caused to the earth and atmosphere, sustainability is the main goal.

To ensure sustainability of housing, its "initiatives should be economically viable, socially acceptable, technically feasible, and environmentally compatible" (Choguill, 2007). Meldon (1998) states that housing comprises "the immediate environment, sanitation, drainage, recreational facilities, and all other economic and social activities that make life worthwhile". As related issues, these also show the significance of sustainability on a multi-scale design. Since generation is a practical phase, this chapter implicitly and explicitly concentrates on the ways to incorporate sustainability in the conceptual design. This approach is similar to the study of Dobbelsteen (2004) about a multidisciplinary concern required to achieve sustainability.

This leadership of sustainability for the design by multiple disciplines, which also conducts the design into action on housing level, continues to the evaluation of the generated concepts, detailing and materialisation for the SRH-SD. In order to enlarge the implementation of design solutions for a complex situation to a public scale, the provision of simple solutions may be helpful (Shahnoori et al., 2007; Langenbach, 2008).

Housing has always been a demanding domain of architecture. Therefore, before providing cases of proposed solutions, a general overview on housing and the main constraints for a SRH-SD will follow. Although each phase of the design process includes most of the relevant activities, they are iterative. Therefore, they evolve and complete gradually with other phases (Schön, 1983; Leupen et al., 2005/1997; Shahnoori et al 2010a); sustainability integrates them and improves the efficiency of the design on different domains.

8.1.1. Housing

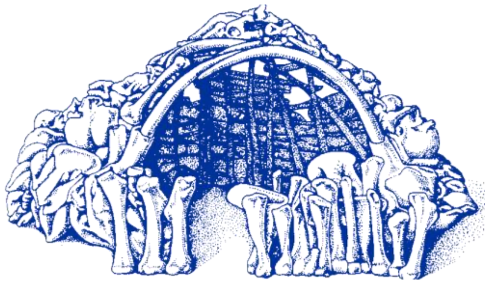


Figure 8.1. The oldest house in the world, Royal Ontario Museum in Toronto (source: Gregorovich)

Housing is one of the earliest concerns of humankind (Durant, 1967). Architectural investigations and studies on house building go back to Vitruvius, who probably lived between 80 and 15 BC (Broadbent, 1996/2005). Housing is a subject that covers much more than only houses, and includes the way houses are occupied. History of the house itself goes back at least to 15,000 BC, to the houses made of mammoth bones (Figure 8.1), found at Mezhirich near Kiev in Ukraine (Gregorovich, 1997/2005). A collection that includes more than few examples can be found in the remnants of houses in Jericho (Ariha) near the Jordan River, which date back to 9,000 BC (Morris, 1979), and Chatal Huyuk in ancient Anatolia, dating from about 7,500 BC (Broadbent, 2005).

According to Forster (2006), the earliest housing was provisional and to some extent mobile. The construction of houses as buildings began with the establishment of the first cities. Housing and dwellings are one of the most important subjects in architecture (Rappaport, 1969; Shahnoori, et al., 2007c), as residential buildings stimulated the first form of architecture (Forster, 2006). Since the early establishment of house construction, there has not been much change in the content; any changes have mainly been in inessential features (Rappaport, 1969). Forster (2006) continues that settlements similar to those “in the 21st century can be found in Antiquity, this applies to both density and high or low-rise”. Although it is the most desired building in an individual’s life (Oliver, 1969), many different approaches towards a house have been found. For example, Le Corbusier wrote about the house as an objectively designed ‘machine for living’ (Cross, 2003). Because a home is very close to human existence, it is formed according to human needs (Pirnia, 2005), so that no fundamental change has taken place throughout history. However, this does not apply to the attention devoted to this subject (Rappaport, 1969; Oliver 1969; Forster, 2006). Because of these two major reasons (i.e., it is the most-desired and the dominant building in the world, and also the least-noticed building in architecture), it needs substantial consideration (Alexander, 1985; Shahnoori et al., 2007e). Therefore, reconstruction houses as SRH-SD are an even more demanding case, affected by both desert circumstance and seismicity.

8.1.2. A worldwide view of problems on the current state of housing

Over the last fifty years, the world’s population has more than doubled, and most of this growth has occurred in developing countries. Half of the population now live in urban areas (WRI/UNEP/ WBCSD, 2002). Khamili et al. (2004) predicted that 98% of population growth in the next two decades will occur in developing countries, most of which will transfer from rural to urban areas. Therefore, an increase in the world's populations means a growth in the inhabitants of urban areas. A comparison of such growth is shown in Figure 8.2.

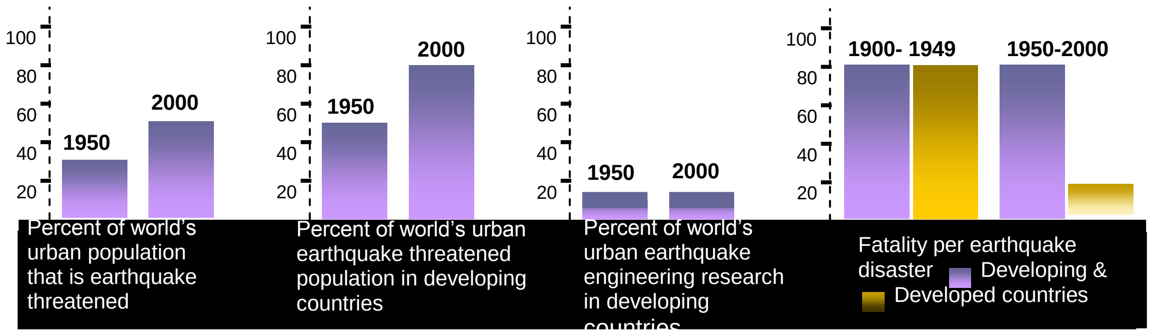


Figure 8.2. Some different items regarding a specific urban growth. data reproduced from PWGHI, 2002

A comparison of urban, rural, and total growth of population is provided in the graph of Figure 8.3.

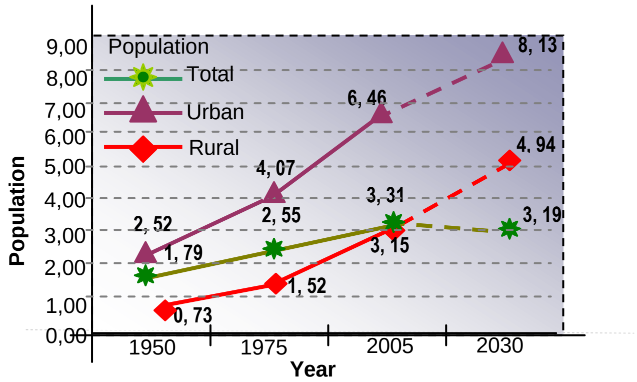


Figure 8.3. World's urban, rural, and total population through different years (source: PWGHI, 2002)

Although population growth in developed countries has almost stopped, they have caused the most significant impact on the environment, which has been recognised in most of these countries since 1990. This has resulted in new regulations for reducing the negative effects of human activities and developments. Progress in controlling the environmental impact is still very limited in developing countries, and population growth negatively amplifies the former.

The immigrants from the rural areas in developing countries need new dwellings, and the impact of these on the environment demands urgent consideration. As stated in chapter 7, most of these immigrants reside in low-quality houses in the vicinity of the urban areas, which cause many problems to not only the urban inhabitants but also to themselves. The low-quality houses aggravate disasters during phenomena as earthquakes, while they may not provide the appropriate indoor climate either.

8.1.3. Conditions of a desert environment for houses

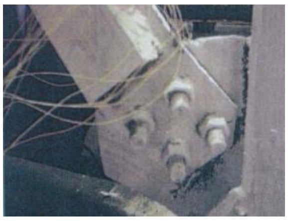
The general problems of desert cities were stated in chapter 3 in addition to a thorough study on desert houses in chapter 5. Besides, a review of the issues in desert circumstances will be treated in section 8.4.1. Therefore, a brief designation of problems suffices the current reviewing background. From a list of problems in a desert environment, further desertification locates on top as the most critical problem. Other significant issues are the harsh climate, great temperature difference between day and night, the great temperature difference between summer and winter, the high velocity of precipitation and the consequent lack of moisture. For the latter issues protection from the intense sunrays and decreasing the receiving energy in the houses is normally the major action to be taken by the designers (see also chapter 5). Therefore, the following discussions mostly relate to the ways that earthquakes affect houses.

8.2. Background and influences of earthquakes on houses

Although about 81% of world's largest earthquakes occur in the Pacific Ring of Fire, many of them occur at other places; around 100,000 of these are felt (USGS, 2010). Almost all the world's earthquake-prone zones are known, but it may occur in places that never experienced seismicity. Most of the seismic areas belong to developing countries. This, with section 8.1.2, shows that one of the main concerns of sustainability should be related to earthquakes. Reconstruction in general and for houses in particular is important on a multidisciplinary scale that involves the three main levels of design: (i) urbanism, (ii) building elements and (iii) materialisation. There are two major issues to be considered on these levels. The first is that, since after a disaster normally reconstruction occurs, the inhabitants are sensitive; this involves social aspects. The second is that urban design also closely relates to the social sciences and their corresponding aspects. Therefore, such a reconstruction is crucially connected to the social systems. This also validates changing the order of the main components of sustainability (see also chapter 4, 6 and 7) for a SRH-SD, which may also become applicable for new constructions in the future.

8.2.1. A brief review on the influences of the seismicity

In earthquake-resistant design, the prime objective is safety of the inhabitants and the passers-by. However, after most strong earthquakes there are always considerable numbers of casualties. Economic issues, although involved (EERI, 2003), are not always the causes of such disasters (e.g. Pino Suarez, 1985). In the past, these damages were mostly due to feeble construction, poor building methods, lack of systemisation and educated labour, and even inappropriate design (Shahnoori, 2005). Such inappropriate or inexperienced designs could be identified after the Mexico City earthquake of 1985. An example is the 'K' bracing earthquake-resistant system (figure 4) that relies on the compressive strength of the members (ESDEP, 1993). In modern buildings, there are many instances of poor-quality construction, involving badly placed reinforcement, poorly compacted concrete, incomplete grouting of masonry, and loose or missing bolts in structural steelwork (EERI, 2003).



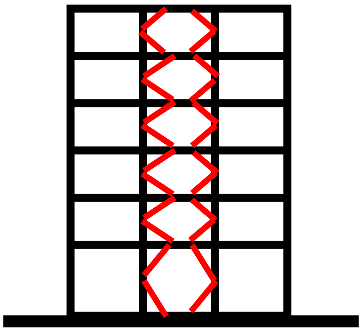


Figure 8.4. Schematic demonstration of the K bracing system

As mentioned in chapter 1, houses are not counted as important buildings in the regulations of most countries. Besides, most earthquake-resistant solutions are either expensive or far too complex for general application in normal houses (see also chapter 4). Nevertheless, the health and safety of the inhabitants is the most crucial duty of designers. Therefore, finding simple solutions, an ever-important task of designers, is very useful. Prior to that, the problem needs to be known in depth. Since earthquakes are not entirely predictable, their intensity may also exceed the design predictions (e.g. Chile, 2010), so collapse, or at least damage, may still occur. Designing a resistant house is possible by knowing the influences of the seismic motion on buildings in practice.

8.2.2. Mechanism of earthquakes and structural collapse

Once people as Geller et al. (1997) stated "earthquakes cannot be predicted", but through progress in the field, it is not entirely unknown anymore. Many studies have been conducted on the mechanisms of collapse. However, the nature of collapse, in terms of "what precisely happens during the few seconds of shaking", is not yet well understood (SD, 2009). To observe the precise procedure, a full-scaled test would be useful, while such experiments are very costly. Hence, it requires special equipment and a test environment (for instance, supporting mechanisms in place, for the moment of toppling over, including the scaffolding for the falling structure).

Failures of buildings of houses in earthquakes due to various causes

With more than 300,000 earthquakes recorded in three decades (1960-90), and an occurrence of 2000 times (including minor, moderate, and destructive earthquakes) a year, earthquakes are the most destructive natural phenomenon on the planet (NDEC, 1999; BBC, 2011). Poor-quality constructions are one of the most common causes of collapse in earthquakes, often involving poor-quality materials and building systems. Additionally, the connections between different elements and between segments of building components are disproportionate major causes of disaster. This includes falling masonry, cladding, dislodged ceiling tiles, window frames separating from the walls and toppling inwards or outwards, and escape paths blocked by jammed doors and fallen masonry, (ESDEP, 1993). Even in modern buildings with good-quality materials, connections remain major issues. This type of problem, leading to disaster, was found in the earthquakes of for example Japan (1964), Ukraine (1977), New Zealand (1987), and Spitak (1988). Other minor design considerations that can cause major disasters are the cases where two adjacent buildings do not have sufficient distance. In this type of situation, adjacent buildings pound against each other. Different floor levels (e.g. figure 5, Mexico City, 1985) these cases can cause major structural damage (Kasai et al., 1991; NR, 1996).

Figure 8.5. Collapse of two adjacent building with different height (source: ESDEP, 1993)

Booth et al. (2006) mention that, in an earthquake, structural collapse may be due to lateral or torsional displacement, local failure of supporting members, excessive foundation movement, and occasionally the impact of another building. Lateral earth pressures are imposed on the retaining structures. Under static conditions, flexible or yielding flexible structures would be subjected to active lateral earth pressures (Lew, 2001). Displacement is a very important factor in the seismic analysis of a structure. The relative displacement of a building is measured by an overall drift ratio or index, which is the ratio of overall displacement to the height of the building (Naiem, 2001).

More specifically, the horizontal translation of earthquake ground motion has the greatest effect on most structures. However, four other components – one vertical translation and three rotations –

also exist and may need to be explicitly taken into account in some cases. Vertical motion affects long-span structures, since they may significantly increase bending and shear forces due to gravity loads. They may also reduce the effect of gravity loads in maintaining overall stability against lateral loads, and so instability calculation should be allowed. In the past, it was normally assumed that the peak vertical acceleration was two thirds of the peak horizontal acceleration and had a similar spectral distribution. However, this is not an appropriate approximation. On firm ground near the epicentre of the earthquakes, the vertical motion can be much greater than the horizontal in the short frequency range, while they become relatively insignificant far from the epicentre. Codes such as Eurocode 8 (CEN 2004) and ASCE 4 (1998) allow for this.

Moreover, on soft soil sites, vertical motion is likely to be amplified much less than horizontal motion, because vertical compressive stiffness of the soil is usually greater than its shear stiffness, so that vertically propagating waves pass through more or less unmodified. Rotational ground motion is not significant. Rocking motion (i.e. rotation around a horizontal axis) is important to very tall slender structures; Eurocode 8 Part 6 requires this to be accounted for in tall masts and chimneys, supplying a suitable rocking spectrum (Vrouwenvelder, 2006). Torsional ground motion (i.e. rotation around a vertical axis) should be included. Serious trouble may be caused by coupled torsional-horizontal response in torsionally unbalanced structures, which can also be triggered by horizontal shaking (Booth, 2006). Finally, referring to Krawinkler et al. (2009), the collapse potential of a building can be stated as the probability of collapse at a discrete hazard level or the mean annual frequency of collapse. As the most utilised building material in the world, structures made of concrete are the case of the following investigations and explorations.

Figure 8.6. A multi- storey concrete frame structure with brick infill wall (photo: USGS, 2006).

8.2.3. Damage categorisation in building structures

According to Moehle et al. (2005), the primary cause of collapse of reinforced concrete buildings in earthquakes is the loss of vertical load-carrying capacity in critical building components, leading to cascading vertical collapse. Failures of columns, beam-column joints or both have been identified as the most common cause of collapse in in-situ cast beam-column frames. At the time of axial failure in structural components, both gravity and inertial effects create vertical loads that are transferred to the adjacent framing components. Therefore, both the capacity of the framing system to transfer these loads to adjacent components and the capacity of the adjacent component to support these extra loads are important. This is because at the time of axial failure the frame needs to continue to support vertical loads, which depend on the factors mentioned (Moehle et al., 2005). In the study of Otani (1999) on the damage statistics of reinforced concrete buildings, these damages were divided into three main categories:

1. Operational damage (light to minor damage): columns or structural walls are slightly damaged in bending, and some shear cracks might be observed in non-structural walls.

2. Heavy damage (medium to major damage): spalling and crushing of concrete. Buckling of reinforcement, or shear failure in columns is observed, while the lateral resistance of shear walls might be reduced by heavy shear cracking.

3. Collapse (partial and total collapse).

Many of the investigated cases of causes for collapse of houses with relevant examples are collected in Table 8.1.

Table 8.1. Causes of collapse and cases of occurrence

problems	Causes	Examples of relevant cases
Materials	Using inappropriate/ incompatible materials	Peru 1970, Mexico 1993, Bam 2003
Materialisation	Inappropriate production & performance. e.g. concrete	Istanbul 1995, Acapulco 1996, Bam 2003
Lack of suitable construction Systems	Design, performance	Chile 1960, Huacho 1966, Peru,1970, Bam 2003, Pakistan 2005
Performance	Uneducated labour	Peru (1970), Bam (2003)
Narrow or zero distance of buildings	Mainly design	Mexico City (1985)
Floor difference of adjacent buildings and pounding damages	Design on different levels in addition to performance	Mexico (1985), Saguenay, Canada (1992), Cairo (1994), Northridge 1994, Kobe 1995, Kocaeli 1999
Connections between: Structural elements; Structure and other parts; Fulfils and other parts	Design and performance	Armenia, Ukraine , New Zealand, Japan, Spitak 1988
Considerable difference of gravity concentration centre between parts of a building (mostly industrial)		
Considerable height difference in a building, structural elements are not appropriately disconnected		
Inappropriate proportions in a building, the ratio of the length compared with the width is too high		
Un-estimated differences in the plan, unidirectional imbalanced shapes and forms		
Inappropriate design (weak or even lack of seismic design or robustness)	Pina Suarez complex in Mexico City (1985)	
Abrupt change in structural stiffness or mass distribution	Mexico City Ministry of Telecommunications' building	
Considerable variations in the strength, mass and stiffness of the stories	Mexico City Ministry of Telecommunications' building	

PEER (2009) notes that if a structure does not have a good alternative loading path, local failure will expand to other components and may end in an entire collapse (i.e. progressive collapse). A local failure is the result of a typical collapse mode, so yielding appears at a weak component of the structure and then results in large concentrated deformation (Xinzheng et al., 2008). Types of collapse in the later classification are also recognisable in some instances of the summarised practical examples of Table 8.1.

After all, the structural design and performance may not directly issue any problems, and thus it may undergo several earthquakes without disintegration. However, they may collapse due to problematic soil conditions. The actions of the soil due to its constituents, property, and structure, as well as the frequency of surface motion, especially when close to the foundations of the building, may increase the extent of the damage (Vrouwenvelder, 2006). Large amplifications are possible (e.g. in very soft soils) in earthquakes with low amplitude (SCI, 1993). For example, for San Francisco Bay, more than 20 mud amplifications have been recorded (NR, 1996). Nevertheless, in strong earthquakes, if the amplitude increases and the soft soil yields, peak accelerations normally decrease (SCI, 1993) due to the transmission through the upper levels of soil.

Figure 8.7. Soft story collapse (DHUD-OPDR, 1994);
Relationship between the natural period of the soil and alluvial depth (Seed, 1970)

Naturally, the layers and levels of soil on the surface and around compose a dynamic system. Although weight of buildings is negligible regarding the earth's mass, the rigidity of the top layer connected to the building at the small spot where the building foundations lie can modify the surface response due to the decline in the local flexibility of this system (at the footprint of the building). This local flexibility modifies the vibration modes, lowers natural frequencies, and generates additional cushioning through energy dissipation in the surrounding soil (SCI, 1993). According to SCI, an increase in response can occur, but the general effect is to produce a reduction in base shear. Although pillar foundations produce lower cushioning effects, compared to bearing foundations, they have a smaller effect on the mode shapes and frequencies, while they may be a lot more expensive.

Regarding these, surveying two essential issues are common, including: (i) the difference between the failure patters due to the cyclic load of earthquake and the ones which are caused by static loads applied in single direction, (ii) the behaviour of the structure after yielding (Krawinkler et al., 2009). In theory, for both of these appropriate design methods and calculations, and dividing the responsibility for a successful performance, are very important. The latter is for not only the design, performance, and executive team, but also applies to the structural membranes.

8.2.4. Simplifying the essential points, background knowledge for the design

- Different from effects such as wind loads, the earthquake forces in a building structure do not arise from externally applied loads. Instead, response is the result of cyclic motions at the base of the structure causing accelerations and hence inertial forces, which require a dynamic response that incorporate consistency and cushioning.
- Inertial force causes an opposite reaction to that in the mass upon the ground (D' Alembert's principle).
- Damage is not due to displacement but to acceleration.
- The amplitude of the vibrations diminishes in time. The speed of the movement in reaching maximum movement causes most of the damage to a building, while the dynamic amplification causes further damages.
- Short buildings are stiffer, while tall buildings are more flexible.
- The decrease in the vibration is highly dependent on cushioning.
- The materials used in the structure have different levels of intrinsic cushioning. Increasing the extent of cushioning is one of the most efficient ways to reduce vulnerability.
- Resonance takes place when the frequency of excitation matches the natural frequency of the structure. Principal ground motion frequencies in a rigid soil or rock are normally within the range of 0.2-0.4 s while they may reach 2 s or more on a very soft soil. Resonant amplification may well take place in common ranges of building height because structures have fundamental frequencies of approximately 0.1 N (where N is the number of storeys).
- According to observations and experiments, the ultimate deformation capacity is associated with a sudden failure mode.
- The certain behaviour of buildings under seismic loads is not entirely known. In this regard, the main problem for buildings to survive earthquakes is a high uncertainty of the load situation, the intensity, orientation, and duration of the load. Therefore, simple load-bearing structural systems that offer more reliability in both design conclusion and the performance are preferable to complex ones regarding unknown lateral and vertical seismic loads.

Although in the above investigations many cases of destruction were taken from deserts, they generally concern houses in earthquakes. Therefore, next section focuses on desert cities as Bam.

8.3. A survey in the building damages and destruction in Bam

As mentioned in previous chapters, on 26 December 2003 an earthquake with a magnitude of 6.5 struck Bam, a desert town in south-eastern Persia (Zare, 2004). The earthquake destroyed 80% of the houses, with 17% of damaged buildings (Havaii et al., 2004) being beyond repair. In addition to the significant damage to the Citadel of Bam, more than 30,000 houses were destroyed (Shahnoori 2005; Astaneh et al., 2006).

8.3.1. Case related survey on collapse of houses of different construction types

In addition to traditional adobe houses with thick walls and roofs (Shahnoori 2005, Maheri et al. 2005) mainly of mud bricks, in the eastern districts of Bam and the villages in the vicinity, the majority of the collapsed and severely damaged houses comprised masonry buildings that had undergone no specialised engineering. These buildings contained brick load-bearing walls and flat roofs. This special flat roof of Taghe Zarbi is called 'jack-arch' roof, after the system inside the covered roof. It has a rise of about 2.5-7 cm between the two adjacent steel beams with an I-shaped cross-section. These I-beams in the roof are placed serially at a distanc

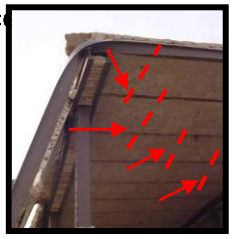


Figure 8.8. Examples of jack arch or Tagh zarbi roof system

To balance the horizontal push-out force of the arch on these beams, the bottom flanges, situated at close intervals, are connected by rebar(s). These heavy masonry houses without appropriate strength and with poor ductility result in huge losses even in moderate earthquakes (Astaneh et al., 2006). This type of non-standard construction has often been at the root of disasters during earthquakes in Macedonia, Skopje, 1963; Peru, 1967; Italy, Friuli, 1976; Yugoslavia, Montenegro, 1979; Mexico, 1985; Slovenia, 1988; Manjil & Roudbar, 1990; Zarand, 2005; Firoozabad e Kojour, 2005.

Figure 8.9. Masonry houses in the earthquake of 1976 Slovenia (Lutman et al., 2002)

Evidence of the effectiveness of inspection and qualification is the row of houses in a (rather) newly built residential zone in Bam. This zone can be divided into two significantly different parts. The first group experienced severe destruction, while damage to houses in the other part was insignificant. Notably, they locate at an equal distance from the fault line, so that they experienced the same energy of motion. Hence, it was either a design- or a construction-related issue. Field investigation revealed that the destroyed rows of houses were built with the same or at least a similar plan. Due to the different and insufficient details for the houses of the destroyed row, the municipality did not approve of their design at the time of construction, but they were built nonetheless due to the influence of some powerful political parties. The other piece of evidence is the housing units and complexes in Arg e Jadid (the New Citadel), which experienced only minor damages in their facades and non-structural elements, due to their proper design and performance (Shahnoori, 2004).

Figure 8.10. The row of houses with horizontal and vertical standard structure

General data about houses in Bam, taken from the census of 1996, are shown in Table 8.2.

Table 8.2. Number of houses with general typologies (adopted from Astaneh et al., 2006)

Housing groups	Numbers
Houses of engineered reinforced concrete or steel structures	31
Adobe built houses, inc. mud brick and traditional systems	17524
Masonry built residential units, brick and mortar with or without steel	13364
Sum of occupied residential unites	34531

In-situ observation included more than these cases, because many of the destroyed buildings other than houses were also made of the same materials and building system. For example, the main water reservoir, made of standard qualified reinforced concrete, experienced minor damages from the quake. Figure 8.11 is an example of the damage level of different categories of buildings in Bam.

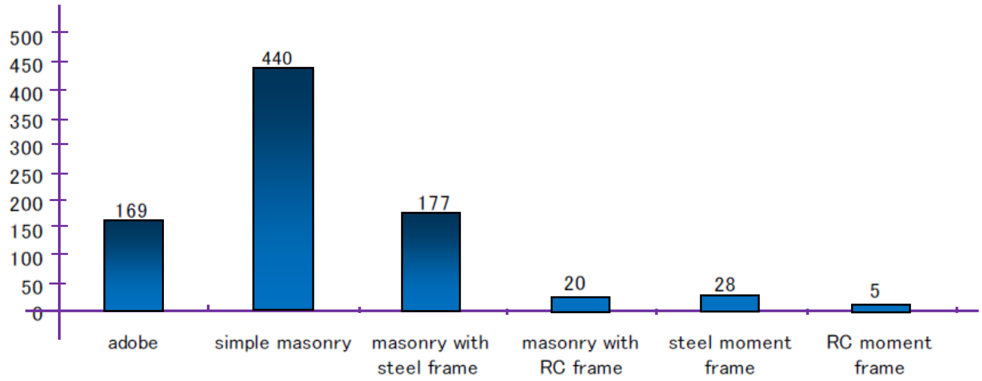


Figure 8.11. Number of each building types from a total number of 830 (data adopted from Hisada et al. 2004

In many instances, heavy construction materials were the cause of injuries and death toll in houses. Several cases were subjected to thickness measurements of their roofs (and walls). Table 8.3 shows some examples of these surveyed cases.

Table 8.3. Average thickness of roofs and walls of different systems of some buildings in Bam

Items Constructions & materialisation	Number Roofs	Average Thickness	Number and average thicknesses of walls			
			Extern	Thickness	Internal	Thickness
Houses of adobe construction	12	57	12	39	24	32
Masonry constructions	12	28	12	33	24	11
Constructions of modern materials	12	31	12	25	24	11.5
Notes	Roofs of masonry houses are considerably thicker than other functions		The thickness of walls in masonry systems vary quite extensively (from 6cm to more than 41cm), this variety was not found in other systems			

Another exception was found within residential buildings. Although houses of this group were built of standard seismic-resistant systems with acceptable quality of materials (e.g. reinforced concrete), they were also damaged. For example, a three-storey house, built in the wider site of the riverbed was destroyed because of soil instability (i.e. soft soil of the riverbed), as shown in Figure 11. Therefore, in the future, prior to building houses on the riverbed of Poshte Roud, the ground needs to be carefully studied.

Figure 8.12. Due to instability of the soil the entire rigid structure was turned (photo: Google image)

8.3.2. Outlines as design supports for going into action

Summarising the considerations on a structural level for a reconstruction building in Bam that can resist earthquakes:

- Suitability on the ground level (houses should be built either on firm ground, or the soft soil should be worked out in order to act properly as the base of a house)
- Form of the building, proportional dimensions, a balanced plan
- Building configuration, concept of the building, weight centralisation/gravity
- Selection of an appropriate load-carrying structural system.
- Providing and enhancing the integrity of the structure

- Avoiding critical connections, instead simplifying them in order to increase the integrity
- Simplifying the details of the structure of the house to ensure the accurate performance
- Minimisation ('zero-misation') of design-oriented problems
- Appropriately materialisation of the house
- Quality control of the materials as well as the building elements and components in the design and the performance.
- Minimisation ('zero-misation') of the performance-related problems
- Simplicity of building systems. Simple systems are the best option and are more useful for various applications in large-scale reconstruction; hence, they fit in the market demands worldwide.

For a SRH-SD, the house needs to survive the earthquake while providing a comfortable indoor (as well as the outdoor) climate. Integrated design can use the potentials of form to avoid the intense desert sunrays and to resist seismic loads, as much as possible. However, for simplicity of the Glocal system, some advantages that uncomplicated traditional forms can offer for desert houses will be discussed next.

8.4. Form, desert houses, and stability

It is often thought that building form is only an aesthetic aspect and therefore not rationally necessary. Even if this interpretation of form is true, the meaning of aesthetic does not interfere with rationality. Especially in vernacular architecture rationality of form is significant (Scott, 1954; Langer, 1957; Atkinson, 1969; Oliver, 1969; Rappaport, 1969; Knuft, 1996; La Vine, 2001; Saliklis, 2006).

Form in architecture has sometimes been architect-centred or client-driven (Howard, 1966), whereas, due to the nature of vernacular architecture, form is absolutely human-oriented. From Antiquity onward, a house has been directly adapted to meet human needs (Pirnia, 2005). The forms in the interior and exterior are exactly according to the use and human need (Oliver, 1969; Kris et al., 2004; Saliklis, 2007), and thus with the human scale. Due to aesthetic aspects, the form touches the feelings of the user, so that everything that deviates from standard needs to be carefully studied first. For example, in the form finding for the houses of SRH-SD, one needs to consider the two major issues of desert climate and seismicity.

8.4.1. Climate and form in deserts

The general specifications of local architecture in Bam were presented and discussed in Chapter 5. Traditional houses in Bam, similar to the ones in many other desert cities in the central desert of Iran, comprise a passive system. In terms of form analysis, it has been stated that the roofscape in these cities is heterogeneous but harmonious, as a result of a combination of cupolas and flat roofs. However, in the specific situation of Bam, domes were the dominant form for the roofs of the houses (Figures 8.13 and 8.14).

Figure 8.13. Houses in Natanz, Yazd, Kashan, and a cistern in central desert, Iran (source: Google image).

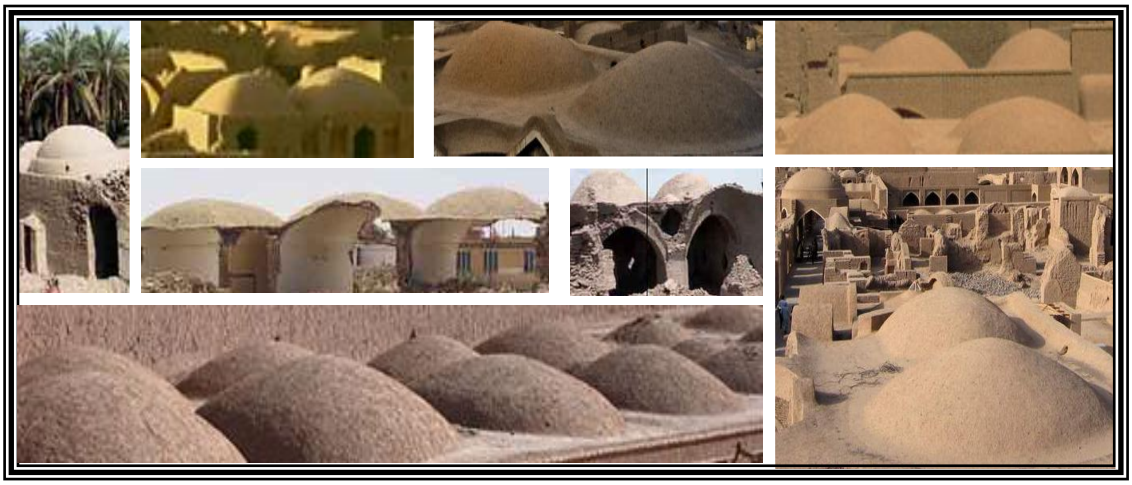
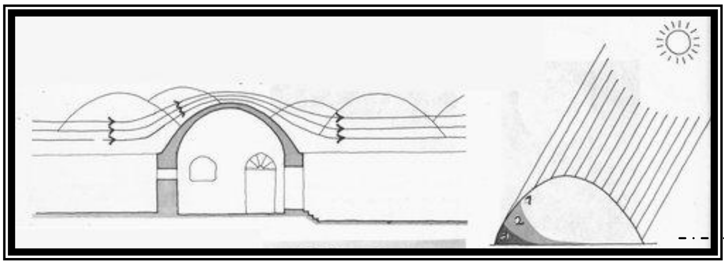


Figure 8.14. Examples of dome-roofs for houses in Bam (photo: AEI-MC 2004)

A global study shows that, traditionally, the dome is the prevailing system for desert houses in many countries as Syria, Israel, Pakistan, Botswana, Mali, Cameron and Ghana) (e.g. Figure 8.15). According to Khalili (2005), more than 50% of the world's population, approximately 3 billion people on 6 continents, live in earthen constructions, many of which have vaulted roofs.

Figure 8.15. Dome houses in (i) Syria (ii) Israel, (iii) Cameron, (iv) Pakistan (source: Google images)

In addition to the availability, thermal mass (delay in the heat transfer), thermal resistance and conductivity of adobe, the dome form provides further advantages for a desert climate. It has been a structural solution to the desert conditions and a passive system (Lute, 1992). It is a compatible form for dealing with both hot summer days and cold winter nights (where the difference exceeds 45°C). When the intense desert sunshine contacts its surface, the dome form provides proper angles of deflection, absorbing the least severe energy (the sketch in Figure 8.16), certainly in comparison to a flat surface.



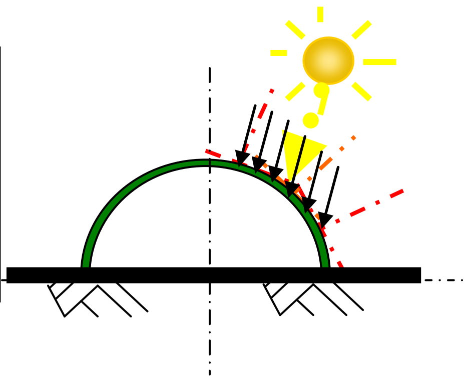


Figure 8.16. A copula under the desert sun rays

Researchers have studied and proven the climate, economic, etc. advantages of using a dome (Pope, 1965; Levy et al., 1992; Gwendolyn, 2003; Pirnia, 2005; Stephenson et al., 2005; Balaguru et al., 2008). Besides, some designers have applied it for various purposes (e.g. in Table 8.4).

Table 8.4. Examples of design of dome constructions and houses

Nr.	The project	Designer	Year
1	El Temple Expiatori de la …	Antonio Gaudi	1883
2	Zeiss plant in gena	Walther Bauersfeld	1922
3	AirForm House	Wallace Neff	1946
4*	Geodesic Dome*	Buckminster fuller*	1949*
5	Dome House (Wood House)	Paolo Soleri	1949
6	Drop City	Bernofsky (et al.)	1965
7	BiniShell	Dante Bini	1967
8	Benghazi Dome	Wallay (1998)	1968
9	Magma Structures Lunar …	Nader Khalili	1984
10	Architecture	Justus Dahinden	1987
11	Glass Dome	Frei Otto	1972
12	Nagoya Dome	Takenaka Corporation	1998
13	Eden Project	Nicholas Grimshaw	2000
14	Eco-Dome	Nader Khalili	2004
15	Modular system for housing	Belmouden (et al.)	2007
16	Styrofoam Dome Home	International Dome House inc.	2008

Fuller (1926) also invented Dymaxion house, a non-orthogonal futuristic concept

As the proportions of the dome vary, the concept offers a range of forms (e.g. spherical, parabolic and egg-shaped). This variety further increases according to structural systems (shell, arches, etc.) and materialisation (adobe, concrete, etc.). However, discussions in this section cover quality of the dome as a form (in general) and its particular characteristics regarding seismicity and a desert context for the SRH-SD.

8.4.2. Using potentials of forms to resist earthquakes

Surveying traditional buildings that experienced earthquakes in Pakistan, Afghanistan, Iraq, Iran, etc. reveals the strength of the dome or copula forms compared to that of the flat roofs. This fact was also indicated about central and south-eastern Persia in chapter five. In the study of Maheri (2004) seismic vulnerability of traditional buildings in Iran was investigated as well. Dome forms for the roofs in these traditional houses undergoing seismic motions were proven stronger than the flat roofs in an equal situation (Maheri, 2004).

Penelis and Kappos (2005) consider that, in order to avoid collapse, the structure should be able to absorb and dissipate the kinetic energy imparted to it during the seismic excitation. This involves not only the materials but also the structural form and organisation, which are related to the stability of the structure. Because this structure is going to be a human home, psychological stability is also fundamental (Dietz, 2003). In the structures, stability is possible by the proper arrangement and interconnection of structural components that acquire adequate strength and rigidity (Merritt et al., 1990). As a case, these points will be incorporated in a seismic application of an appropriate building configuration, such as a homogenous form as a desert dome.

8.4.3. Form and principles for the houses in a SRH-SD for the cases as Bam

In this part the local survey and study is combined with the outcomes of Zare, 2004; EERI, 2004; Un, 2004; Hanssen, 2004; Havaii et al., 2004; Kyono et al., 2004; UNDP, 2005; Astaneh et al., 2006; Belmouden et al., 2007; etc. These studies showed that to cope with and withstand an earthquake of 6.5 (as that in Bam), local specifications for the structural design involves:

- Highly seismic hazard with a value of 0.3*g (in which the highest value is 0.35*g; for future design, this could be extended to 0.45*g). The hazard level depicted on the hazard map, a reiterative period of 475 years corresponds to a hazard value that has 90% probability of non-exceedance over 50 years. This is standard level chosen for ordinary constructions (e.g. private houses).

- A maximum acceleration (PGA) of the order of 0.3*g for a return period of 475 years.
- In some places, the local soil corresponds with the class **IIa** (moderately soft soil). This implies that a 3 to 4 times amplification of the ground motion in these places of Bam is possible.
- With the three previous characteristics we obtain a value between 1.2*g to 1.8*g for the maximal ground acceleration (PGA).
- The earthquake depth in Bam was about 7 to 10 km (Hanssen, 2004); so here it will be about 8 km, which explains the high acceleration value (higher than the model for a magnitude of 6.5).
- According to the EC8 Eurocode, the elastic spectrum was **Se** for soil type class **D** (soft soil).
- The vertical ground acceleration is 0.7 times the horizontal one (based on Eurocode consideration)

Variation of dome forms and examples

As mentioned, a cupola may also include different forms. For example, for an egg-shaped roof (parabolic/styloid), the surface and volume may be found by using the following formulas:

$$A = \int_{-r}^{r} \int_{-\sqrt{r^2-x^2}}^{\sqrt{r^2-x^2}} \sqrt{1+4x^2+4y^2}\,dxdy \qquad V = \int_{-r}^{r} \int_{-\sqrt{r^2-x^2}}^{\sqrt{r^2-x^2}} (r^2 - x^2 - y^2)\,dxdy$$

From the Lagrange interpolation method: $V = \pi \int (P(x)^2) d_x$

By using similar methods as the ones in the examples above, it is possible to calculate the surface area and volume of various geometries, as crucial issues for sustainability in desert circumstances. Examples of comparing some forms are subject of a research in the following.

Methodology for exploring the capacity of a dome form

Three examples of simple forms but with various geometries (figure 8.17) – a dome together with two other uncomplicated forms of a cube and a tubular concept – were compared. This comparison is shown in Table 8.5. In this table, the proportions of three radiuses are calculated for each of the three forms, mainly for the purpose of indoor air volumes and exposed surfaces to the sun, based on geometrical homogeneity as a principle for stability.

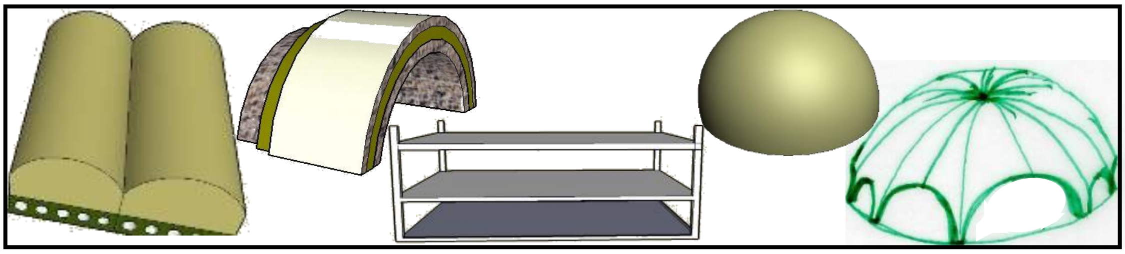


Figure 7.17. Three concepts of a Dome (frame & shell), tube/cylinder, and an orthogonal frame structure

Table 8.5. Comparison of various proportions of the alternative forms base on different radius

R (Radius)	Height	Shape	Plan foot print	Volume	Surface area
5	5	Dome	78.5	261.67	157.00
		Cylinder	100	399.50	235.5
		Cubic	100	500.00	400.00
5.5	5.5	Dome	94.99	348.28	189.97
		Cylinder	121	522.42	284.96
		Cubic	121	665.50	484.00
6	6	Dome	113.04	452.16	226.08
		Cylinder	144	678.24	339.12
		Cubic	144	864.00	576.00

The structures in all three concepts are made up of a two-open-floor building as a typical town house for two average families. Analysis of these results, in conjunction with the principles discussed previously, provides the opportunity to compare them, as shown in Table 8.6.

Table 8.6. Comparing three types of structure with three important criteria

Structure	Stability	Energy saving	Material minimisation
Dome	Excellent	Excellent	Good-excellent
Cylinder/tubular	Good	Good-excellent	Acceptable- good
Orthogonal	Conditional	Conditional	Not good-Acceptable

According to the results of comparison, the two forms of dome and tubular house seem to acquire priorities compared to a rectangular flat roof of a cubic building. This advantage of energy saving and compatibility with the climate and the environment is significant for a desert circumstance. However, these houses also need to be tested and compared in terms of stability and structural behaviour under the seismic loading (e.g. figure 8.18). The main problems issued by the conventional frame and the flat roof (e.g. vulnerable connections) were discussed in Chapter 4, and practically with reference to damage cases in section 8.2. Therefore, for both seismicity and desert climates the two other forms are followed.

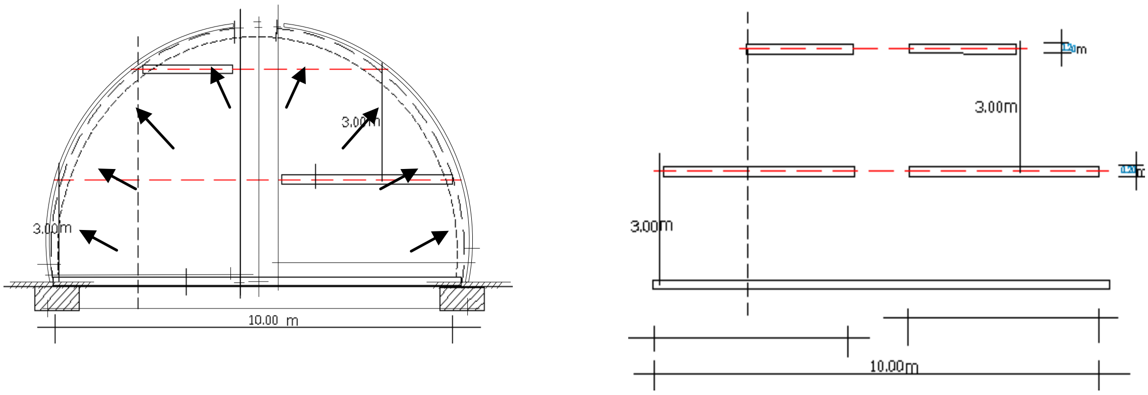


Fig 8.19. The dome concept modelled under the loads and the internal divisions

Therefore, the analysis continues with simulation of loading an example of the dome (figure 8.19a) and the one of a tubular structure (figure 8.19b).

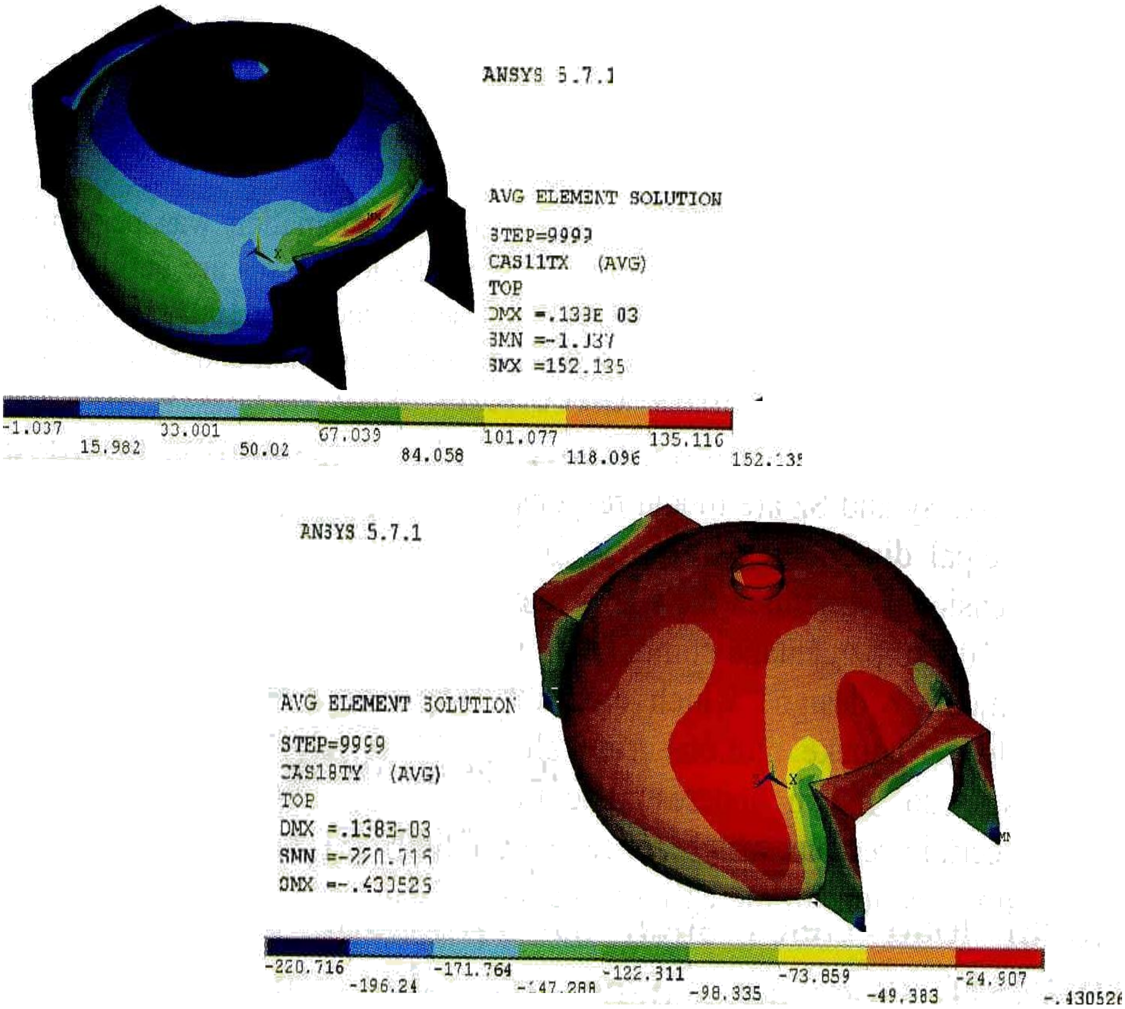


Figure 8.19a. Membrane normal forces in x-element direction Tx in load case 11 (left) and in y-element direction Ty in load case 18 (left)

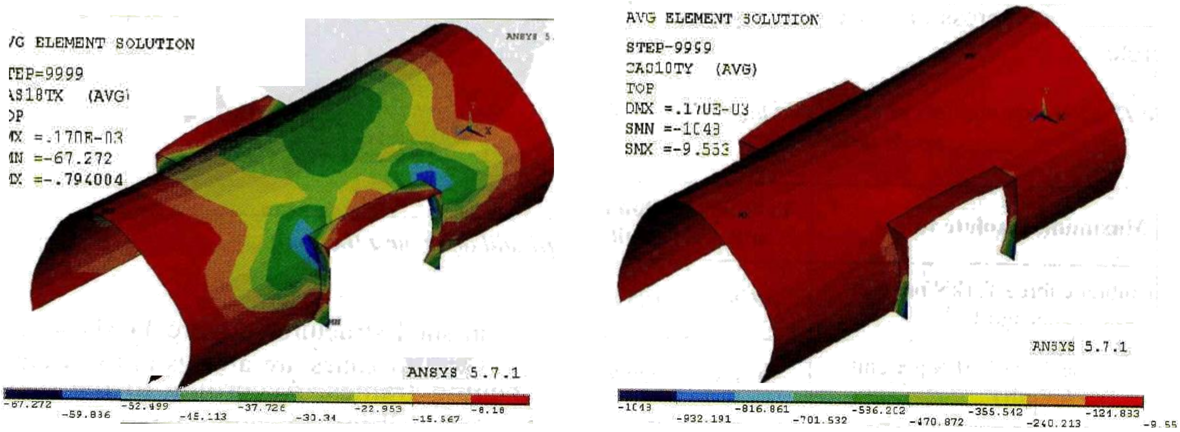


Figure 8.19b. Membrane normal forces in x-element direction Tx (left) and in y-element direction Ty in load case 18 (left) (source: Belmouden et al., 2007)

Compared to the tubular, under an equal loading (figure 8.19a and b), the case of a dome structure with a maximum absolute horizontal displacement equal to 0.097 mm in X direction is more rigid than the cylinder structure in the X direction (Belmouden et al., 2007).

8.5. Discussion and finalisation

A city in a desert circumstance is basically vulnerable not only for the desert expansion and desertification (Kibert, 2005), but also potentially challenging with the desert harsh climate (Pope, 1965). Two foremost ways for a sustainable development of buildings in deserts are (i) protecting the building against the unwanted energy in the hot seasons and losing the heat from inside in the cold seasons, and (ii) optimal use of the solar energy. To ensure a high level of sustainability, integration of both of them in the building construction and its circumstance is a good method (Ray-Jones, 2000). Similar to Ray-Jones this study proposes a combination of the natural and green protection in a building enclosure and on the urban level (see also chapter 7). As Sekkei (2000) uses the design, form and its capacity to deal with the nature, this study proves that the quality of form has a great effect on energy saving. This is in one way an economical advantage and in another way is environmentally sound (Luke, 2004). Another sustainability aspect that the form offers is optimisation in the energy in a way to save the energy resources for the future as it can minimise the indoor volume. According to the book of WCED (1987) and the Brundtland-report (1987), future development crucially depends on long-term availability and quantities of sources. Finally, as Pope (1965) proved the quality of a dome form fitting in the desert circumstance, and Maheri (2004) showed the seismic resistance of this form, this study found that using the technique of a free form Blob (Eekhout, 2004) for a local application appearing in a copula form, technically is a good solution. This solution also fits in the results that Pirnia (2005) and Khalili (2005) presented. Fuller also experienced this in 1940 in a geodesic dome, achieving the least surface area by a sphere enclosing.

For the load-bearing purpose, as constructed by the firm of Dykerhoff and Wydmann on the roof of the Zeiss plant in Jena, Germany, in 1922, a dome is a form posing potential for optimisation. Another famous case, as mentioned before, is the geodesic dome invented or at least developed by Buckminster Fuller in 1940 in the US. The geodesic dome was greatly respected because it was extremely strong for its weight; its surface provided an inherently stable structure. With the seismic condition, the structural stability is even more important (Penelis & Koppos, 2005). Although earthquakes were identified as the most destructive natural hazards (MIT, 2004) the amount of destruction and the intensity in detail in different regions sometimes show very different results. For example, the 7.1 magnitude earthquake of Buin Zahra in 1962, caused 12,200 deaths (Berberian, 2001), whereas during the Loma Prieta, California, earthquake of 1989, with the same magnitude only 62 people died (Gillard et al., 1995). Of course this was also due to the differences in disaster preparedness (inc. the construction and standardisations), and disaster mitigation (MIT, 2004).

No study can prevent the occurrence of earthquakes yet, but the effect of preparation (e.g. construction, structural enhancement, building codes improvement) was historically proven. One important item that can help to improve the structural behaviour in a severe load (as that of strong earthquakes) is using the quality of form (Habraken, 2000). Deleting or minimising the critical joints and connections of the structural members to make them react as a uni-body under the dynamic load is a quality of free-form blob (Eekhout, 2004) that makes it a good solution for the seismic resistance. However, the homogenous reaction as the critical goal is not dependent only on the blob form. Nevertheless, this will increase the safety (Merritt et al., 1998) of the structure at the time of the movement (Hart et al., 2000).

Belmouden et al. (2007) that modelled the cylinder and dome form for analysing it under the seismic load found that distribution of reinforcing elements in the concrete composite as a shell structure for such a purpose is one important element. According to Levy et al. (1992) the “dome owes its stability to the curved, continuous shape”. Levi et al. (1992) regard it as being similar to a man-made mountain, offering the corresponding advantages. Similar to the study of Belmouden et al. (2007) this research found the dome form to be technically a good alternative solution for a typical building, reacting to a desert earthquake the magnitude of 6.5 (i.e. the one in Bam).

A very important factor involved in the sustainability of construction is the materials for reconstruction (Hendriks, 2002). In order to provide sustainability of the construction, minimisation of the material use is an important factor (Dickson, 2002), and for this, using the potential of form is a good option (Habraken, 2000). Because the material minimisation is highly important in Bam, the form assistant for the minimisation should be seriously taken into the account. This minimisation will save the natural resource from depletion (Brundtland-report, 987) to ensure sustainable development (Dobbelsteen, 2004). The economic and climatic compatibility of the dome structure was experienced before in a similar situation in the Arizona desert in the USA in 1964 in Drop City (Sadler, 2006). However, a different problem during the time caused this city to be emptied of its population now. Therefore, using Drop City as a lesson learnt from history, different aspects involving in a living surrounding should be taken into the account. These will be investigated during evaluating sustainability of the design in the next chapter. Therefore, in a comparison between the cubic, cylindrical and copula form, similar to Nader Khalili in the US desert, this research indicated that from the material minimisation viewpoint, the copula form is preferable.

Sustainability is a multidisciplinary area. Therefore, although the potentials of a dome house have been explored, using this form for the SRH-SD needs to be validated in respect to various aspects. This evaluation will be pursued in the next phase of the GPM, which is the subject of chapter 9. Finally, design on the building level (i.e. houses) is a bridge between urban design and design on the element and materialisation level. Therefore, sustainability criteria for houses are also in a similar interconnection stage between these two levels. An example of application of such criteria for a SRH-SD in practice will follow hereafter.

A connecting criteria for the SRH-SD, a case of practical applications

To provide criteria for a sustainable reconstruction of houses at the level of urban planning and design, narrowing down to the building level, focusing on materialisation, checklists are useful (as argued in Chapter 6). For example, the hierarchy or prioritisation in sustainability and the scale of items involved in a checklist for such a sustainable planning for a SRH-SD is shown through examples in Table 8.7.

Table 8. 7. Priority in the main categories of sustainability and example of checklist

Nr	Main Categories	Sub-categories	Criteria on urban planning level
1	**Environment**	Air	Type of pollution Degree of air pollution Effects on ozone…
		Water	Amount of water usage Type of water pollution Degree of pollution …
		Nuisance	Degree of pollution (level of noise), noise complaints…
		Natural resources	Raw material required Accumulated depreciation of natural resources Type of extracting system(landscape degradation) Total extracted materials (resource degradation) Sum of waste per unite …
		Landscape	Land required for housing, sheltering and rescue General Land-use in town planning Scenery, hills, parks, water and public accesses Green protection for desert town Combining agriculture with recreation facilities Protected sites Land degradation effects of each type of land use …
		Energy	Amount of required energy (energy consumption) Renewable source of energy Non- renewable energy

			Fossil& non-fossil fuel for household/residential transport …	
		Waste	Liquid	Level of toxicity of the waste Amount of non-toxic waste …
		…	Solid	Degree of toxicity of the waste Amount of non-toxic waste Required time for degradation Required place for deposition …
2	**Social systems**	Basic needs (water, food, education, health)	Male and female population Total population Rate of population growth Population density Dominant age Migration in and out Life expectancy …	
			Water	Public accessibility Private accessibility…
			Food	First aid supports Job …
			Education	Basic education nr. school, number of students (girls and boys) Higher education (nr. university or others) Number of students (girls and boys)…
			Health	Basic health care system Insurances…
		Socio-cultural issues	Social desires Cultural identities General social trend Main socio-cultural activities and required supports Social connectivity Public spaces and accesses Type and effects of crime prevention activities…	
		Lifestyle	Households system Family finance Job status in family life Entertainments (effective also on drag/ crime prevention) Healthy diets (children, adults, seniors) Mental influences on life…	
3	**Economy**	Local politics	Growth rate, local and global Adjustation of regulation Incorporation of sustainability in business & industry…	
		Global politics	Sustainability of economy in a global comparison Eco-costs Global changes Global share of interests…	
		Raw materials	Materials consumption per capita Export and Import Various transportation required Renew and recycling Side activities…	
		Jobs	Share/variety of main activities Number of job offered per each activity Skill level required various jobs Average income per family Net income per family in each branch of activities…	
		Market & profit	Unite per capita Local financial resilience Retail sales per capita Tourism Transportation …	

* the items are only samples, the main categories are the only completed area of this table, sub-categories and checklist of criteria may continue and subject of further detailing.

8.6. Summary and remarks

Apart from the passive system provided by the dome house, the volume of space created with an equal footprint (compared with the two other alternatives), requires less energy for heating and cooling. The smaller surface area provided by a dome also minimises material use in the structure of the house. Additionally, disintegrity of the structural elements, a major issue of which was the weak connections between the elements, was found as critical causes of collapse. Regarding the integrity of elements in the dome, the entire concept can act as one integrated structural component, as a super-structure that requires only proper connections to the foundation. Hence, the dome house is also a stable concept, which is important in earthquakes. In view of the advantages mentioned, it can be concluded that, economically and environmentally, the dome seems a good solution for the SRH-SD as an outcome of the generation phase on a practical level.

Earthquakes in many cases (Bam, 2003; Kojour, 2004; Pakistan, 2005; Wenchuan, 2008; Haiti, 2009; Chile, 2010….) caused disaster on the one hand, but on the other hand, it created the opportunity of redevelopment. Therefore, reconstruction of houses in destructed cities can occur on a basis of sustainable development, easier than in a normal non-destructed situation.

- For a desert town (or a small city), a house means a single-family house.

- Regarding the desert climate, using indirect sunlight in the house by combining introvert spaces and trees is helpful. For a desert city as Bam, trees in houses are important to provide shading by their dense leaves in the summer and allow the sunrays to enter the house in the winter when they have no leaves.

- A dome proved to be a technically sound alternative for the SRH-SD in areas as Bam, but the concept of the dome is only an example and may change. The main generic conclusion relates to the integrity of the structural elements that needs to be applied in the practice for a SRH-SD. This means avoiding connections in critical parts of the structure by using the potentials of form.

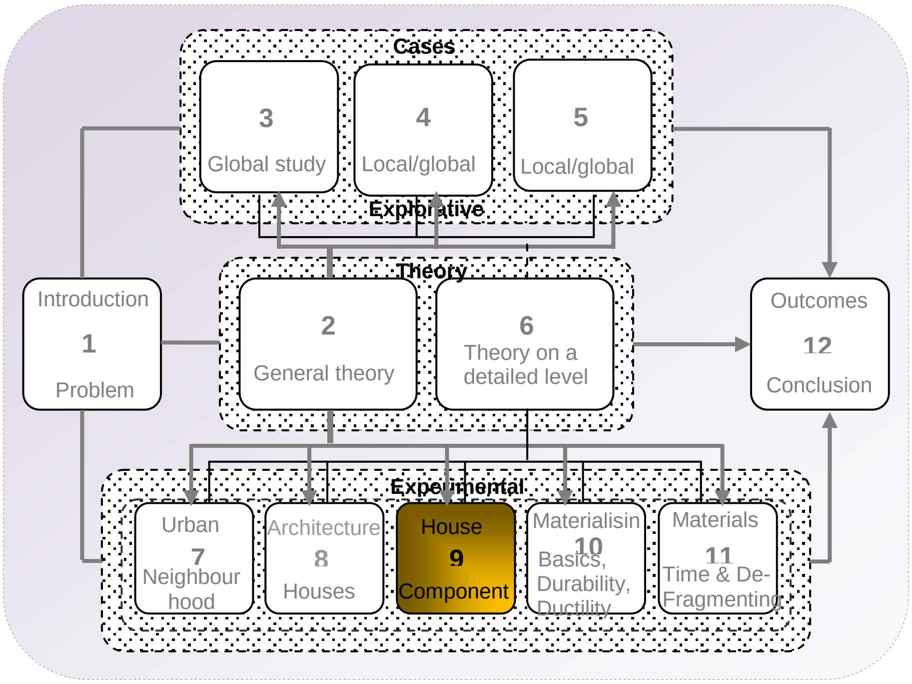
- For the structure of houses in a SRH-SD, industrialisation can ensure the quality. In this regard, if suitable for the local conditions, proper prefabrication will be a good solution.

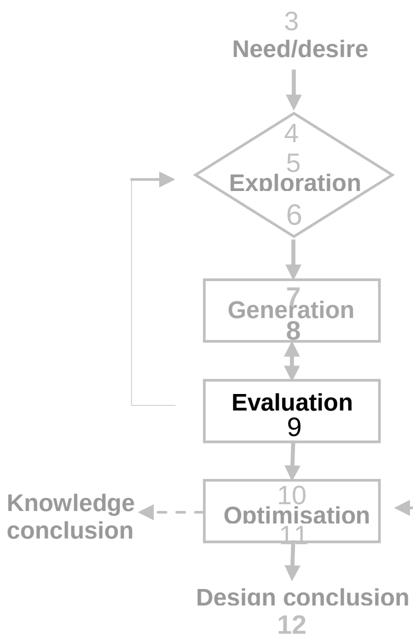
- As sustainability of a SRH-SD is dependent on sustainability in various domains, construction of houses also needs to be validated for sustainability. As an example, the checklist deducted from table 8.7 is shown in table 8.8 for the theme of water. This table is continuation of the one on the urban level in the previous chapter.

Table 8.8. Item of water on building & materials level, example of a checklist deducted from table 8.7

Item	Domain	Checking the use		S	U
	House/building	Quality of the water provided for family use/households			
		Encouraging methods for saving and optimising the use			
		Water system/technology in the houses			
		Renewing & recycling the used water			
		Reuse of the used water			
		Waste water produced per family	H		
			Nh		
		Sewage	R		
			Nr		
	Materialisation	Water/tone for extraction of raw materials			
		Required water/tone for processing raw materials			
		For others (between extract & production of raw material			
		Required for production processes, target materials			
		Water/tone for the target material itself (e.g. concrete			
		Renewing the entire used water			
		Use of renewed water for materials			

S= surface water, and U= Underground water
H= Hazardous, and Nh= Non- hazardous
R= Reusable, and Nr= Non-reusable


Cases
3
Global study
4
Local/global
5
Local/global
Explorative
Theory
Introduction
1
Problem
2
General theory
6
Theory on a detailed level
Outcomes
12
Conclusion
Experimental
Urban
7
Neighbour hood
Architecture
8
Houses
House
9
Component
Materialisin
10
Basics, Durability, Ductility
Materials
11
Time & De-Fragmenting


3
Need/desire
4
5
Exploration
6
7
Generation
8
Evaluation
9
Knowledge conclusion
10
Optimisation
11
Design conclusion
12

CHAPTER 9

EVALUATION OF THE DESIGN FOR A SUSTAINABLE RECONSTRUCTION OF HOUSES

After several concepts were produced for the generation phase (chapter 7 and 8), the selected options for a successful design in the complex situation ought to be validated according to pre-selected criteria. This evaluation will be done in this chapter, based on case studies for a Sustainable Reconstruction of Houses in a Seismic Desert area (SRH-SD).

The focus of this chapter is on interrelation of the design at building-component and elements level with the upper design levels to increase the efficiency of the proposed solution. In this regard, the main goal is integration of the design on a multidisciplinary as well as interdisciplinary level. The flexibility of the design and the product development are of crucial importance, as is a building technology approach that bridges the gap between architecture and structural engineering. Appropriate detailing of the design at the component and element level is necessary.

This chapter further explains the previously mentioned necessary links between evaluation and exploration (i.e. returning loops in the schematic concept of the GPM). As an outcome, the evaluation of a complex design warrants the recognition of critical issues in the selected conceptual design, so that the risk of failure in the outcome can be avoided. Furthermore, the role of sustainability in practice is gradually becoming recognisable. After evaluation comes the phase of optimisation, an elaboration of the evaluated concept on the material level, which will be discussed in the next chapter.

9.1. Introduction

Previous chapters, specifically chapter 7 and 8, have discussed how the potentials of design (e.g. form) can help to simplify construction and bring stability to a desert house during earthquakes. For example, a cupola was proposed as a concept in the previous chapter. This form, when materialised properly, provides good stability during earthquakes while it is also an appropriate alternative ancient form that absorbs less energy from the intense desert sunshine.

Sustainable Reconstruction of Houses in a Seismic Desert area (SRH-SD) can contribute significantly to sustainability. The crucial issue in this is that it also is confronted with seismicity and desert circumstances. Regarding the first problem, houses demolished by an earthquake have a mental, physical, and economic effect on the inhabitants. This also has significant influences on the environment, which may be seen on a broader level than that of the individual. Furthermore, the question is how to rebuild houses on a site that also in the future is prone to earthquakes? Regarding the second problem, rather than the harsh desert climate, SRH-SD is severely influenced by the global problem of desertification. The preservation of desert cities is essential not only because of local issues but also because it serves as a means to protect land from expanding deserts on the planet.

In some contexts of SRH-SD, other local issues may also arise. For example, in cities such as Bam the long history created a strong cultural background, which adds certain identities, sometimes tacit. The strength of the indigenous culture and identities in cities as Bam was argued in chapter 5. These local identities are of design considerations and may entail extra limitations. The proposals in Chapter 7 and 8 were developed accordingly.

9.1.1. About the criteria for evaluation

Although decision-making in the design process is a very important part of finalising the exploration phase (see chapter 6), each phase of the design may also require particular decisions to be made. It is essential to finalise the design principles with prioritisation and with the appropriate decisions, while the optimal alternative concept, which is developed according to these principles, also needs to be prioritised and selected. In addition, it needs to be evaluated on the basis of required values.

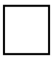
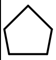
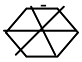
The criteria for decision-making have been stated as being rational ones (Singh et al., 2007). However, rationality and the way it is to be measured both need to be defined. Rationality has been studied in general and in particular (e.g. Rescher, 1975; Nussabaum, 2001; Spohn, 2002; Boudon, 2003), but it needs to be further specified for an architectural design (at the macro-, meso- and micro-levels). Many domains, aspects, and criteria are involved in the field of architecture. Although with a long history, not all the criteria in the field have been determined. This is due to the broadness and scale of the items involved. However, a critical cause of the non-determination of criteria for the entire design is that social, human, and aesthetic aspects are mostly missing. Because the design is basically meant for humans, it is strongly connected to their feelings, which can never be entirely known. Therefore, the evaluation in this study starts within the frame of a conventional design, and gradually goes toward research-oriented validation. The concept developed in the previous chapter will be reviewed and its particular values re-tested.

9.1.2. Critical points and the SRH-SD

The SRH-SD is an undefined domain in the field of architecture. Due to the unavailability of special regulations, particularly for reconstruction of houses after an earthquake, knowledge evolved as research was developing. An important discovery relates to social sensitivity (i.e. found in some case studies). Additional research was desired to comprehend emotional moments after earthquake disasters and the effects that they could have on dwellers. This dissimilarity of the design situation to a normal construction process was well understood at the stage of generating design concepts. The exact problems arising in the design (as well as the construction) needed to be understood and established well. Therefore, the intention was to investigate every single step of the conceptual design (sub) process. The selected dome concept from the previous chapter was reinvestigated at the component and element level by providing various alternative structures. Some of these are shown in Table 9.1.

Table 9.1 also represents parts of an analytical research in which the main intention was to minimise the number or the variety of structural elements in order to simplify production, transportation, installation or transformation.

Table 9.1. Examples of alternative elements for the structure of the dome/cupola house

Element type / Model	 Elements	 Element	 Element	 Element	Notes	Resulted component
Wooden component 1	6 in the form of one	12	6	-	Three types of elements in this component are connected with angles of 30, 45, 60, 120	
Wooden component 2		14	-	7	The middle part of the structure is open as a potential yard	
Concrete shell structure	Sintered clay was added in to the aggregations, Glass fibre as reinforcement for a shell structure of concrete. The internal and external surface is supported with stretched polypropylene					
Cardboard beams	8 **** arched-beams are the main body of load bearing structure including 4 main crossed beams and 4 support beam beams' section differs from the 1/3 of the starting point					
Steel beams	2 round supports, 1 in the upper end, and 1 lower end, in addition to the 8-arched beam as the main load bearing structure (connected on the top and the bottom.					
Concrete structure 2	Repeated mix. The concrete structure composes four different materials as reinforcement including coconut fibre, carbon, Aramid, and glass fibres (including long and short fibres).					

Based on Chapter 8, a dome/cupola is the concept for further development of the structure

Because the homogeneity of a structure is critical in withstanding an earthquake, the shell structure (schemes in fig. 9.1) was the best of the proposed alternatives for the dome house. A material study led to the decision that concrete is one of the best materials for this (Shahnoori et al., 2007c). However, materialisation is the subject of the next chapter.

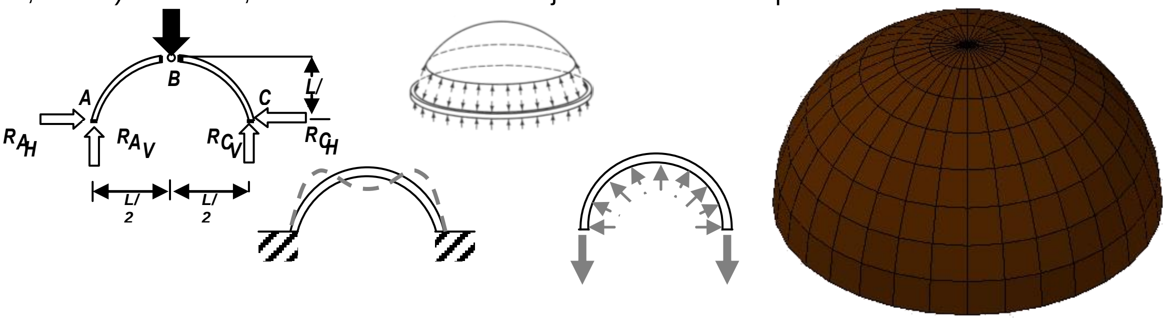


Figure 9.1. The homogenous dome concept for a house and the shell structure for it

In one of the earliest concepts for the materialisation of the dome house, which was done with reinforced concrete, the reinforcing elements can be fibre or steel bars. For example, in one of the experiments conventional concrete was reinforced with steel bars. In that case, based on Belmouden et al. (2007) it was assumed that this material is linearly elastic, isotropic and homogeneous. Hence, these properties can be adjusted and enhanced by the design (e.g. form). However, the cupola shell structure can also be materialised with different concrete materials, such as advanced or fibre reinforced high-strength concrete (see also Shahnoori et al., 2008a & b).

Regarding the three-dimensional development of their surface, shell structures are able to carry external loads primarily through in-plane stresses rather than bending. For a cupola shell structure, the internal force and stress distribution is spatial (Belmouden et al., 2007). In situations that the seismic load is combined with gravity, the analysis will become more complex, because the bending and membrane reinforcement involve the inelastic behaviour of steel and concrete

(Medwadowski et al., 2004). For example, for the dome house with the shell structure, two main regions should be taken into consideration:

The region where the stresses are primarily in plane or membrane, for which direct tensile stresses should be resisted entirely by reinforcing elements (e.g. steel bars) in concrete shells. Stability requirements generally control the regions with direct compressive stresses.

The region with significant bending action. It is possible to resist the stress couples or moment by a wide flexural member, provided the concrete section near the surface is reinforced (Belmouden et al., 2007).

Therefore, this shell structure needs adequate depth to include steel appropriately in two layers and to cover each layer of the steel with concrete. In this situation, the ideal direction for the reinforcing elements is the general direction of the principal tensile stress. This orientation is more sensitive in regions of high tension to resist in-plane stresses; therefore, the reinforcing elements need to be placed at least in two directions. According to Belmouden et al. (2007), to resist stress couples these reinforcing bars should be placed near both faces since the bending moments may vary rapidly along the surface. Besides, proportioned openings and edge members should resist forces impaired by the shell. Otherwise, these will be the sensitive sections of the shell structure under seismic loads (Shing et al., 2001). Penelis and Kappos (2005) believe that, in order to avoid the collapse of a structure, we should enable it to absorb and dissipate the kinetic energy imparted to it during seismic excitation. This involves not only the materials but also the structural form and configuration, which contribute to the stability of the structure. Stability means the structure is unable to move freely and to allow damage to property or injury of the occupant. This is possible by proper arrangements, interconnections, and integration of structural components that have adequate strength and rigidity (Merritt et al., 1990), but only up to a certain level. After the structure has been forced to the limit up to which it is supposed to be stable, or when the load by seismic motion exceeds the capability of the structure, damage may occur (Vrouwenvelder, 2006).

In the proposed concept of the dome house, the rigid connection between the structure and the foundation makes a continuous support, while the arch action mechanism of the shell along the meridianal direction represents the structural behaviour (Belmouden et al., 2007). Hence, as shown in Chapter 8, the dome concept provides a minimum surface area and thus the absorption of less heat from the desert sun, an optimal spatial volume, and a maximum footprint for the plan. Besides, along with other advantages such as harmonisation with traditional local architecture, this concept offers the potential of material minimisation. These aspects are crucial in an environmentally friendly simple solution to cope with a harsh desert climate (Lute, 1992). Although stability of the dome structure was also a reason to evolve in vernacular architecture in many desert towns worldwide (Pirnia, 2005), it has mostly been materialised in mud brick (Pop, 1965; Khalili, 2004).

9.2. Finalisation of the cupola house concept for SRH-SD

As discussed in chapter 8, keeping the social integrity of the area is even more important than being prepared for possible earthquakes re-occurrence. Rebuilding damaged cities in an attractive way is a major issue. In most instances, it is essential that the original inhabitants and landowners stay on their lands, as they know how to work the land and the city in the most effective way. This has even a higher priority in a desert city, where desertification is a constant threat (Pachauri et al, 1997). Therefore, the developed concept for the desert town house should also be tested regarding the social aspects and for desirability. This part of the study focuses on establishing the valuation that people give for living in a dome construction.

Although the geography and history can cause extreme differences in both people and building over very small distances (Atkinson, 1967), dealing with common conditions can also create similarities in various regions. Thus, case studies as Bam are representative of seismic desert towns Therefore, interviews and questionnaires were prepared aiming at finding out whether a dome structure that technically seems suitable for the SRH-SD is also socially acceptable or not.

9.2.1. Approach for evaluation of the concept regarding social desires

The main approach was a combination of research and design that circularly completed each other in different phases. In the research, five rounds of interviews played a key role. As the focus of this stage of the study was to confirm the feasibility of the Blob dome to be a home for local application, questionnaires contained relevant questions. The researcher personally submitted them to each interviewee in annual rounds. The interview also included some questions about other purposes, which were out of the scope of this chapter. The context for this part of the study was the city of Bam. The distribution of questionnaires started in the old districts of the city, consisting of compact neighbourhoods, dome roofs and adobe materialisation. Each group of interviewees and respondents comprised an average of 75 families that were interviewed on five different occasions. At the time, the first group was still living in emergency housing. The third interview round was done two years later when the reconstruction of houses was on going, and the rest was organised at intervals of about a year. It must be mentioned that because the second round of local research did not focus on this subject, interviews and questionnaires were prepared and distributed differently, so they have not been included in the current discussion. The questions were repeated, but sometimes in a different set-up, distribution and questionnaire. On average, 25 families were chosen to answer again, to qualify the questions for reproducibility. Furthermore, on average 55 new families were asked. The questionnaire was also sent to Japan, and also later handed out personally in Tokyo, but not every interviewee responded to the questionnaires. The number of respondents therefore is not comparable to the number in the desert cities. Notably, a rather small-scale but similar survey was conducted in the Netherlands too. It was done with two groups of people, the first respondents being highly educated people, whereas the people in the second group were chosen at random, so that it was a mixture of different levels of education, age, employment and even nationality.

In the case of the desert city of Bam, all people interviewed were divided into groups based on education, age, extent of damage to their house, and the degree of personal damage or loss they suffered in the last earthquake. Figure 9.2 shows a sample of the classification of the interviewees.

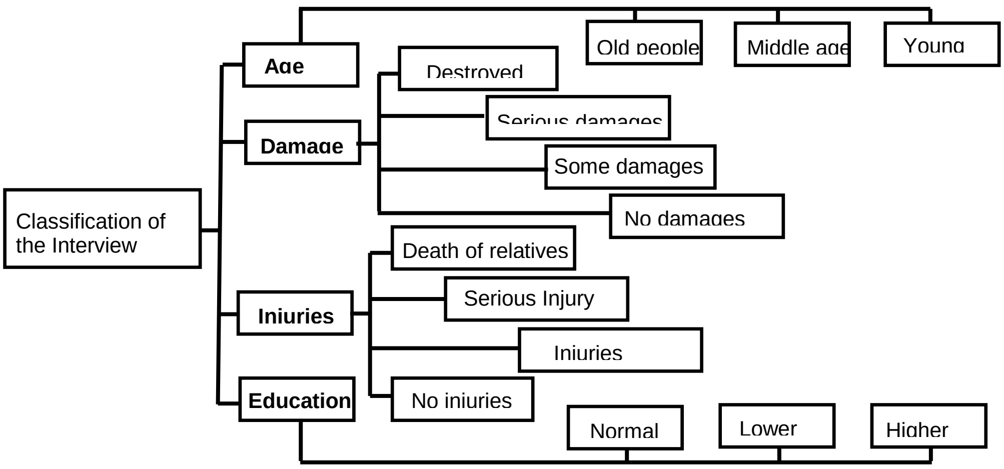


Figure. 9.2. Classification of the two local interview and questionnaire

Questions in the interview and the questionnaires were also focused on the experiences of the people within the period of sheltering and the social demands for the reconstruction of a house. They included name, age, education, situation, homes, shelter, and so on. These questions triggered people to think about the construction of their houses. Results of different classifications were analysed, and with the literature study, the final evaluation of the design led to the conclusion.

9.2.2. Case-related results for testing the concept on social desirability

In the first interview and questionnaire, 25 forms were submitted to the families that were interviewed and 25 answers received. In the second questionnaire from the submitted forms to those 25 people, 21 answers were obtained. From the 100 questionnaires in the third round, 86 returned, of the fourth 109 from 125 in total. From the 125 questionnaires in the fifth round, 106 responses were received. Results of all questionnaires were classified by three or four different categories: age, education, and damage and/or injury. However, after the answers were collected these classifications appeared to be dividable into more branches. Each class of these were also branched into subdivisions as shown in tables 9.2, 9.3, 9.4, and 9.5. Although these questionnaires contained various questions, regarding the current tables the most important question related to the opinion of the people about a dome shape as a concept for reconstruction of their houses.

Table 9.2. Sub-classification and results of the local interview and questionnaire, divided according to age (from the second interview round onward some people no longer responded)

	Number	**Answers on a dome shaped house**			
Age		**Negative**	**positive**	**Neutral**	**No answer**
15-25	6, 1, 16, 20, 20	4, 1, 8 , 9 , 11	2, 0, 2, 2, 2	0, 0, 3, 5, 4	0, 1 , 3, 4, 3
25-35	7, 5, 15, 21, 19	5, 5, 13, 17, 15	0, 0, 1, 0, 0	1, 0, 1, 2, 2	1, 0 , 0 , 2, 2
35-45	8, 11, 17, 21, 21	5, 9, 15, 17, 16	1, 1, 0, 0, 1	2, 1, 2, 2, 3	0, 0 , 0 ,2, 1
45-55	3, 4 , 14, 18 ,18	1, 4, 10, 13, 13	0, 0, 1, 1, 1	1, 0, 2, 3, 3	1, 0 , 1, 1, 1
55-65	1, 0 , 13, 16, 16	0, 0, 6 , 12, 11	0, 0, 2, 2, 2	1, 0, 3, 1, 2	0, 1 , 2, 1, 1
65+	0, 0, 11, 13, 12	0, - , 3 , 1 , 2	0, -, 2, 2, 0	0, 0, 3, 5, 5	0, 0 , 3, 5, 5
Sum& percentage	25, 21,86,109,106	60%,76%,62.8%, 63.3%, 64.2%	12%,4.8%,9.3% 6.4%,5.7%	20%,.14.3%, 22%, 22%, 26.4%	8%,9.5%,17.4%, 17.4%, 17.9%

Table 9.3. Sub-class and results of the local interviews and questionnaire, according to education

	Number	**Answers**			
Education		**Negative**	**Positive**	**neutral**	**No answer**
Master	0, 2 , 5 , 7 , 7	0, 2 , 5, 7 , 7	0,0,0,0,0	0,0,0, 0 ,0	0,0,0,0,0
Bachelor	2, 4 , 9 ,12,12	2, 4 , 8, 11,10	0,0,1,0,0	0,0,0, 1 ,1	0,0,0,0,1
Technician	1, 3 , 11,11,11	0, 2 , 6, 8 , 8	1,1,1,1,1	0,0,2, 2 ,2	0,0,2,1,0
Diploma	16,10,47,59,55	12,9,28,36,34	2,0,4,3,3	1,1,8,10,11	1,0,7,10,7
< Diploma	6 , 2 ,15,20,21	1, 2 , 8 , 10, 9	0,0,3,2,2	4,0,4,5 ,5	1,0,0,3,5
Sum& percentages	25,21,86,109,106	60%,76%,62.8%,6 .3%, 64.2%	12%,4.8%,9.3% 6.4%,5.7%	20%,14.3%,22% 22%, 26.4	8%,9.5%,17.4%, 17.4%, 17.9%

Table 9.4. Sub-classification of the local interview and questionnaire, according to the level of human impact (death of relatives, injuries, etc.)

	Number	**Answers**			
		Negative	positive	neutral	No answer
Lost relative	16,10,49,61,62	9,9,42,55,56	1,0, 2,1,1	4, 1,3,4,4	2,0,2,1,1
Severe injury	11,12,45,53,48	7,11,35,42,40	1,1,3,2,1	2, 0,3,5,4	0,0,4,4,3
Injuries	7 , 4,17,25,28	6, 4 , 9 ,15,14	0,0,2,1,2	0, 2,3,5,7	0,1,3,4,5
No injury	7 , 5,24,31,30	5, 4 ,11,15,15	1,0,3,2,2	1,1 ,5,7,7	0,1,5,7,6
Sun& percentages	25, 21,86,109,106	60%,76%,62.8%, 63.3%, 64.2%	12%,4.8%,9.3% 6.4%,5.7%	20%,.14.3%, 22%, 26.4	8%,9.5%,17.4%, 17.4%, 17.9%

Table 9.5. Sub-class of the interview and questionnaire, according to the level of damage suffered

	Number	Answers			
Damage		**Negative**	**Positive**	**neutral**	**No answer**
Destroyed home	13,13,47,55,54	7,12,34,43,42	1,1,2, 1,1	3,0,7,5,5	2,0 ,4,6,6
Serious damages	4 , 5 ,14,17,16	3, 5 ,9,9, 7	1,0,1, 1,0	1,0,4,4,4	1,0 ,0,3,5
Damaged home	4 , 2 ,11,17,15	2, 2 , 6 ,9, 9	0,0,2, 2,2	1,0,1,2,3	1,0 ,2,4,1
No damage	4 , 4 ,14,20,21	2, 3 , 6 ,10,10	1,0,3, 2,3	1,1,2,7,7	0,0 ,3,1,1
Sum & percentage	25,21, 86, 109, 106	60%,76%,62.8%, 63.3%, 64.2%	12%,4.8%,9.3% 6.4%,5.7%	20%,14.3%,22%, 22%, 26.4	8%,9.5%,17.4%, 17.4%, 17.9%

From the first interview, it was found that 16 houses were destroyed, 4 houses severely damaged, and 5 left without considerable damages. Most of the people interviewed in the first round suffered severe injury or had a death toll in the family. From the second round, more people were unaffected by the earthquake. By the third round, the emotions after the earthquake were gradually disappearing and most interviewees were busy repairing or starting the reconstruction of their houses. At this stage, economic matters formed the most important concern for the people in Bam. Individuals were still hoping for and expecting support from the government, but this did not seem to happen in line with their expectations. The reactions observed in the fourth and fifth rounds show people becoming less hopeful and more concerned.

In almost all of the research rounds, the answers gathered and the questionnaires completed showed details that made that every questionnaire different from the others. Some questions on the forms remained unanswered. A summary of answers to the question about living in a dome-shaped house is shown in the graph of figure 9.3.

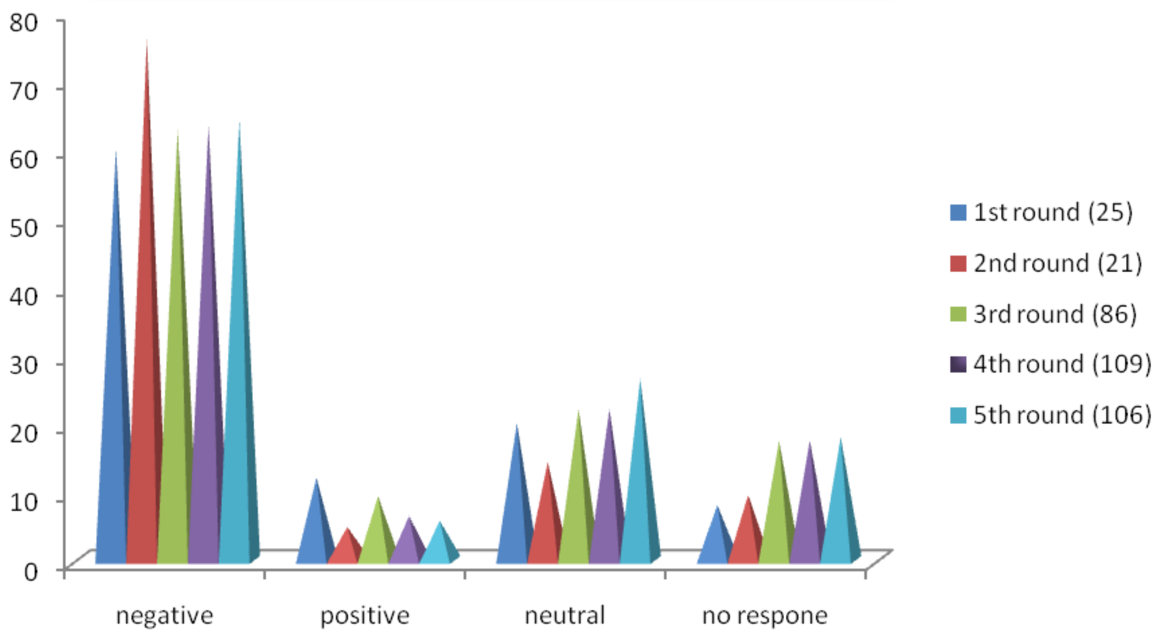


Figure 9.3. The answers of Bami people to the question of 'whether or not they want to live in a dome house'

Table 9.2 shows the answers for the different age groups on the question about the wished form of their future home. There was a positive relation between age and the effect on the people's appreciation of the dome shape for a home. Younger people liked the dome form more, compared to the elderly. The age group of 15-25 liked the dome shape the most. Education did have a significant effect on the liking of the dome form. Highly educated people liked the dome form less compared to uneducated people. The damage to the home of people was relevant to their feeling for the dome home. The higher the damage the more they had negative feelings about the dome-shaped house. The personal damage was also relevant to the opinion of people about a dome concept for a house.

The answer to the question about their future house and idea about the form of the house are presented in the graph of figure 9.3. Correspondences to the questionnaires were mostly focused on normal, orthogonal strong houses.

9.2.3. Various aspects for evaluating the dome concept for the SRH-SD

Because of the social (and environmental) impact of the changes and incidents in the rebuilding of Tokyo after the Kanto earthquake in 1923 (EC, 1999), the initiative was taken to study the social attitude towards SRH-SD with dome-shaped houses. It could be argued that dome-shaped houses relate to the old vernacular buildings in desert areas and that this relation would satisfy the local inhabitants (Pirnia, 2005). However, the demand for change that is occurring across the globe (Leupen, 2005) due to internet connections and satellite receivers covers many places, including desert towns (Kries, 2004). Besides, after an earthquake, housing is even more sensitive (Mileti, 1974) and as a home is different from a house, rebuilding a home needs extra consideration in such a situation (Kronenburg, 2002). Therefore, there are two possible views on the matter. Technically a dome has interesting features that lead to the idea that SRH-SD with dome houses would be a good idea (similar to Belmouden et al. 2007), but this research shows that that would be a social miscalculation.

This is a common finding, as history shows that dome houses were never a success to be used as normal homes in modern days. Something similar happened to Drop City (Voyd, 1969). Drop City (figure 4), in Colorado (US), was called "*a Model Hippie commune"* by CLUI (1996), began in 1965 (Vassar, 2007), with the idea to be an environmental sculpture (Voyd, 1969).

Even though this case was to be a place for artists (Oliver, 1969), it needed an implementation process. Although Voyd (1969) believed "*all the actions involved with construction were to be the easiest, most efficient, with least cost"*, and although it won the Dymaxion award in the US, Sadler (2006) called it *"a worrisome, structural soundness, uncomfortable, at times unhealthy and by most measure socially dysfunctional*". The city was inhabited only until 1973.

Figure 9.4. Drop City, Colorado (1, above, Sadler 2006; 2, left, Richerd 2010; & 3, left, Hippie Museum 2010)

Soleri built dome constructions as a passive system at suitable places (such as Arcosanti) in the Arizona desert (Soleri, 1987). His ideas about using local materials, producing/preserving water in the desert, protecting the inhabitants from the sun, and creating humidity in the meantime were the essential points of his project. With all potential in Soleri's designs for desert housing, his modesty toward nature and his respect for the indigenous are always recognisable and identical. As another manifest example, the well-known Dymaxion house of Buckminster Fuller (1929) was a perfectly conceived mobile shelter. The hexagonal plan of Dymaxion comprises radial rooms, suspended from a central mast. After planting the central support structure into the ground, the rest of the house was easily assembled and completed. The organisation of the production line, transportation and assembly, the materialisation and the plan itself all caused the house to be called a 'house of the future'. The aluminium house, based on an industrial production system for Beech Aircraft of Wichita, Kansas, was a perfect project in 1945. However, it was not designed to provide the first aid needed when sheltering numerous stricken people.

9.2.4. Collective points of the evaluation phase to be taken to the next action

The minimisation of material is necessary with a large amount of rebuilding (e.g. mass production for the reconstruction) in which structural quality and shape play a major role. Therefore, use of modern techniques in order to ensure sustainability should be locally adapted.

The dome form in a seismic desert city seems a good alternative. For a city with a background similar to Bam, however, recently it proved not a suitable home for indigenous people with a normal life style. Therefore, the quality of such structures should be encapsulated in a new definition and a new concept in order to make the design desirable and to make use of its advantages.

Structural integrity, resistance to the seismic motion of an earthquake with a magnitude of about 6.5, with an adjustable structure, coupled to various desires, local identities, sizes and proportions, etc., form the aims of future proposals for the SRH-SD.

Combining the research of Chapter 7 and 8, with the research introduced in this chapter, it is evident that a proper configuration of the structure and detailing of the structure especially for critical members of the structure for earthquake induced loading and excitation is crucial in order to sustain the necessary structural integrity during earthquakes. Regarding the social demand, it is preferable for the next concept to acquire the potential of being adapted as a standard cube. The 'develop-ability' of the house (e.g. plan extension when required) in the future can also be a good advantage for this type of house.

Shahnoori et al. (2007a) already discussed the advantages of an industrial production system for the SRH-SD. The production (incl. typology, geometry, etc. of the structural element as the product) should not only be economically efficient but also environmentally sound. Due to the normal distances between desert cities, transportation is a very important issue, so that the structure needs to be dividable into elements and even sub-elements. These elements need to be either locally producible or should be easy to transport. The finishing or the final surface of the structure can also provide the free choice of whether to be purely exposed or entirely covered by other materials, textures, colours, in order to survive in the market. The form and size of the structure also need to be locally adapted.

An average house size of about 100 m^2 for the SRH-SD for Bam (4 -5 people per family) seems appropriate. For a desert town, materialisation, lighting, heating, cooling, and combination of these systems with the outdoor climate and natural environment are other important factors.

9.3. A product development approach when providing proposals for the SRH-SD

According to Oliver (2003) more than ninety per cent of the world's buildings are built according to 'the architecture of ordinary' (i.e. not special). This includes some 800 million homes. The relations and concerns of the human towards a 'home' is a major issue.

Based on the outcomes of the research on the applicability of proposed solutions, as discussed in the previous section, the concept for the houses in SRH-SD should not look old, special or futuristic, but strong, inviting and familiar. In desert habitats, with a particularly resilient historical background, local identities need to be combined in the design with other outcomes of the research.

Although conventional reinforced concrete could also be an alternative material for this type of structure, ECC (see chapter 10) composites are the most preferable for the SRH-SD. Industrial production is the prerequisite, so that quality, which is crucial for application in a seismic area, is assured. To achieve more effectiveness in production, transportation, assembly, dismantling, reuse, repair etc., the structural elements can be divided into sub-elements.

9.3.4. Building elements as products for development

Because of the enormous amount of houses that are required for a reconstruction after destructive earthquakes, the production is a major concern for the sustainability of the reconstruction, in addition to the product itself. According to Freivalds et al. (2009), for successful production, predetermined standards first need to be met. Second, workers must be adequately compensated for their output. Third, workers should gain a feeling of satisfaction from the work that they do. They divide the overall procedure into five parts:

(i) Defining the problem

(ii) Breaking the job down into operations

(iii) Analysing each operation to determine the most economical manufacturing procedures for the quality involved, with due regard for operator safety and job interest

(iv) Applying proper time values

(v) And then following through to ensure that the prescribed method is put into operation

These manufacture-related points also help to emphasise some other issues during the design process, especially in the detailing phase of the design. Appropriate engineering and time study are common and crucial items in both the design and production with regard to product development.

Several tensions may also influence a product's value (Steen, 2006). Of course, there are different ways of dealing with these tensions. According to Spinuzzi (2005), the difference between the world of the researcher and designer, versus the world of users generates such tensions. In these worlds, each one has its own knowledge and practices in addition to its well-defined boundaries (Muller, 2002). Movement from one world to the other is very difficult. Muller states: "We can see this difficulty manifested in our elaborate methods for requirement analysis, design, and evaluation – and in frequent failures to achieve products and services that meet the users' needs and/or are successful in the market place. An important activity in this field, therefore, is bringing these worlds together in different/various ways." Steen (2009) states that in some approaches (to these activities), researchers, and designers attempt to move towards the users, their worlds and their experiences; and in other approaches, researchers, and designers attempt to encourage users to participate in and contribute to research and design. According to Limonard and De Koning (2005), this tension can also be thought of in terms of designing for users, versus designing with users; or one can envision a continuum between ‘proactive user involvement’ and ‘reactive user involvement’.

This study has taken both of these approaches into account. First of all, the building element that has been identified as a ‘product’ is also a result of social study and the wishes expressed. This has also been combined with so many other involved aspects and criteria that have been discussed in various contexts. Therefore, the user’s involvement has been proactive. Second, during the evaluation phase, relevant items along with the user’s demands have been restudied, and users interviewed, so that the user was reactively involved.

As was previously indicated (also in several chapters) simplicity of the proposed solutions increases their application. This is also relevant to the design of the building elements. For instance, the alternative elements can connect various foundations; examples of mono-, bi- and multi-directional foundations for such purposes are shown in Figure 9.5.

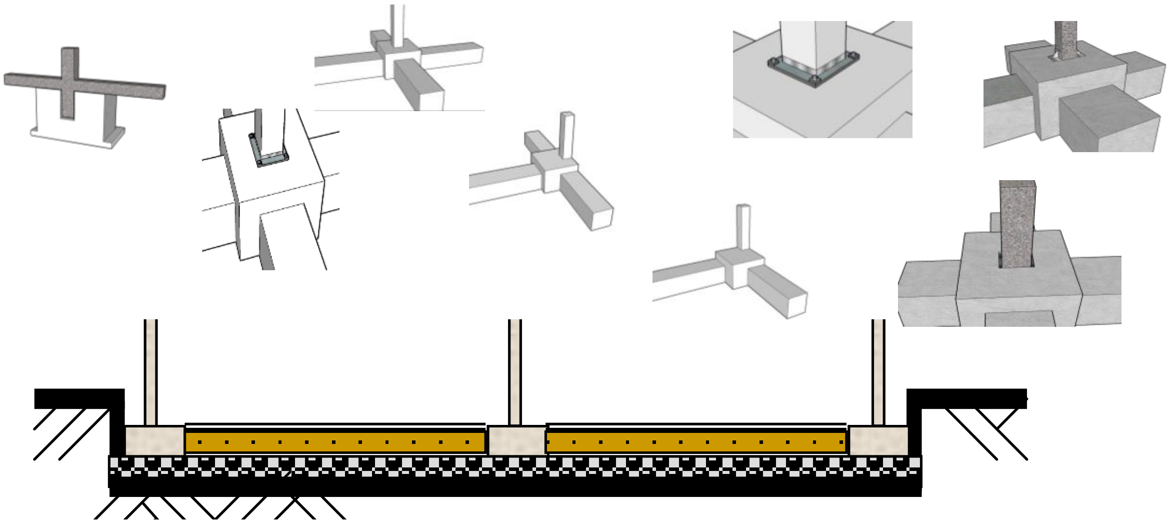


Figure 9.5. Examples of possible concepts for foundations to join the super-structure, which locate and connect to each other on a layer of dry balanced sand base as a first and simple dissipater.

The foundations concept in figure 9.5., is an example of simplicity of the design on detail level. This foundation is to be integrally connected to the super-structure. In this example concept to dissipate the initial energy that the motion transfers into the foundations, they are located on a layer of sand after the ground has been compacted and prepared and before the concrete boxes are being placed. Similarly, various simplified details (in order to ease the application in different context) can be provided based on the provided principles of SRH-SD.

9.3.5. Harvesting the details in an integrated concept, a bottom-up view of proposing alternatives

In the Model for SRH-SD, the sustainability of the whole model is addressed in a multidisciplinary approach to the integration of the entire levels. Additionally, as previously mentioned, the integrated approach that covers the entire study includes both top-down and bottom-up approaches. The study started explorations and proposed alternatives for a SRH-SD from the urban level as a top-down method. However, in this section, the bottom-up approach allows the integration of details and theories in a sample SRH-SD concept, which is also a checking and evaluation method.

The locally desirable concept for a house in a desert city such as Bam can be configured at district level, as shown in Figure 9.6, which is also similar to the way that the reconstruction is currently taking place in the city.

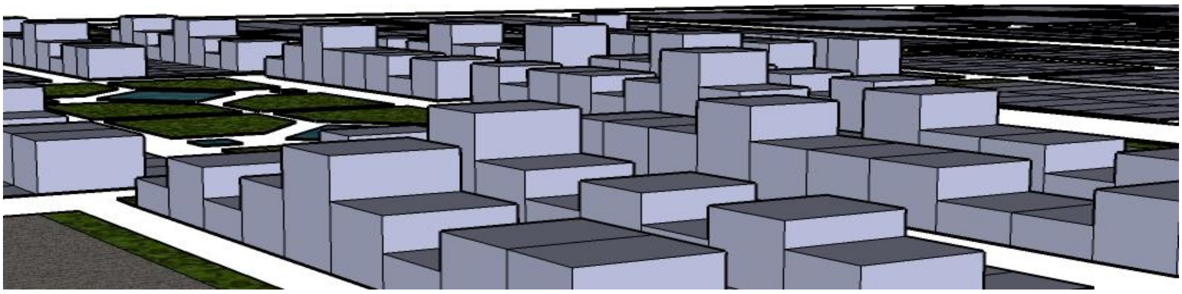


Figure 9.6. Urban composition, an urban tissue of a desert neighbourhood with the cube concept of a house

For the designer to realise an identical concept for the house in respect to the desert architecture, creating interesting variation in the façades, and therefore in the urban street view is a good alternative. These effects of the interrelation of the domains (i.e. the element and the building level of the design), required to be regarded in a SRH-SD is shown through examples in Figure 9.7.

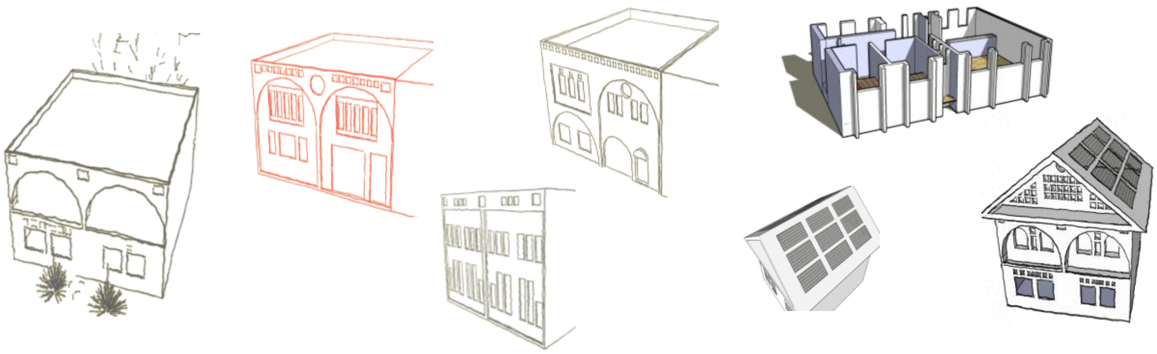


Figure 9.7. Refining the concept by locally identical details

The street view will be harmoniously heterogeneous. Therefore, with these types of alternative proposals the structural components or the building products domain is not only interconnected to the domain of building concepts but also to the neighbourhood or urban level of the design. An example of this type of neighbourhood and district is shown in Figure 9.8.

Figure 9.8. The neighbourhood view refined by detailing and exposing identical structural elements in the façade

9.4. Summary, conclusions and recommendations

Evaluation of an appropriate concept of a dome or cupola house showed great potential as a concept for a house in the context of SRH-SD. However, the final round of evaluation produced the ultimate conclusion that this concept is socially undesirable in some desert areas such as Bam, although it was well received in some societies in the Netherlands and Japan. Therefore, the research concludes that, on the one hand, the proposed solutions need to show local characteristics while, on the other, they need to be flexible and to present global features rather than only local configuration. Therefore, the final conclusion is that the solutions in the structure of the house can focus upon element level instead of component level. The above-mentioned flexibility of such structural elements may highly increase the applicability of the concept as well. The second part of this research has concentrated on analysing proposing concepts and providing examples for the validation of the theory and knowledge model as well.

The effectiveness of possible solutions with a multidisciplinary approach to SRH-SD has been discussed on various levels. The final point and end evaluation of sample proposals relates to the sustainability of the final proposal. The sustainability of the building element is expressed in Table 9.6.. As was argued in Chapter 7 and 8, this table is composed of items to measure the Sustainability of a Reconstruction of Houses in a Seismic Desert town. For a simplification and in terms of general application, these items are summarised as 8ISRH-SD, a term that may only be used within the context of the following chapters. In this table, an evaluation of the concepts at urban, building, component, element, and sub-element level is presented. Evaluation of the sustainability of the proposals at a material level will be concluded in the next chapters. Important remarks are dividable into three different but interconnected and interactive domains of (i) urban, (ii) building and (iii) materials. The main points on urban level have been mentioned in the chapter 7. The conceptual design on building level was mainly discussed in chapter 8, and further detailed in here. As a result, remarks for evaluation on building level include:

-Reconstruction after earthquake disasters involves more social aspects than that in a normal construction. In this situation, societal expectations may not be predictable.

-For a SRH-SD the concept for the house must be socially desirable, at least socially adjustable, and acceptable

-Orthogonal forms that look normal and not futuristic are preferable for some SRH-SD's.

-For application on a large scale in a SRH-SD, a flexible proposal on element level that can be transferred into several concepts on houses level is more suitable than a concept for one house (the entire house).

-For such a flexible concept for the house, product development approach is appropriate. With which building elements or sub-elements will be the product, producible accordingly.

-Transportation and the relevant costs are always important, but due to the distances between many desert habitats, it is more serious in such areas.

-Structural design can also benefit from the local architecture, such as using forms for declining the vulnerability of the structure in earthquake motions. This form can also be deduced from the vernacular architecture.

-Because normally flat roofs attract more energy from the desert intense sunrays (than a dome roof), to use a flat roof instead of a copula integration of collaborative details to decline the effect of this energy are preferable (e.g. reflection, insulation, thermal mass, and photovoltaic).

--Introvert windows to use moderated sunlight, integrated shading provided by different details (such as deep frames), natural shading (trees with seasonal leaves) are of simply applicable solutions.

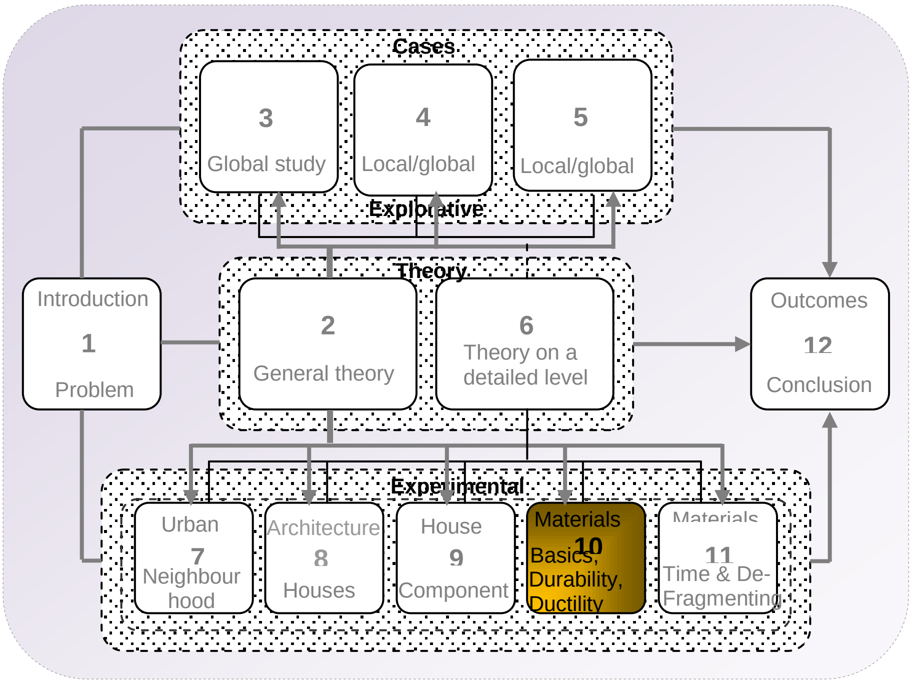
-The mentioned details such as in the window's frames that provide daylight can refine the façade, thus creating differences in a homogenous street and neighbourhood view.

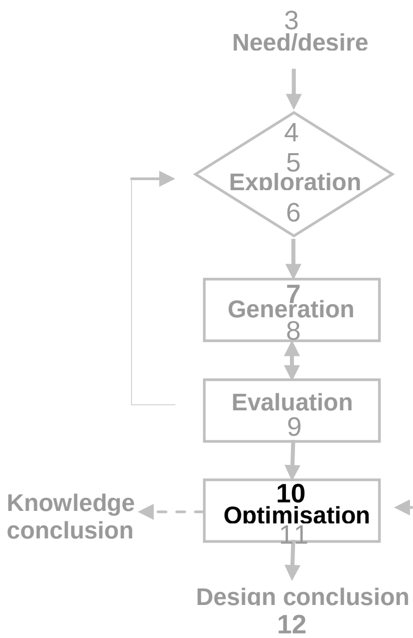
-A sample of the main criteria for the houses in a SRH-SD is provided in table 9.6.

Table 9.6. Aspects of a SRH-SD on urban level

Target	Possible effects of the alternative	Aspects
Air	Producing Co 2 Other toxic/harmful gases	*1. The concept is based on local technology
Water	Overuse of water Producing sewage Water pollution Desertification	*1 Using renewing System and amount of use of underground water System and amount of use of other sources Sewage produced per tonne Level of pollutant agent Access of households to water
Surrounding	Unsustainable land-use Unpleasant/ dangerous surrounding Release of hazardous waste Release of non-hazardous waste Noise pollution Land degradation & floating Heat islands &Desertification	Land usage (functions, percentages, future view) Transportation Agriculture Sheltering spots Number of complaints about effects on scenery Hazardous waste per tonne Non-hazardous waste per tonne Recycle-able waste per tone Number of air pollution complaints Land deformation system Land deformation level (+ future view) System of climate compatibility Heat produced (+ future view) Heat exchange with the surrounding (construction and materials capacity, insulation…) (+future view) Percentage of green items added to surroundings Type and number of plantation (+ future view)
Energy	Various environmental harms	Energy required for manufacture/product processes Amount of solar energy use Use of other clean sources of energy Ratio of passive/ active system for cooling, … Courage for conducting energy use of household Estimation for near future, future, and far future Energy source required for transportation
Natural resources	Misuse or overuse Depletion of resources	Use of various natural resources Scale of use from each resource Extraction system Scale of recycling and reuse of materials Durability of building construction and materials Recycling and reuse of building elements, material
Climatic comfort	Missing Indoor comfort Distraction of outdoor Un-satisfaction=Desertification	Level of indoor comfort in hot summer days Level of indoor comfort in cold winter nights System and level of moisture added to the dry air Air circulation and ventilation system and level System for outdoor comfort (private/semi-private) Incorporation of local traditional solution in practice
Social comfort	Undesirability/economic loss Societal miss-match Aggression and crime Leaving the desert=desertification	Scenery, combining water and greenery in desert Health of the houses (mentally & physically) Social desirability Societal involvement in changes on urban areas Courage for efficiency in agriculture Durability, safety, and security of the building Boosts for agriculture, accesses, combining it with life, protecting its area from construction…
Market and profit	Economic losses, financial disability Crime, aggression and drug addiction Crises for jobs Leaving desert=desertification	Flexibility of components and elements of houses Community oriented market Job opportunities Side activities for agriculture …

*1. -material level in next chapter


Cases
3
Global study
4
Local/global
5
Local/global
Explorative
Theory
Introduction
1
Problem
2
General theory
6
Theory on a detailed level
Outcomes
12
Conclusion
Experimental
Urban
7
Neighbourhood
Architecture
8
Houses
House
9
Component
Materials
10
Basics, Durability, Ductility
Materials
11
Time & De-Fragmenting


3
Need/desire
4
5
Exploration
6
7
Generation
8
Evaluation
9
10
Optimisation
11
Knowledge conclusion
Design conclusion
12

CHAPTER 10

MATERIALISATION OF HOUSES FOR SUSTAINABLE RECONSTRUCTION IN A SEISMIC DESERT AREA,

GETTING MORE FROM LESS FOR THE ENVIRONMENT IN OPTIMISATION

This chapter is about materialisation of houses in seismic desert areas. Although in an inclusive optimisation all the design levels and design stages have to be addressed, this chapter only deals with materialisation of Sustainable Reconstruction of Houses in Seismic Desert areas, short SRH-SD. Materialisation as the focus of optimisation in this study comprises two general parts:

(i) Materialisation of the main structure, which is the subject for this chapter, and

(ii) The De-Fragmentation Element (DFE), which is the subject of chapter 11.

The research on materialisation consists of two main parts:

1. Selection of materials from the sustainability point of view

This first part is about selecting an appropriate material for houses in a SRH-SD by a global study, local exploration, and case oriented research. After identifying some major characteristics (e.g. locally availability, strength & safety, durability, and thermal mass) for materialisation of the SRH-SD, some materials are evaluated for this purpose.

2. Materials properties for optimal response in seismic design

This part concentrates on specific materials properties that are considered essential for optimal response of structures when subjected to seismic loads. The specific weight and ductility are two of the properties that will be discussed in more detail.

10.1. Materials for SRH-SD - Alternatives

10.1.1. Wood, clay, and adobe materials

When people think of using environmentally friendly materials in buildings they often come up with natural materials as wood and clay. Hence, in the recent century these were excessively combined with the new materials in the masonry work (Takada et al., 2004). However, about half of the approximately $40 billion loss resulting from the Northridge earthquake in Los Angeles region in 1994 was associated with wood structures (Symans, 2006). The danger of a spread of fire after earthquakes in wood structures was also proven in earthquakes as great Kanto (1923).

Although in theory clay is a sustainable material, a large scale excavation/use of clay also causes many negative side effects to the land and soil as already experienced in countries as Russia, India, China, Australia, Iran etc. Besides, clay excavation in addition to harming the local ecology (MA- NHDMEA, 2005; MA-DMEA, 2006), highly influences the arable land in the desert areas that are at risk of deforestation and desertification, which is one of the world's most threatening affections (Kibert, 2005). Therefore, intensive use of clay or similar materials would make desert cities one of the regions that are damaged by human induced soil degradation.

10.1.2. Brick

As the principles are similar, brick has the same impact as the adobe has with the addition of the impact that brick kilns create in their footprint areas (EPA, 1992), as the affected areas around Delhi, which once were highly important agricultural areas. According to Bentinck (2000), these are recently not only useless for agriculture but also in danger of being flooded. Besides, brick manufacturing has also the impact of air pollution on the environment.

The use of brick in seismic areas requires special attention (Vrouwenvelder 2006). An example of combination of the environmental impact and structural problems for brick constructions in the seismic areas was found in China. Due to the huge growth of population, the use of brick constructions increased since 1990 (Zhu, 2005). As brick is made by firing clay-rich topsoil at very high temperatures, its production process in addition to the air pollution, consumes a large amount of coal and destroys arable land. Zhu (2005) illustrates the problems coming from the brick industry in China with some figures: Occupation of 400,000 hectares land by the brick factories; Destroying 63,333 hectares of arable land every year for brick making; Consuming 100 million metric tons of coal per year by brick firing. As this kind of material is normally not well insulated nor weather proof, in winter times poor people in villages in China have to spend a lot on fossil energy. Besides, as brick is weak to absorb seismic energy, these constructions are vulnerable in earthquakes; as many houses and schools were destroyed by the earthquake of magnitude 5.9 in Chifeng in inner Mongolia in 2003. Therefore, use of brick was banned in 170 cities of China from 2001 and to the rest of the country from 2004.

10.1.3. Concrete

Regarding the briefly discussed items, concrete has several advantages. It has good mechanical properties and is a very flexible material (Lie, 2005). It is relatively cheap and often easily available (Yu et al., 2006). Therefore, it has the potential to be easily implemented in different situations. The technical characteristics of this material make it a good alternative for reconstruction after an earthquake disaster in a desert area (see also Shahnoori et al. 2007c). This was also proven, as reinforced concrete structures were the only structures to survive the earthquake of Los Angeles/ San Francisco in 1906. This has been observed in well-designed and detailed reinforced concrete structures after many other earthquakes as well (e.g., San Fernando/Los Angeles, 1906; Long Beach/ Huntington Beach, 1933; Mexico City, 1985; Kobe, 1995; Bam, 2003). Hence, concrete, and particularly reinforced concrete, can be considered a good solution for a seismic design of structures.

10.2. Materials selection in view of sustainability

10.2.1. Minimizing material use in buildings

Material minimisation has big economic advantages, while it has also been identified as a very useful way to decrease the environmental impact (Dickson et al., 1999). To develop a sustainable construction eco-costs should be taken into consideration (De Jonge, 2005). According to Hendriks et al. (2002), the direct and indirect environmental impact costs generated by the use of resources are called eco-costs. The ecological impact of each step in the product chain is based on technical measures to prevent pollution and resource depletion to a level, which is sufficient to make the human society sustainable. Hendriks et al. (2002) divided the eco-costs into five components, 3 direct and 2 indirect. In relation to the material minimisation, two are very relevant:

1. Virtual pollution prevention costs, being the costs required to reduce the emissions of the production processes to a sustainable level (Vogtlander et al., 2001).
2. Materials depletion costs, being (costs of raw materials) (1-α), where α is the recycled fraction

According to Hendriks et al. (2001), the sustainability of construction also includes durability, and 'durability refers to the properties of the material, building section or construction that can resist any unacceptable deterioration of relevant function characteristics through specific chemical, physical and mechanical loads, over a certain period of time'. The resistance of a material against any type of degradation is essential and conditional for the durability of the construction.

Due to the distances in desert areas, the construction related transport is an important factor in the sustainability of a SRH-SD project. Using local potentials for materialisation and weight reduction are, therefore, very useful.

10.2.2. Availability of materials for SRH-SD

For a SRH-SD, because a huge amount of materials may be required for the large number of houses, to ensure sustainability, many aspects need to be taken into account. Local availability is one of the major issues in this respect. Relevant availability issues are (See table 10.1):

1. Local availability and extraction of the raw materials,
2. Production of the basic materials (i.e. concrete, bricks),
3. Production of structural components (beams, columns, slabs, walls).

Each of the steps to produce the final product, i.e. structural component, needs to meet certain criteria, while all sustainability aspects summarized in Table 10.1 should be considered as well. Besides typical sustainability criteria also structural and functional aspects have to be considered, like a.) Safety & strength (ductility, dissipation & de-fragmentation), b.) Durability and c.) Thermal mass (and resistance). Foregoing considerations have to be borne in mind when we look in more detail to the specific case of the Bam earthquake.

Table 10.1. Steps to produce structural components and major aspects of materialisation of a SRH-SD

Steps to the material	Environmental criteria	Aspects
Extraction	Landscape deterioration, Impacts on nature /eco-system, Water required, Air pollution, nuisance, water pollution, waste dispersion	Availability, Technological possibilities, accessibility & transportation, economic,
Refinement material	Embodied energy, Water required, Air pollution, Nuisance, Water pollution, Waste dispersion, costs	Locally process-ability, Usability, Health, Recycle-ability, Costs (eco & economic)
Production	Embodied energy, Water required, Air pollution, Nuisance, Water pollution, Waste dispersion, costs	Locally produce-ability, Required raw materials, Usability, Normal Strength & Seismic Strength, Technical life span, Health & safety, Climatic characteristics, Fire resistance, Repair-ability, Reusability, Demolition, Recycle-ability, Costs (eco & economic),

10.3. A brief overview of materials in the case study of Bam

10.3.1 Structural damage in the Bam earthquake

In a close look to the materials experiencing seismic motions, the desert city of Bam was one of the cities that suffered tremendous loss in both economy and lives. In the 6.5 magnitude earthquake of December 2003 in Bam, lacking appropriate design, construction and execution systems in addition to the low quality of materials were identified as the main reasons for the losses (Shahnoori, 2005). The only structures that safely withstood the quake were good quality reinforced concrete structures (e.g., the water reservoir- shown in figure 10.1).

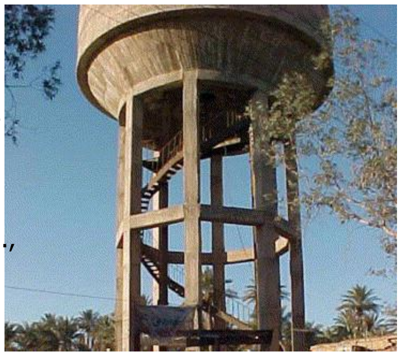


Figure 10.1. Water reservoir tower in Bam made of reinforce concrete (photo: Ramazi et al., 2006)

The adobe constructions were badly damaged (Konagai et al., 2004) and 80-90% of the brick structures collapsed (Kimiro et al., 2005). Table 10.2 presents an example of categorisation of damages with reference to the materials, surveyed in Bam.

Table 10.2. Site observation Bam for structural damages (information from JCSE, 2004 is also incorporated)

Cases of investigation	Principal Material	Degrees of Damage	Note
Bridge No. 1	RC	**	14 spans (simple girders)
Bridge No. 2	RC	*	3 spans (simple girders)
Bridge No. 3	RC	*	7 spans (simple girders)
Water reservoir	RC	*	Reinforcing steel bar buckled
City hall	Adobe	****	Total collapse
Mosque No. 1	Brick	****	Centre pillar made of steel
Mosque No. 2	Adobe	****	Total collapse
Mosque No. 3	Brick	***	Reinforcing steel bar buckled
Mosque No. 4	RC	**	Occurrence of crack on the pillar only
Houses (1-5)	Adobe	****	Total collapse to structural dis-function
Houses (5-10)	Brick	****	Total collapse to structural dis-function
Houses (10-15)	Steel	***	Disconnection and torsion of members
Houses (15-20)	RC	**	Reinforcing steel buckling & lack of overlap

Degree of damage: ****= collapse or serious damages, ***= damages, **= minor damages, *= no damage

The main reason for the use of adobe on a large scale in the past was its availability, referred to the ancient situation of Bam, and the advantages these materials offer for a desert city (see chapter 5). However, since a century ago many people use masonry. Even though modernisation in Bam has started about half a century ago, modern materials as steel and concrete were not always used appropriately, but in the form of masonry. In surveying construction materials in Bam, it has been observed that source of various materials are available.

10.3.2. Availability of materials and resources in Bam

A key consideration about Bam

Bam is a town where most of the economy depends on agricultural exploitation, surrounded by date plantations, citrus, and farming. Thus, any changes to the quality of the top soil may seriously harm the economy. Any solution should consider the fact that Bam needs sufficient arable lands. Constant excavation of the top soil to come to for instance the clay would have a big impact on the quality of the available arable land and therefore on the economic situation in Bam.

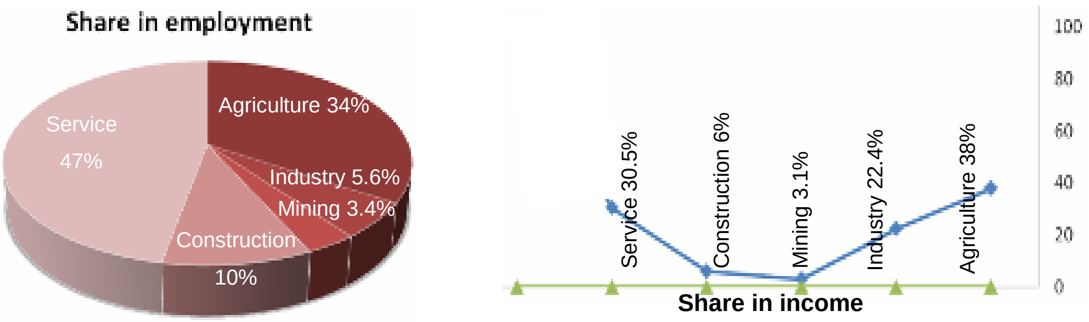


Figure 10.2. Share of different sectors of the economy in Bam (based on Report No.1, 2004, pp11 SCI).

Water

Normally in desert cities, surface water is rare, but the evaporation on the soil level is not a problem in Bam. This is guaranteed by existence of a large numbers of Qanat, an ancient water management system used to provide a reliable supply of water to human settlements or irrigation in hot, arid, and semi-arid climates in Persia. Because Bam is surrounded by mountains and the water from rain and snow is transported via the mountains into the deep layers of the ground, there is a constant supply of water.

Material resources and use

For availability of the building materials the main sources in Bam is from the Poshterud River, in the northern boundary and Birdbrain River in Khaje Askar (a close village). The quantity of the sources have been investigated and confirmed by the local government. However, for a check of the applicability of the local sand in view of durability samples have also been analysed in The Netherlands. One reason for this check was that in the past the desert areas are known to be part of the bottom of ancient seas. It is possible, therefore, that the sand is too salty to be suitable for producing durable building materials.

10.3.3. Evaluation of the alternatives for a SRH-SD in the Bam area

A lot of the vernacular architecture in deserts is based on clay and bricks (see chapter 5), still producible in many desert areas. However, as indicated in section 10.1.2., already, conventional adobe constructions and masonry were proven vulnerable to earthquakes and many of them were destroyed by earthquakes (e.g. Peru 1970, Mexico 1985, and Bam 2003). Besides, for desert cities as Bam, using clay for reconstruction of about 40000 houses is very problematic; instead, concrete is technologically well evolved and it adheres to the local possibilities. The strength, stiffness and durability of concrete, together with the fire resistance, make concrete very suitable for the reconstruction of a seismic desert city. However, the great advantages of concrete go along with some negative aspects (Table 10.3). These mainly relate to the cement production process, which goes along with substantial CO_2 emissions. Nevertheless, many reasons pale these negative impacts and make it a sustainable alternative material; for example:

(i) Modern technologies propose innovative solutions for reducing carbon emissions caused by cement plants. Replacing wet kilns with dry ones, filtration and refinement of the smoke and pollution on top of the kilns, etc. are of these.

(ii) Burning waste in cement kilns mitigates environmental problems.

(iii) The durability of concrete is a significant advantage that adds to its other great properties. As was indicated, the long life cycle, makes it a unique option for application on a large scale in a SRH-SD.

(vi) Concrete of demolished structures in a large scale is being used as land fill.

Table 10.3 Evaluation of the impacts of the three major phases of production of a concrete composite

Steps to the materials	Environmental aspects	Quality (acceptable or not-acceptable)		
		Acceptable	Not acceptable	Comments
Extraction of Raw materials	Landscape deterioration		*	
	Impacts on nature/eco-system	*		
	Water required	*		
	Air pollution	*		
	Nuisance		*	
	Water pollution	*		
	Waste dispersion		*	
Refinement material	Embodied energy		*	
	Water required	*		
	Air pollution		-	0.8 T CO_2/1T cement
	Nuisance		*	
	Water pollution	*		
	Waste dispersion	*		By use of waste
	Costs	*		
Production	Embodied energy	*		
	Water required	*		
	Air pollution		*	
	Nuisance		*	
	Water pollution	*		
	Waste dispersion	*		Burn by-product, hazard
	Costs	*		

In summary it can be stated that concrete is an appropriate material for the SRH-SD, as its properties have been checked for the impact of materialisation of SRH-SD. Material optimisations will enhance the appropriateness of concrete for a SRH-SD.

10.4. *Optimisation of the selected alternative for a SRH-SD in Bam*

10.4.1. Reduction of weight

For reconstruction of buildings in a seismic desert, we are confronted with two contradictory phases. For a seismic design, decreasing the weight is important. The high weight of conventional RC (steel Reinforced Concrete) makes a rather heavy structure causing extra dead load, transport and performance-related costs (Beukers et al., 2005). The extra weight also increases the vulnerability of the inhabitants of buildings in earthquakes (Booth et al., 2004). However, for the desert situation, the thermal mass helps to save energy, which will be used for the cooling in the summer and heating during the winter.

Technically, the weight of a composite material like concrete can be decreased as long as it does not affect the required mechanical and other properties. The weight reduction in a concrete composite is possible by using substitutive materials for the ingredients of a conventional concrete (Li, 2003; Kahl, 2004). A weight reduction of reinforced structural components is possible by:

1. Using lightweight aggregates (instead of gravel or crushed rock);
2. Changing the conventional reinforcing methods;
3. Using high strength concrete.

10.4.2. Crack width control – The use of fibres

One of the issues with reinforced concrete that has to be tackled is the cracking and crack control around the steel bars and at critical points in the structure. Small fibres can be used to mitigate the crack width effectively (Markovic, 2006).

Reinforcing materials that are weaker in tension than in compression to achieve better properties by incorporation of fibres is not new. For example, in the city of Aqur Quf (i.e. near Baghdad, Iraq) straw was used to strengthening the sun-baked bricks used in buildings in about 3500 BC (Bentur et al. 2007). However, from 1900 the first widely used manufactured composite was that of asbestos cement, which was derived from the invention of the Hadscheck process (Bentur et al. 2007). Since 1960's polymers have been used as reinforcements for concrete, which was accompanied by further application of such methods as reinforced concrete systems (Dolan et al. 1999). More recently significant improvements are achieved in performance as compared to the, perhaps, ordinary progression since this system was introduced in the 60's.

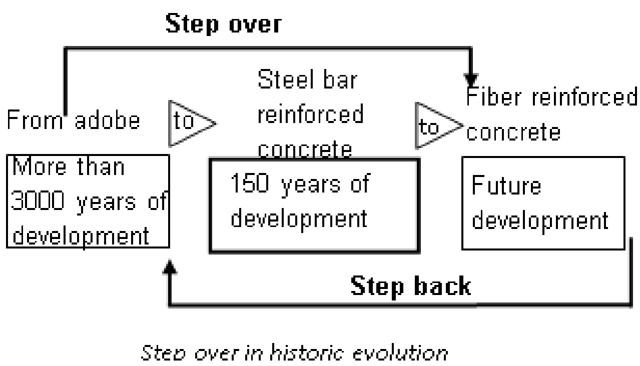


Figure 10. 3 . A schematic demonstration of application of fibres in the building construction

Natural fibres

As a biodegradable and renewable source, bio-fibres recently attracted the attention of many scientists (e.g. Lawrence et al., 2001; Bledzki et al., 2003; Twarowska-Schmidt, 2004; Ramakrishna et al., 2005; Ursem et al., 2007; Davis, 2007; Banthia, 2008). The basic structure of bio fibres consists of cellulose, hemi-cellulose, and lignin. The cellulose molecules consist of glucose units linked together in long chains, while hemi-cellulose are polysaccharides bonded together in branching chains. The relative high strength and low density and the heat, sound, and electrical insulation are of main advantages of these fibres. However, they are prone to water absorption and many of them are hygroscopic, thus the water absorption is high. Although this problem can be reduced and controlled by some methods (e.g. acetylation and heat treatments), it needs extra improvements and costs. These extra costs influence their applicability in buildings.

Synthetic fibres for the SRH-SD

Among various options, polymeric fibres showed a high potential for the SRH-SD with regard to different aspects (availability, weight reduction, thermal insulation capacity, water resistance, etc.). The fibre in concrete should be effective in restraining drying shrinkage or other cracking. The modulus of elasticity of fibres needs (for structural application) to be higher than that of concrete (Kuraray, 2007). One of the most promising for a large-scale use in the building industry in near future is PVA (Poly Vinyl Alcohol). These fibres are lightweight and affordable (Kuraray, 2007).

10.4.3. Engineered Cementitious Concrete an example of optimisation

Today, concrete technology provides us with a large range of high-quality concretes suitable for various applications such as the Engineered Cementitious Composite (ECC). The ECC composite is a highly progressed version of a ductile concrete while being 40% lighter in weight (Li, 2005). The economic efficiency of this composite lies in its long life; achieved from a better bonding of micro-scale fibres that act as ligaments thus rendering it more durable than conventional RC (SNR & ECSS, 2005). Adding appropriate fibres to the composite, as a way to increase the ductility of the structure, also improves the tensile strength.

As the name ECC suggests, the ingredients of this composite have been engineered, thus bringing many advantages in comparison to RC. These advantages are mostly based on the microstructure of the composite, which, similar to that of conventional concrete, relates to the microstructure of its ingredients, mainly the cementitious agents (Li, 2003). In the ECC composite the added fly ash, as a by-product from electricity generation process, compensates the lowered cement ratio, while providing other advantages as well (Li, 2004). A combination of the PVA fibres and composites as the ECC creates a significantly advanced composite of PVA-ECC, called hybrid or ‘bendable concrete’ (Li, 2003). Therefore, the PVA-ECC is a good alternative concrete for seismic areas (Li, 2007). In this method, the safety of the inhabitants, as the main point of the entire study, is ensured and the thickness of the concrete elements can also be considerably reduced. Therefore, less material is required for a qualified structure, which is good from the sustainability point of view.

Similar to that for the durability of concrete (Shahnoori et al. 2008a and b) in a limited experimental study by the author the ductility of ECC could be confirmed (Shahnoori et al. 2009). Worthwhile to mention is that the length of the PVA had minor effects on the compressive strength of the concrete samples, whereas samples including the 12 mm long fibres display a better tensile strength (Shahnoori et al., 2009).

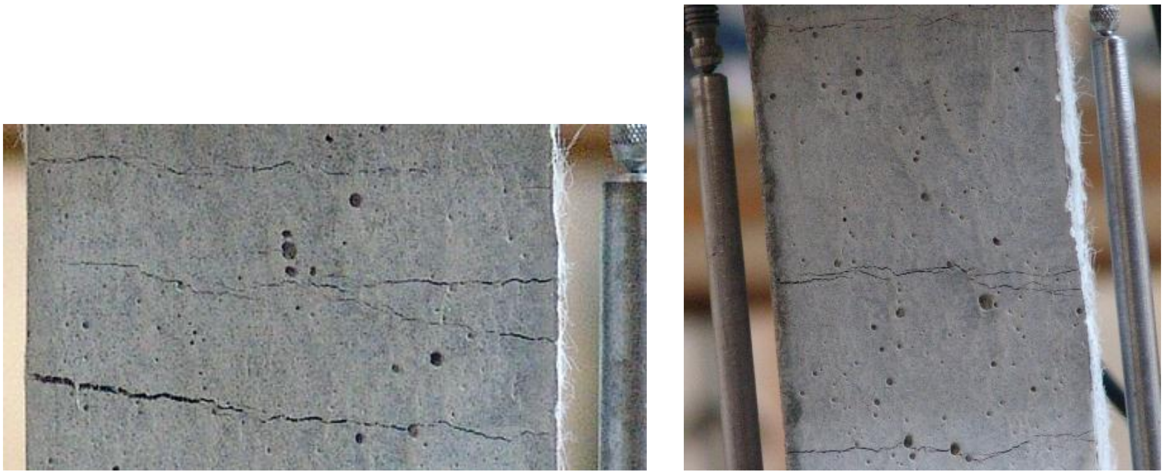


Figure 10. 4. Examples showing the ductile behaviour of the PVA-ECC, generating zones with multiple cracking by using the PVA fibres in two different specimens.

10.5. Summary and conclusions as regards materialisation

The important characteristics required for materialisation of the structure of houses in a SRH-SD have been discussed. With regard to the current state of technology, concrete was selected as an appropriate material. An example of comparing the most important issues for a SRH-SD is shown in table 10.4; a table in which a qualitative evaluation of different building materials is made.

Table 10.4. Comparative evaluation of some building materials for selection for a SRH-SD

Material / **Consideration**	Clay	Wood	Brick	Reinforced concrete
Availability	***	-	***	***
Earthquake resistance	-	****	-	****
Heat transfer/weather	****	***	-	****
Fire resistance	*	-	*	****
Environmental impact	(****)	****	-	(**)
Transportation	****	-	***	****
Material minimisation	-	*	*	****

Each * represents a relative positive point for the material regarding different items. For clay the ( ) means there are other side effects for the environment, and for the concrete ( ) means it comprises other advantages for the environment

In the observation for the crack progression in various mixes and specimens, a homogenous behaviour of the PVA-ECC under the loads as compression is obvious. In these samples instead of a sudden crack and failure, the branching of progressive minute cracks postponed the time to ultimate failure. For materialisation of houses in a SRH-SD, the ECC reinforced with PVA fibres is a good alternative.

Various results from the experiments on similar samples of the PVA-ECC confirm the substantial influences of minor differences in the ambient (production) conditions. Therefore, it can be concluded that controllable production methods such as industrially producing the structural elements are preferable.

- Although fibre reinforced concrete (with an appropriate fibre) significantly improves ductility and declines the brittleness of the structural element, further improvement in this direction ensures safety of the inhabitants of houses while it can also upgrade the overall sustainability of the reconstruction (summarised in the scheme of figure 10. 5). This will be explored in the second stage of optimisation on material level that discusses structural safety elements in the next chapter.

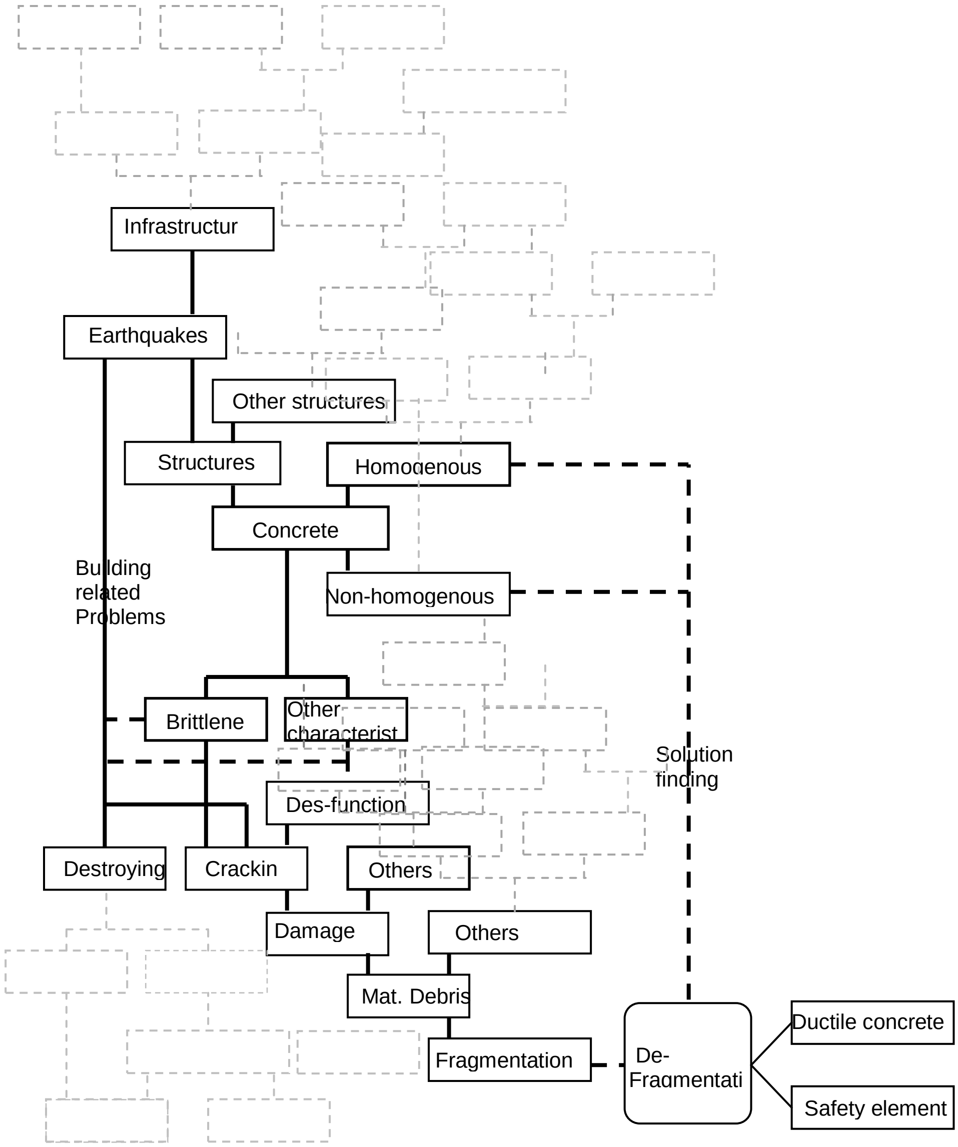
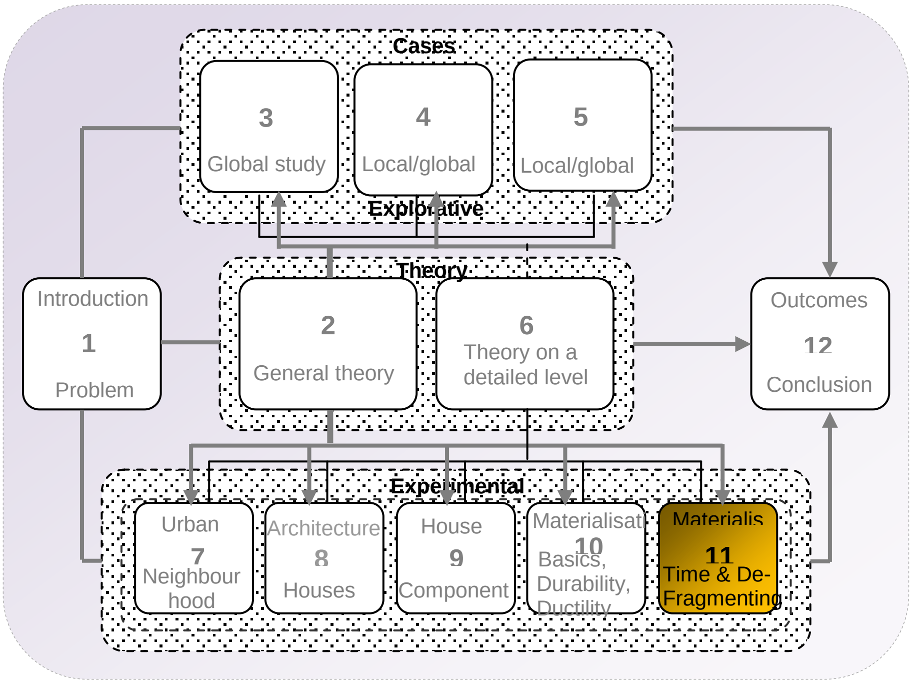
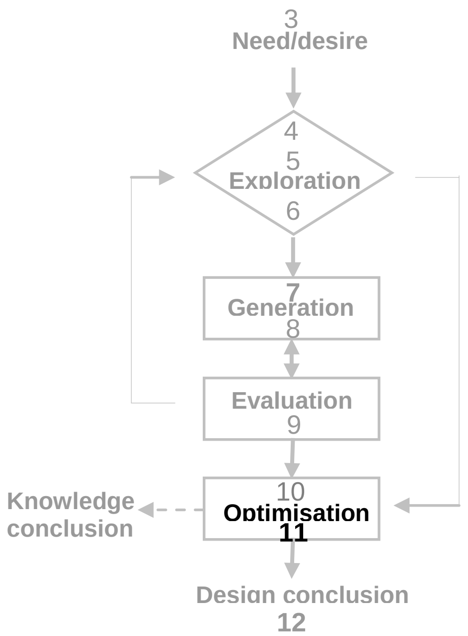


Figure 10. 5. Schematic demonstration of the procedure from the influence of earthquakes on the structure of houses to the solution of de-fragmentation, which is the subject of the next chapter.



Cases
3
Global study
4
Local/global
5
Local/global
Explorative
Theory
Introduction
1
Problem
2
General theory
6
Theory on a detailed level
Outcomes
12
Conclusion
Experimental
Urban
7
Neighbour hood
Architecture
8
Houses
House
9
Component
Materialisat
10
Basics, Durability, Ductility
Materialis
11
Time & De-Fragmenting



3
Need/desire
4
5
Exploration
6
7
Generation
8
Evaluation
9
Knowledge conclusion
10
Optimisation
11
Design conclusion
12

CHAPTER 11

ENHANCED ROBUSTNESS BY MAKING USE OF DE-FRAGMENTATION PROPERTY OF STRUCTURAL ELEMENTS, OPTIMISATION ON MATERIALS LEVEL

As the second stage of design optimisation on material and structural level, the focus of the current chapter is on the design of structural components with enhanced defragmentation properties. This strategy aims at enhancing the robustness of the structures in the Sustainable Reconstruction of Houses in a Seismic Desert area, or SRH-SD. This strategy includes various methods and solutions to avoid fragmentation after an earthquake motion excites the structure for a certain period. Therefore, it is called De-Fragmentation Strategy, or DFS. The proposed solution of DFS focuses on the development of a De-Fragmentation Element (DFE). The concept consists of an extra layer wrapped around the critical structural components to ensure a delay between the moments that the building undergoes the seismic motion and the moment of final collapse. Thus, it gives people a certain period to escape from the damaged building.

Before discussing the design of a DFE in more detail, we first have to know more precisely the length of the period people need to leave an ordinary house. To find the average required evacuation period, a large number of tests have been conducted, involving various groups of people and different building configurations.

11.1. Determination of required evacuation period

For determining the required evacuation period an extensive experimental program has been conducted at several locations and involving various groups of people. The goal was to find out the average time required for people to run out of their houses in earthquake disasters. The rescue means that the inhabitants of houses salvage themselves before the lumps of materials trap them. This crucial time is the minimum extension required for the materials fragmentation.

11.1.1. Measuring the required evacuation time

For measuring the required time for running in an emergency situation, such as in an earthquake, tests with 108 individual volunteers were carried out. These people are of different age, living in various types of dwellings in the Netherlands as well as in Persia. Although few tests were also conducted in Japan and the USA, due to the involvement of completely different boundary conditions the results of those tests are not presented here. For the tests, the people were divided into 4 age categories and 4 types of houses, as shown in Table 11.1.

Table 11.1. Categories of buildings and relevant participants for the tests

Age groups / Type of housing	10-32	32-52	52-69	+70	Sum
Multi floor	6	10	1	1	23
Two floor	10	12	5	-	37
One floor	11	23	10	4	48
Sum	28	45	16	4	108

Although in social and human-related sciences, age categorisation varies quite considerably, the current research is about the rescue time in an earthquake. Therefore, the references have been geared to age categorisation according to running capability, which still varies significantly. Different studies have shown the influence of age on running (e.g., Bottiger, 1973; Spirduso, 1995; Chambers et al., 1998; Cannon et al., 2001; Gibson et al., 2004). These studies show that for short fast running activities (e.g. within a few seconds), the effects of age are different, in terms of duration and in the type of running. However, in our case, this depends more on other issues that are not normally taken as influential in normal running activities. For example, the rescue test in the present research assumes that a sudden sprint can be applied to simulate the required running activity for rescue in an earthquake (i.e., a natural reaction for humans). This is different from normal running, which starts with preparations. Therefore, the position that people have at the moment of starting running significantly influences the length of the duration. The feeling of the people before and during running when stressed also significantly influences the activity

11.1.2. The test method

The participating people in the tests were assumed to run in an emergency situation of an earthquake. Therefore, many results from the people who were not particularly trained and equipped for such a situation were taken out. For this particular situation, a specific mobile phone, equipped inside the houses and provided for each person, played the role of an alarm for the earthquake. The ring tone of the mobile phone was also selected as a buzzing tone with vibration. It has been exactly explained to the people to run as soon as feeling (e.g. hearing, vibration/touching …) the alarm, provided by an external phone call. For each participant a chronometer capable of measuring 0.01 seconds was provided, to be carried the whole time. As soon as the specific phone rang this chronometer was pushed for starting to measure the running time. The participants were told to run from whatever position/situation they had (the same as in natural daily life) to the outdoors (preferably to the street).

Based on aforementioned studies and the provided information, the age categorisation in this particular situation is different from other normal situations, and accordingly divided as previously shown in Table 11.1. For young children (0-9 years), it is assumed that adults will take care of them in such emergency situations. Moreover, seniors (more than 70 years old) are assumed to live in elderly houses with appropriate equipment's for such situations.

11.1.3. Results of the emergency running tests

With explanations in the previous sub-section, the results of the tests in this research are applicable mainly to those aged 10-69 years. Although more than 120 people participated the experiments only 114 results were collectible, 108 of which were useful within the current research frame. These results have been gathered in Table 11.2.

Table 11.2. Results of the achieved time (in seconds) by testing the participants for the rescue time tests,

Age / Houses	Time for group 10-32	Time for group 33-52	Time for group 53-70	Time for group +70	Average of averages	Note
Multi story	17.08	30.33	31.35	42	26.25 (without+70)	Averages are only on 3 floor house (onl for comparison)
Two floor	11.21	13.73	17.32	-	14.09	No old people participated
One floor	5.67	7.28	11.14	13.4	8.03 (without old)	9.37 with old people

It needs to be stated that children of 10-20 years (especially from 10-15 years) do not show similar results in marathon running (or long-distance competitions) and in short running situations. For example, most of the youngest participants are much faster than the rest, while this group is not more successful than the others at marathon running are.

11.1.4. Analysis of the tests and the results

Notably, some participants living in a moderate climate have a considerable number of stairs in their houses; while in desert climate as Bam this number is much smaller (hardly 1 to 2). In the latter, the stairs may even go down instead of up. Surveyed houses in different climates have proven the influences of these staircases on the running activities. Most of these tests were repeated after achieving the presented results, several times in some cases. The results showed a significant difference between the first times that each participant performed the test and the second time. After the first experiment participants were more aware of the situation; they understand the reasons for this emergency escape (i.e. rescue from an earthquake). For example, the average difference between the time in the first and second tests for the age group of 32-52 years was 1.1 seconds. This means that the runners are 1.1 second faster than the first time. Besides, this quick reaction (running after hearing the alarm) differs among men and women. However, the estimation for obtaining separate average for such cases requires further tests with more participants and in equal conditions, which is beyond the timeframe of the current study. Nevertheless, one of the observations was that the difference between men and women in the time required for reacting increases with the age. Finally, in the categories of age that are closer to one another, the influence of health on the speed of emergency escape is greater than that of age, especially in the ages more than 52.

It is of some concern that the age classes that have been defined in current research may be sub-divided in future researches. Another concern is that the tests have not always been based on equal conditions. For example, a few residents had health issues, regardless of their category of age. Therefore, their running activity could not be a value for the relevant group (i.e. from 120 to 114, and statistics finalised with 108 people).

Noticeable issues about the particular tests and the findings

- Age influences the escaping time in earthquakes. This influence is significantly related to the number and the height of the stairs that connects the house to other spaces.
- Proportion of indoor spaces influence the escaping time (more time for larger houses),
- Building configuration (i.e. space configuration, relationship, and accesses) significantly affects the required time for a sudden escape from inside the house to the outdoor.
- Local and cultural aspects have also effects on escaping time. For example, the appearance of a woman that can delay the starting (to run) time, may be influenced by religion or culture.

- Between the age of 25 and 40, there were not huge differences in the running period as compared to that of other groups.

Finally, people who experienced disasters, similar to the eager researchers, (plus the relatives) were more willing to participate in this research

11.1.5. Evaluation of the tests and the results

The numbers of stairs highly influence the escaping/rescue time. Desert houses as those in Bam do not normally include many stairs. Thus, houses with many stairs can be disregarded, consequently reducing the required escaping time significantly. Therefore, the required time for an emergency rescue for one floor desert house is probably less than 11 seconds. Beside, for a two-story desert house this time will be less than 17 seconds.

Based on studies on psychological effects, which are conceivable in disasters like earthquakes, still more research is required to find optimum situation for such tests in order to get realistic results. Further research is required for determining evacuation times for people at the age of +70.

In summary: For a two-floor house, at least a minimum time of 17 seconds is required for the inhabitants to rescue themselves from the houses. This time for a one-floor house is 11 seconds. Therefore, the DFE (made of fibre reinforced composite in this research) should be able to provide this time.

11.2. De-Fragmentation as a strategy for enhanced robustness

Although building regulations aim to reduce the possible risks, providing an entirely risk-free situation is not always possible. For example, because of economic, technological, or other limitations, it is not possible to design all structures against earthquakes. In the regulations, buildings are classified to resist seismic motions to a certain degree, mainly based on their functions. For instance, military buildings or industry buildings need to be highly resistant, while houses are less important buildings in the regulations of many countries. Consequently, houses belong to the most vulnerable structures. At the same time, they comprise the majority of buildings and are the most-used ones. Accordingly, unsophisticated strategies/ solutions to reduce the risk for the inhabitants of houses are significantly effective and required.

11.2.1. De-Fragmentation Strategy

De-Fragmentation is an important element and a sub-strategy of the Sustainability Strategy for Reconstruction of Houses in a Seismic Desert area, or SSRH-SD, (see also chapter 6.). The main goal in De-Fragmentation Strategy (DFS), as was indicated before, is to reduce the vulnerability of the inhabitants of houses in earthquakes by a short delay in the collapse of structures. The DFS covers a wide range of methods that aim at providing a rescue time for dwellers to leave their houses before the building materials are fragmented. A case of such solution is designing De-Fragmentation Element, or DFE. The main function of a DFE is providing the time needed to leave the building. Note that the purpose in using a DFE is not to guarantee a strong long lasting structure, but only to delay and extend the fragmentation time.

11.2.2. Introducing a support for concrete: The strategy into application

The idea is that after a structural element reaches the limit of its load-bearing capacity, it may incur severe damage or even collapse. However, with the safety element, i.e. the DFE, fragmentation of the collapsed materials of the structural element will be postponed for some seconds, providing evacuation time. By adding the safety element, the design is free of the burden of extra costs spent on strengthening the entire structure.

11.3. Design for De-Fragmentation of structural components

This section focuses on exploring and designing the De-Fragmentation Element as a bonding system by using Fibre Reinforced Polymers/ Plastics (FRP). Therefore, from a building technology point of view to achieve the delay time, some essential steps are crucial; thus must be met first.

11.3.1. Application of the FRP bonding system

In this study, a new application of externally bonding the concrete structure rather than repairing or strengthening the existing structures, is the DFE Made of FRP. Similar to the present research, many studies (e.g., Van Gemert, 1980, 2004; Dolan et al., 1993; Lopez, 2000; Taerwe, 1999, 2005; Bakis, 2002; Brosens et al., 2002; Ignoul, 2003; Leung et al., 2005; McSweeney, 2005; Taillade et al., 2009; Teng, 2010) have performed experiments with wrapping FRP around the concrete structures (incl. bridge and building structures). Many of these experiments also proved that FRP increases the compressive, shear and tensile strength of the element. For example, RC is recognised as being liable to fail due to brittleness without shear reinforcement (Stratford et al., 2009). This is important especially for the performance of beams in earthquakes, but can be compensated by appropriate use of FRP's. For seismic-application, brittleness, crack-enlargement, and failure have been challenges to engineers for a long time. Similar emphasizes have been found in the studies such as Selvaduray et al. (2003) that also show the ductility and shear load capacity of FRP's that is very important for the design of De-Fragmentation for a SRH-SD. Selvaduray et al., (2003), understood the many advantages FRP comprises (e.g., low lifecycle costs due to zero maintenance and easy installation). They observe that the RC columns carrying the largest load in many concrete structures are particularly vulnerable to failure during seismic activity that can be compensated by using FRP bonding (Selvaduray et al., 2003).

What was not found in the former researches?

From 1982 onward, numerous researches on FRP's have been done (e.g. Kaiser, 1989; Meier, 1987, 1992, 1993; Deuring, 1993 Wu et al., 2006, Stratford et al. 2009, etc.). As a summary, many studies concentrate on the field of externally bonded FRP plates for enhancing existing concrete structures or infrastructures. Lopez (2000), Brosens et al. (2002), Ignoul et al. (2003), Leung et al. (2005) and McSweeney et al. (2005) studied different aspects or approaches in this field. However, most of these studies were aimed at enhancing existing buildings rather than investigating a strategy for new buildings. Furthermore, no scientific study into the possibilities of using externally bonding FRP as a safety material to delay the time of fragmentation of concrete structures could be found. Thus, there is no defined work on the time difference between the cracking and collapsing stages, and between the structures with and without the FRP bonding in this regards.

11.3.2. De-Fragmentation Element, design& experimental research

The design for De-Fragmentation here includes investigation and selection of materials in the bonding system and their effects on the extension of the time of collapse. However, the materials cover the surface of the concrete samples; therefore, the surface effects were also important. Two important issues concerning the use of FRP's for DFE include first, the type of safety materials and their combination. Second is the method for wrapping the FRP's. Of course, the bases are similar to the bases of the existing research about bonding the concrete for strengthening the structures.

11.3.2. a. Tests' variety in the experiments

The tests indicated or presented in this section are dividable into two main categories. The first category relates to the fundamental aspects about materials selection for the bonding system regarding the workability and production. This includes

- Observing the thickness and veneering when the matrix and fibres combine.
- Observation of interactions/ combination of various materials used in the bonding composites concerning morphology of fibres and the behavioural relationship
- Adhesion, reaction, and combination of the different bonding systems with the concrete,
- Molding methods regarding various bonding compositions (materials and systems)
- Production and the systems for bonding (e.g. monolayer or multiple layers etc.),
- Curing procedure and properties,
- Colour composition of the various bonding systems for exposed structural elements
- Finishing properties of the bonding system for the non-exposed structural elements

However, the second category relates to mechanical properties and focuses on the time extension between the first crack and the final collapse after the element is wrapped by the FRP.

11.3.2. b. Approach to the experimental research for the DFE

(i) Materials

Various bonding systems composed of diverse composites were tested. These materials are indicated by abbreviations in the tables and texts, most of which are shown in table 11.3.

Table 11.3. Most of the used materials for bonding systems in the presenting experiments

Materials	Abbreviation
Polyester	
Glass Fibre Reinforced Polyester	GFRP
Silicon with a Shore of A10	SA10
Poly Urethane rubber with a Shore of 60	PU60
Glass Fibre Reinforced Silicon with a Shore of 10	GFRSA10
Glass Fibre Reinforced Poly Urethane, Shore 60, in three versions: - Chopped - Woven - Compressed (similar to woven) multi-directionally distributed long fibres	GFRPUA60
Glass Fibre Reinforced Polyester + Silicon with a Shore of A10	GFRP+ SA 10
Glass Fibre Reinforced Polyester + Poly Urethane rubber with a Shore of 60	GFRP+ PUA60

Despite the fact that in majority of tests these materials were used, some other materials were also tested (e.g. carbon and Aramid fibres); but, were not always precisely characterised.

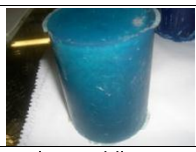
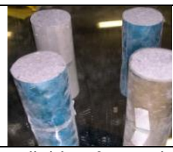
(ii) Approach

For a successful design for De-Fragmentation first the fragmentation was studied, that was partly (associated with concrete composites) discussed in the previous chapter. Therefore, the current research mostly focuses on fragmentation and defragmentation of the bonding materials.

This started by covering concrete cylinders mainly, but cubic specimens and rectangular prisms were also tested. Examples of several bonding techniques are to use a separate adhesive, steel powder-actuated (PA) and expansion anchors (EA), or wet lay-up process, which means bonding and curing *in situ* directly through the epoxy (Bakis et al., 2002). The wet lay-up was adopted for most parts of the current research that was performed in a hand lay-up method. In this way, the first group that has been tested consist of cylinders with radius 65mm covered by polyester (poly-pol PS60), with a thickness of about 1.5mm. The liquid polyester was mixed with hardener (Polyester-PigmentPasta) and brushed onto the concrete. A second group of cylinders with the same diameter was coated with silicone rubber, SA10, with an average thickness of about 5mm using a cylindrical cardboard mould. In the third group of samples, the polyester was reinforced with 4mm chopped glass fibres. In addition to cardboard, some other materials as PVC were also used to cast the FRP's. However, molding/casting was not the only method of bonding the specimens.

To observe the collapse process, the bonded samples (e.g. the first row of Table 11.4.) were compared with the samples without coating materials first in compressive testing. For optimisation, several materials in single or multi-layers were applied to wrap around the concrete specimens. Because the structural element needs to suffer or transfer the loads homogenously, integrity of the segments in the element is very important. Thus, observing and investigating the adhesion and interface between concrete samples and the bonded materials were of other purposes.

Table 11.4. Examples of first and second phase of the bonding process on the concrete samples

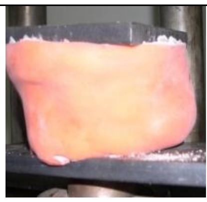
Stages of coating on the concrete samples, preparation for collapse process observation				
Casting, de-moulding, and polishing Process				
Materials:	Mould preparing ,	placing/casting	de-moulding	polishing for testing
Externally bonded concrete samples				
	1.Poly-pol PS60	2.Sil/Rub Shore A10		3.glas.fib4+ polypolPS60

Finally, various specimens of conventional and fibre-reinforced concrete were also wrapped with strips or layers of Glass, Aramid, and Carbon fibres for optimising thickness, width, and length of the bonding. For this also compressive, tensile, and 3-point bending moment tests were applied.

11.3.2. c. Results of the experiments for the DFE

The tests results presented here are only comparative in order to find a suitable alternative in the range of easily available materials, appropriate for the mentioned application. Examples of the comparative De-Fragmentation behaviour of samples are shown in table 11.5.

Table 11.5. The collapse process/ behaviour of the bonded samples under compression (comparative results)

Different Collapse in 3 samples, first set of tests				
	Poly-pol PS60	SR Shore A 10	GFRpoly-polPS60	
Collapse process in one of the samples	1. 	2. 	3. 	4 

First row: the failure mode in three samples with three types of bonding materials,
Second row: the collapse process in the bonded polyurethane rubber (transparent) concrete

- Samples of a common concrete mix that were cut with a saw cutting machine (thus with a smooth and homogenous surface) under the compression tests showed more similar results. These results were much different from the tests on the ones of the same concrete mix, but without the surface preparation. However, an effect of the surface strength was more influential in the shear tests.
- In addition to the priorities of some production methods in relation to the applied materials, various interface typologies were observed by implementing different matrixes for the bonding systems (e.g. shown in figure 11.1.).

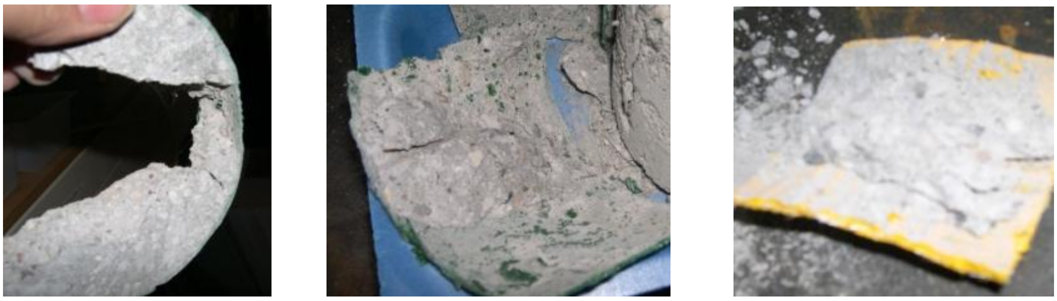


Figure 11.1. Examples of adhesion of the bonding and concrete samples, the bonding materials are not completely separated from the concrete body even after collapse under compressive test.

- The effect of distribution of fibres on the cracking behaviour of the surface was considerable. This was experimented in the tests to achieve a good surface in order to avoid the interface problems between the concrete specimens and the bonding.

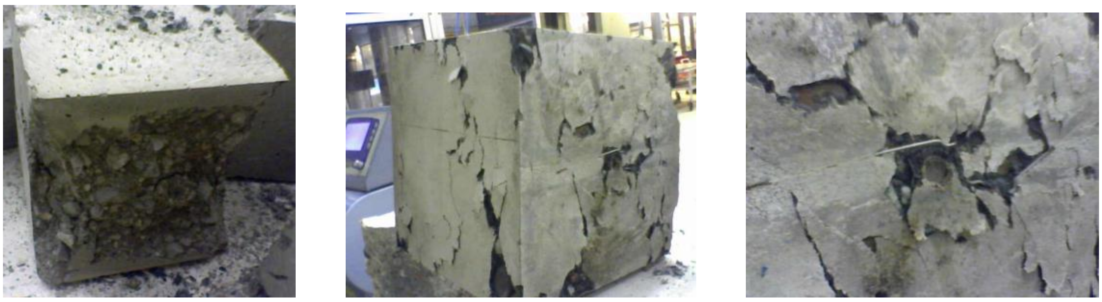


Figure11.2. Conserving the surface behaviour in order to achieve a smooth even surface to be wrapped

- A summary of comparative results for the de-fragmentation of the materials is given in table 11.6.

Table11.6. Comparative design values in the alternative bonding materials (respectively)

Coating materials	Supporting Level	Thick ness	Bonding	Flexibility	Material use	Product simplicity
Polyester	-	+++	++	--	++++	++++
GFRP	+	+++	++	-	++	++
SA10	++	--	--	++++	+++	+++
PUA60	++	-	+++	+++	+++	+++
GFRA10	++	-	--	+++	++	++
Chopped GFRPUA60	+++	+	++++	+++	++	++
Woven GFRPUA60	+++	+	++++	++	+	+
Compressed GFRPUA60	+++	+	++++	++	+	+
GFRP+SA10	++	-	++	++	-	-
GFRP+PU60	++	+	++	++	-	-

++++ = the highest comparative value, and,
---- = the lowest comparative value
Level of support = the ability of the bonding material to keep the concrete from falling apart.

- Because of the observed properties and the resulting potentials, further experiments were conducted only selectively on some materials (e.g. Glass Fibre, Carbon fibre, Aramid Fibre FRP's). These were composites with a matrix of polyurethane. Two important distinctive characteristics make these options appropriate for selective use in different situations. Although carbon fibres and Aramid are capable of sustaining higher stresses over the expected lifespan, glass fibres are affordable while simultaneously providing adequate strength for normal use (e.g. for the structure of a house). While the Carbon Fibre FRP (CFRP) samples seem cracking under compression load, samples of Glass Fibre FRP (GFRP) bonded in a similar situation, look like shrinking.
- In both specimens of conventional and fibre-reinforced concrete, increasing the thickness, width and length of GFRP, AFRP, and CFRP-bonding, extended the time until ultimate failure. The cracking noise was heard much earlier than the final collapse of the entire element. This was confirmed by the curve of compression strength of the sample on the computer's data screen of the test-monitoring computer.
- The influence of the bonding system on the fragmentation of the entire specimens in conventional concrete is more significant than that of the ECC concrete.
- Increasing the thickness of the bonding layers had a significant effect on postponing the collapse and fragmentation. However, these have relatively minor effects on strength of the concrete element itself. It should be notified that the mentioned time extension is a comparative measure. This means that although the extended time between the major cracking and the final collapse has been increased by particular experiments, only few (e.g. 5 to 7) seconds of extension were achieved.

11.4. Discussions

The results of the experiments showed that even in cases where the concrete entirely collapses, for instance under compression, it does not fall apart if it is supported by a proper DFE. This was observed not only in the final experiments, but also in many of the alternative composites that were tested beforehand (GFR-PUR, thick layer of SR, GFRP+PUR, GFRP+SR, GFRPUR). However, some other factors involved in the design for De-Fragmentation, as adhesion or bonding properties, fabrication and costs are also involved in the materials selection. Although increasing the strength was not the main purpose of this study, most DFE equipped samples appeared stronger than those without the DFE did. Analogously, in the study of Wu et al. (2005), Bank et al. (2007) and Kim et al. (2008) externally bonding of concrete improves some mechanical properties, like strength.

11.4.1. Influences of morphology of fibres in the bonding system and DFE

Similar results to Balaguru et al. (2009) about carbon fibres were found. Significant influences of ratio, geometry, aspect ratio of fibres, distribution of fibres throughout the matrix, regardless the type of FRP were partly observed by some other studies as well (e.g. Fu et al., 2002; Namaan, 2003; Latifa et al 2004, Epaarachchi et al., 2009). For example, Latifa et al (2004) point at fibre orientation, volume fraction, and fibre spacing, fibre packing arrangement, curing parameters that significantly influence the composite's properties. As a more specific example, in specimens of FRP reinforced by woven fibres under the load the composite seemed to be more directly under the load. In these cases, dependency of the FRP on fibres increases. Karl Hope (2009) states that long fibres in the resin have much higher impact resistance, creep resistance, safer failure mode, higher temperature conductivity, and more stable properties in some special environment like high moisture environment. Some of these were similarly achieved here as well. However, for enhancing the impact resistance the resilience of resin is crucial. Geometry and size of fibres have significant effects on properties of FRP, but other factors may involve in the selection as well. For example, long carbon fibres are not as available as the others are. Of other involved factors regarding the size is that generally, short fibres pose ease of fabrication for the FRP bonding. They comprise isotropic nature, and flexibility, compatible with several methods and for various applications. Besides these fibres can be distributed inside the matrix mainly in three forms of random distribution, align discontinuous, and aligned off axis discontinuous distribution. The composites with randomly oriented short fibres (SFRC= Short Fibres Reinforced Composites) have a quasi-isotropic nature on microscopic scale. Although aligned fibres have excellent in plane-mechanical properties, the randomly distributed fibres are the most widely used, mainly because of their easy production process. However, in continuous fibre composites the external loads are directly applied to the fibres. This is while in the SRFC the load applied to matrix materials is transferred to the fibres via fibre ends and the surface of fibres. Therefore, the properties of the SFRC greatly depend on fibre length and the diameter of the fibres.

Bonding, interface, surface, and geometry

In line with the results found by Leung et al. (2005), failure occurs in many cases through the de-bonding, which mainly initiates from the bottom of a major flexural crack in the concrete. In more than 20 samples, the failure was predominantly caused by the friction part where the concrete was cracked. However, first elasticity of the matrix and secondly increasing the thickness of the DFE had significant effect on final failure of the entire sample. Nevertheless, the argument of Leung et al. (2005) about aggregates, although relatively similar for the samples of conventional concrete, does not apply to the whole experiments of this research. This is because ECC is composed of very fine ingredients and acts homogeneously.

The general outcome of the experiments was that the ultimate failure of the various specimens was not noticeably related to the strength of the concrete but rather to the DFE including the properties of the bonding materials. Some other studies, such as those by Lopez (2000) and McSweeney et al. (2005) have also obtained similar results albeit with a different aim and approach. It should be noticed that surface strength is more effective than the strength of the concrete in the collapse and failure of the structure. Therefore, for reliable results for the efficiency of the DFE, the surface should be well prepared. This applies fist, to the surface of the concrete specimen and later to the surface of this specimen after being bonded with the FRP. Similarity of the results on samples with homogenous surfaces and large differences between the specimens with unprepared surface proved this.

Geometry of the concrete sample not only influences results of the bonding but is also very important in the fabrication. Regarding the fabrication, circular samples have high-performance potential; non-orthogonal samples also comprise this advantage. However, they need to be thoroughly studied for their unpredicted properties, which is out of the scope of this study. Brosens et al. (2002) also found some results similar to those we obtained. In the samples where the DFE was fabricated and then put onto the concrete, a non-homogenous de-bonding process under load stress was observed more often. This, analogous to the study carried out by Ignoul et al (2003), proves the sensitivity of both the bonding method and the interface between the concrete and the FRP. Leung et al. (2005) summarise the effectiveness of FRP bonding in (i) surface preparation of concrete, (ii) the type of adhesive, (iii) geometric factors, such as FRP bond length, the thickness of FRP plate, FRP width etc., (iv) interfacial fracture energy. However, these important statements are for strengthening the concrete structures, not for the De-Fragmentation.

11.4.2. The time extension in concrete materials

"The exact behaviour of buildings within the seconds of undergoing the seismic load is not precisely known yet".

Researching the time for rescue in earthquakes has not been found in other studies. However, few indications were found from two sides. First, was where the main body of the structures is made of ECC, in which the fracture energy is 3000 times that of hardened cement paste (Lepech et al., 2003). Besides, in addition to the effect of the bend-ability property of the ECC, a possibility of the time difference between the yielding and collapse of ECC elements can be deduced from the indications in the study of Fisher et al (2002). He concluded that the ECC matrix stiffens the specimens at un-cracked sections and also strengthens it at cracked sections. These are similar to some parts of the observations in current research, in which the crack enlargement and widening with a constant loading needed times (e.g. 3- 4 seconds). An example is provided in figure 11.3.

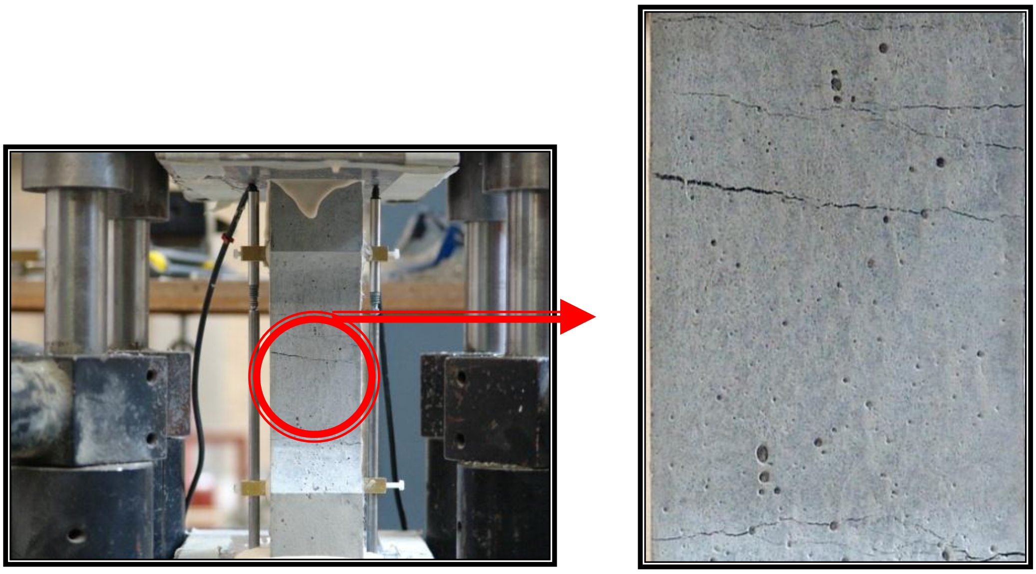


Figure 11.3. An example of cracking processes under the tensile tests

The second indications were found in sources that studied the FRP bonding for raise of the strength. For example, McSweeney (2005) indicated the time indirectly and as a side issue. He stated that "*additional bonded length only increased the time to failure for the system". "longer bonded length did not reduce the magnitude of strain at the location of the strain gages, but it did* *ensure that strain redistribution could occur (again, increasing the time up to failure of the system).* However, he did not qualify the time.

It can generally be concluded that, in several aspects, FRP showed promising potential for the purpose of the current research. Among the tested samples, the GFRPUR (Glass Fibre Reinforced Poly Urethane Rubber) hold the collapsed materials very efficiently. It bonds with the sample and is a readily available material. Although during the tests at the end of the experiments, excellent bonding behaviour of CFRP and significant increase of strength was observed, it is not the best alternative for the DFE. In general, qualities of FRP make it useful as a DFE for structures in a seismic area. With these safety materials, clearing rubble after demolition, reuse and recycling is one-step ahead in the phase of collecting and separation process of rubble. Moreover, DFE increases the durability of the concrete, at least from weathering. The mentioned advantages of the DFE and its effects on the durability, improve the sustainability of the entire structure of the house in a SRH-SD. Finally, the weight of DFE is very low, and that is important for a seismic application, while simultaneously implementation, transportation, etc. are eased.

11.5. Summary, conclusions and recommendations

- The average minimum time required for inhabitants of a normal one floor desert town house to leave their houses is about (Δt_1 =) 11 seconds. This time period for a two floor house is about (Δt_2=) 17 seconds.

- Based on the previous statement, the DFE should provide a delay of about 17 seconds for a two-floor desert house of the SRH-SD, in which most of the inhabitants evacuate their houses. Of course, the more this delay extends, less will be the risk for different categories of people (e.g. elderly, sick…) to be trapped in the collapsed buildings.

-To ensure declining vulnerability of the inhabitants of a house in seismic desert towns from being trapped under the rubbles, boosting the concrete by the DFE, at least in the critical spots of the structure, is a good solution. By using the DFE, the collapse and fragmentation processes of the concrete structural component, can be postponed.

- FRP materials are proven to be good alternatives for designing the DFE system.

Based on the findings in the experiments, it can be claimed that for a time delay in the DFE system, the most important involved factors include:

● geometry of the concrete elements

● surface preparation of the concrete elements as the interface area

● adhesion of the bonding materials to the surface of the concrete elements

● adequately coverage of the resin around the impregnated/saturated fibres

● thickness of the bonding composite

● length, width, and overlap of the bonding composite around the concrete element

● various issues related to the interface of the concrete element and the bonding layers

● the bonding method

Among these factors, the thickness of the appropriate composite that covers the surface of the structure (issued for de- fragmentation) is the most influential item with regard to the time of final collapse and fragmentation. It can also be concluded that a different period of time for the collapse delay may also be achievable by changing the design and altering the materials and methods. However, this may simultaneously involve other conditions (e.g., extra costs) as well.

- Design for De-Fragmentation is environmentally friendly for a seismic desert area. In addition to improving the durability, it can ease the disassembly and re-assembly of the damaged element for repair or changing the structural component.

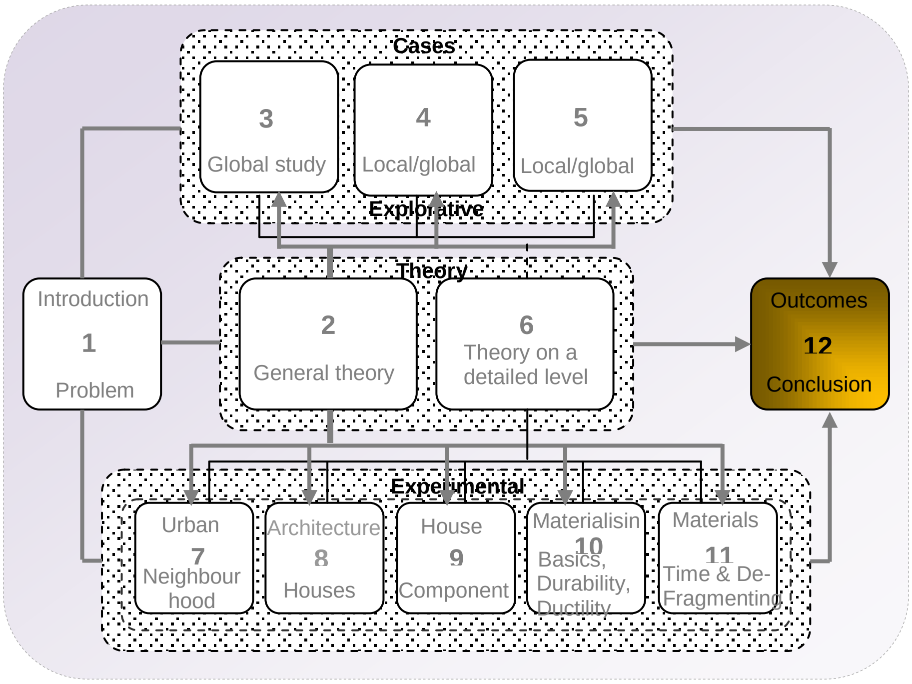
The extended fragmentation time (e.g. 5-7 for conventional concrete and 3-4 seconds for the ECC), are only presented to show the feasibility and validation of the accuracy of the design. Otherwise, a large range of further experiments is required to achieve a solid scientifically arguable collapse extension time period.

Next

The research on measuring the required time for emergency rescue in earthquakes has generated many questions that opened interesting areas of research for different fields.

Although the study has proven the feasibility and effectiveness of the hypothesis of adding the DFE to gain a few seconds, further research is required for an adequate extension of the time yet. This means that the achieved collapse time extension from 5-7 seconds needs to be increased to 11-17 seconds of the collapse delay in the future research. The used FRP materials can be further optimised. Prototypes need to be made with larger dimensions and tested as scaled models in practice (rather than only laboratory experiments). Optimising ratio of the FRP reinforcing fibres is of other recommendations. As was indicated, these experiments and the recommended ones are planned on the small-scale specimens in the laboratories. Therefore, at the end of all of these preparing scale models is required in order to make the results one-step closer to the application for the real practice for the houses.

Nevertheless, an important item that makes the DFE system even more significant for a seismic area is an alarming sub-system, although it is out of the scope of this research. This part of the hypothesis aims at providing an alarming system in DFE that warns people as soon as possible. In this way, DFE reacts to the first pulse of energy that comes from the seismic motion through the building. The optimum situation for this alarming system is to achieve the micro scale of alarming system by advanced technology transfer. For example, a combination of semiconductor technology and the light transfer with other required supporting technologies in the frame of an advanced design may provide an excellent alarming system. This can warn the people of an earthquake occurrence, while the DFE itself keeps the structural materials from fragmentation.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Conclusion
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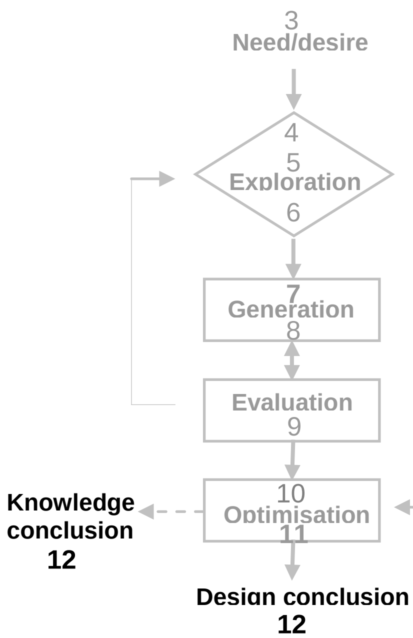
Time & De-Fragmenting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Design conclusion
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CHAPTER 12

CONCLUSIONS and RECOMMENDATIONS

12.1 Introduction

After previously discussing the 'optimisation' and detailing of the design in a Complex Design Situation by referring to a case of SRH-SD (Sustainable Reconstruction of Houses in Seismic Deserts), this chapter is the final stage of the GPM (Glocal Process Model) for a complex situation. It articulates the general conclusions, remarks and recommendations of the study. Because of the complex design circumstances, profound research was required, but not all observations could be addressed in the framework of the present dissertation. Although several conclusions to sub-questions and other components were already addressed in various chapters, in this chapter the main question is the crucial one: How can we develop a suitable system for a complex situation as sustainable reconstruction of houses in a seismic desert area?

12.1.1 Recapitulation of the thesis structure

As answering the main question required a multidisciplinary approach, the thesis was structured accordingly, and was divided in twelve chapters. The schematic procedure of the research question and the problem statement, along with the processes applied within the whole of this thesis, are shown in Figure 12.1.

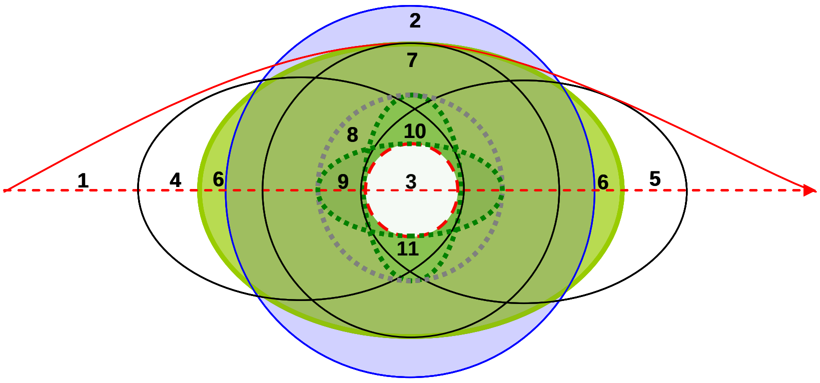

Figure 12.1. Chapters in the thesis specified by their number in a schematic relationship with each other and the main elements involved in the study.

As shown in the scheme of Figure 12.1, there is a large problem area related to the design in a complex situation (i.e. Ch. 1). An appropriate theory covers a big part of the problems while touching upon larger areas beyond the problem boundaries and going into other imaginary areas (Ch. 2). The need at the centre of the problem is also the central issue of the design task, but this is not limited to the original problem area, so it requires possible area solutions and may touch upon external ideas (Ch. 3). Exploration is such a fundamental part of the design procedure and is so essential for the foundation of an effective successful design that this was discussed in three separate chapters. One chapter provided the background and requirements for one of the severe constraints, seismicity (Ch. 4). The second of these concentrated on the other forcing constraint: the condition of a desert context (Ch. 5). In the third one, the theoretical conclusion was oriented toward action as the final stage of the exploration in a complex situation, so that systemisation was the main message here. In addition to modelling the design processes, this systemisation was proposed in two main ways. The first involved emphasising the importance of prioritisation, selection, and decision-making as the final step in the exploration phase, before the generation and the practical design phases. Second, a controlling element had to be conceived to prevent the design from being lost in chaos. This controlling element has been called a ‘general strategy’. A strategy of sustainability is an appropriate strategy for this large-scale controlling element to be applied in the specific case of Reconstructing Houses in a Seismic Desert (all discussed in Chapter 6). The subject of the Generation phase (Ch.7 & 8) involved a practical design case to prove the validity of the GPM model in a Complex Design Situation (CDS) at the urban level as well as at the building/architectural level, in addition to evaluating and moving to apply the sustainability strategy. Further practical cases for the evaluation were experienced through the design cases for the optimisation of buildings and building components at the element level. Apart from the fact that selecting appropriate alternatives depends on many factors in a reconstruction design of houses – much more than those involved in a normal construction (e.g. social aspects) – the selected alternative may even have to be modified due to other influences during the optimisation phase. This also is one of the requirements for the sustainability of a project. This part of the research concluded with a list of checking criteria for the sustainability of the SRH-SD (Ch. 9). After this, to ensure the sustainability of the SRH-SD in the integrated design and materialisation of the houses, various aspects were successively discussed. In an integrated design for the SD situation, the basic/main materials of the structure of the house must provide at least adequate strength, durability, possible ductility, thermal properties. As the crucial factors, they had to be tested (Ch. 10). To reduce the risk and vulnerability of the inhabitants of the houses, a design for Defragmentation resulted in DfE (Defragmentation Element) which provides some vital extra seconds for the rescue of the inhabitants. The required escape time was explored and the basic requirements were identified. The crucial element to rescue people in earthquakes, the ‘rescue time’, was found and feasibility of the proposed solution for the Defragmentation Design to provide this ‘rescue time’ was proven (Ch. 11). Based on these procedures, the current chapter summarises the main findings of all chapters, with an emphasis on answering the main research question.

12.1.2 Essential basis

A giant ice island, covering 100 square miles – more than four times the size of New York’s Manhattan island – has broken off the Petermann Glacier, northern Greenland. (Muenchow, 2010).

Figure 12.2. Greenland’s broken melting ice, and the mass loss rate between 2003 & 2009 (Planetsave 2010)

The importance of houses for human life and for the construction industry is evident and was touched upon in various chapters. Nevertheless, these important buildings also play a major role in energy use worldwide. In principle, buildings are responsible for 40% of the world's annual energy consumption, while 20-30% of energy in developed countries is used in homes (Rahman et al., 2006). Although energy use and sustainability have been the subject of debates for more than three decades, and standards with supporting regulations have been accordingly established in developed countries, energy use per capita in developed countries is by far greater than that by developing nations. Nevertheless, the energy use by developing countries is expected to rise, especially in emerging economies. Therefore, a huge effort is required to activate sustainability in developing countries and enforcing it in both types of countries. This thesis considered sustainability in theoretical terms, and in terms of the action to be taken in the (re)construction of houses in general. The core of this dissertation concerns the design of town houses and the main message relates to the integrity, organisation, and systemisation of the sustainability framework.

The arguments about the sustainability of the SRH-SD addressed two important issues of the topic. First, sustainability in general needs to be put into action, rather than only being a subject of debate. Second, in addition to the seriousness of the need for a sustainable system for SRH, these arguments provide a knowledge model that is applicable in practice. Besides, the systematic approach to managing the complex design facilitates this application of knowledge in practice. Addressing the delicate issues in various chapters proved the flexibility of the proposed framework and the applicability of the method on various scales and levels, so that a strong base grounded for developing relevant research in the future facilitating a wide range of further research. Examples of such research were provided at the end of the previous chapter, and some more examples will be added to this chapter. Further subtle modelling of the finer parts, if required, can be done within the frame of a SRH in the SD, based on the emerging knowledge model and proposed system.

The complexity and required understanding of the situation and the danger of the chaos and the subsequent failure were the topic of discussion in more than half of the chapters. A central system is required to address various issues of the relevant subjects in a SRH-SD. On the one hand, the current state of knowledge and technology provides tremendous opportunities for designers as well as practitioners. On the other hand, this knowledge and advancement acquired make the situation even more difficult to deal with. Nevertheless, the general approach to technology transfer proposed in this study, either stated directly or approached tacitly, emerges as a trans-connector for the multidisciplinary nature of architecture. Although architecture has always been a multidisciplinary area, the more knowledge and technology advances, the larger the relevant branches in architecture become. This requires more consideration, therefore more organisation. Regarding these, systemisation of the design in a complex situation was applied to various ways such as the integration of various levels, conducting the integrated design by the sustainability strategy as a general leader, modelling the design processes as a system, and modelling the exploration phase of design as a subsystem.

12.2 Main findings and outcomes

The major efforts of this doctoral research were directed towards obtaining a correct understanding of an extremely complex design situation, of which the complexity is defined by circumstantial complications that interfere with well-known solutions. These complications may be referred to as design constraints. The study concentrated on formulating the problem and this complexity and on proposing theories at a general level (e.g. chapter 2 and chapter 6) and providing models in specific cases (e.g. chapter 7, 8 and 9). It is extremely important to understand

and recognise the interaction of these constraints and to deal correctly with the possible consequent conflicts. Thus, the aim was to develop a system (e.g. Glocal Sustainable System based on ISS (Inclusive Sustainability Strategy) in chapter 6) for organising, reorganising and taxonomising (when required) complex design by an adaptation of methods, such as design processes and technology transfer (e.g. tools for decision-making in a sustainable design).

Categories of findings

The emphasis of this thesis lies in defining the domain of a sustainable reconstruction of houses in a seismic desert as a critical part of the answer to the main research question. However, similar to the first hypothesises; the findings of the study can be divided into four main categories:

1. Findings regarding the process model as a broad framework for systemising the design in a complex situation in order to avoid chaos and risk of failure, to be applied in the case of Sustainable Reconstruction of Houses in a Seismic Desert Situation.
2. The knowledge model as an evolutionary pack emerged either by making progress in the process of research, design and complying with requirements, or by validating the theory and gradually evaluating the GPM for a Complex Design Situation.
3. Conclusions regarding further systemisation within the frame of sustainability of the reconstruction. This includes a proposal strategy and corresponding criteria, and provides sample checklists that can be applied in practice with regard to liveability and sustainability in a seismic desert town. Examples of applicable sustainability index for a SRH-SD are found in table 7.6, 7.7, 8.7., and 8.8 of chapters 7 and 8. Setting such an appropriate strategy helps to avoid the possible harmful consequences of the design conclusion in a long run.
4. Conclusions regarding 'reducing the vulnerability of the inhabitants of houses' (e.g. in chapters 10 and 11). After proposals on the upper levels of design in chapter 7, 8 and 9, these are expressed in the form of proposed solutions, particularly with regard to DfE (Defragmentation Elements), and are based on findings from practical design on the material level). These can either be applied directly, in the construction stage, or can be used for further developments and progression in other directions.

12.2.1 The Systemisation for a Complex Design Situation

In this study, the systemisation of design in a complex situation focuses on SRH-SD (Sustainable Reconstruction of Houses in a Seismic Desert). This systemisation was incorporated into the entire research. First, systemisation of the design was applied to avoid chaos and to prevent the design conclusion from possible failure by modelling the design processes and setting up an appropriate guiding strategy. Second, the product development approach is a modern approach dealing with both conditions – a desert circumstance and seismicity – which incorporates technology and knowledge transfer. An important result of this approach was the identification of structural elements as products that can significantly help earthquake resistance while also being a perfect approach to transportation in the desert environment. This outcome as a part of the system (which may be referred to as a sub-system) is significant for the sustainability of the whole reconstruction project as well. The last point of the integrated systemisation was the system used to prevent fragmentation of the structural materials. In this (sub)system, the main structural body was realised in a strong material (i.e. a concrete composite) that was as ductile as possible. When the main materials provide the strength, a bonding layer for Defragmentation can be added to the structure as a rescue-enabling element. This can be applied to various concrete composites. Thus, SRH-SD systemisation is generally applied right from the beginning of the design to the end of the materialisation of houses and production.

12.2.2 The knowledge model

Although destruction of houses by earthquakes has been going on for at least 7000 years (e.g. Sialk Hills, Kashan, 5000 BC) not all cities destroyed were able to recover and be reconstructed (e.g. Ancient Atlantis, 10000 BC, or Shahre Sookhte in 2000 BC). This destruction and its subsequent recovery was one of the long-lasting problems requiring modern design solutions. Even in modern times, solutions to particular cases involving a combination of more than one severe constraint are seldom integrally provided. Because of the frequency of earthquakes and their huge impact, especially in areas vulnerable due to the risk of desertification, a lack of well-organised solutions is badly felt.

With this dissertation, the design for a Sustainable Reconstruction of Houses for Seismic Desert towns is defined as a new domain in the architectural design field. The main characteristics in this new domain can be identified as:

a . Crucial connections and relationships of reconstruction with political issues, both locally and globally.

b. Complex design procedures caused by different factors, such as a serious involvement of social and psychological/emotional aspects in design practices and performances.

c. Different types of communication between design team, client and stakeholder.

d. A sensitive stage between the design and practical reconstruction, which includes two important components:

(i) The first relates to local workers and engineers as the main personnel of the reconstruction works. Workers need to learn the modern or even the traditional building methods correctly. Meanwhile designers and engineers need to learn the potentials of the local and traditional methods, their meanings, their connections with the socio-cultural issues.

(ii) The second component relates to the local authorities (mostly local governments) enforcing the achieved solutions in the practical reconstruction.

e. Involvement and effects of the post-earthquake sheltering and relief in reconstruction.

f. Vital role of sustainability to lead the design, also to guide the practical reconstruction.

g. Vital priority for transferring the global modern technologies and knowledge into local applications, into the language of the audience.

h. Significant opportunity for town development towards sustainable housing.

12.2.3 Sustainability of reconstruction

There are two noticeable issues concerning the sustainability of the reconstruction of houses: (i) the problem of reconstruction is different and much more complex than normal construction; (ii) the available references for sustainability and the relevant knowledge are mostly related to developed nations. Meanwhile the population is still growing in developing countries, whereas it is stabilising or even decreasing in developed countries. Hence, the contribution of developing countries, in terms of energy use and the dominant lifestyle, is increasing. Notably, most instances of destruction, fatalities, and injuries in earthquakes occur in developing nations. Hence, sustainability apparently still needs a lot of attention and effort, especially in some particular fields.

What the former generation did to the environment is beyond our control, but we are responsible for what we impose on the environment ourselves, for our own benefit and with consequences to future generations. The definition of benefit also needs to be reconsidered; the values that a 'benefit' carries include more than can be calculated. Planting a climatically adaptable tree in a desert, supported by an appropriately designed water source, not only provides a certain amount of shadow, but is also a step to stop desert expansion and hence the desertification threat to cities at the borders of deserts. This is an example of what I mean with 'benefit'. Therefore, the prioritisation of components of sustainability in a normal situation was adapted to the different situation of this thesis' topic. In this prioritisation the steps were arranged as follows: (i) environmental aspects (that provide long time safety as well), (ii) social aspects, and (iii) economic aspects.

12.2.4 Defragmentation

Defragmentation was an important point of discussion in the chapters that focused on proposing practical solutions for cases to validate the theory and strategy. In an integrated design, all scale levels in a design domain collaborate towards the joint aim. Thus, for instance, the materialisation of a structural element has a mutual relationship with the element that is called a building product. In this regard, if the materialisation is appropriate and flexible in the building product, changing the function of the building product will not terminate the lifecycle of the material. The product development approach in this study ended with the characteristics of the flexible elements that are applicable in different locations and applications. The strong durable materials discussed are for prolonging the 'service life' to fit the technical life span. Furthermore, a third type of life span was added on a different scale and with a slightly different terminology; in this study it is called the 'safety life span'. The safety lifecycle is dependent on a prolongation of the technical life span. This means that, under a seismic load, at the end of the technical life span, the final throe of the structural element or product, which is mostly characterised by material fragmentation, will be extended for several seconds. As a vital component, the required time was identified. However, it needs to be noted that longer periods (exceeding some seconds) may be achieved for the postponed fragmentation in a near future.

There is a difference between the moment that an earthquake motion hits and spreads through a building, and the moment that the structure collapses and the materials fragment. The recognition of this period is crucial knowledge to designers, because then they may be able to combine and accommodate these extra seconds to a safety system that could save lives. This safety system may also be equipped with an emergency alarm system that works with the first earthquake to hit the structure, and may well work even with the energy introduced by the seismic motion (to be studied in future research). Although the structure of houses may not be strong enough to withstand heavy earthquakes, using appropriate materials and design details provides the inhabitants with the opportunity to rescue themselves before the materials fragment and start falling down.

Straightforward to the research question

Either throughout previous chapters or with the above discussions it is recognisable that the answer to the main research question cannot be stressed as a single item. Instead, an approach was developed based on understanding of the complexity of a design, especially in a seismic desert context. The critical roles of some particular aspects (e.g. socio-cultural, psychological and political) that make reconstruction different from a normal construction project were illustrated either directly or indirectly and tacitly. In this study, large frames were proposed for systemisation (in different cases). This was a way to organise the complex design without limiting freedom of the architect. Besides, this broadness offers the opportunity of adjusting the relevant criteria for different projects of reconstruction (may even include new construction), which is crucial for a public applicability. Furthermore, hypotheses as the larger system of GPM for modelling the design processes were validated through chapters (e.g. chapter 3 through chapter 11).

It should be reminded that sustainability is only achievable through the integration of the design on various levels. This was tested by applying a combination of two old methods of bottom-up and top-down approaches (schematically shown in figure 12.3). Finally, the emerging knowledge was completed as the chapters were finalised to give an answer to the research question. Of course, this may also be available in a web-based model to make it easily accessible for researchers. Although the structure of the later was provided, the content needs to be filled afterwards, informed by this dissertation.

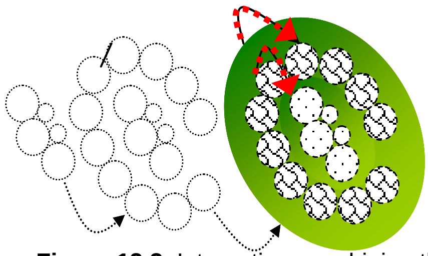

Figure 12.3. Integration, combining the top- down and bottom-up

12.3 *Reflection, white spots, and weaknesses*

In general, every revolutionary step, specifically in the building industry, opposes strong resistance, but experiences in other fields are significantly valuable to foresee the possible future. It means that this conservative approach is changing enormously. For example, what is going on with regard to change and the social requirements in car manufacturing as well as in computer and electronics sector is very useful to prove the quality of the product development approach in the design of building elements that have to serve the market appropriately. Reducing the high level of impact building-related activities have on the environment, a product development approach to design and production of structural elements is not only beneficial in terms of lifecycle and use, but can also be significantly advantageous in reuse, repair, recycling and reproduction. Both of these aspects are environmentally friendly while they are also economically sound. Moreover, technology transfer as a generic energy- and time-saving method has already been applied in some sections of architecture (e.g. digital design tools, domotics and building services), and on a larger scale in other fields, so that its quality has certainly been proven.

12.3.1 Applications of the outcomes of this research

Although the focus and framework of this study is on ‘reconstruction’, various other studies were integrated into it, which may be applied for other purposes as well. The most probable use for these is application of the research findings in the design and performance of to be constructed buildings, especially houses in seismic desert areas. In addition, the study can contribute as knowledge support restricted by the defined domain and models but also by example criteria and indexes for future research in, for instance:

- organising other complex designs by a similar approach
- decision-supporting tools regarding sustainability

- sustainable neighbourhoods in seismic desert areas
- a Global-Local concept for the structure of a house in a seismic desert
- materials selection and application in a seismic desert area
- eye-opener to the design possibilities to achieve environmentally sound solutions for buildings on the component and element level as well as on the materialisation level.

However, here are other noticeable issues in the next section.

12.3.2 Reflection on content and process

During the process of this research some issues limited the progress, sometimes influencing the research period, and at other times limiting the boundaries of the research in two ways. The first was because in many desert cities the statistics were either unavailable or unreliable. The second issue was caused by reluctance of some professionals, mainly architects, to respond to the interviews, questionnaires, etc. For instance, many simple data needed to be recollected and recalculated, efforts that otherwise could have been put in further qualifications and elaborations.

Because of the newness of the domain of SRH-SD every segment and aspect involved in this domain needed to be defined, argued and validated. Although the domain was successively defined, its segments and aspects involved were not similarly considered. However, examples of these form guidelines for doing a completed research on every single item (e.g. the economic aspect of the SRH-SD). This also applies to the case-oriented research, for example in the following three ways: (i) in research on the durability of concrete, (ii) in denoting and defining the time required for escaping to the outdoor, (iii) extension of the delay period of a concrete structure to a specific number with precise characteristics of bonding materials, etc. The design for an earthquake-resistant structure or structural element is an important example of weakness. Many efforts were made in general as well as in this particular study, with scientific achievements in literature. However, the exact behaviour and the absolute procedure that a building goes through within the seconds of shaking are not completely known yet. The particular test environment, expensive equipment, and dangerous consequences of experimental research constituted main limitations and weaknesses to perform adequate research in this direction.

12.3.3 Future research and recommendations

This study started with a few questions and finalises with many. Answering these would require continuation of the research in several directions. Although the research has been limited to a particular framework and structure, it has opened a larger view on the research field, raising many questions. Based on the area defined in this thesis, relevant research in the future ought to include:

- The design of software for transferring the inputs from the current study.
- Development of a digital web-based system that connects all segments of the design for SRH-SD.
- Development of sub-systems for each of the segments, with integrity regarding the central system as well as other segments.
- Development of the prioritisation, selection and decision-support tools for the design team to measure sustainability of the SRH-SD with different inputs from circumstantial differences and interferences.

- Developing simulation programs to anticipate the consequences of the design solution for the SRH-SD in longer term.
- Finding a complete answer to the defined question of: what exactly happens to the bearing structure in terms of collapse behaviour and procedure, especially in terms of time?
- Simulation of human behaviour in different positions and various building categories in reaction to a seismic excitation. Further developments in this direction would also be useful, for instance, to show the difference in response to a strong earthquake between desert inhabitants and those in a temperate climate.
- Developing the design for Defragmentation on a different scale (e.g. self-reacting elements).
- Economising the DfE by further experiments to specify precise thicknesses.
- Further tests/experiments regarding the expanded range of materials for the DfE.
- Design of a particular test set-up for a time-oriented measurement for the DfE.
- Enlarging the test field by including more varieties in the groups of people participating in the 'escape' experiments with the inhabitants of houses (e.g. the ill, elderly, little children).

Some instances of progress that were found in the design field, as well as in the community of policy-makers, refer to significant achievements in sustainable development by the previous generation of researchers and knowledge providers. Examples include projects as the Green Building Movement, Healthy Buildings, Eco-house, Green Home Building, Passive House Standard, OMSH (One Million Sustainable Homes), etc. However, as indicated previously, to ensure a healthy environment it is necessary to imbue recognition of sustainability options into the lives of people. Furthermore, standards and policies are significant for enhancing the application of sustainable methods. Hence, enforcing such policies in design as well as in the performance and use is another crucial requirement. For example, home owners in the US who wish to extend their houses upward, can be enforced to improve thermal insulation in the walls and cover the roof with photovoltaic.

On a case study scale, although design for desert cities involves some particular technical issues regarding the climate, a longer time perspective, which is essential, involves many more items than just the climate. The influence of this design may go even beyond the boundaries of sustainability, because lives in urban desert areas, especially in the marginal cities, may be affected by it. Therefore, in such a context, providing secure design methods and solutions is even more crucial when it is also prone to earthquakes. The integration of all design levels is recommended, as well as the application of broad strategies such as the sustainability strategy in addition to further development towards systemisation of both design and material performance. The other important recommendation is the development of and motivation for the application of decision-support tools in design and performance. It needs to be repeatedly emphasised that although the product of this study focuses on reconstruction, it is also applicable to new design and construction in a complex situation such as a seismic desert context.

12.4 A final massage

Because of the huge increase of the world's population, especially in the decades immediately before the year 2000, and because of rapid construction in suburbs, mostly in developing countries, the increasing number of fatalities caused by earthquakes (shown in Figure 12.4) is the object of serious attention (e.g. Kobe, Istanbul, Gujarat, Bam, Northern Sumatra, Pakistan, eastern Sichuan, Haiti). Most of these deaths were caused either by structural collapse and construction materials trapping people under the rubble, or by other consequences of earthquakes such as fire, which again may involve properties of building materials. However, with integrated design and development approaches as the Glocal System, not only is sustainability ensured and do desert cities not need evacuation, but also do fatalities curve (in the graph of Figure 12.4) since the excitation of seismic motions will be different. Design solutions such as DfE also alter the direction of the line and change the relationship between population growth and death toll. The possible scenario after such applications can be demonstrated by the red dotted line of the graph in Figure 12.4.

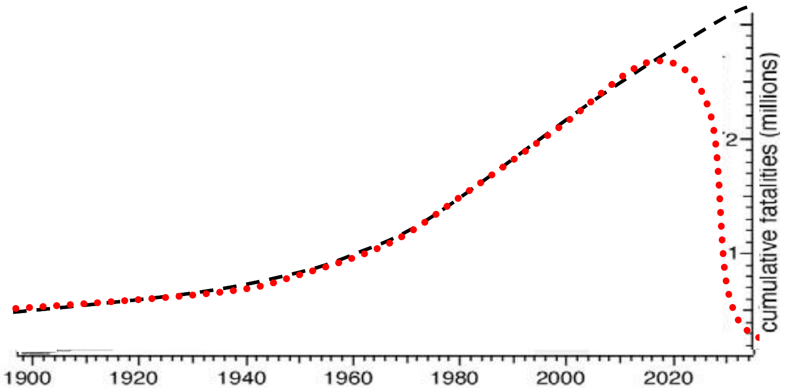

Figure 12.4. The cumulative fatalities from earthquakes, the red line relates to the change that can be achieved by applying appropriate methods. (Basic data source: after Bilham, 2004).

A similar scenario is foreseeable for the sustainability of (re)construction in seismic desert areas. Figure 12.5 shows the change in house size. It is evident that this has an impact on the environment and use of energy. Tippett says (DZG, 2009): “Globally, the building industry contributes up to 30-40% to the emission of GHGs and 30-40% to the production of waste”. Although energy consumption has increased to the level that buildings currently use (the indicated 40% of the world’s annual energy), new trends are mostly towards reducing this consumption. By appropriate strategies such as the above-mentioned methods, these can be conducted and changed into the form that is depicted in the scheme in green. Of course, this prediction is also based on social desire, especially in desert towns, where people aim at larger houses. This wish can be moderated if people recognise and understand the possible effects of constructing extra floor area, so that social faith and appreciation of the natural environment is crucial. This can be achieved through the integration of sustainability into design on a multidisciplinary scale, from the supply chain to operational phase, from the designer to the user, on the short and long term.

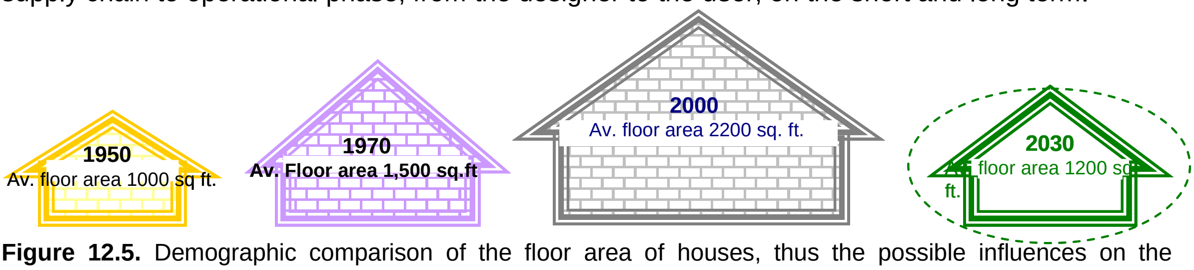

Figure 12.5. Demographic comparison of the floor area of houses, thus the possible influences on the environment in different periods of time (the average floor areas apply to the US). Prediction of a change regarding the use of proper strategies (e.g., sustainability strategy) is also incorporated by the green colour in the scheme (Basic data source: Treehugger, 2009) r5m

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Shohre Shahnoori born in Shahsavar/Tonekabon, Iran, graduated from high school in mathematics and physics. She has received a bachelor in Architectural engineering and a Master of Science in urbanism and architectural engineering from Tehran University of Science & Technology. When finalising her bachelor she was hired by the university as design and research assistant at its technical office. After graduation, she continued working for the university while also working at Zheir Design & Consulting Company in Tehran. After which Shohre worked as an individual designer, consultant, and constructor while working with several organisations as well. These include -leading the design and urban planning group at the technical office of Provincial Governor, -teaching at the Technical Graduation Centre for Higher Education of the Hormozgan province, -teaching at Azad University of Bandar Abbas, -and at the Civil Engineering Department of Hormozgan University, -head of the Department of Civil Engineering at Hormozgan University. With these, she enjoyed planning & design, detailing, and construction of numerous neighbourhoods, houses, community and shopping centres & Bazar, guesthouses, landmarks & monuments, watchtower, City Hall, and other buildings. These were not only for the cities of Hashtgerd, Bandar Abbas, Bandar Lenge, Kong, Charak, and Khamir, Hajiabad, Minab, Rudan, Jask, Bastak, Gavbandi, and Sirik, but also in the islands of Gheshm, Kish, Abu Moosa, Hengam, and Hormoz. At the same time she was -a member of the Engineering Organization of Hormozgan, -jury and advisory member in the committee of the Neighbourhood Designers headquarter Hormozgan province, -Member of the CEO (Construction Engineering Organization), - member of “Environmental protection agency” etc.

Shohre Shahnoori has been selected as the Best female engineer and the Selected Active woman of the year 1997 and 1998 in Hormozgan Province. In addition to several national events, the candidate organized some international conferences and symposia on building construction, materials, and emergency housing in both Iran and the Netherlands. She was a chair person not only for these conferences but also has been selected as such for the conference of Building Stock Activation which was hold in Tokyo in November 2007. Before starting the PhD research her research interests included impacts on the environment by emerging services on the coasts of Persian Gulf and Oman Sea, energy saving, modern construction detailing, collapse of materials by earthquakes, corrosion, and weathering etc. She moved to the Netherlands as a researcher in Building Technology at TU Delft in 2004. Since then and before starting the PhD work, she was doing research on a complex design situation, which later became focused on modelling the complex design environment in addition to sustainability of building construction and materials for the PhD research. These have been the subject of her publications in journals, books, and conferences and symposia. After submitting the first draft of the manuscript in September 2010 she left the TU Delft as a full time researcher to work at Hormozgan University as an assistant professor while being a gust researcher at TU Delft.

During her PhD period, she was also a student member of ACI, EERI, IEEE, IET, CIB, World Housing Encyclopaedia, Reliefweb, Composite World, Concrete Construction, BetonDispuut, Betonvereniging, etc. In her personal life, she enjoys spending time with family and friends, is a mountaineer, practices Yoga, swims, and as an amateur plays a Persian instrument called Setar.

FIRST- AUTHOR PUBLICATIONS LIST

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