

# **Earthquake Disaster Risk Assessment for Cultural World Heritage Sites: The Case of “Bam and its Cultural Landscape” in Iran**

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*Dedicated to my wife, Baharak  
for her patience and love*

*“Understanding something in just one way is a rather fragile kind of understanding (...) you need to understand something in at least two different ways to really understand it. Each way of thinking about something strengthens and deepens each of the other ways of thinking about it. Understanding something in several different ways produces an overall understanding that is richer and of a different nature than any one way of understanding” (Resnick, 1994, p. 103).*



**Bam and its Cultural Landscape (Author, 2013)**

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## Abstract

Despite the continuous effects of natural hazards on cultural heritage and growing body of research on disaster risk assessment, cultural heritage still suffers from the lack of integrated risk assessment methodologies. Within the context of natural hazards, earthquakes need to be differently considered mainly due to the sudden massive destruction without warning and the unpredictability of the exact occurrence time and place. Although earthquake hazard cannot be eliminated, its disaster risks can be reduced through risk management strategies, which rely heavily on the hazard- and site-specific risk assessment information. Risk assessment, which is the focus of the current study, is the integral and central component of the broader disaster risk management. So far, limited sources have been adequately dedicated to developing risk assessment methodologies for cultural heritage. The challenge is to integrate the principles and methods of risk assessment in heritage conservation on one side, and to incorporate particular characteristics of cultural heritage and World Cultural Heritage properties (e.g. the Outstanding Universal Values and associated conditions of authenticity and integrity) into the risk assessment procedure, on the other.

There are numerous cultural properties that have been extremely affected by seismic events, such as the historic city of Bam in Iran. The World Heritage site of ‘Bam and its Cultural Landscape’, as a unique example of a traditional human settlement, is investigated in this research. Because Bam and its Cultural Landscape is located in a high-probability earthquake region and appeared to be highly vulnerable to seismic events, an integrated risk assessment for the property needs to be developed in response to potential earthquakes.

Recognising the challenge, this research aims to develop an integrated and systematic methodology of earthquake disaster risk assessment for cultural heritage, in particular for the case of Bam. The interdisciplinary theoretical framework of the research reviews the conceptual discourses and analytical procedures of risk assessment to support the methodological framework. A triangulation of qualitative and semi-quantitative methods is applied in the data collection and analysis process in order to promote the quality of the measurements and results. While considering the key attributes of Bam and its Cultural Landscape, specific criteria and indicators are derived to support the analysis of risk components. In-situ observation of the heritage properties within the core zone of Bam and its Cultural Landscape purposively grasps their particular attributes. Furthermore, document analysis and expert questionnaire survey provide the vulnerability and risk assessment with the essential data.

A Cultural Heritage Risk Index for Bam is performed to measure the level of risk by aggregating the risk components, which are ‘hazard’ (earthquakes), ‘exposure’ (significance of the site elements), and ‘vulnerability’ (susceptibility and coping capacity). According to the risk index, an earthquake risk map is generated by applying Geographic Information System (GIS) to demonstrate a common understanding of the level of potential impacts on the property. Furthermore, a multiple impact identification matrix supports determining the potential impacts of an earthquake as well as its related secondary hazards and human-induced threats that need to be addressed in a risk preparedness plan.

The findings of the research emphasize that in addition to the hazard itself, diverse factors associated with the heritage significance, structural susceptibility, and institutional capacity highly influence the level of risk. The outputs of the risk assessment contribute to the decision-making process in defining the tolerability of risks and prioritising the exposed properties. Moreover, the information provided by the analysis procedure allows determining site-specific risk reduction strategies, particularly seismic susceptibility reduction and coping capacity building. This provides specialists and practitioners from multiple sectors engaged in the protection of (World) cultural heritage with a practical tool to facilitate risk communication and appropriate risk management planning.

**Keywords:** Earthquakes, Bam and its Cultural Landscape, Disaster risk assessment, Vulnerability assessment, World Cultural Heritage

## Zusammenfassung

Ogleich der anhaltenden Auswirkungen von Naturgefahren auf das Kulturerbe und des wachsenden Forschungsangebots zur Beurteilung des Katastrophenrisikos, leidet das Kulturerbe immer noch unter dem Fehlen integrierter Risikobeurteilungsmethoden. Im Vergleich zu anderen Naturgefahren, müssen Erdbeben vor allem aufgrund ihrer plötzlichen und massiven Zerstörungskraft, als auch der Unvorhersehbarkeit des genauen Auftretens bezüglich Zeit und Ort anders betrachtet werden. Obwohl die Erdbebengefahr nicht ausgeschlossen werden kann, können die Katastrophenrisiken durch Risikomanagementstrategien reduziert werden; die vor allem die Gefährdung und standortspezifische Risikobeurteilungsinformationen umfassen. Die Risikobeurteilung, die im Mittelpunkt der vorliegenden Studie steht, ist der integrale und zentrale Bestandteil des Katastrophenrisikomanagements. Es existiert bisher nur eine begrenzte Anzahl an spezifischer Literatur für Risikobeurteilungsmethoden für das Kulturerbe. Die Herausforderung besteht darin, einerseits die Grundsätze und Methoden der Risikobeurteilung bei der Erhaltung des Kulturerbes zu übernehmen und andererseits die besonderen Merkmale des Kulturerbes und der Weltkulturerbestätten (z.B. die außergewöhnlichen universellen Werte und die damit verbundenen Bedingungen der Authentizität und Integrität) in das Risikobeurteilungsverfahren einzubeziehen.

Es gibt zahlreiche Kulturstätten, die stark von seismischen Ereignissen betroffen sind, wie zum Beispiel die historische Stadt Bam im Iran. In dieser Analyse wird das Weltkulturerbe ‚Bam und seine Kulturlandschaft‘, als einzigartiges Beispiel einer traditionellen menschlichen Siedlung, untersucht. Weil Bam und seine Kulturlandschaft in einer Region mit hoher Erdbebenwahrscheinlichkeit liegt und sich als sehr anfällig für seismische Ereignisse erwiesen hat, muss eine integrierte Risikobeurteilung für das Kulturerbe als Reaktion auf mögliche Erdbeben vorbereitet werden.

In Anbetracht dessen, zielt diese Forschung darauf ab, eine integrierte und systematische Methodik der Risikobeurteilung von Erdbebenkatastrophen für das Kulturerbe zu entwickeln, insbesondere für die Fallstudie Bam. Der interdisziplinäre theoretische Rahmen der Forschung überprüft die konzeptionellen Diskurse und analytischen Verfahren der Risikobeurteilung zur Unterstützung des methodischen Rahmens. Eine Triangulation von qualitativen und semi-quantitativen Methoden wird im Datenerhebungs- und Analyseprozess angewendet, um die Qualität der Messungen und Ergebnisse zu gewährleisten. Unter Berücksichtigung der Schlüsselmerkmale von Bam und seiner Kulturlandschaft werden spezifische Kriterien und Indikatoren abgeleitet, die die Analyse von Risikokomponenten unterstützen. Die In-situ-Beobachtung der Kulturgüter in der Kernzone von Bam und seiner Kulturlandschaft erfasst gezielt deren besondere Eigenschaften. Darüber hinaus liefern Dokumentenanalyse und Expertenbefragung der Vulnerabilitäts- und Risikobeurteilung die wesentlichen Daten.

Für Bam wird ein Kulturerbe-Risikoindex entwickelt. Die Aggregation der Teilkomponenten, ‚Gefahr‘ (Erdbeben), ‚Exposition‘ (Bedeutung der einzelnen Kulturgüter) und ‚Vulnerabilität‘ (Anfälligkeit und Bewältigungskapazität) im Risikoindex ermöglicht die Analyse des Risikos. Unter Zuhilfenahme eines geographischen Informationssystems (GIS) wird der Index räumlich als Erbeben Risikokarte dargestellt. Die Karte zeigt ein gemeinsames Verständnis des Ausmaßes der möglichen Auswirkungen auf die einzelnen Kulturgüter. Darüber hinaus wird eine Matrix zur Identifizierung multipler Auswirkungen entwickelt. Die Matrix erleichtert die potenziellen Auswirkungen eines Erdbebens sowie die damit verbundenen sekundären Gefahren und vom Menschen verursachten Bedrohungen, die in einem Risikovorsorgeplan berücksichtigt werden müssen, zu bestimmen.

Die Ergebnisse der Forschung zeigen, dass neben der Gefährdung selbst, verschiedene Faktoren im Zusammenhang mit der Bedeutung des Erbes, der strukturellen Anfälligkeit und der institutionellen Kapazität, das Risikoniveau stark beeinflussen. Die Ergebnisse der Risikobeurteilung liefern dem

Entscheidungsprozess die Grundlage für die Definition der Verträglichkeit von Risiken und die Priorisierung der exponierten Kulturgüter. Darüber hinaus ermöglichen es die im Rahmen des Bewertungsverfahrens bereitgestellten Informationen, standortspezifische Strategien zur Risikominderung festzulegen, insbesondere zur Reduzierung der seismischen Anfälligkeit und zum Aufbau von Bewältigungskapazitäten. Damit steht Fachleuten und Praktikern aus verschiedenen Bereichen, die sich mit dem Schutz des (Welt-) Kulturerbes befassen, ein praktisches Instrument zur Verfügung, das die Risikokommunikation und eine angemessene Risikomanagementplanung erleichtert.

**Schlüsselwörter:** Erdbeben, Bam und seine Kulturlandschaft, Katastrophenrisikobeurteilung, Vulnerabilitätsbewertung, Weltkulturerbe

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## Acronyms and Abbreviations

**AEMC:** Australian Emergency Management Committee  
**AHP:** Analytic Hierarchy Process  
**ALARP:** As Low As Reasonably Practicable  
**ArcGIS:** GIS for working with maps and geographic information  
**CCAAA:** Coordinating Council of Audio-visual Archives Associations  
**CCI:** Canadian Conservation Institute  
**CRED:** Centre for Research on the Epidemiology of Disasters  
**DRA:** Disaster Risk Assessment  
**DRM:** Disaster Risk Management  
**DRR:** Disaster Risk Reduction  
**EC:** European Commission  
**EM-DAT:** International Emergency Disasters Database  
**FEMA:** Federal Emergency Management Agency, USA  
**GIS:** Geographic Information System  
**HFA:** Hyogo Framework for Action  
**HIA:** Heritage Impact Assessment  
**IATF:** Inter-Agency Task Force  
**IEC:** International Electrotechnical Commission  
**ICA:** International Council on Archives  
**ICBS:** International Committee of the Blue Shield  
**ICCROM:** International Centre for the Study of the Preservation and Restoration of Cultural Property  
**ICHO:** Iranian Cultural Heritage Organisation  
**ICHHTO:** Iran Cultural Heritage, Handcraft and Tourism Organization  
**ICOM:** International Council of Museum  
**ICOMOS:** International Council on Monuments and Sites  
**ICORP:** International Scientific Committee on Risk Preparedness of ICOMOS  
**IFLA:** International Federation of Library Associations and Institutions  
**IPCC:** Intergovernmental Panel on Climate Change  
**ISO:** International Organization for Standardisation  
**MMI:** Modified Mercalli Intensity  
**MMS:** Moment Magnitude Scale  
**NERAG:** National Emergency Risk Assessment Guidelines, Australian  
**NGO:** Non-governmental Organization  
**OUV:** Outstanding Universal Values  
**PGA:** Peak Ground Acceleration  
**RA:** Risk Assessment  
**RM:** Risk Management  
**SDGs:** Sustainable Development Goals  
**UN:** United Nations  
**UNDP:** United Nations Development Programme  
**UNDRO:** United Nations Disaster Relief Organization  
**UNESCO:** United Nations Educational, Scientific and Cultural Organization  
**UNESCO WHC:** UNESCO World Heritage Centre  
**UNISDR:** United Nations Office for Disaster Risk Reduction  
**USGS:** United States Geological Survey  
**WCH:** World Cultural Heritage  
**WH:** World Heritage  
**WHC:** World Heritage Centre

## Terminology

**Adobe:** “Outdoor, air-dried, unburned brick made from a clayey soil and usually mixed with straw or animal manure. The clay content of the soil ranges from 10% to 30%“ (Tolles et al. 2002, p.133).

**Authenticity:** “The ability to understand the value attributed to the heritage depends on the degree to which information sources about this value may be understood as credible or truthful” (UNESCO WHC, 2017, para. 80).

**Conservation:** “Conservation means all the processes of looking after a place so as to retain its cultural significance” (Australia ICOMOS, Article 1, 2013).

**Coping capacities:** “The ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters” (UNISDR, 2009).

**Cultural heritage:** “The tendency today is to understand cultural heritage in its broadest sense as containing all the signs that document the activities and achievements of human beings over time” (Feilden and Jokilehto, 1993, p. 11). UNESCO WHC (2017, Article 1) states that “(...) the following shall be considered as (tangible) "cultural heritage":

- groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of Outstanding Universal Value from the point of view of history, art or science;
- monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of Outstanding Universal Value from the point of view of history, art or science;
- sites: works of man or the combined works of nature and of man, and areas including archaeological sites which are of Outstanding Universal Value from the historical, aesthetic, ethnological or anthropological points of view.”

**Cultural landscapes:** “Cultural landscapes are cultural properties and represent the "combined works of nature and of man" designated in Article 1 of the Convention. They are illustrative of the evolution of human society and settlement over time, under the influence of the physical constraints and/or opportunities presented by their natural environment and of successive social, economic and cultural forces, both external and internal” (UNESCO WHC, 2017, para. 47).

**Cultural significance:** “Cultural significance means aesthetic, historic, scientific, social or spiritual value for past, present or future generations”. “Cultural significance may change over time and with use” (Australia ICOMOS, Article 1, 2013). The term ‘cultural significance’ is now commonly used to refer to the collection of the various values associated with a place which together identify why it is important” (Worthing and Bond, 2008, p. 47).

**Disaster risk management (DRM):** “Disaster risk management is the application of disaster risk reduction policies, processes and actions to prevent new risk, reduce existing disaster risk and manage residual risk contributing to the strengthening of resilience” (UNISDR, 2015a).

**Disaster risk reduction (DRR):** “Disaster risk reduction is the policy objective aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contributes to strengthening resilience” (UNISDR, 2015a).

**Disaster risk:** “Disaster risk is considered to be a function of hazard, exposure and vulnerability. It is normally expressed as a probability of loss of life, injury or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time” (UNISDR, 2015a).

**Disaster:** “A serious disruption of the functioning of a community or a society due to hazardous events interacting with conditions of vulnerability and exposure, leading to widespread human, material, economic and environmental losses and impacts” (UNISDR, 2015a).

**Earthen Architecture:** Properties in which earth materials (e.g. rammed earth, adobe, cob, hand-shaped earth) is the main construction material and were used in the load-bearing walls, mortars, roofs, and floors (Gandreau and Delboy, 2012, p. 8).



**Earthquake:** “Earthquake is a term used to describe both sudden slip on a fault, and the resulting ground shaking and radiated seismic energy caused by the slip, or by volcanic or magmatic activity, or other sudden stress changes in the earth” (USGS, 2018).

**Exposure:** “People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses” (UNISDR, 2009). “The term exposure is frequently used in the field of insurance where the total value at risk (exposure) is determined, e.g. the value of buildings, and next the vulnerability of the considered value at risk under a certain stress (e.g. a defined type of flooding) is analysed” (EC, 2010, p.16).

**Hazard:** “A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or Environmental damage” (UNISDR, 2009).

**Impact:** “Impacts describe the consequences for the elements at risk from exposure to the source of risk, that is, the emergency” (AEMC, 2010, p.25).

**Intangible cultural heritage:** “The “intangible cultural heritage” means the practices, representations, expressions, knowledge, skills – as well as the instruments, objects, artefacts and cultural spaces associated therewith – that communities, groups and, in some cases, individuals recognize as part of their cultural heritage” (UNESCO WHC, 2013a, Article 2).

**Integrity:** “Integrity is a measure of the wholeness and intactness of the natural and/or cultural heritage and its attributes” (UNESCO WHC, 2017, para. 88).

**Khesht:** Sun-dried mud brick, which is in fact unburned brick, in adobe construction that is applied to the load-bearing walls, floors, and roofs (ICHO, 2004).

**Landslide:** “A landslide is a movement of surface material down a slope” (USGS, 2018).

**Liquefaction:** “A process by which water-saturated sediment temporarily loses strength and acts as a fluid, like when you wiggle your toes in the wet sand near the water at the beach. This effect can be caused by earthquake shaking” (USGS, 2018).

**Mitigation:** “Disaster mitigation accepts the fact that some natural event may occur but tries to lessen the impact by improving the community’s ability to absorb the impact with little damage or disruptive effects” (Perez & Thompson, 1986, p.49).

**Natural hazard:** ‘natural hazard’ is associated to the geophysical processes in the environment that embodies the potential for loss or damage that exists in the presence of the vulnerable elements (Stillwell, 1992).

**Outstanding Universal Value (OUV):** “Outstanding Universal Value means cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity” (UNESCO WHC, 2017, para. 49).

**Peak ground acceleration:** “During an earthquake when the ground is shaking, it also experiences acceleration. The peak acceleration is the largest increase in velocity recorded by a particular station during an earthquake” (USGS, 2018).

**Preparedness:** “The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current disasters” (UNISDR, 2009). “Disaster preparedness assumes that the disaster will occur and focuses on structuring response and laying a framework for recovery” (Perez & Thompson, 1986, p.49).

**Recovery:** “Decisions and actions aimed at restoring or improving livelihoods, health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development, including build back better to avoid or reduce future disaster risk” (UNISDR, 2015a).

**Resilience:** “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions” (UNISDR, 2009). In the context of heritage,

“resilience may be understood as the ability to experience shocks while retaining heritage values” (Australia State of the Environment, 2011).

**Response:** “Actions taken during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected” (UNISDR 2015a).

**Retrofitting:** “Reinforcement or upgrading of existing structures to become more resistant and resilient to the damaging effects of hazards” (UNISDR, 2009). “Retrofitting entails the replacement or rehabilitation of building and structural systems to improve their ability to withstand structural forces” (FEMA, 2005, p. 3-10).

**Risk analysis:** “Risk analysis is the systematic process to understand the nature of and to deduce the level of risk” (ISO 31000, 2009). “Risk analysis aims at assigning each identified risk a rating in accordance with the agreed risk criteria” (AEMC, 2010, p.31).

**Risk assessment:** “Risk assessment is the overall process of risk identification, risk analysis and risk evaluation” (ISO 31000, 2009). “A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend” (UNISDR, 2015a).

**Risk evaluation:** “The purpose of risk evaluation is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment to prioritize treatment implementation” (ISO 31000, 2009).

**Risk treatment:** “Risk treatment involves selecting one or more options for modifying risks, and implementing those options” (ISO 31000, 2009).

**Risk:** In the context of natural hazards, the term ‘risk’ is defined as the “expected losses from a given hazard to a given element at risk, over a specified future time period” (Coburn et al. 1994, p.10).

**Setting:** “Setting means the immediate and extended environment of a place that is part of or contributes to its cultural significance and distinctive character” (Australia ICOMOS, Article 1, 2013).

**Susceptibility:** “Susceptibility means that societies or communities have deficiencies and limited capacities to deal with adverse events” (Birkmann and Welle, 2015, p.6).

**Threat:** “Threat is a potentially damaging physical event, phenomenon or activity of an intentional/ malicious character” (EC, 2010, p.11).

**Vulnerability:** “Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to hazard, either a perturbation or stress/stressor.” (Turner et al., 2003, p. 8074).

# **CHAPTER 1**

## **INTRODUCTION**

## 1.1 Introduction<sup>1</sup>

Cultural heritage, as an integral part of the evolution of our environment, still plays a significant role in contemporary socio-economic development. Historic urban environments attract considerable tourist revenue while creating diverse types of employment; this can improve economic coping capacities of urban systems to build back better following disasters. Furthermore, the shared cultural identities and sense of belonging among a community can foster public participation that is vital for public acceptance and effectiveness of planning strategies, including risk preparedness and post-disaster recovery. Indigenous knowledge and techniques associated with historic built environments represent the evolution of human settlement adaptability to surrounding environments and a culture of living with natural hazards.

However, cultural heritage sites have been exposed to natural hazards, with consequences ranging from gradual deterioration to tragic losses. Sudden-onset hazards have not only caused serious damage to physical elements of heritage properties, but they have threatened their intangible attributes, such as building typologies, traditional knowledge and techniques, and rituals and ceremonies. In the context of World Heritage properties, disasters may cause a loss of the OUV and associated conditions of authenticity and integrity; and subsequently, their associated socio-cultural and economic significances for the local and intentional communities might be lost.

Stovel (1998, p.1) argues “we respond to tragedy when it occurs; we respond (...) in the face of immediate need, but we are reluctant to extend our capacity for event-specific response to embrace the larger processes for which we bear responsibility”. Following severe damages to cultural heritage by natural hazards over the past few decades, initiatives by the scholars and international organisations have been carried out to concentrate on risk prevention and mitigation in conservation policies. UNESCO WHC et al., (2010) emphasise that reducing the risk is the most effective management approach; and suggest investing in preventive risk management planning of heritage properties in the pre-disaster situation than to spend a large amount of resources in post-disaster rehabilitation and recovery.

Within the disaster management cycle, this research is dedicated to disaster risk assessment phase. Risk assessment is an essential part of the overall risk management to provide the decision-making process with the site- and event-specific information regarding disaster risks. The output of risk assessment can significantly facilitate determining appropriate risk mitigation and preparedness strategies to safeguard heritage properties from potential hazards.

## 1.2 Statement of the problem

Earthquake hazard, unlike some other natural hazards, cannot be eliminated or mitigated. The challenge of dealing with seismic events becomes more complicated also due to their sudden massive destruction without warning and the unpredictability of the exact occurrence time and place. Despite the recent development in the seismic reinforcement and mitigation knowledge, cultural heritage has experienced extreme quake-induced devastations. The 1997 Assisi earthquake, the Bam earthquake in 2003, the Great East Japan earthquake and tsunami in 2011, earthquakes in Haiti, Chile, and Christchurch in 2010, Italy earthquake in 2012, and 2015 Nepal earthquake are some of the recent examples of the earthquakes with severe damages to historic structures.

Despite the disastrous consequences of earthquakes, many World Cultural Heritage properties do not have an appropriate risk management plan. There are numerous cultural sites that have been

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<sup>1</sup> This section is based on a paper published by the author (Ravankhah et al., 2017b).

extremely affected by seismic events, such as the historic city of Bam in Iran. The 6.6 magnitude earthquake of 2003 in the historic desert city of Bam caused the tragic loss of many lives and the extreme destruction of the cultural heritage of Bam. Following the earthquake, ‘Bam and its Cultural Landscape’ was inscribed on the World Heritage List (under criteria ii, iii, iv, and v) in 2004 through an emergency nomination, and simultaneously on the List of World Heritage in Danger.

The problem is not merely related to the case of Bam. According to a rough estimate of a composite map of WCH sites (2013) in the earthquake-prone areas (please see *Chapter 2-Study area, Section 2.2*), around 16% of the WCH properties are located in the high and very high seismic zones, and 34% are situated in the moderate seismic zone. The Bam Citadel is a well-known earthen heritage based on the adobe construction technique. A composite map of the earthen WH sites (2012) in the earthquake-prone areas (please see *Chapter 2-Study area, Section 2.2*) demonstrates that there is a correlation between the distribution of earthen constructions and the earthquake-prone zones. A rough estimate of the map indicates that around 21% of the earthen WH properties are located in the high and very high seismic zones, and around 34% are situated in the moderate seismic zone.

The recent examples of the destruction of cultural heritage, together with the considerable number of WCH properties exposed to seismic events, stresses a need for developing risk assessment and management plans. In the case of Bam, because the property is located in a high seismic zone and appeared to be vulnerable to earthquakes, an appropriate risk assessment procedure needs to be developed for potential earthquakes. It should be noted that assessing disaster risks of future earthquakes to the key attributes of the site conveying the OUV plays an essential role in determining the adequate risk reduction strategies. Importantly, without an integrated and site-specific risk assessment, current conservation and management measures in Bam may additionally increase the vulnerability of the property to future earthquakes as it occurred in the Bam earthquake 2003.

### 1.3 State of the art<sup>2</sup>

Until recently, there has been a trend to concentrate, on the one side, on the technical and structural damage caused by earthquakes to historic fabrics (e.g. Tolles et al., 2002; Langenbach, 2005), and on the other, on the overall process of risk assessment and management for cultural heritage (e.g. Stovel, 1998; FEMA, 2005; UNESCO WHC et al., 2010; ICROM and CCI, 2016). In regard to earthquakes and historic sites, in his book *Between Two Earthquakes*, Feilden (1987) suggests mitigation and restoration measures for cultural properties before, during and after an earthquake mainly within the heritage conservation framework. Stovel (1998) in his book, *Risk preparedness: A management manual for world cultural heritage*, proposes a risk-preparedness framework for cultural heritage in three major steps of preparedness, response, and recovery. He emphasises that direct and indirect damages of earthquakes need to be addressed in the risk preparedness framework.

UNESCO WHC et al. (2010) underscore the importance of scenario building to assess the risks of a disaster. In the UNESCO guideline, *Managing Disaster Risks for World Heritage*, a risk assessment process for heritage properties has been drawn within the overall risk management cycle. In the assessment procedure, particular considerations are dedicated to hazard analysis information, vulnerability factors, and loss of the OUV. A systematic process of risk assessment for historic properties has been developed by FEMA (2005) in *Integrating historic property and cultural resource considerations into hazard mitigation planning*. However, the process mainly follows an economic-oriented approach.

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<sup>2</sup> This section is based on two papers published by the author (Ravankhah, Schmidt, and Will, 2017a; Ravankhah and Schmidt, 2016).

Within the Disaster Risk Management (DRM) agenda, cultural heritage has been emphasised in the UN World Conference on Disaster Reduction in 2005 that led to the *Hyogo Framework for Action (HFA) 2005-2015*. In the context of World Heritage, “the [World Heritage] Committee suggests that State Parties include risk preparedness in the management plans of World Heritage site and training strategies” (UNESCO WHC, 2017, para. 118). Admittedly, disaster risk reduction has to be an integral part of the heritage management plan to safeguard the OUV from natural and human-induced hazards. The UNESCO *Strategy for Reducing Risks from Disasters at World Heritage properties* (UNESCO WHC, 2007, p. 3), which is based upon the HFA, indicates “identification, assessment and monitoring disaster risks at World Heritage sites” among its five main priorities for action to stress a need for approaching disaster risks in a systematic and long-term perspective.

Goal 11 of the 2030 Agenda for Sustainable Development – “make cities and human settlements inclusive, safe, resilient and sustainable” – explicitly acknowledges ‘Heritage’ in target 11.4: “strengthen efforts to protect and safeguard the world’s cultural and natural heritage” (UN, 2015, p.18). Following the Sustainable Development Goals (SDGs), the integration of the concept of ‘Cultural Heritage’ in disaster resilience has been emphasised in the recent UN’s Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030, particularly in the Priority for Action 1: “Understanding disaster risk and Priority”, and in Action 3: “Investing in disaster risk reduction for resilience” (UNISDR, 2015b, p.14).

There are few examples of cultural properties for which integrated risk assessment procedures have been developed. Looking at concrete examples, UNESCO Amman Office (2012) proposes a methodology to assess the risks of disasters through qualitative and quantitative approaches. According to this plan, which was prepared for Petra World Heritage Site in Jordan, the level of risk can be calculated based on particular criteria while considering the specific requirements in heritage conservation.

Regarding the case of Bam, according to the existing documents, most of the pre-earthquake activities in the citadel were concentrated on the archaeological excavations and building restorations without an adequate consideration on risk management. Following the earthquake 2003, an international workshop on the *Recovery of Bam’s Cultural Heritage* was organised by the Iranian Cultural Heritage Organization (ICHO) with the cooperation of UNESCO, ICOMOS, ICCROM, the Getty Conservation Institute and some other organisations. The workshop resulted in *the Bam Declaration and Recommendations* (ICHO et al., 2004b) for the short- and long-term planning of the post-earthquake recovery. In 2008, multi-stakeholder cooperation for the management of Bam led to the *Comprehensive Management Plan for Bam and its Cultural landscape (2008-2017)* that includes territorial and environmental management, urban development control, safeguarding of built and intangible heritage, tourism development, and a brief risk preparedness and disaster mitigation plan (ICHHTO, 2008a).

Following the earthquake, valuable investigations by the national and international scholars have been dedicated to the citadel. It was revealed that not only the earthquake caused such severe destruction of Bam Citadel, but also other factors (e.g. improper interventions, loss of the cohesion of the clay, termites and deterioration) contributed to increased seismic-vulnerability of the citadel (Langenbach, 2005; Vatandoust et al., 2008a). In the recovery process, stabilisation measures have been carried out, such as injection grouting of cracks, applying tension elements, and reinforcing adobe structure with palm fibres to increase the ductility of the adobe materials (Vatandoust et al., 2008a). Some research projects (e.g. by Shad, 2014) have been also conducted on the strengthening of historic adobe structures in the citadel, mainly with a focus on structural seismic performance while considering the heritage conservation principles.

While the above-mentioned investigations and efforts have considerably facilitated the progress of promoting heritage resilience, cultural heritage still suffers from the lack of integrated and event-

specific risk assessment methods. This is also the case for Bam and its Cultural Landscape. Most of the current methodologies have been mainly concentrated on technical and structural features or the whole cycle of DRM without providing a systematic and detailed procedure of risk assessment. Furthermore, the contribution of non-structural factors (e.g. coping capacity of the management system) and heritage values to the risk assessment and risk mapping needs further development.

## 1.4 Research hypothesis

Although earthquake hazard cannot be eliminated, its associated disaster risks can be reduced through risk mitigation and preparedness strategies; the effectiveness and applicability of the strategies to cultural heritage rely heavily on the integrated disaster risk assessment methodologies. The research approaches the problem on the basis of the following hypothesis:

The risk assessment procedure needs to be developed in an integrated approach to incorporate the risk assessment standards and methods as well as the heritage conservation principles into the procedure. The assessment procedure needs to follow a systematic methodology that incorporates a set of structural and non-structural criteria and their associated indicators in order to adequately assess disaster risks to heritage sites.

## 1.5 Research objectives

This research aims to develop an integrated and systematic methodology of earthquake disaster risk assessment for WCH properties, in particular for Bam and its Cultural Landscape. The methodology adopts the principles and methods of risk assessment and management on one side, and incorporates particular characteristics of cultural heritage and WCH properties (e.g. the OUV and associated conditions of authenticity and integrity) in the procedure, on the other. The key attributes of the World Heritage site of Bam and its Cultural Landscape will be particularly taken into account. In order to fulfil the aim, the following objectives are pursued:

- To develop a systematic risk assessment procedure for cultural heritage through deriving specific criteria and indicators for analysing the components of risk;
- To identify the potential impacts of earthquake-induced disasters on Bam and its Cultural Landscape, including its OUV and associated conditions of authenticity and integrity;
- To develop a Cultural Heritage Risk Index for Bam in order to measure the seismic vulnerability and risk to the elements of Bam and its Cultural Landscape;
- To generate an earthquake risk map for the elements of Bam and its Cultural Landscape; and
- To evaluate the risks to the elements of Bam and its Cultural Landscape in order to determine which elements and on which level of priority need risk treatment strategies.

## 1.6 Research methodology

A review of relevant approaches, methods, and practices was carried out through the current literature of disaster management, heritage conservation, and seismology. The extensive literature review aimed to analyse the theoretical and conceptual discourses regarding earthquake disaster risk, risk assessment approaches, and risk management for cultural heritage. The theoretical framework contributed to the selection of an appropriate research methodology.

The overall methodological approach of the research is a triangulation of qualitative and semi-quantitative methods in the data collection and analysis process in order to promote the quality of the

measurements and results. The semi-quantitative methodology has been increasingly applied in the area of natural hazards and risk management using the numerical ranking scales.

An in-situ observation and photography of the heritage properties within the core zone of Bam and its Cultural Landscape were performed to purposively grasp their particular attributes. The pre- and post-earthquake reports and visual materials of Bam supported the site observation. This condition assessment of the property observed the structural elements and building materials, construction techniques, current damages and deterioration patterns, as well as the post-earthquake stabilisation and restoration measures. It has been followed by the office activities to sort the data and prepare the useful fieldwork information to be integrated into the different steps of the risk assessment, particularly into the vulnerability assessment.

An expert questionnaire was conducted to evaluate the status of the risk assessment and management of the property before and after the earthquake. The questions correspond to the criteria or indicators derived in the risk assessment methodology while considering the theoretical framework and the case study description. The primary data was also cross-checked with the information extracted from pre- and post-earthquake reports of Bam, official records of the Bam recovery process, and visual materials.

In different steps of the risk assessment procedure for the case of Bam, particular data analysis methods, such as significance assessment matrix, indicator-based vulnerability assessment index, risk index, risk mapping in ArcGIS have been applied. As mentioned before, a semi-quantitative method was applied for analysing the data in order to make the calculation process more reliable. However, qualitative ranking scales are also used to make the results more perceptible for the site managers and potential stakeholders.

## 1.7 Scope of research

Within the risk management procedure, the focus of this thesis is on the step of risk assessment, but not determining risk management strategies. Recognising the gap in the state of the art, the research aims to develop **an overall risk assessment procedure** to provide multi-disciplinary specialists, site managers and decision-makers with a systematic tool practical for the risk management and heritage management plan. The research does not concentrate on one specific discipline (e.g. heritage conservation, structural engineering, or seismology), but aims to promote the overall assessment procedure through integrating both structural and non-structural criteria in an interdisciplinary way.

This research aims to develop a risk assessment methodology in the context of **natural hazards**, specifically **earthquakes**. Human-induced hazards are beyond the scope of this research. Although some natural hazards and human-induced threats following an earthquake have been addressed to provide a comprehensive impact identification framework, those are not considered as primary hazards in the assessment procedure.

The proposed methodology has been developed for cultural heritage, in particular for **World Cultural Heritage** sites. While the overall procedure could be applicable to cultural heritage in general, for the reasons of clarity and applicability, the research concentrates on World Cultural Heritage sites. Natural heritage is beyond the scope of this study; however, key natural features of the Bam's cultural landscape that conveying its OUV have been incorporated into the research. Although the overall methodological framework could be applicable to other cultural sites, the indicators (e.g. susceptibility indicators) may need to be adapted considering the characteristics of the new cases.



## 1.8 Thesis structure

This research comprises six chapters, as it is outlined in Figure 1-1. *Chapter 1* describes the state of the problem to emphasise why there is a need for developing a risk assessment specific to cultural heritage sites situated in seismic zones, and in particular to the case of Bam. Following a brief review of the current state of the art, the objectives of the study as well as the methods to fulfil the objectives are outlined in this chapter.

*Chapter 2* outlines the geological and historical overview of the city of Bam and its cultural heritage. The chapter provides a description of the 2003 earthquake in Bam and the inscription of Bam and its Cultural Landscape following the earthquake. It explores the construction technique and building material, pre-disaster interventions, post-disaster recovery process, and the conservation and management status of the property. This information provides further chapters with the site-specific information required for developing a risk assessment for Bam.

*Chapter 3* reviews the conceptual and analytical frameworks and procedures of risk assessment and management as well as the current methods that have been specifically developed for cultural heritage. A review of some concrete cases also supports the proposed methodology. This provides *Chapter 4-Methodology* with a theoretical background to develop a risk assessment methodology for the study area.

A detailed description of the overall methodological framework of the research is provided in *Chapter 4*. Activities undertaken regarding the primary data collection, including site observation and expert interview are explained in detail. Different methods and tools for analysis of data are also outlined. In the second part, this chapter develops a risk assessment methodology for the case of Bam and its Cultural Landscape while considering the current approaches and methods that have been reviewed in *Chapter 3-Literature Review*.

The methodology of risk assessment is applied to the case of Bam and its Cultural Landscape in *Chapter 5*. A detailed description of the elements of Bam is provided according to the fieldwork and document analysis; and subsequently, the significance of the elements is assessed to explore the exposure patterns. The risk components are analysed in this chapter; and then, they are incorporated into the risk index for measuring the level of risks. Accordingly, an earthquake risk map of the property is generated by in ArcGIS.

*Chapter 6* provides a summary of the research process, and outlines how the objectives of the research have been fulfilled. The findings of the risk assessment procedure are discussed, and the quality of the research is evaluated through the particular criteria. Furthermore, the implication of the research in theory and practice is outlined, and future research directions are suggested.

During the PhD period, the author has published several peer-reviewed journal articles and book chapters to which the major contributions have been made by the author. The following papers have been incorporated into the different chapters of this thesis:

- Ravankhah, M., and Schmidt, M. (2014). *Developing Methodology of Disaster Risk Assessment for Cultural Heritage Sites*. RDS at 4th International Conference on Building Resilience, incorporating the 3rd Annual Meeting of the ANDROID Disaster Resilience Network, 8th -10th September 2014.
- Ravankhah, M. (2015). *Disaster Risk Management for Bam and its Cultural Landscape in Iran*. 10th UNESCO International Training Course (ITC) on Disaster Risk Management of Cultural Heritage, Kyoto, Kobe and Tohoku area, Japan, 12th-28th September 2015.
- Ravankhah, M., and Schmidt, M. (2016). Earthen architectural heritage in earthquake prone areas: an integrated approach to disaster risk. *The Book of Earth Constructions and*

*Tradition*. Austria: Vienna University of Technology and Institute of Comparative Research in Architecture. 1, pp.159-166.

- Ravankhah, M., Schmidt, M., and Will, T. (2017a). Multi-hazard disaster risk identification for World Cultural Heritage sites in seismic zones. *Journal of Cultural Heritage Management and Sustainable Development*, 7(3). Emerald Publishing. pp.272-289.
- Ravankhah, M., Chmutina, K., Schmidt, M., and Bosher, L. (2017b). Integration of Cultural Heritage into Disaster Risk Management: Challenges and Opportunities for Increased Disaster Resilience. *Going Beyond – Perceptions of Sustainability in Heritage Studies*. Springer Publishing, (2), pp.307-321.

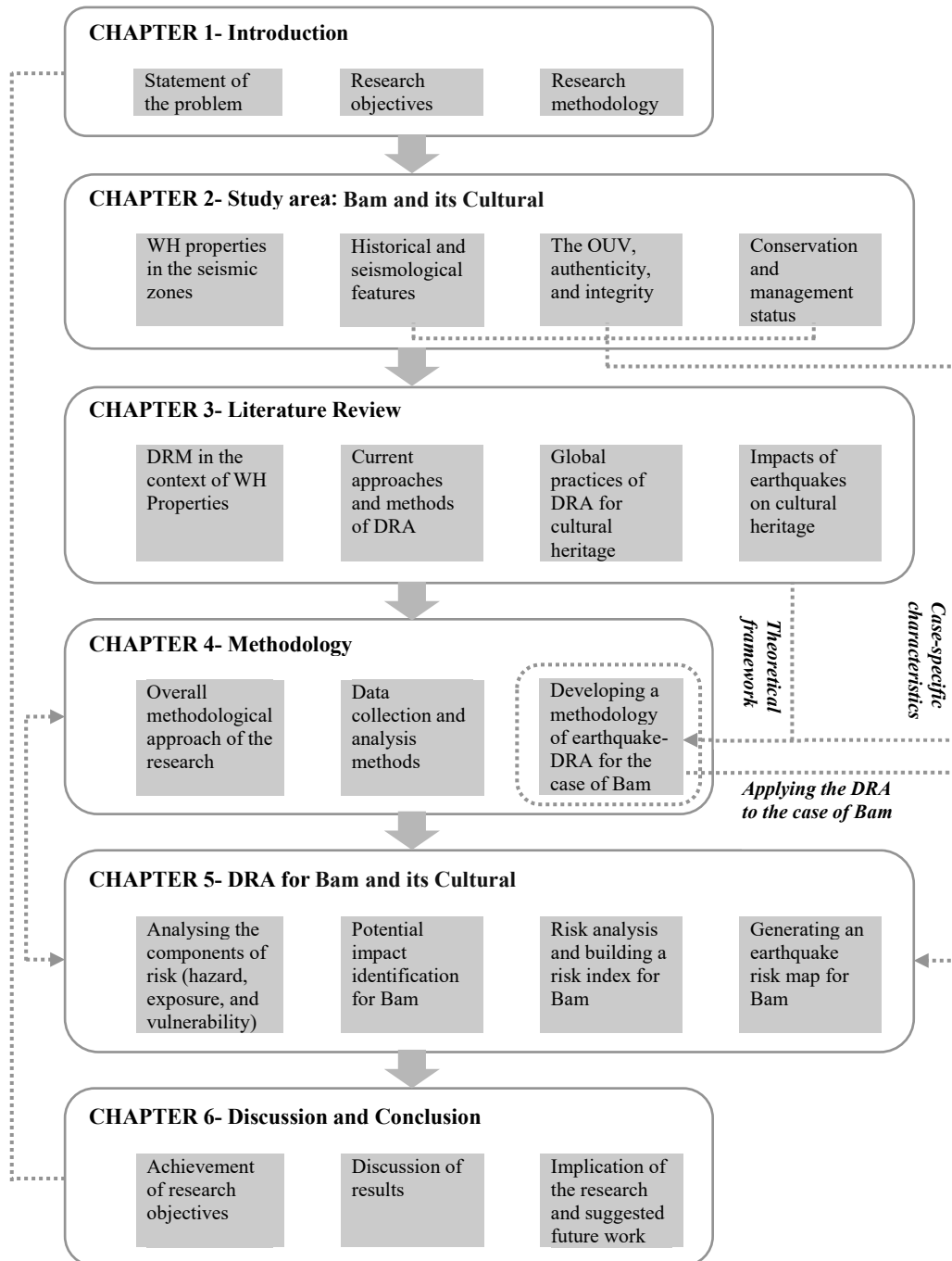


Figure 1-1 Visual outline of thesis structure

**CHAPTER 2**  
**STUDY AREA: BAM AND ITS CULTURAL**  
**LANDSCAPE**

## 2.1 Introduction

At first, to adequately recognise the importance of the subject in the global level, composite maps of WCH properties and Earthen WH properties in the seismic zones are generated in this chapter. Some examples of the past earthquakes on historic properties in Iran are given while highlighting the relevance of the seismic threats to the WCH sites in Iran. The chapter provides a geological and historical overview of the city of Bam and its cultural heritage. It also outlines the description of the 2003 earthquake in Bam and the inscription of Bam and its Cultural Landscape on the UNESCO World Heritage List. To provide further chapters with the site-specific information required for developing a risk assessment for Bam, this chapter explores the construction technique and building material, pre-disaster interventions, post-disaster recovery process, and the conservation and management status of the property.

## 2.2 World Heritage properties in the seismic zones<sup>3</sup>

To adequately recognise the importance of the subject worldwide, a composite map of WCH properties in the seismic zones (Figure 2-1) has been generated based on superimposing the location of World Cultural Heritage sites (UNESCO WHC's website, 2013) and the Global Seismic Hazard map (Giardini et al., 2003). This provides a rough estimate of WCH in the seismic zones. According to the UNESCO WHC' website (2013), there were 745 Cultural World Heritage properties in the world. A statistical reading of the map (Figure 2-1) indicates that around 16% of the WCH properties are located in the high and very high seismic zones, and 34% are situated in the moderate seismic zone.

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<sup>3</sup> This section is based on a paper published by the author (Ravankhah, Schmidt, and Will, 2017a).

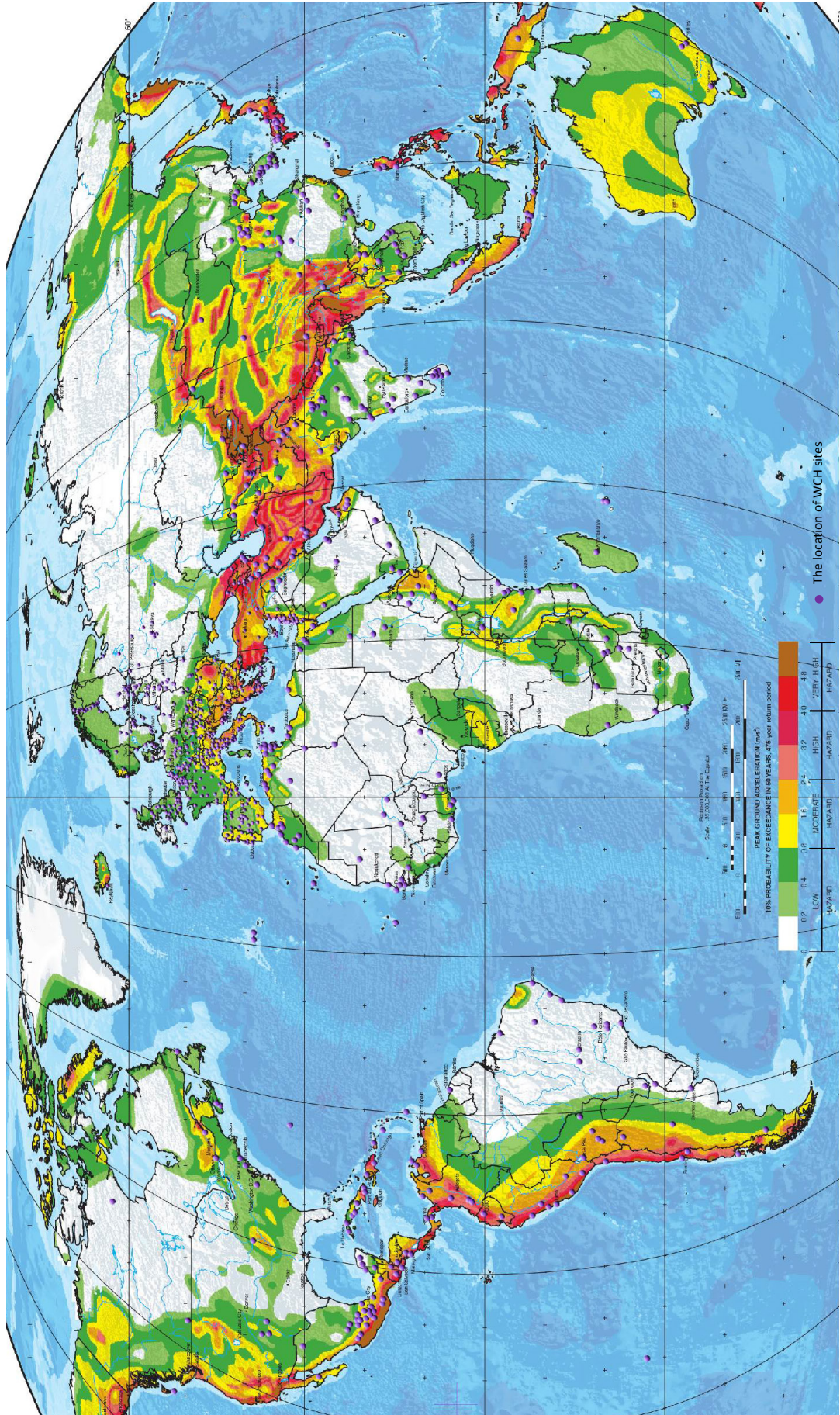


Figure 2-1 Composite map of WCH sites in the earthquake-prone areas, based on superimposing the location of World Cultural Heritage sites (UNESCO World Heritage Centre's website, 2013) and Global Seismic Hazard map (Giardini et al., 2003)

According to the *State of Conservation* of World Heritage properties between 1979 and 2013 (UNESCO WHC, 2014), sudden ecological or geological events affected 76 properties out of 469 properties. A total of 2.642 SOC reports corresponding to 469 properties have been submitted for the examination by the World Heritage Committee. As Table 2-1 shows, 27 properties have been affected by earthquakes and 70 reports have been received by the committee in the mentioned period.

**Table 2-1 The number of properties affected by ‘sudden ecological or geological events’ between 1979 and 2013 (UNESCO WHC, 2014)**

Threat (secondary factor)	Number of reports	Number of properties affected	Average number of reports / property
Erosion and siltation/ deposition	101	29	3,5
Earthquake	70	27	2,6
Fire (wildfires)	47	14	3,4
Avalanche/ landslide	28	9	3,1
Volcanic eruption	9	4	2,3
Tsunami/tidal wave	3	2	1,5

The World Heritage site of Bam and its Cultural Landscape in this thesis is one of the largest earthen architectural complexes around the world, applying sun-dried adobe construction technique. According to the UNESCO WHC’s website (2013), more than 10% of the World Heritage properties incorporate earthen structures in 2011. In order to demonstrate the number of WH sites with almost the same materials and construction technique exposed to earthquakes, a composite map of earthen WH sites in the earthquake-prone areas was produced. The map (Figure 2-2) is based on superimposing World Heritage Inventor of Earthen Architecture (Gandreau and Delboy, 2012) and Global seismic hazard map (Giardini et al., 2003). This provides a rough estimate of the earthen WH in the seismic zones. A statistical reading of the map (Figure 2-2) indicates that around 21% of the earthen WH properties are located in the high and very high seismic zones, and around 34% are situated in the moderate seismic zone.

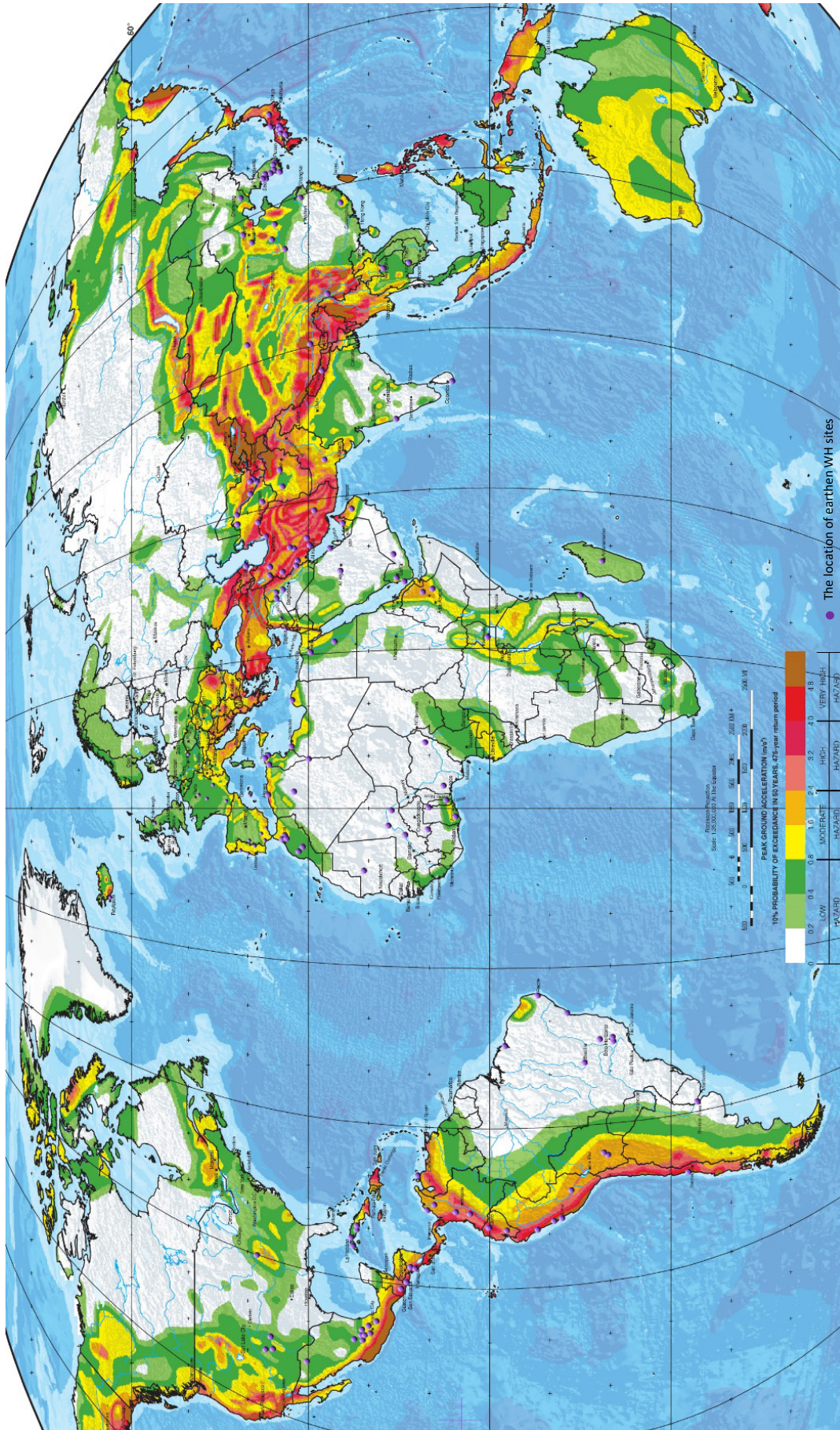


Figure 2-2 Composite map of Earthen WH sites in the earthquake-prone areas, based on superimposing World Heritage Inventor of Earthen Architecture (Gandreau and Delboy, 2012) and Global Seismic Hazard map (Giardini et al., 2003)

While looking at the above composite maps and statistics, the high level of exposure to seismic events clearly demonstrates a need for developing the risk assessment and management plans for WCH sites in the seismic zones. The following sections explore the historical and seismological features of Bam to illuminate the state of the problem and the need for developing a risk assessment for the property.

## 2.3 An overview of historical seismicity in Iran

### 2.3.1 Geological and seismological features

Iran is situated in the Middle East and borders the Caspian Sea, Persian Gulf, and the Gulf of Oman. Due to its specific location, the country is exposed to various sudden-onset (e.g. floods, storms, and earthquakes) and slow-onset (e.g. droughts and desertification) natural hazards. “The Iranian plateau is part of the major Eurasian plate with the tectonic setting of the region dominated by the collision of the Arabian, Eurasian and Indian plates” (Manafpour, 2003, p. 4) that results in destructive earthquakes in different parts of Iran. The Arabian plate is moving northward against the Eurasian plate at a rate of roughly 30 mm/year with deformation of the Earth’s crust happening across a broad zone 1000 km wide, that spans the entire region of Iran and extends into Turkmenistan in the Northeast of Iran (USGS, 2003). “Earthquakes occur as a result of both reverse faulting and strike-slip faulting within the zone of deformation” (Manafpour, 2003, p. 4).

Figure 2-3 shows the seismic hazard zoning map of Iran and the distribution of historical earthquakes since 1900. The Iranian plateau has been hit by almost 17 earthquakes of magnitude 7 and higher, more than 100 earthquakes of magnitude between 6.0 and 6.9, and more than 1800 earthquakes of magnitude between 5.5 and 5.9 since 1900 (Berberian, 2014). Major earthquakes in Iran since 1900 is presented in Table 2-2 . Accordingly, some of the recent tragic earthquakes were the 2017 Iran–Iraq earthquake (Mw 7.3), the 2013 Saravan earthquake (Mw 7.7), the 2012 East Azerbaijan earthquakes (Mw 6.4), the 2003 Bam earthquake (Mw 6.6), and the 1990 Manjil–Rudbar earthquake (Mw 7.4). Earthquakes in Iran have not only caused a serious loss of life, but extensively damaged natural resources and built environments, including infrastructures and cultural heritage properties.

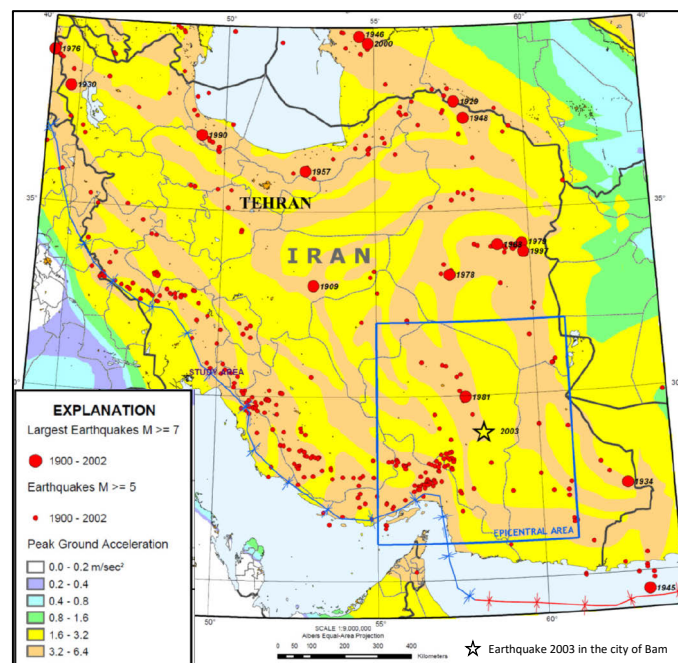


Figure 2-3 Seismic hazard zoning map of Iran (USGS National Earthquake Information Centre, 2004)



**Table 2-2 Major earthquakes in Iran since 1900 (DRES, 2018) <sup>4</sup>**

Date	Location, Epicenter	Magnitude	Fatalities	Name
2017	Tehran, Meshkin Dasht	5.2	2	2017 Tehran earthquake
2017	Kermanshah, Ezgeleh	7.3	630	2017 Iran–Iraq earthquake
2014	Ilam, Mormori	6.2	-	2014 Mormori earthquake
2013	Saravan	7.7	35	2013 Saravan earthquake
2012	Tabriz	6.4	306	2012 East Azerbaijan earthquakes
2010	Hosseinabad	6.7	11	2010 Hosseinabad earthquake
2008	Qeshm	6.1	-	2008 Bandar Abbas earthquake
2006	Borujerd	6.1	70	2006 Borujerd earthquake
2005	Zarand	6.4	At least 602	2005 Zarand earthquake
2004	Māzandarān	6.3	At least 35	2004 Māzandarān earthquake
2003	Bam	6.6	At least 30,000	2003 Bam earthquake
2002	Qazvin	6.5	262	2002 Bou'in-Zahra earthquake
1997	Birjand-Qaen	7.3	1,567	1997 Qayen earthquake
1997	Ardabil	6.1	1,100	1997 Ardabil earthquake
1990	Manjil–Rudbar	7.4	40,000-50,000	1990 Manjil–Rudbar earthquake
1981	Eastern Iran	7.1	1,500	July 1981 southern Iran earthquake
1981	Southern Iran	6.9	3,000	June 1981 southern Iran earthquake
1978	Tabas	7.8	15,000	1978 Tabas earthquake
1972	Gir	7.1	5,054	1972 Gir earthquake
1968	Dasht-e-Bayaz Ferdows	7.3	12,000	1968 Dasht-e Bayaz and Ferdows earthquake
1962	Bou'in-Zahra	7.1	12,225	1962 Buin Zahra earthquake
1957	Sahneh	7.1	1,130	1957 Sahneh earthquake
1957	Māzandarān	6.6	1,200	1957 Māzandarān earthquake
1953	Torud	6.6	970	1953 Torud earthquake
1947	Pasni	7.3	500	1947 Pasni earthquake
1930	Salmas	7.2	2,500-4,000	1930 Salmas earthquake
1929	Koppeh Dagh	7.2	3,800	1929 Kopet Dag earthquake
1923	Torbat-e Heydariyeh	5.7	2,200	1923 Torbat-e Heydariyeh earthquake
1909	Silakhor of Borujerd	7.3	6,000	1909 Borujerd earthquake

<sup>4</sup> Recent earthquakes since 2013 have been added to the table.

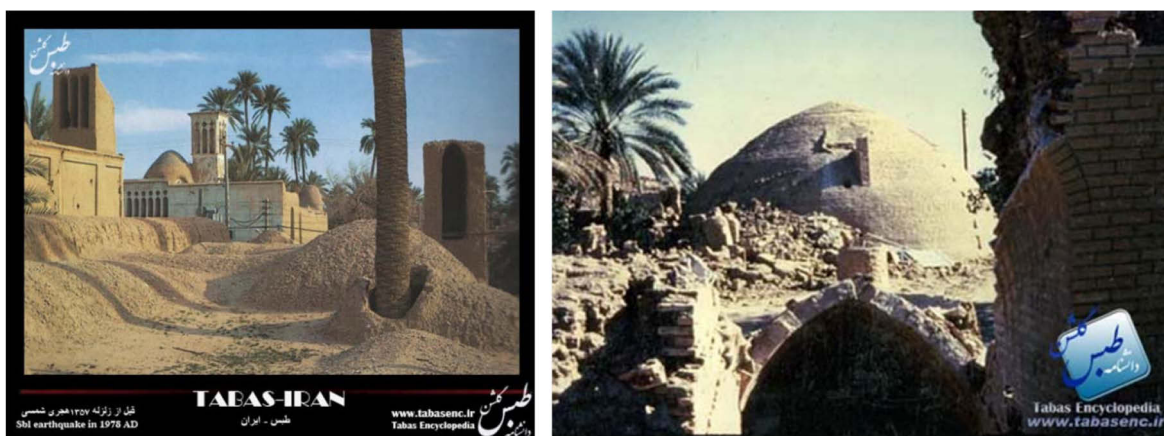
### 2.3.2 Impact of seismic events on historic properties in Iran

Iran is one of the oldest civilization worldwide according to its cultural evidence such as Shahr-i Sokhta (Burnt City) dating back to 3200 BC and Arg-e Bam dating back to 600 to 400 BC. Currently, twenty-two cultural properties and two natural sites in Iran have been inscribed on the UNESCO World Heritage list. Table 2-3 shows the list of the WH sites (2015) in different parts of Iran that are potentially exposed to natural hazards, particularly earthquakes, based on the properties' nomination files, "Section 4.b. factors affecting the property".

**Table 2-3 Natural hazards threatening the WH sites (2015) in Iran (extracted from nomination files prepared by ICHHTO, UNESCO WHC's Website, 2015)**

WH properties	location	Natural hazards
Armenian Monastic Ensembles	north-west	<u>earthquakes</u> , freezing winters, heavy rainfalls, seasonal floods
Bam and its Cultural Landscape	south-east	<u>earthquakes</u> , extreme temperature change, sandstorms
Bisotun	north-west	<u>earthquakes</u> , surrounding biochemical installations
Cultural Landscape of Maymand	south-west	<u>earthquakes</u> , temperature change, precipitation decrease, Floods, strong winds, drought
Golestan Palace	north	<u>earthquakes</u> , air pollution, heavy rain, newly sandstorms
Persepolis	south-west	Flooding
Masjed-e Jāmé of Isfahan	centre	<u>earthquakes</u> , air pollution, humidity
Pasargadae	South-west	<u>earthquakes</u>
Tabriz Historic Bazaar Complex	north-west	<u>earthquakes</u> , pollution
Shahr-i Sokhta	south-east	sandstorms
Soltaniyeh	north-west	<u>earthquakes</u> , temperature change, air pollution

Two examples of the historical earthquakes, which extensively damaged historic buildings in Iran, are the 7.7 magnitude earthquake occurred in Tabas in 1978 (Figure 2-4) resulted in a demolition of the historic city of Tabas, and the 2002 Bou'in-Zahra earthquake of magnitude 6.5 that caused a serious damage to Kharragan Tomb Towers in Qazvin (Figure 2-5).



**Figure 2-4 left: Tabas before the earthquake 1978 (www.tabasenc.ir), right: Tabas after the earthquake 1978 (www.tabasenc.ir)**



**Figure 2-5** *left: Kharraqan Tomb Towers before the earthquakes 2002 (ICHHTO), right: Collapse of the tower's dome (Hazrati 2003)*

One of the most recent disastrous seismic events in Iran was a magnitude 6.6 earthquake which hit the city of Bam in December 2003 and caused a serious loss of life and enormous destruction of cultural heritage. The historic city of Bam with its well-known earthen fortified heritage is located in a desert environment in the south-eastern of Iran, dating back to 6-4th century BC. Immediately following the earthquake 2003, Bam and its Cultural landscape has been inscribed on the UNESCO WH List in 2004 through an emergency nomination. Below, a detailed description of the property and the Bam earthquake is provided.

## **2.4 City of Bam: a geological and historical overview**

### **2.4.1 Geological and seismological features**

The city of Bam is located in the south-eastern part of Kerman province, in the southeast of Iran (Figure 2-6). The area of the city is around 5,400 hectares with a smooth topography and morphology; its altitude is roughly 1,050 metres above the sea level (Nadim, 2004). Bam is situated in the Lut-e-Zangi Ahmad desert; however, it also comprises a range of mountains to the North of Bam extending northwest and the Jebal-e-Barez mountain range to the Southwest of Bam extending in a Northwest-Southeast direction (Manafpour, 2003, p. 4). According to the Iran Meteorological Organization, Bam has hot summers with temperatures up to 47.6 °C, and mild winters but with a record low temperature of -9 °C.

Bam is located in a high seismic zone in Iran, as shown in Figure 2-3 *Seismic hazard zoning map of Iran*. “The major faults in this region include the Nayband fault with a North-South trend, the Kuh Banan fault which trends Northwest-Southeast and the Gowk fault that starts at the junction of the two aforementioned faults and trends in a North-South direction towards the Jebal Barez mountains in the Southwest of Bam” (Manafpour, 2003, p. 6).



Figure 2-6 Location of the city of Bam in Iran, and Iran in the world (2018 Google, ORION-ME)

## 2.4.2 Historic background of Bam

The origin of the current city of Bam is Arg-e Bam (Bam Citadel). According to the archaeological evidence, the citadel dates back to the Achaemenid period between the 6<sup>th</sup> and 4<sup>th</sup> Centuries BC (ICHO, 2004). Arg-e Bam and its associated medieval city (Figure 2-7) is probably one of the oldest Islamic city models in Iran, representing a rich cultural civilisation in a desert environment.

According to Islamic writers in the 10<sup>th</sup> century, Bam was a fortified marketplace connected to the Silk Road, surrounded by a wide agricultural area, and well-known for its cotton fabrics, silk industry, bazaars, and its palm trees (Auroville Earth Institute, 2015). According to a study conducted by Berberian (2005), the medieval circumvallated inner city of Bam was destroyed and restored several times, and most of the current remains of the Arg date back to the mid-Safavid period (late 18<sup>th</sup> century).

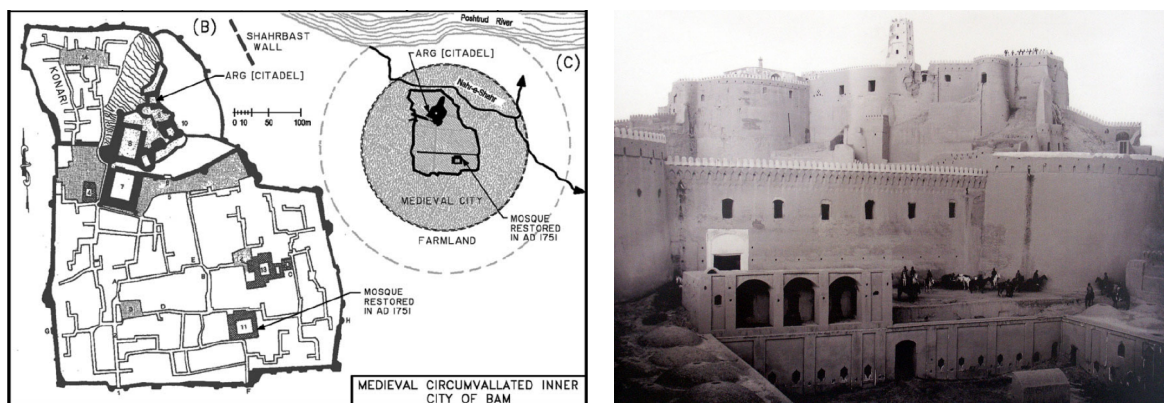


Figure 2-7 *left*: Medieval circumvallated inner city of Bam in (C) and the citadel (Arg-e Bam) in (B) (Gaube 1979, cited in Berberian 2005), *right*: Arg-e-Bam: view to the Barracks and Governor's quarter, 1890 (ICHO)

The citadel was gradually abandoned in the 19<sup>th</sup> century, and local residents moved into the adobe buildings within their date palm orchards surrounding the citadel that led to the foundation of the current city of Bam. Arg-e Bam is located in the north-eastern part of the current city of Bam (Figure 2-8). A brief history of Bam (according to Auroville Earth Institute, 2015) is outlined below:

- The first human settlement in the area can be traced back to the fort built by the Achaemenians around 579-323 BC.

- During the Parthian Empire (247 BC – 224 AD), the fort was expanded and became the Bam Citadel.
- During the Sasanian Empire (224–651 AD), new fortifications and walls were constructed.
- In 645 AD during the invasion of Arabs, the Bam Citadel probably suffered damages during the war.
- In 869 AD, Yaqoob Laith Saffari, who was fighting the Abbasids took over the Arg-e-Bam.
- After the Mogul invasion of Iran, Bam and the Kerman region were turned over to the Qarakhataian dynasty who ruled the region from 1240 to 1363 AD.
- During the Safavid rule (1502 to 1722), the different parts of the citadel were restored.
- By the end of the Safavid period, the founder of the Qajar Dynasty, Agha Mohammad Khan turned the citadel into a military complex.
- The increasing military presence within the citadel gradually forces people to move to the outside the fortification. In 1840, the present city of Bam was founded (Berberian (2005).
- The citadel was used as a garrison until 1932; consequently, the old city has been completely abandoned since 1932.
- In 1953, the site was recognized as a nationally significant historic site and since 1973, the main restoration of the citadel began.
- After the Islamic Revolution in 1979, Arg-e-Bam was placed under the responsibility of the Iranian Cultural Heritage Organisation (ICHO), and in 2004 the Bam and its Cultural Landscape has been inscribed on the UNESCO World Heritage List.



**Figure 2-8** *left:* The location of the Bam Citadel in the city of Bam (Google Earth: Image © 2018 CNES/Airbus; Image © 2018 DigitalGlobe), *right:* Aerial view of the Bam Citadel (Google Earth: Image © 2018 CNES/Airbus)

### 2.4.3 The 2003 Bam earthquake and its impacts<sup>5</sup>

A 6.6 magnitude earthquake struck the city of Bam in December 2003, and this caused a tragic loss of life (more than 26000 people died) and partially destroyed Arg-e Bam, the world-renowned historic monument for its earthen architecture (Figure 2-9). The earthquake caused the destruction of more than 90% of the traditional adobe dwellings, a large number of engineered and unreinforced

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<sup>5</sup> This section is based on two papers published by the author (Ravankhah et al., 2017b; Ravankhah and Schmidt, 2014).

masonry buildings, as well as the failure of underground channel walls and wells of the underground water distribution system in the city of Bam (Moghtaderi-Zadeh et al., 2004).

The epicentre of the Bam earthquake was located at 29:00N-58.34E, 185km Southeast of Kerman, with a focal depth of about 10km (USGS, 2003). Based on interferograms derived from coseismic satellite maps, the fault responsible for the Bam earthquake was a blind strike-slip fault located about 5 Km to the west of the visible surface traces of the Bam fault (Talebian et al., 2004, cited in Manafpour, 2003, p. 7). Berberian (2014) emphasises that even though the Bam earthquake was geologically predictable, and the active fault was introduced in 1976, no adequate risk mitigation measures have been performed in the city during the 27-year between the recognising of the fault and the occurrence of the earthquake. He states the *Iranian Building code for seismic-resistant design*, which was approved in 1969, has not been adequately implemented in Bam.

The damage observed in the city of Bam varied depending upon the location (higher damage in the old part of the city in the Northeast compared to the newly constructed parts of the City in the Southeast) and building construction (adobe, masonry, steel, and reinforced concrete) (Manafpour, 2008). In respect to adobe buildings, he believes that their heavy walls and roofs develop large inertia forces that cannot be resisted by walls often resulting in large cracks or collapse during an earthquake, resulting in a sudden collapse of the structure with insufficient time for evacuation (ibid).



**Figure 2-9** *top: Arg-e Bam, before earthquake 2003 (Auroville Earth Institute), down: Arg-e Bam, after earthquake 2003 (author, 2008)*

In the Bam Citadel, those structures that had been previously restored suffered more damages compared to those structures that had not been subject to repair or restoration activities (Langenbach, 2005; Parsizadeh et al., 2015). It was revealed that several factors, including improper interventions resulting in changes to the original plan layouts, loss of the cohesion of the clay from drying out, termites and deterioration, contributed to increased seismic-vulnerability of the citadel (Langenbach, 2005; Vatandoust et al., 2008a).

Another improper intervention which contributed to the poor seismic performance of the citadel during the earthquake was that “traditional shredded date tree materials were replaced during renovation works by big quantities of straw which is a material very much on the appetite of termites” (Parsizadeh et al., 2015, p. 6). Palm fibres, which are easily available in Bam, proved to be perfect

in enhancing the ductility of adobe materials in the laboratory test, and were applied in the post-earthquake seismic-reinforcement of Sistani-House in Arg-e Bam (Fuchs and Jaeger, 2008).

## 2.5 Bam and its Cultural Landscape

Following the 2003 earthquake, ‘Bam and its Cultural Landscape’ was inscribed on the World Heritage List (under criteria ii, iii, iv, and v) in 2004 through an emergency nomination. Simultaneously, the property was inscribed on the List of World Heritage in Danger. It should be noted that the word ‘Bam’, in the name of the property, refers to the fortified old settlement of Bam, and does not mean the current city of Bam. Bam and its Cultural Landscape was placed on the List of World Heritage in Danger mainly due to massive impact to the site caused by the earthquake in 2003 as well as potential development pressures associated with the post-disaster reconstruction. The property was removed from the List of World Heritage in Danger in 2013 when the Iran State Party had adequately addressed some corrective measures proposed by the World Heritage Committee.

### 2.5.1 Criteria of the inscription on the World Heritage List

Immediately after the earthquake 2003, Bam and its Cultural Landscape has been inscribed on the UNESCO World Heritage List through an emergency nomination process under the following criteria (UNESCO World Heritage Centre’s Website, 2013):

- **Criterion (ii):** Bam developed at the crossroads of important trade routes at the southern side of the Iranian high plateau, and it became an outstanding example of the interaction of the various influences.
- **Criterion (iii):** The Bam and its Cultural Landscape represent an exceptional testimony to the development of a trading settlement in the desert environment of the Central Asian region.
- **Criterion (iv):** The city of Bam represents an outstanding example of a fortified settlement and citadel in the Central Asian region, based on the use mud layer technique (Chineh) combined with mud bricks (Khesht).
- **Criterion (v):** The cultural landscape of Bam is an outstanding representation of the interaction of man and nature in a desert environment, using the Qanats. The system is based on a strict social system with precise tasks and responsibilities, which have been maintained in use until the present, but has now become vulnerable to irreversible change.

Based on the ICOMOS Evaluations (2004), in terms of the categories of cultural property set out in Article 1 of the 1972 World Heritage Convention, the property falls in the category of ‘site’; and its landscape represents a ‘continuing cultural landscape’. According to the *Operational Guidelines for the Implementation of the World Heritage Convention* (UNESCO WHC, 2017, Annex 3), “Cultural landscapes are cultural properties and represent the ‘combined works of nature and of man’ designated in Article 1 of the Convention”. In the description of the property on the UNESCO World Heritage Centre’s Website (2013), the Bam’ cultural landscape is defined as an “organically grown relict cultural landscape” probably because its evolutionary process associated with the citadel itself stopped in the 19th century. However, in respect to the Bam’s landscape itself, it is mentioned in the description that “the living cultural landscape [of Bam] retains a high level of integrity with the continued use and maintenance of the historic hydraulic systems Qanāts and continued territorial land use for agricultural activities” (ibid). Regardless of the terminologies and categories, the specific characteristics of the elements of Bam and their current role in the socio-economic development of the local community should be adequately considered within the conservation and management plan.

## 2.5.2 The core zone and the buffer zone of the property

The core zone of the property comprises the Bam Citadel, its immediate surrounding (e.g. Ice House, the remains of the medieval town wall, and Qaleh Dokhtar), and a broad cultural landscape including the Bam seismic fault, Qanat irrigation channels, and the remains of architectural structures (ICHHTO, 2008a). The red line in Figure 2-10 shows the “limits of site’s suggested core zone”.

To ensure the full protection of the property from the development projects and policies, two buffer zones were defined for the property. The yellow line in Figure 2-10 is “limits of site’s buffer zone 1”, and the green line is “suggested tentative limits of the landscape protection buffer zone”. According to ICHO (2004a), the buffer zone 1 covers the urban area next to the citadel that any construction activity or alteration in this zone is prohibited without the permission and supervision of the Iranian Cultural Heritage Organisation; While, the buffer zone 2 is an extended landscape protection zone mainly for land use control that covers the entire town, the Qanat irrigation system, and the gardens.

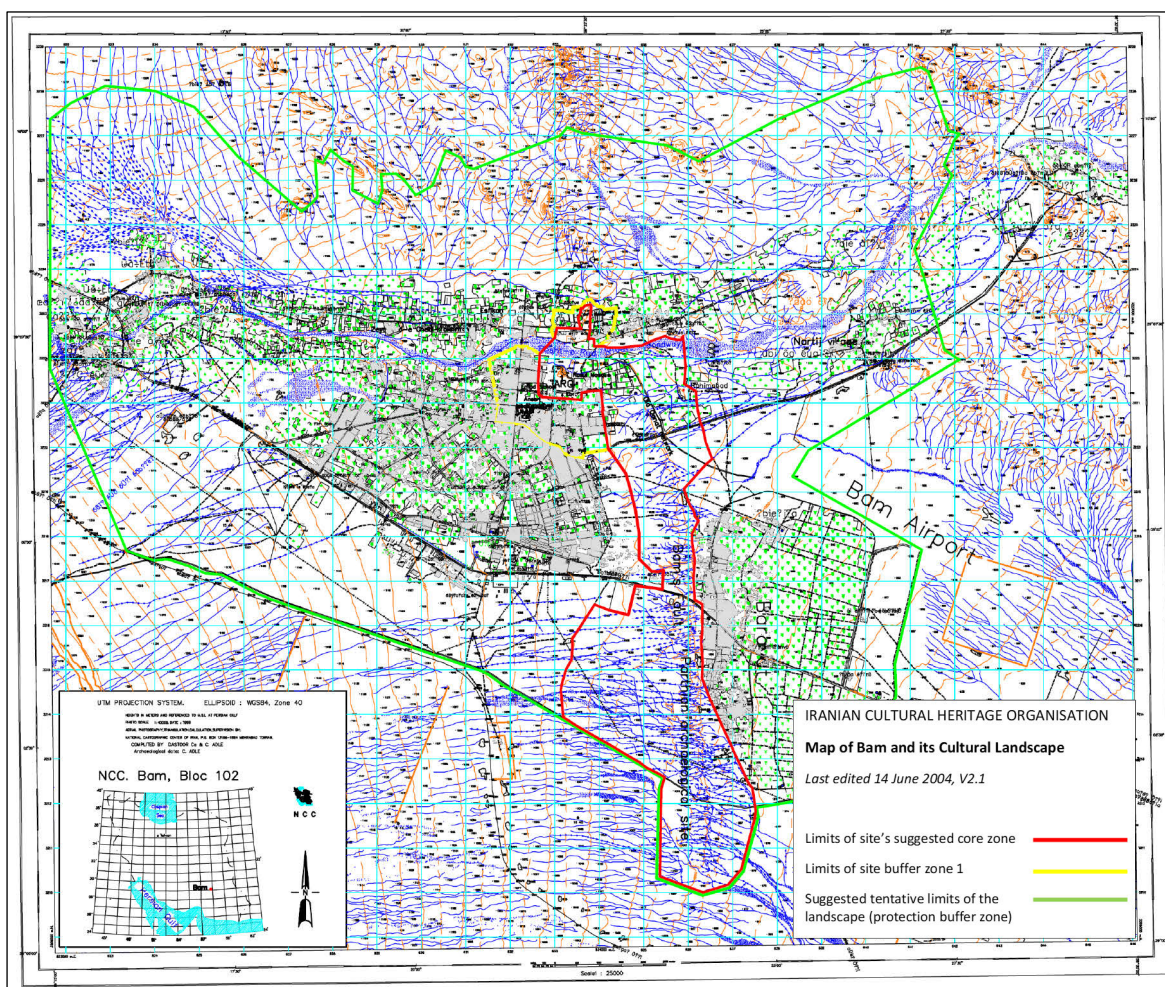


Figure 2-10 The boundary of the core zone and buffer zones of the property (ICHO, 2004a)

## 2.5.3 Properties within the core zone<sup>6</sup>

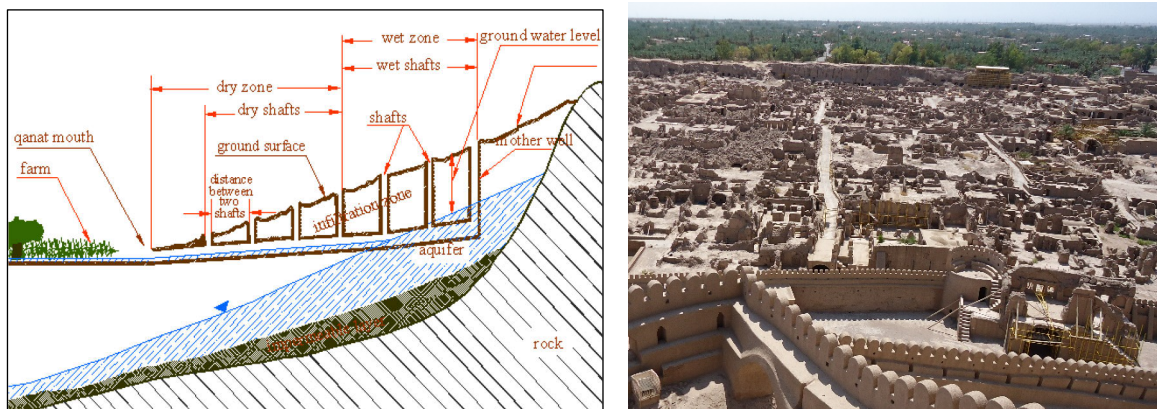
The most visible part of the property is Arg-e Bam, which was a fortified and trading settlement located at the crossroads of the Silk Road trade routes (ICHO, 2004). The structure of this well-

<sup>6</sup> This section is based on two papers published by the author (Ravankhah, 2015; Ravankhah et al., 2017b)



known earthen architecture is based on combined mud layer (Chineh) with sun-dried mud bricks (Khesht). “The nucleus of the Arg is a rough rectangle (430 m in the south, about 390 m in the north and north-east, 280 m in the east, and 540 m in the west) corresponding to the fortified enclosure (with 38 watch-towers), to the north of which lies the Citadel” (ICHO, 2004, p. 13). The unique urban complex of the citadel comprises the Governor’s quarter, and a residential area that includes a bazaar, school, mosque, and other structures, all employing a unique sun-dried mud construction technique. Although Bam Citadel was seriously damaged, it continued in its role as an economic driver linked to the tourism industry, in particular providing employment opportunities for the local community. The damaged citadel was turned into a museum of earthen construction, seismic engineering and traditional knowledge for national and international multidisciplinary specialists.

Another important element of the property is Qanat, which is an ancient underground irrigation system vital for the continuity of cultivation in the arid environment of Bam. Qanat, which consists of a gradually sloping underground channel and vertical shafts, is a method of supplying groundwater that transfers water from an aquifer to a human settlement in arid and semi-arid regions. After 1950, the role of Qanats, which were supplying almost 70% of the water in Iran, has been reduced by the modern water supply methods such as deep wells and large dams (Manafpour, 2003). In Bam, however, Qanat is still vital for the continuity of the cultivation and irrigation of date palm orchards that is another significant component of the property. Many date palms, on which the Bam’s economy heavily relies, survived the earthquake and are still considered as the main source of agricultural production.



**Figure 2-11** *left: Section of a Qanat (Semsar Yazdi, 2007), right: View from the Bam Citadel to the date palm orchards (Author, 2013)*

It should be noted that the Persian Qanat itself has been inscribed on the World Heritage List in 2018, under Criterion iii and iv. According to the description of the Qanat (UNESCO WHC’s Website, 2018), Qanat encompasses horizontal tunnel to collect water from an alluvial fan, into which a mother well is sunk to the appropriate level of the aquifer; well shafts are sunk at regular intervals along the tunnel to enable removal of soil and provide ventilation; due to the gentle slope of the tunnel, the water is transported along underground tunnels to the Qanat mouth near the settlement; and then, it is distributed by surface channels to the agricultural lands (Figure 2-11).

#### 2.5.4 Statement of authenticity and integrity

Although the property was partially destroyed by the earthquake, it met the condition of integrity because “the property and the buffer zone are of sufficient size and encompass the attributes that sustain the Outstanding Universal Value of the property, including the elements that express the

relationship between man and the environment” (ICHO, 2004, p. 9; UNESCO WHC’s website, 2012). The following aspects are mentioned to substantiate the condition of integrity (ibid):

- The central part of the oasis of Bam, including the Arg-e Bam and the area along the Bam Seismic Fault, and historical evidence of the evolution of Qanat construction exist.
- The urban forms and type of construction in the citadel remain despite the interventions and the earthquake damages.
- A high level of integrity of the Bam’s cultural landscape can be seen through the continued use and maintenance of the historic hydraulic systems Qanats and continued territorial land use for agricultural activities.
- The traditional visual relationship of the fortified settlement with its setting can be still perceived.

According to the ICHO (2004a) and the UNESCO WHC’s website (2012), the property met the condition of authenticity because:

- Much of the lost fabric destroyed by the earthquake belonged to the modern restorations while the original parts have been revealed.
- Regarding the historic fabric, despite some deterioration and partial restorations between 1976 and 2003 (but using traditional techniques and materials), the property retains several attributes to verify its authenticity.
- Traditional earthen construction workmanship and know-how is preserved.
- The setting has also retained many of the historical features regarding the integration of man and environment.

### **2.5.5 Construction technique and building material**

Bam Citadel is an adobe masonry construction that sun-dried mud bricks (so-called ‘Khesht’) combined with mud layers (so-called ‘Chineh’) have been applied to its walls, vaulted and domed structures (Figure 2-12). Adobe thick walls have been used to support the arc and domed roofs while applying the clay-straw mortars. The clay-straw plaster so-called ‘Kah-gel’ is used for finishing and decorative purposes. Langenbach (2005, p. 27) in respect to the Iranian Chineh technique in Bam states that it “[...] is characterized by a series of bands of clay that are about 50 cm high that represent each “lift” in the construction process. These lifts were constructed along the wall from one end to the other and then made smooth and level on the top before proceeding with the next lift”. He emphasises that this is different from northern European cob construction, which lacks such clear interfaces between the lifts (ibid).

Adobe is one type of earthen construction that its material mainly comprises clay, straw, and water. It is one of the oldest materials used in the human settlements situated in the hot and dry climate. Adobe material is the main material used in many historic monuments in Iran, such as WH sites of Meidan Emam, Persepolis, Shushtar historical hydraulic system, Soltaniyeh, Tabriz Historic Bazaar Complex, Tchogha Zanbil, and the Persian Gardens.

Following the earthquake 2003, some stabilisation measures have been carried out such as, injection grouting of cracks, applying tension elements (e.g. glass and palm fibres), and reinforcing adobe structure with palm fibres to increase its ductility (Vatandoust et al., 2008a). In the citadel, most of the buildings lack foundations and built on soft soil, except the Governor’s quarter which lies on a rock bed. In the post-earthquake recovery, some structures are connected to the ground with tension elements (cables) made of artificial fibres (Vatandoust et al., 2008a). Apart from the gradual

deterioration due to past natural hazards and climate factors, the termite-related damage was a factor mentioned (Langenbach 2005; Vatandoust et al., 2008a) in the post-disaster investigations.



**Figure 2-12** *left: Sun-dried mud bricks (Khesht) in a collapsed adobe roof (Author, 2013), right: Earthquake-induced cracks on an adobe wall made of Khesht and Chineh (author, 2008)*

Regarding the seismic performance of earthen material, Vatandoust et al. (2008a, p. 314) believes that it is not very resistant to the lateral forces of earthquakes, and thus, “early builders used advantageous wall thickness, slenderness-to-height ratios, strategic positioning of window and door openings, and geometric patterns in laying the adobes in the roofs and walls”. As mentioned in *Section 2.4.3-The 2003 Bam earthquake and its impacts*, there were different factors, such as past incompatible interventions and termites’ damages, that contributed to the destruction of the adobe complex of Bam. This underscores the importance of adequate monitoring and maintenance as well as applying compatible seismic stabilisation methods to the earthen structures.

## 2.6 Conservation and management status

### 2.6.1 Past interventions before the earthquake 2003

A number of restoration and monitoring activities in the citadel are recorded since 1976. Below, some of the recent ones are mentioned (ICHO, 2004):

- Archaeological research on the chronology of the Arg;
- Consolidation and restoration of the structures, walls, and vaulted roofs in the different parts of the citadel, for instance:
  - Restoration work in the Stables concerning consolidation and plastering of walls, repair of the entrance gate of the western stables and the ground of the eastern stables;
  - Restoration of the water reservoir inside the Stables, removal of rubbles, consolidation of foundations, restoration of staircases, entrances, and vaults;
  - Restoration work at the Tekiyeh including the removal of additional parts, consolidation of foundations, restoration of rooms, vaults and arches in the west wing and north-west, north-east and south-east corners;
  - Conservation work in the Mosque, Mir Akbar’s house, Sabat Lotf Ali’s house, the East Sabat house, west wall of the enclosure, public baths and a house in the eastern quarter;

- Conservation work in different parts of the eastern quarter, part of the western quarter, in the Konari sector, the East Sabat house, Governor’s Residence, northern and western façades of the gate of the Citadel;
- Survey and mapping of the Icehouse, outside the citadel; and
- Continuation of the documentation research and mapping.

Below, the main structural and non-structural activities carried out after the earthquake as well as the institutional framework of the property are outlined.

### 2.6.2 Recovery process of the property after the earthquake

Following the earthquake, an international workshop on the *Recovery of Bam’s Cultural Heritage* was organised by the Iranian Cultural Heritage Organization (ICHO) in April 2004 in order to facilitate an adequate recovery of Bam’s cultural heritage. National and international professionals and organisations, such as UNESCO, ICOMOS, ICCROM, the Getty Conservation Institute, International Centre for Earth Construction (CRATerre-EAG, France), the World Bank, World Monuments Fund, representatives of the Governments of France and Italy, and representatives of the engaged Iranian authorities, have participated in the workshop (ICHO, 2004). The workshop resulted in *the Bam Declaration and Recommendations* ((ICHO et al., 2004b; please see Appendix 2 for more information) that encompasses the following major objectives (ibid):

1. Conserving the full significance of Arg-e Bam and its setting;
2. Conserving the character and the heritage of the city and landscape;
3. Integrating heritage in the recovery process and the future development of Bam;
4. Preserving and enriching the tradition of earthen architecture;
5. Protecting and preventing damage to earthen heritage in seismic areas;
6. Sustaining co-operation to realize the conservation goals;
7. Recommendations:
  - Recommendations for immediate action;
  - Recommendations for short-term actions (2004-2005);
  - Recommendations for mid-term actions (2004-2010);
  - Recommendations for long-term actions (2004-2015);
8. Sustaining the momentum and focus to implement the present Declaration and Recommendations.

In response to the above-mentioned recommendations, the following measures in three phases have been carried out by ICHO (Vatandoust et al., 2008b):

- Planning during the crisis (planning immediately after the earthquake): removing debris, securing and stabilisation, documentation, establishing an earthen material laboratory, creating a wooden visitor passage and providing access to visitors (Figure 2-13);
- Post-crisis planning (short-term planning): organising the expert meetings and exhibitions, studies on geology, seismology, and water resources, inscribing Bam and its Cultural Landscape on the List of World Heritage in Danger, attendance in international conferences and the organisation of expert meetings; and
- Comprehensive planning (long-term planning): completing the practical part of the Bam Cultural Heritage Rescue Project, compiling a charter for the restoration of earthen architecture, and establishing an earthen architecture conservation laboratory.



**Figure 2-13** *left: Post-disaster restoration of the Governor's quarter and the wooden visitor passage (Author, 2008), right: Post-earthquake stabilization of collapsed walls (Author, 2013)*

One of the main challenges in the structural recovery of the citadel was considering traditional earthen construction and materials on one hand, and the modern stabilisation methods, on the other. Applying appropriate conservation approaches were vital in retaining the OUV and the condition of authenticity and integrity of the property, which was on the List of World Heritage in Danger at that time. To fulfil this aim, in particular regarding the seismic resistance of the adobe structures, the following actions are performed following the earthquake (Vatandoust et al., 2008a, p. 314):

- Survey, study, and selection of a suitable soil deposit to acquire a high-quality material for adobe production;
- Evaluation of various additives to improve the mechanical properties of adobe;
- Improved methods for the production of adobe (e.g. applying tension elements such as palm fibres to the adobe bricks); and
- Development of two methods for injecting repair grouts.

### 2.6.3 Removal of Bam from the List of World Heritage in Danger

According to the *State of Conservation* of Bam and its Cultural Landscape from 2005 to 2015 (UNESCO WHC's website, 2016), the following factors caused the property to stay on the List of World Heritage in Danger:

- In 2004: earthquake-related damages;
- In 2005: earthquake-related damages, lack of a comprehensive management plan, and the discrepancy between the OUV and the proposed core zone;
- In 2006 and 2007: lack of a comprehensive management plan, the discrepancy between the OUV and the proposed core zone, and development pressures related to the post-disaster reconstruction;
- During 2008 to 2012: Post-disaster development pressures and management systems and management plan;
- In 2013: Post-disaster development pressures; and
- In 2014: No reported threats.

In 2007, the World Heritage Committee set up a list of corrective measures, adopted in Christchurch, to facilitate the removal of the property from the List of World Heritage in Danger, as below (UNESCO WHC, 2007):

- Stabilisation and protection of the Arg-e-Bam and other significant cultural heritage assets within the World Heritage property by:
  - Stabilisation of both the lower and upper parts of the citadel;
  - Removal and documentation of debris;
- Completion of necessary scientific studies for the recognition, registration, and legal protection of properties with historical, cultural and natural significance within the cultural landscape zone; and accordingly, marking the protective boundaries around each property within this zone;
- Management plan implemented by:
  - Approval at final stakeholders' meeting;
  - Legal Adoption by late 2007;
- Precise definition of the outer boundaries of the heritage areas surrounding the property by completing the mapping of the archaeology and geomorphology of Bam and its Cultural Landscape; and
- Adequate security of the heritage areas within the World Heritage property in addition to the Arg-e Bam by the increased number of guards and vehicles.

Bam and its Cultural Landscape was removed from the List of World Heritage in Danger in 2013 because the World Heritage Centre and the Advisory Bodies stated that the State Party has addressed the above-mentioned corrective measures and has now met the desired state of conservation (UNESCO WHC, 2013b). Placing Bam on the List of World Heritage in Danger provided the property with additional financial, human, and technical resources at the national and international level to facilitate the adequate recovery of the property in the core zone. It also helped to prevent potential threats of post-disaster reconstruction in the buffer zones to the property's values.

#### **2.6.4 Post-disaster new reconstruction versus maintaining cultural heritage<sup>7</sup>**

While there is a unique opportunity for transformation and modernisation in the post-disaster rehabilitation and recovery, heritage properties are expected to be preserved with minimal change in order to retain the values and authenticity. Such a conflict arose between two principles of the post-disaster *Bam Sustainable Reconstruction Manifesto* in 2004 (Fallahi, 2007, p.31) that were “preserving the city identity in urban design” and “strengthening the new houses against the national building code”. In the case of Bam, Asgary et al. (2006, p. 7) believe that “most of the damaged buildings in the affected area were constructed by sun-dried brick masonry with extremely poor seismic resistance”, while Langenbach (2005, p. 23) states that “the houses in which people died were modern houses. Their walls may have been of Khesht, but many also had roof beams of steel, and floors or roofs of fired brick”. In fact, improper reconstruction of the adobe buildings was the principal cause of damage rather than merely the traditional adobe materials (ICHO et al., 2004).

Bam's declaration (ICHO et al., 2004, p. 5) emphasised that “it is important to upgrade the social image of vernacular architecture among the local people, without which this kind of architecture will

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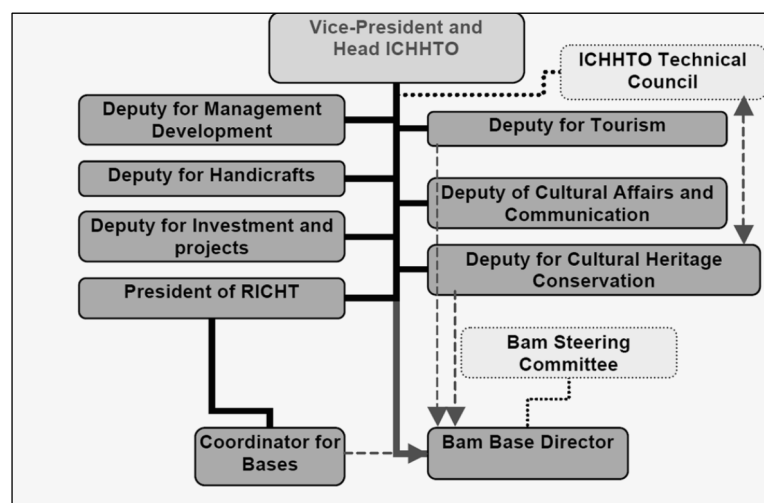
<sup>7</sup> This section is based on a paper published by the author (Ravankhah et al., 2017b).

be inevitably lost due to the loss of the relevant traditional skills and know-how”. However, the Council of Architecture and Urban Development decided to rebuild the houses in the city by applying modern building codes to increase the seismic performance of the urban fabric. The earthen construction technique has been mainly applied to the World Heritage site, in particular to the Bam Citadel. In fact, recovery processes of the World Heritage boundary (the core zone) and the city (the buffer zone) have experienced almost two different approaches in respect to the recovery of the earthen heritage. Consequently, the adobe buildings of the city, which are mostly located in the buffer zone, have been mostly replaced by steel-frame structures and reinforced concrete with a view to building a disaster-resilient city.

### 2.6.5 Institutional and management system for Bam<sup>8</sup>

Iran Cultural Heritage, Handcraft and Tourism Organization (ICHHTO) is responsible for the protection of cultural heritage properties in Iran. The Iranian Cultural Heritage Organization (ICHO) was founded in 1985, as an organization affiliated with the Ministry of Culture and Higher Education. ICHO was merged recently with two other organizations: the National Handicrafts Organization and Tourism Organization. The new organization is called the Iran Cultural Heritage, Handicrafts and Tourism Organization (ICHHTO).

The main management authority of Bam and its Cultural Heritage is ICHHTO, an independent directorate who collaborates with other national and local authorities and follows a programme that is regularly updated. Some of the listed buildings outside the Arg are the property of other government institutions but changes are subject to permission by ICHHTO.



**Figure 2-14 Bam Base Director integrated into the organisational chart of ICHHTO (ICHHTO, 2008a)**

Management involves collaboration particularly with the Religious Endowment Organization (Sazeman-e Owqaf), Ministry of Housing and Town Planning (Vezarat-e Maskan va Shahr-sazi), and the Municipalities (Shahrdari) of Bam and Baravat (ICHHTO, 2008a). ICHHTO has two offices in the region, the regional office of Kerman, and the Task Force office in Bam (ibid). The Bam Base, which is the local office responsible for the management of Bam, is linked to the different deputies working directly under the supervision of the head of ICHHTO (Figure 2-14).

According to the *National Report of the Islamic Republic of Iran on Disaster Reduction* (2005), the disaster management mechanism in Iran is under the direct supervision of the Ministry of Interior

<sup>8</sup> This section is based on a paper published by the author (Ravankhah et al., 2017b).

and its overall structure is corresponding to three levels of national authorities, regional (provincial) structure, and local (district) structure. A number of technical ministries and organizations, such as the Ministry of Housing and Urban Development, the Ministry of Roads and Transportation, the Ministry of Agriculture, the Ministry of Energy, the Ministry of Health, play different roles in the planning and implementation of disaster management strategies in Iran. There is a sub-committee for earthquake and landslides in the Iranian National Committee for Natural Disaster Reduction (ibid).

Bam's post-disaster reconstruction involved multi-stakeholder cooperation with a large number of local and national stakeholders (e.g. National Disaster Task Force, International Institute for Earthquake and Earthquake Engineering, and the Bam Municipality) and international organizations (e.g. UNDP, UNESCO), as well as various Non-Governmental Organisations (NGOs). Despite such unique collaboration, which became a turning point in the disaster management of Iran, Asgary et al. (2006) state that the post-disaster physical planning of Bam was the most challenging aspect of the reconstruction due to conflicting interests among stakeholders (e.g. landowners, municipality and reconstruction office). However, such conflicts might occur in the post-disaster new developments and need to be addressed in the disaster risk management plan in advance of potential natural hazards.

*A comprehensive management plan (2008-2017) for Bam and its Cultural Landscape* was prepared by ICHHTO through multi-stakeholder cooperation. The plan encompasses cultural and natural aspects, including territorial and environmental management, urban development control, safeguarding of built and intangible heritage, tourism development, and a risk preparedness and disaster mitigation plan that did not previously exist (ICHHTO, 2008a). According to the management plan, stakeholders from non-heritage sectors (e.g. environment and urban planning) have been also engaged in its preparation, but the agency responsible for disaster management of the property is solely heritage sector. The management plan was approved by the Iranian Higher Council for Architecture and Urban Planning, as an annexe to the existing Bam Spatial Structural Master Plan for Bam City, in 2010 (UNESCO WHC' website, 2016).

### 2.6.6 Legal provision for protection of the property

In general, the monuments registered on the National Heritage List are under the State's protection and supervision according to the *Law of Conservation of National Monuments* approved on November 1930. Furthermore, the national monuments are being supported by other protection laws, such as, the *Law of Foundation of National Council of City constructing and Architecture*, *Law of City Properties*, *Law of City constructing and Architecture*, *Law of Purchase of properties, buildings and archaeological monuments* as well as some chapters of the Law of City Halls (ICHO, 2004, p. 30).

The ensemble of the Bam Citadel is the property of the ICHHTO. In the core zone of the property, any violation or construction activities without the permission and the supervision of the ICHHTO is forbidden (ibid). As motioned before, two Buffer zones defined in order to fully protect the citadel and its associated landscape. In the buffer zone 1 (please see Figure 2-10), any activities are subject to the following regulations (ibid):

- Construction of building with more than three floors (including the ground floor) which exceeds 10 m. in total is forbidden.
- The style and facades of the buildings must not be in contradiction to the traditional style of the architecture in Bam. Expertise in this regard belongs to the ICHO.
- Widening of streets and paths in case they damage historical monuments is forbidden.



The buffer zone 2 is representing the extended tentative landscape protection zone (please see Figure 2-10), in which any activities are subject to the following regulations (ibid):

- Agricultural and related activities are allowed as long as they do not demand building or inclusion of high constructions or water reservoirs disturbing the cultural landscape of Bam and its sky's cape (sky and horizon line) in an adverse way.
- Any mining activity that affects the sight of the mountains visible from Bam is forbidden. Furthermore, the discharge of rubbles and dump in any quantity within the landscape buffer zone is forbidden.
- The height of buildings within the limits of the town cannot exceed 10 m maximum. Beyond this limit and within the limits of the tentative landscape protection buffer zone, the height of the buildings can vary according to their distance to the Arg and other core zone areas. Expertise in determining the above issues is reserved for the ICHO.
- Protection and conservation of the environmental setting of the town especially in the south and south-west that contain water resources and Qanats are of prime importance; any destructive activity endangering these resources is forbidden.
- Protection of the skyline and the view of the Arg and other related historical monuments will be ensured and developments that negatively impact upon the visual skyline of the core zones will be forbidden.
- The balance between the palm gardens and residential areas according to pre-earthquake conditions should be preserved.

Defining the buffer zones does not only prevent the post-disaster reconstruction threats to the property (e.g. visual impacts and encroachments), but helps to retain the identity of the city of Bam regarding its traditional earthen architecture and land-use patterns.

In respect to the seismic legal instruments, the first Iranian regulations for seismic design so-called *Seismic Safety Code for Building* published in 1967 after the Buein-Zahra Earthquake in 1963; afterwards, the *Iranian Code for Seismic Resistant Design of Buildings* (Standard No. 2800) was published by the Building and Housing Research Centre in 1988 (Manafpour, 2008). It should be noted that, according to the Building and Housing Research Centre of Iran (2007), the current seismic code regulations so-called *Iranian Code of Practice for Seismic Resistant Design of Buildings* (Standard No. 2800) is applicable to reinforced concrete, steel, wood and masonry constructions, but not mud and adobe structures. Thus, a lot of historic buildings that are made of unfired-mud bricks or mud layers in Iran need to be studied according to their own specific seismic performance.

## 2.7 Summary

The 6.6 magnitude earthquake of 2003 in the city of Bam caused a tragic loss of many lives and the severe destruction of cultural heritage, particularly in Arg-e Bam. Following the earthquake, Bam and its Cultural Landscape was inscribed on the UNESCO World Heritage List in 2004 through an emergency nomination, and simultaneously, on the List of World Heritage in Danger. However, the property has been removed from the List of World Heritage in Danger in 2013 when the Iran State Party has addressed the corrective measures recommended by the World Heritage Committee.

According to the post-earthquake investigations (Langenbach, 2005; Vatandoust et al., 2008a), it was revealed that not only the earthquake caused such a severe destruction of Bam Citadel, but also other factors (e.g. improper interventions, loss of the cohesion of the clay, termites and deterioration) contributed to the increased seismic-vulnerability of the citadel.

Because Bam and its Cultural Landscape is located in a high-probability earthquake region and appeared to be highly vulnerable to seismic events, an integrated risk assessment for the property needs to be developed in response to potential earthquakes. Lack of an adequate risk assessment and management plan, apart from adverse effects on the socio-economic development of the region, may cause a serious loss of the OUV and associated conditions of authenticity and integrity of the property. It should be noted that an integrated and site-specific risk assessment plays an essential role to reduce the seismic susceptibility of the property and to determine effective risk mitigation and preparedness strategies against potential earthquakes.

**CHAPTER 3**  
**LITERATURE REVIEW: CURRENT**  
**APPROACHES AND METHODS**

### 3.1 Introduction

Recognising the state of the problem, this chapter reviews the literature corresponding to the engaged disciplines in the subject to provide an interdisciplinary theoretical framework. Following a description of natural hazard categories and specific characteristics of earthquake hazard, the need for disaster risk management for cultural heritage is discussed. Within the context of WH sites, references to disaster risks in the *Operational Guidelines for the Implementation of the World Heritage Convention* are examined.

This chapter reviews the conceptual and analytical frameworks and procedures of risk assessment and management as well as the methods which have been specifically developed for cultural heritage. This provides *Chapter 4-Methodology* with a theoretical background to develop a risk assessment methodology for cultural heritage, in particular for the study area. Besides, a review of some relevant concrete cases will support the practicality of the proposed methodology.

Furthermore, through an extensive review of the literature and past earthquake examples, the chapter develops a multiple impact identification matrix. The matrix explores potential impacts of quake-induced disasters on cultural heritage by incorporating the primary effects of earthquakes as well as secondary natural hazards and human-induced threats that may occur after the earthquakes.

### 3.2 Managing disaster risks in the case of natural hazards

#### 3.2.1 Natural hazards and disasters

The term ‘hazard’ is defined as “a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation” (UNISDR, 2015a). Hazards can be classified into two major categories of natural hazards (e.g. earthquakes and floods) and human-induced hazards (e.g. technological hazards and wars). Natural hazards can be categorised as follows:

- Geological (geophysical) hazards: geological hazards are those “originating from solid earth”, such as earthquakes and landslides (EM-DAT, n.d.).
- Hydro-meteorological hazards: hydrological hazards are “caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater”, such as flash floods and coastal floods. Meteorological hazards are “caused by short-lived/small to mesoscale atmospheric processes (in the spectrum from minutes to days)”, such as thunderstorms and tornados (ibid); however, hydrological and meteorological factors are highly interconnected in causing their respective hazards.
- Biological hazards: biological hazards are associated with “process or phenomenon of organic origin or conveyed by biological vectors, including pathogenic micro-organisms, toxins and bioactive substances” (UNISDR, 2015a), such as biological infestations caused by insects and fungi.

The hazard- and disaster-related terms might be differently defined in the social, natural, and applied sciences; however, understanding the link between different components of disaster risk is a key in risk management. Stillwell (1992) defines ‘natural hazard’ as a phenomenon which is associated to the geophysical processes in the environment that embodies the potential for loss or damage that exists in the presence of the vulnerable elements. “It is not solely the hazardous event that leads to a disaster, but the conditions of societies exposed to such hazards that determine whether a natural phenomenon can trigger a disaster” (Wisner et al., 2004; Birkmann, 2006). Considering such a link between the natural and social system, Bokwa (2013, p. 715) emphasises that “over time, attribution

of natural hazards and disasters has been shifted from supernatural or mystical forces, to nature (physical forces in natural system), and with some reluctance, to humans who have made changes to natural systems”. Kelman (2018), while emphasising the role of the long-term human values, decisions, and activities in the socio-physical vulnerability, states that a disaster is a long-term process and require much more than a hazard, whether sudden- or slow-onset. Such holistic approaches to natural hazard-induced disasters will be explored in further sections.

### 3.2.2 Characteristics of earthquake hazard

In comparison to most other natural hazards, earthquake-related disasters need to be differently considered mainly due to sudden massive destruction without warning and the unpredictability of the exact occurrence time and place. Although with support of the new instruments and data transmission and processing, some advancement has been done in real-time warning systems (from seconds to one minute) and long-term predictions on some active faults, earthquake prediction remains still a challenge in seismology (Cassidy, 2013). Despite the low probability of earthquakes, they can cause sudden-onset and large-scale disasters that may beyond the regional and national capacity to cope with. “An earthquake is a sudden motion or trembling that is caused by a release of strain accumulated within or along the edge of Earth's tectonic plates” (FEMA, 2001, p. 2-16). According to FEMA (2001), there are several common measures of earthquakes, including Richter Magnitude, Modified Mercalli Intensity (MMI), Moment Magnitude and Peak Ground Acceleration (PGA). Table 3-1 shows the Modified Mercalli Intensity Scale with respect to the four types of construction (Feilden, 1987):

- Construction type A: good workmanship, mortar and design; reinforced, especially laterally, and bound together using steel, concrete, etc.; designed to resist lateral forces;
- Construction type B: good workmanship and mortar; reinforced but not designed to resist strong lateral forces;
- Construction type C: ordinary workmanship and mortar; no extreme weaknesses such as failing to tie in at corners, but neither reinforced nor designed to resist horizontal forces; and
- Construction type D: weak materials such as adobe; poor mortar, low standards of workmanship; horizontally weak.

**Table 3-1 Modified Mercalli Intensity Scale (adapted from Feilden, 1987)**

Intensity	Shaking	Level of expected damage
<b>I</b>	Imperceptible	Not felt. Registered only by seismographs.
<b>II</b>	Very slight	Felt in upper stories solely by persons at rest.
<b>III</b>	Slight	Felt indoors. Vibrations like those caused by light trucks passing by.
<b>IV</b>	Moderate	Hanging objects swing. Vibrations like those caused by heavy trucks or a jolt such as that occasioned by a heavy object striking the wall. Parked cars are set in seesaw motion. Windows, doors, and crockery rattle.
<b>V</b>	Fairly strong	Felt outdoors. Sleeping persons wakened. Small objects not anchored are displaced or overturned. Doors open and close. Shutters and pictures are set in motion. Pendulum clocks stop and start or change their speed.
<b>VI</b>	Strong	Walking is difficult. Windows, crockery, and glass break. Knickknacks, books, etc., fall off shelves; pictures fall from the walls. Furniture moves or is overturned. Cracks in weak plaster and materials of construction type D. Small bells ring (church, school).
<b>VII</b>	Very strong	Noticed by car drivers, passengers. Material of construction type D sustains serious damage. In some cases, cracks in material of construction type C.

		Weak chimneys break at roof level. Plaster, loose bricks, stones, tiles, shelves collapse.
<b>VIII</b>	Destructive	Steering of cars made difficult. Very heavy damage to materials of construction type D and some damage to materials of type C. Partial collapse. Some damage to materials of type B. Stucco breaks away. Chimney, monuments, towers, and raised tanks collapse. Loose panel walls thrown out. Branches torn from trees. Changes in flow or temperature of springs. Changes in water level of wells. Cracks in moist ground and on steep slopes.
<b>IX</b>	Highly destructive	General panic. Material of construction type D completely destroyed. Serious damage to material of type C and frequent collapse. Serious damage also sustained by material of type B. Frame structures lifted from their foundations, or they collapse. Load-bearing members of reinforced concrete structures are cracked. Pipes laid below ground burst. Large cracks in the ground. In alluvial areas, water, sand, and mud ejected.
<b>X</b>	Extremely destructive	Most masonry and wood structures destroyed. Reinforced steel buildings and bridges seriously damaged, some destroyed. Severe damage to dams, dikes, and weirs. Large landslides. Water hurled onto the banks of canals, rivers, and lakes. Rails bent.
<b>XI</b>	Disaster	All structures collapse. Even large, well-constructed bridges are destroyed or severely damaged. Only a few buildings remain standing. Rails bent and thrown out of position. Underground wires and pipes break apart.
<b>XII</b>	Major disaster	Large-scale changes in the structure of the ground. Overground and subterranean streams and rivers changed in many ways. Waterfalls are created, lakes are dammed up or burst their banks. Rivers alter courses.

Although the intensity of earthquake effects depends on various factors, the typical effects of earthquakes of various magnitudes near the epicentre can be roughly predicted to be applied to the hazard and risk assessment (Table 3-2).

**Table 3-2 Typical effects of earthquakes of various magnitudes near the epicentre (USGS, 2012)**

Magnitude	Description	Mercalli intensity	Average earthquake effects
1.0–1.9	Micro	I	Micro earthquakes, not felt, or felt rarely. Recorded by seismographs.
2.0–2.9	Minor	I to II	Felt slightly by some people. No damage to buildings.
3.0–3.9		III to IV	Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.
4.0–4.9	Light	IV to VI	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.
5.0–5.9	Moderate	VI to VII	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone.
6.0–6.9	Strong	VIII to X	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometres from the epicentre. Strong to violent shaking in epicentral area.
7.0–7.9	Major	X or greater	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great

			distances with major damage mostly limited to 250 km from epicentre.
8.0–8.9	Great		Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions.
9.0 and greater			At or near total destruction – severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography.

As mentioned, a lot of investigations have been carried out regarding the time, place, and intensity of earthquakes, but their exact time and some other characteristics are still unpredictable. Alexander, (1999, p. 58) believes that a comprehensive prediction of earthquake should identify: “the location of the event, and the geographical area likely to be affected; the time interval during which the event is expected to occur; the expected magnitude range of the tremors, and other physical parameters, and the effects likely to be provoked at the earth’s surface, including the intensity and the probable distribution of damage”. Although such a complete prediction has not been achieved so far, several measures (e.g. seismic hazard boundary maps) can give a long-term perspective of the future earthquakes in a specific region.

The most visible and perceptible impact of earthquakes on human settlements is its direct physical damage induced by potential primary effects of earthquakes. According to the seismological studies (e.g. Alexander, 1999; FEMA, 2001; Jäger and Napitupulu, 2008) three major primary effects of earthquakes can be recognised as ground motion, surface faulting, and soil failures.

Severe **shaking of the ground** can cause serious damages to structures or total collapse of buildings. “When a fault ruptures, seismic waves radiate, causing the ground to vibrate” (FEMA, 2001, p. 2-16). Evaluation of ground motion is applied to the seismic hazard assessment and design of engineering structures. The strong motion “(...) is characterised by its duration (in seconds), the frequencies that are present, the maximum waves amplitude, attenuation which distance from the fault, the maximum velocity in metres per second and the maximum acceleration” (Alexander, 1999, p. 43).

**Surface faulting** “is the differential movement of two sides of a fracture – in other words, the location where the ground breaks apart”. “If the rupture reaches the surface, regions on opposite sides of the fault may move relative to one another. Displacement may be as large as 20-30 m for magnitude 8+ earthquakes” (Cassidy, 2013, p. 214). Surface faulting depends on the length, width, and displacement of the ground (FEMA, 2001, p. 2-16).

**Soil failures or ground failures** can be also seen as the effects of earthquakes on the ground. “Soil failure, such as liquefaction, is the process by which saturated, non-cohesive soil loses its shear strength during seismic shaking and behaves like a liquid rather than a solid” (Jäger and Napitupulu 2008, p. 82). According to FEMA (2001, p. 2-16) two types of ground failure can be caused by liquefaction: “Lateral spreads develop on gentle slopes and entail the sidelong movement of large masses of soil as an underlying layer liquefies” (e.g. landslides) and “Loss of bearing strength results when the soil supporting structures liquefies” causing a building to settle.

Moreover, earthquake hazard may affect a wide range of urban infrastructures and may trigger secondary hazards, such as flooding and fires, resulting in additional losses during disasters. Tsunamis, which are also known as seismic-induced ocean tidal waves, are another secondary natural hazard triggered by earthquakes. The level of damage relies on several factors associated with earthquake hazard, geological condition, and structural performance. According to Perez and Thompson study (1986) regarding the causes and effects of seismic activities, the following five primary factors can influence the level of physical damages to the built environment:

- Strength of the seismic waves reaching the surface: the stronger fault movement causes stronger earthquake waves.
- Length of earthquake motion: the fluctuating series of tremors, lasting from 10 seconds to 3-5 minutes, produces a cumulative effect of this motion resulting in structural cracks or collapse. Alexander (1999, p. 43) says that “The duration of the strong motion may be the single most important factor in producing damage to buildings”.
- Proximity to the fault: generally there is greater danger closer to the fault than farther away.
- Geologic foundation: structures built on solid rock perform better than those built on the softer ground or, worse yet, those built partly on solid ground and partly on soft ground or fill—a condition commonly found on hillsides. Similarly, Alexander (1999, p. 45) says “Seismic waves normally travel faster and generate more consistent resonances in hard, uniform rock formation than in soft sediments, in which they have a tendency to lose their energy and interfere with one another”; “interfaces are more numerous and irregular in waves that pass through bodies of soft sediment or soils”.
- Building design: buildings must be adequately braced to resist seismic lateral forces. A building must have structural continuity with secure anchoring and bonding of all components, and it must be well balanced and tied together.

However, other factors with respect to the structural and non-structural coping capacities can highly influence the level of seismic risks during and after a disaster. Such factors, particularly related to historic properties, will be discussed in the further sections. To adequately understand and respond to the earthquake risk, Petak et al. (2008, p. 1) believe that an interdisciplinary work needs to be carried out through a collaboration of various disciplines of design and engineering (e.g. architects, structural engineers, and civil engineers), earth science (e.g. seismologists, geologists, and geophysicists), the health, social, and policy sciences (e.g. public health, sociology, social psychology, history, urban planning, economics, and emergency management). Such an interdisciplinary approach can better link hazard and vulnerability in risk assessment and management.

### 3.2.3 Disaster risk management

UNISDR (2015a) defines the term ‘disaster’ as “a serious disruption of the functioning of a community or a society due to hazardous events interacting with conditions of vulnerability and exposure, leading to widespread human, material, economic and environmental losses and impacts”. Disasters can be linked to sudden-onset hazards (events that emerge quickly or unexpectedly, e.g. earthquakes and hurricanes) and/or slow-onset hazards (those that emerges gradually over time, e.g. deforestation and heat waves) (ibid). As mentioned earlier, disasters do not solely depend on their corresponding hazards, but on the characteristics and capacity of systems exposed to the hazards. Concerning the complexity of disasters, Smith and Petley (2009, p. 8) define hazards and disasters as two sides of the same coin that neither can be entirely understood or presented from the standpoint of either social science or physical science alone.

Risk Management (RM) procedure is “the systematic application of management of policies, procedures and practices to the tasks of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk (AEMC, 2010, p. 53). ISO 31000 (2009) outlines the risk management procedure through five main stages of communication and consultation, establishing a context, identifying, analysing and evaluating risks, treatment of the risks, and monitoring and review.



UNISDR (2015a) defines Disaster Risk Management (DRM) as “application of disaster risk reduction policies, processes and actions to prevent new risk, reduce existing disaster risk and manage residual risk contributing to the strengthening of resilience”. The UN’s *Sendai Framework for Disaster Risk Reduction 2015-2030*, in March 2015 set four key *Priorities for Action* as follows (UNISDR, 2015b, p. 14):

- Priority 1: Understanding disaster risk;
- Priority 2: Strengthening disaster risk governance to manage disaster risk;
- Priority 3: Investing in disaster risk reduction for resilience; and
- Priority 4: Enhancing disaster preparedness for effective response.

According to the UNISDR (2015a, p. 13-14), DRM planning needs to be conducted in three different phases of pre, during, and post-disaster as follows:

- Prospective disaster risk management: actions designed to avoid the creation of new risks (e.g. better land-use planning);
- Corrective disaster risk management: measures to address pre-existing risks (e.g. reduction of social vulnerability and retrofitting of critical infrastructure); and
- Compensatory disaster risk management: actions to address residual risk and reducing effects on societies (e.g. preparedness and social safety nets).

The above-mentioned definitions and approaches to DRM underscore the importance of a holistic and systematic view to disasters and managing its associated risks. In fact, DRM needs to address the pre-, during, and post-disaster phases through both structural and non-structural policies in order to adequately promote the community resilience to natural hazards.

### **3.3 Disaster risk management in the context of World Heritage Properties**

#### **3.3.1 Why disaster risk management for World Cultural Heritage properties<sup>9</sup>**

Cultural heritage is an integral part of the built environment, and thus, needs to be adequately considered within the multi-sectoral disaster management frameworks. There has been a trend in highlighting contributions of heritage in promoting disaster resilience of communities and stressing the ‘culture’ as a missing dimension in disaster risk reduction; this has recently been set out in the UN’s *Sendai Framework for Disaster Risk Reduction 2015-2030* (UNISDR, 2015b, p. 10). Such approaches will not only protect irreplaceable cultural resources and avoid potential socio-cultural and economic losses, but can also provide communities with unique and locally available coping strategies. In fact, many of the lessons for DRM can be learnt from traditional knowledge in planning and building design and construction, and therefore, deserve sympathetic consideration when drawing up new policies and regulations (Ravankhah et al., 2017b, stated by Chmutina).

UNESCO WHC et al., (2010) emphasise that reducing the risk is the most effective management approach; and suggest investing in preventive risk management planning of heritage properties in the pre-disaster situation than to spend large amounts in post-disaster rehabilitation and recovery. In the application of risk management to collection conservation, Waller (n.d., p.21) believes that “a risk management approach can be used, not only to organize thoughts on any decision (...), but also

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<sup>9</sup> This section is based on a paper published by the author (Ravankhah et al., 2017b).

to provide a method for considering the most difficult decision we face - how limited resources can best be applied to the protection of collections”.

However, the European Parliament's committee's report on *Protecting the Cultural Heritage from Natural Disasters* (Drdacky, 2007, p. iii) clearly emphasises that “effective risk management of cultural assets is rare because of inadequate understanding of the assets, failure to calculate the true cost of loss and damage, and difficulty in putting a value on the non-market nature of many cultural heritage values”. In this regard, Will (2012, p. 5) says that vulnerability of historic buildings is mainly measured based on structural aspects because there is no tangible economic loss estimation for heritage values; and therefore they “(...) are ranked in terms of their insurance damage assessment beneath mere material property such as industrial complexes or consumer goods”. In the context of World Heritage, it could be more challenging because the specific requirements regarding the Outstanding Universal Values (OUV), authenticity and integrity need to be also addressed in the risk assessment and management.

### 3.3.2 Heritage and disaster resilience<sup>10</sup>

In the context of heritage, “resilience may be understood as the ability to experience shocks while retaining heritage values” (Australia State of the Environment, 2011, p. 780). In fact, heritage disaster resilience relies greatly on the continuity of cultural significance and values rather than merely on fabric. Disaster resilience of a system is highly influenced by its coping capacity to disasters. UNISDR (2015a) emphasises several factors, such as learning and training, continuous efforts to develop institutions, political awareness, financial resources, and technology systems that can promote the capacity of communities to cope with and recover from disasters. Coping capacity of cultural heritage indeed needs to be perceived within the broader context to which cultural properties belong. In respect to the reconsideration of mitigation in heritage conservation, Boccardi (2015, p. 94) states that “in the new circumstances, the heritage paradigm should thus be reassessed by dissolving the artificial boundaries that kept it for so long segregated from the non-heritage”. Within DRM planning, instead of merely focusing on the regional geographical and hydro-meteorological conditions, such an approach could contribute to reducing structural and non-structural vulnerability on which disaster resilience greatly relies. Below, this section addresses some challenges and opportunities in establishing DRM for the protection of cultural heritage and promoting disaster resilience.

#### 3.3.2.1 Challenges for increased disaster resilience

While DRM seeks to maximise safety by enhancing structural and non-structural performance, heritage conservation aims at keeping a balance between safety and value. Heritage conservation principles, such as “minimal changes to significant fabric and use” in the Burra Charter (Australia ICOMOS, 2013, p. 4), play a vital role in formulating adequate disaster mitigation strategies to retain a balance between structural stability and heritage values. Methodology to assess the loss of value, which demands a qualitative and systematic multi-risk analysis in a value-based system, is still extremely complex (Ravankhah and Schmidt, 2014). This is particularly true of World Heritage properties, for which loss of Outstanding Universal Values (OUV) as well as associated conditions of authenticity and integrity should be adequately estimated within risk assessment procedures.

In a more holistic view, heritage resilience can be linked to three different assessment tools: disaster risk assessment, climate change impact assessment, and Heritage Impact Assessment (HIA). With respect to the implementation of DRM policies in historic environments, for example, new challenges

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<sup>10</sup> This section is based on a paper published by the author (Ravankhah et al., 2017b).

may emerge calling for mitigating the potential effects of structural risk reduction measures (e.g. flood control embankments, urban drainage system, and fire prevention installations) on cultural heritage. Such conflicts should be considered earlier in the planning procedure, through multiple risk assessment and weighing risk reduction and heritage protection strategies in a multi-criteria decision making context.

Within post-disaster rehabilitation and recovery, there is a unique opportunity for transformation and modernisation, but heritage properties are expected to be preserved with minimal change in order to retain their values and authenticity. This might be compromised for individual monuments, but heritage buildings that exist in a context of a non-heritage built environment (e.g. in urban areas) cannot be overlooked since failure in some elements will result in declining resilience of the whole system. However, post-disaster reconstruction and new development versus maintaining cultural heritage values is one of the challenging issues which needs to be responded considering the specific characteristics of a site and its setting.

Another important factor in increasing the coping capacity to disasters is multi-sectoral collaboration. In the protection of cultural heritage from natural hazards, several sectors such as cultural heritage organisations, civil protection, and municipalities, need to be proactively involved in the risk preparedness planning. Multi-stakeholder cooperation is vital for the efficiency and effectiveness of the emergency response. However, if it is not synchronised adequately in advance, may result in delaying the recovery process due to potential conflicts of perceptions, expectations and capacities of the sectors engaged in the process (Aysan and Davis, 1993). To ensure that cultural heritage is considered in multi-dimensional disaster resilience planning, raising awareness of heritage values among stakeholders involved in DRM should be encouraged while increasing their capacities in dealing with cultural heritage in cases of emergencies.

### 3.3.2.2 Opportunities for proactive long-term resilience

Cultural heritage as an integral part of the economic evolution of the built environment plays a significant role in contemporary economic development models. Historic urban environments attract considerable tourist revenue while creating diverse types of employment; this can improve economic coping capacities of urban systems to build back better following disasters. Cultural resources in both tangible forms (e.g. palaces, museums, gardens, and architectural monuments) and intangible forms (e.g. traditional performance and festivals) can facilitate financial resources needed for risk preparedness programmes and public awareness-raising.

*The recent ICOMOS Concept Note for the United Nations Post-2015 Agenda and HABITAT III* also highlights the economic role of heritage at a local level, where it says “culture based livelihoods have the potential for small and micro-entrepreneurship that empowers local communities and can contribute substantially to poverty alleviation” (Hosagrahar et al., 2015, p. 9). Such diversification of the economy through cultural resources can provide various alternatives for financial resources in disaster resilience planning. In respect to post-conflict recovery, for instance, cultural heritage-related programmes have been recognised by the World Bank as a significant opportunity for rehabilitation and revival of conflict-affected economies (Worthing and Bond, 2008, p. 52). As mentioned earlier, Bam’s heritage has considerably accelerated the post-quake economic recovery of the city through the tourism industry and financial and technical assistance provided by UNESCO, donor countries, and NGOs.

In contrast to post-disaster physical and economic reconstruction, social and cultural losses to communities cannot be tangibly compensated through external assistance. This demands an inclusive socio-cultural structure based on patterns of previous societies and approaches to adapt to shocks. Heritage can contribute to this in generating and strengthening social capital through the promotion of cultural diversity and intercultural discourses (EU, 2014). In a disaster resilience model, a system

with diverse elements can better absorb shocks since it has more alternatives for response capacities (Pisano, 2012).

One of the main factors affecting DRM strategies is different risk perception and prioritisation between DRM organisations and local inhabitants (Krüger et al., 2015). Community risk perception, which needs to be adequately considered in DRM procedures, can be better recognised through analysing their historical socio-cultural background. Furthermore, the shared cultural identities and sense of belonging among a community can also foster public participation, which is vital for public acceptance and effectiveness of risk preparedness policies and post-disaster recovery. A community-based resilience approach can increase adaptive capacity to disasters and climate change extremes; it can also enhance risk reduction policies to meet sustainable development criteria in disaster-prone regions.

Indigenous knowledge and techniques associated with historic built environments represent the evolution of human settlement adaptability to surrounding environments and a culture of living with natural hazards. Traditional knowledge for promoting the coping capacity to natural hazards can be available as indigenous management systems, indigenous monitoring systems, traditional skills and techniques, local ecological relationships and indigenous planning (UNESCO WHC et al., 2010). Traditional know-how in planning, building design and coping mechanisms, which developed historically through trial and error, deserve adequate consideration when drawing up new policies and regulations in disaster-prone areas.

### 3.3.3 World Heritage and disaster management in the international agenda

Several initiatives on an international level have been carried out to protect cultural heritage from natural hazards as well as to incorporate cultural heritage into the broader DRM framework. Below, some of the most remarkable conventions, frameworks, and recommendations are outlined.

*The 1972 Convention Concerning the Protection of the World Natural and Cultural Heritage*, in its Article 5, asks each state parties “to ensure that effective and active measures are taken for the protection, conservation and presentation of the cultural and natural heritage situated on its territory” (UNESCO 1972, Article 5). In its Article 11, by setting the ‘list of World Heritage in Danger’ for those properties are threatened by serious hazards, including fires and earthquakes, floods and tidal waves, offers emergency assistance for risk mitigation and recovery. Disaster management for cultural heritage has been further highlighted by the UNESCO general conference on *the desirability of adopting an international instrument on the protection of the cultural heritage against natural disasters* and their consequences in 1983. The report was one of the first documents that clearly addressed the vulnerability and risk assessment by looking at the vulnerability factors regarding movable and immovable cultural assets. Furthermore, it emphasises that the regional and local physical planning should be taken into account in order to ensure the effectiveness of the vulnerability reduction measures.

In 1992, an *Inter-Agency Task Force (IATF) for Cultural-Heritage-at-Risk*, including ICCROM, UNESCO, ICOMOS and ICOM, has been established with a specific focus on risk preparedness and related international activities for cultural heritage. Afterwards, in 1996, *the International Committee of the Blue Shield (ICBS)* was founded in 1996 to protect the World Cultural Heritage by coordinating preparations for emergency situations and post-disaster recovery. The ICBS comprises the non-governmental organisations of International Council on Archives (ICA), International Council of Museums (ICOM), International Federation of Library Associations and Institutions (IFLA), ICOMOS, and Coordinating Council of Audio-visual Archives Associations (CCAAA). One of the main results of the IATF partnership was a comprehensive guideline *Risk*

**preparedness: A Management Manual for World Cultural Heritage** by Stovel, in 1998 to address the specific considerations of cultural heritage in respect to different hazards.

Meanwhile, several relevant declarations have been prepared particularly in the hazard-prone areas, including *Declaration of Quebec* (1996), *the Kobe-Tokyo Declaration on Risk Preparedness for Cultural Heritage* (1997), and *the Declaration and Recommendations of the International Workshop on the Recovery of Bam's Cultural Heritage* (2004), and *the Kyoto Declaration on Protection of Cultural Properties, Historic Areas and their Settings from Loss in Disasters* (2005).

Within the DRM international agenda, ***the Hyogo Framework for Action 2005-2015 (HFA): Building the Resilience of Nations and Communities to Disasters*** was adopted in the UN World Conference on Disaster Reduction held on 18-22 January 2005 in Kobe, Hyogo, Japan. Cultural heritage considerations in DRM framework was particularly highlighted in the HFA when in its Priority for Action 3 emphasises the role of “traditional and indigenous knowledge and culture heritage” in building resilience (UNISDR, 2005, p. 9).

In the light of the HFA's main priority areas, UNESCO adopted its ***Strategy for Reducing Risks at World Heritage Properties*** in Christchurch in 2007, not only to enhance World Heritage protection from hazards, but also to advocate cultural heritage in the international agenda. The document clearly emphasises “strengthen[ing] support within relevant global, regional, national and local institutions for reducing risks at World Heritage properties” as one of the main objectives, with a view to “promote cultural and natural heritage, and its potential positive role for disaster reduction as part of sustainable development...” (UNESCO, 2007). The main purposes of this strategy are as follows (UNESCO, 2007, p. 2-3):

- “To strengthen the protection of World Heritage and contribute to sustainable development by assisting States Parties to the Convention to integrate heritage concerns into national disaster reduction policies and to incorporate concern for disaster reduction within management plans and systems for World Heritage properties in their territories; and
- To provide guidance to States Parties, the World Heritage Committee, the World Heritage Centre, and the Advisory Bodies to integrate disaster risk reduction into World Heritage strategic planning and management, including the allocation and use of Emergency Assistance under the World Heritage Fund.”

Considering the HFA's main priority areas, the UNESCO strategy for risk reductions comprises the following key actions (UNESCO, 2007, p. 3):

- “Strengthen support within relevant global, regional, national and local institutions for reducing risks at World Heritage properties;
- Use knowledge, innovation and education to build a culture of disaster prevention at World Heritage properties;
- Identify, assess and monitor disaster risks at World Heritage properties;
- Reduce underlying risk factors at World Heritage properties; and
- Strengthen disaster preparedness at World Heritage properties for effective response at all levels.”

The above activities further continued with several conferences and guidelines to enhance the approaches and methods of risk management, including ***Cultural Heritage and Natural Disasters*** (ICOMOS, 2008) and ***Managing Disaster Risks for World Heritage*** (UNESCO WHC et al., 2010). The latest was developed by UNESCO, ICCROM, ICOMOS, and IUCN as a comprehensive but user-friendly guideline in disaster risk management to help the conservation of World Heritage sites exposed to natural and human-induced hazards. It emphasises that risk should be assessed through a

holistic view to analysing risk factors and cause-effect relationships while considering particular characteristics of World Heritage including Outstanding Universal Values (OUV) and the conditions of authenticity and integrity. On the policy level, incorporating cultural heritage protection into the *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risk* and *Venice Declaration on building resilience at the local level towards protected cultural heritage and climate change adaptation strategies* can be mentioned.

Subsequently, a collaborative paper entitled *Heritage and Resilience: Issues and Opportunities for Reducing Disaster Risks* was prepared by ICOMOS-ICORP, UNISDR, UNESCO, and ICCROM, and was presented to the fourth session of the *Global Platform on Disaster Risk Reduction* in Geneva in 2013 (Jigyasu et al., 2013). Apart from highlighting cultural heritage issues in reducing disaster risks, it aimed to draw the attention of the global community of disaster risk reduction to cultural heritage, and later to stress cultural heritage in the upcoming international agenda.

The UN's report for the Post-2015 UN Development Agenda entitled *Realising the Future We Want for All*, highlights the importance of disaster risk reduction and resilience within the context of environmental sustainability; one of the four core dimensions of sustainability (UN, 2012). According to this report, the four core dimensions of sustainability include: inclusive social development, environmental sustainability, inclusive economic development, and peace and security; here, environmental sustainability may refer to protecting biodiversity, stable climate and resilience to natural hazards (UN, 2012). The concepts of sustainability and resilience underscore the importance of holistic and long-term perspectives while considering a wide range of interrelated indicators. Goal 11 of the 2030 Agenda for Sustainable Development Goals (SDGs) – “make cities and human settlements inclusive, safe, resilient and sustainable” – explicitly acknowledges ‘Heritage’ in target 11.4: “strengthen efforts to protect and safeguard the world’s cultural and natural heritage” (UN, 2015, p. 18).

Following the SDGs, the integration of the concept of ‘Cultural Heritage’ in disaster resilience has been emphasised in the recent *UN’s Sendai Framework for Disaster Risk Reduction (2015-2030)*, particularly in the Priority for Action 1 “Understanding disaster risk and Priority”, and in Action 3 “Investing in disaster risk reduction for resilience” (UNISDR, 2015b). The Sendai Framework for Disaster Risk Reduction 2015–2030 was adopted at the Third United Nations World Conference on Disaster Risk Reduction, held from 14 to 18 March 2015 in Sendai, Japan. While the above-mentioned efforts have considerably facilitated the progress of promoting heritage resilience and heritage contribution in disaster resilience, it may in reality pose a number of challenges associated with disciplinary boundaries, competing priorities at the urban and regional levels, and eventually multi-sectoral institutional arrangements, as mentioned in *Section 3.3.2- Heritage and disaster resilience*.

### 3.3.4 References to natural hazards and disaster risks in the Operational Guidelines

The *Operational Guidelines for the Implementation of the World Heritage Convention* make references to natural disasters and risk preparedness within their policies in addressing the potential threats and supporting the state parties for mitigation strategies (UNESCO WHC, 2017). The Operational Guidelines (ibid) refer to “risk preparedness” in their paragraph 118 where indicate that “the Committee recommends that States Parties include risk preparedness as an element in their World Heritage site management plans and training strategies.” In section 4b of the nomination procedure of a property (Annex 5 of the Operational Guidelines), ‘natural disasters’ is mentioned as one of the following major factors that may affect a property (ibid):

- Development pressures (e.g. encroachment, adaptation, agriculture, mining);

- Environmental pressures (e.g. pollution, climate change, desertification);
- Natural disasters and risk preparedness (earthquakes, floods, fires, etc.);
- Responsible visitation at World Heritage sites; and
- Number of inhabitants within the property and the buffer zone.

The state parties are requested to “itemize those disasters which present a foreseeable threat to the property and what steps have been taken to draw up contingency plans for dealing with them, whether by physical protection measures or staff training” (ibid). The committee advice to consider particularly the following items (ibid):

- The estimated frequency of such disasters and the likely scale of impact;
- Risk preparedness while considering the frequency and scale of impact;
- Risk preparedness while including pre-disaster preparations as well as response measures during and after the disaster, and
- Referencing to other documents (e.g. contingency and disaster plans).

Paragraphs 161 and 162 introduce the “Nominations to be processed on an emergency basis” for those properties “(...) which would be in Danger, as a result of having suffered damage or facing serious and specific dangers from natural events or human activities” (ibid). As described in the case of Bam and its Cultural Landscape, for instance, such nominations will be conducted through an emergency procedure; they might be inscribed on the World Heritage List, and simultaneously should be inscribed on the List of World Heritage in Danger (ibid). Paragraph 177 refers to the requirements in order for inscribing a property on the List of World Heritage in Danger, as follows (ibid):

- “The property under consideration is on the World Heritage List;
- The property is threatened by serious and specific danger;
- Major operations are necessary for the conservation of the property; and
- Assistance under the Convention has been requested for the property (...).”

According to Paragraph 179-a, the “threatening impacts of climatic, geological or other environmental factors” in the case of cultural properties needs to be addressed among the other potential factors, as below (ibid):

- “Modification of juridical status of the property diminishing the degree of its protection;
- Lack of conservation policy;
- Threatening effects of regional planning projects;
- Threatening effects of town planning;
- Outbreak or threat of armed conflict; and
- Threatening impacts of climatic, geological or other environmental factors.”

The Operational Guidelines offers an ‘Emergency Assistance Fund’ in paragraph 241, to those properties which have been seriously affected by hazards, including land subsidence, extensive fires, explosions, flooding. “This assistance may be requested to address ascertained or potential threats facing properties included on the List of World Heritage in Danger and the World Heritage List which have suffered severe damage or are in imminent danger of severe damage due to sudden, unexpected phenomena” (ibid). The assistance may be requested for conducting emergency measures for the protection of the property and preparing an emergency plan (ibid).

However, it should be noted that the “emergency Assistance funds will not be automatically granted after a major disaster has occurred. This type of assistance will be provided only in cases when an

imminent danger related to a natural or human-made disaster is threatening the overall Outstanding Universal Value of a World Heritage property and its authenticity and/or integrity, to prevent or at least significantly mitigate its possible negative impact on the property” (ibid, p. 129).

Following the progress of the corrective measures for a property in Danger and the review of its state of conservation, the Committee will decide whether: additional actions need to be done for the protection of the property; to remove the property from the List of World Heritage in Danger if the threats have been avoided or mitigated; or to remove the property from both the List of World Heritage in Danger and the World Heritage List if the property has lost its characteristics conveying the OUV (ibid, para. 191). The decisions will be made in consultation with the State Party concerned.

### 3.4 Current approaches and methods of risk assessment

#### 3.4.1 The role of risk assessment in disaster risk management

Risk assessment is “the overall process of risk identification, risk analysis and risk evaluation” (ISO 31000, 2009) (Figure 3-1). Risk assessment, through predicting potential hazards and their associated consequences, aims to shift the strategies from rehabilitation and recovery to mitigation and preparedness to lessen the potential losses. It is the central component of the risk management process to determine the nature and level of risk, and to support developing adequate risk reduction strategies. It provides the decision-making process with the required information regarding hazards, exposed elements, and vulnerability that influence the level of risk. Furthermore, “the process of producing a risk assessment will enable both public authorities and businesses, NGOs, and the general public to reach a common understanding of the risks faced as a community and help fostering an inclusive debate about the relative priority of possible prevention and mitigation measures” (EC, 2010, p. 8).

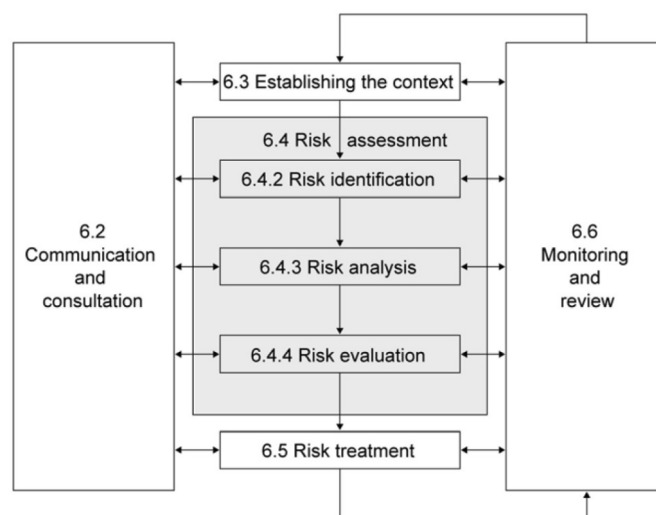


Figure 3-1 Risk assessment within the risk management process (ISO 31000, 2009)

#### 3.4.2 Risk components and risk analysis approaches

In the context of natural hazards, the term ‘risk’ is defined as the “expected losses from a given hazard to a given element at risk, over a specified future time period” (Coburn et al. 1994, p.10). FEMA (2005, p. a-11) defines risk as “the potential loss associated with a hazard, defined in terms of expected probability and frequency, exposure, and consequences”. Apart from the mentioned factors, risk is also influenced by “resilience or coping capacities” (UNISDR, 2012, p. 7) of a system.



In this regard, AEMC (2010, p. 25) emphasises the “level of existing prevention and preparedness control, and level of existing response and recovery control” which will influence the risk level. Understanding disaster risk relies greatly on a clear perception of the risk components.

According to ISO 31010 (2009, p. 13), risk analysis methods can be generally classified into qualitative, semi-quantitative, and quantitative methods, depending on “the particular application, the availability of reliable data and the decision-making needs of the organization”. There are various tools for assessing risks, including scenario analysis, fault tree analysis, risk matrix, and risk index (ibid). However, three fundamental standardisation schemes can be recognised in assessing disaster risk (Kappes et al. 2012; Papathoma-Köhle 2016, cited in Poljanšek, et al. 2017, 99), as below:

- Matrices: hazard matrix, vulnerability matrix and risk matrix;
- Indices: hazard index, vulnerability index and risk index; and
- Curves: hazard curves, vulnerability curves and risk curves.

### 3.4.3 Matrices for risk analysis

One of the most common tools to analyse the risk is the risk matrix. A consequence-probability matrix is drawn with ‘consequence’ on one axis and ‘probability’ or ‘likelihood’ on the other axis to rate the risks and to prioritise risks for the risk treatment purposes (ISO 31010, 2009). This is mainly a qualitative analysis by applying ranking scales, for example from ‘Very low’ to ‘Very high’. Although it is easy-to-use, it is difficult to define the scales unambiguously (ISO 31010, 2009). Figure 3-2 illustrates a risk matrix based on the (Australian) *National Emergency Risk Assessment Guidelines* (AEMC, 2010). The guideline provides practical solutions for risk identification and analysis, including likelihood rating and emergency scenarios, according to the particular risk criteria established at the beginning of its procedure.

Likelihood Level	Consequence Level				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Low	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium
Very Rare	Low	Low	Low	Low	Medium
Almost Incredible	Low	Low	Low	Low	Low

Figure 3-2 Example of a qualitative risk matrix (AEMC, 2010)

### 3.4.4 Indices for risk analysis

A more systematic risk analysis can be conducted by applying risk indices. Different elements of risk may be defined, depending on natural and human-induced hazards and the elements at risk in order to be incorporated into a risk index. Risk indices, through a semi-quantitative analysis method, allow for aggregation of the scores assigned to the different components of risk (ISO 31010, 2009). Vulnerability indices provide a ground for analysing the physical and non-physical condition of elements exposed to hazards. World Risk Index, as a recent example in risk assessment, is an indicator-based concept to systemize and operationalize features of vulnerability and risk to natural hazards and climate change (Figure 3-3). In this approach three components are aggregated to determine the level of vulnerability (Birkmann, 2015): susceptibility to analyse the conditions of exposed societies and other elements; coping capacity to assess the immediate reaction during a

disaster; and adaptive capacity which reflects a long-term change and transform in response to the effects of disasters.

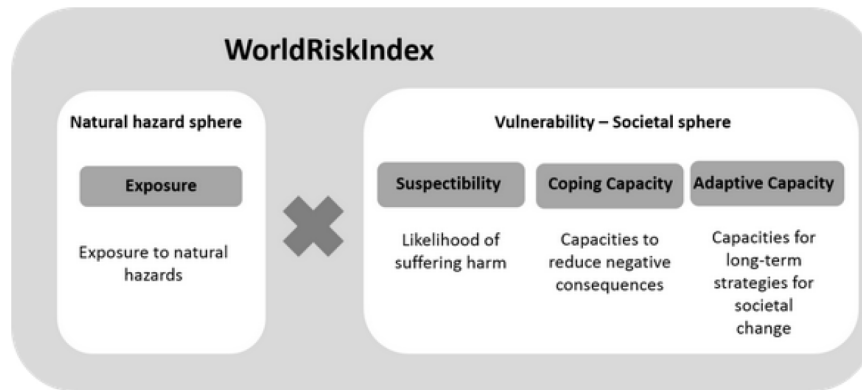


Figure 3-3 The WorldRiskIndex and its components (Birkmann and Welle, 2015)

### 3.4.5 Curves for risks analysis

In comparison with matrices and indices, curves provide a more quantitative analysis of risk. While hazard curves show the exceedance probabilities for the intensities of a hazard in a specific period, vulnerability curves link the loss or the conditional probability of loss exceedance to the hazard intensity (e.g. ground motion or wind speed) to quantify the vulnerability of elements at risk (Poljanšek, et al. 2017, p. 100). Risk curves, through a probabilistic approach, provide a more accurate estimation of tangible damages and losses of natural hazards (ibid) (Figure 3-4). This method needs a sufficient amount of quantitative data for the analysis of risk components that may not be always available.

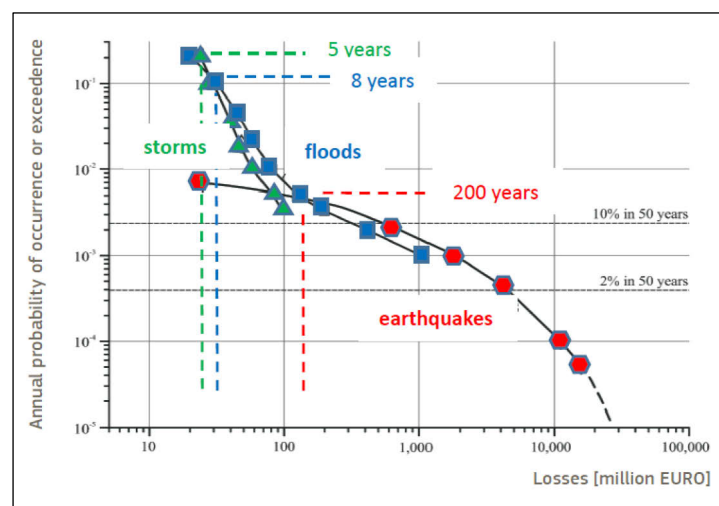


Figure 3-4 Risk curves for the city of Cologne (Grünthal et al. 2006, cited in Poljanšek, et al. 2017)

The appropriate technique for the risk assessment should be taken based on the complexity of the problem, availability of data and resources, and characteristics of elements at risk. The risk assessment method should be able to adequately address the specific objectives of risk management regarding structural and non-structural attributes.

### 3.5 Current DRA and DRM methods specific to cultural heritage<sup>11</sup>

Regarding the importance of the risk-oriented assessment approaches, Taylor (2005, p. 128) emphasises, “Risk assessment (...) is an extremely useful concept for preventive conservation and planning because it does not rely on the existence of damage to establish priorities for its prevention”. He believes in the integration of condition surveys method and risk assessment in order to consider both current deterioration evidence and potential damages in conservation planning. Risk assessment based on theoretical prognostics should consider traditional or analytical knowledge gained from empirical evidence of past hazards; theoretical and experimental modes of analysis should then be combined, and their results critically weighed against each other.

Until recently, there has been a trend to concentrate, on the one side, on the technical and structural damage caused by earthquakes to historic fabrics (e.g. Tolles et al., 2002; Langenbach, 2005), and on the other, on the overall process of risk assessment and management for cultural heritage (e.g. Stovel, 1998; FEMA, 2005; UNESCO WHC et al., 2010; and ICROM and CCI, 2016). This section provides an overview of the existing methods and frameworks of risk assessment and management developed specifically for cultural heritage.

#### 3.5.1 ICCROM’s framework for risk preparedness

One of the initial demonstrations of the collaboration among international partners engaged in the protection of (World) Cultural Heritage, including UNESCO’s World Heritage Committee, ICCROM, ICOMOS, in promoting a cultural-heritage-at-risk framework was a manual entitled *Risk preparedness: A management manual for world cultural heritage*. The manual provides multiple stakeholders involved in the heritage management and conservation with prevention and mitigation strategies and their associated administrative, operational and technical measures. The author of the guideline, Stovel (1998, p. 25), proposes a comprehensive “planning framework for risk-preparedness” that involves the following major phases:

- Preparedness phase: for the purpose of mitigating risk, promoting disaster resistance and advance warning system, and developing a response plan in advance;
- Response phase: to ensure the availability of an emergency response plan and mobilising a conservation team; and
- Recovery phase: for reducing disaster consequences, rebuilding physical structures and social systems, and further monitoring and improvement of the preparedness plan.

While looking at different natural and human-induced hazards, the manual provides hazard-specific strategies for the protection of heritage properties. It determines potential seismic damages on different typologies of heritage properties: buildings and their contents (e.g. structural collapse and damage), historic districts (e.g. damage to transport infrastructure), and cultural landscapes and archaeological sites. Regarding the earthquakes, Stovel emphasises the importance of focusing effective earthquake-protection strategies on risk preparedness and emergency response rather than hazard mitigation. Accordingly, seismic-protection strategies involve reducing risks (e.g. high levels of property maintenance), increasing earthquake resistance (e.g. reinforcement of structural systems), earthquake detection and monitoring (e.g. in-ground sensors and communications systems), and earthquake-response planning (e.g. earthquake-reaction training and drills). Although the manual does not deliver a specific methodology for the assessment of disaster risks, it provides the site

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<sup>11</sup> This section is based on a paper published by the author (Ravankhah, Schmidt, and Will, 2017a)

managers, decision-makers, and professionals with a holistic framework and practical hazard-specific recommendations for the protection of cultural-heritage-at-risk.

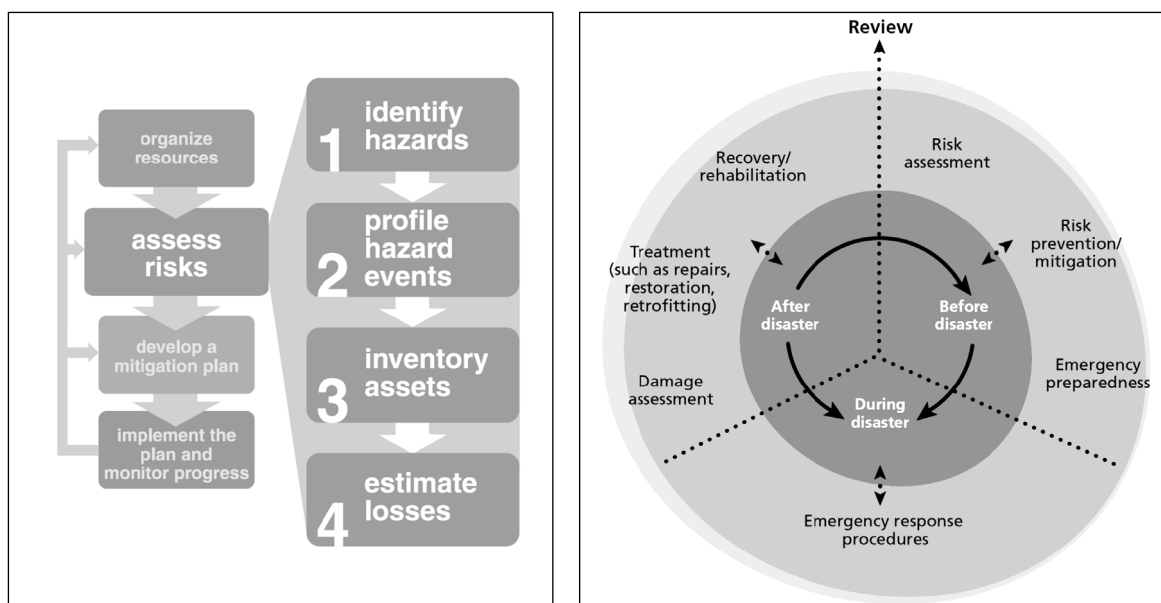
### 3.5.2 FEMA's process for hazard mitigation planning

A systematic procedure of risk mitigation for historic properties and cultural resources has been developed by the Federal Emergency Management Agency (FEMA), in 2005 that is mainly targeted city planners and emergency managers. It provides a guidance tool for a wide range of stakeholders, including professionals, planning and environmental agencies, community interest groups, and cultural heritage organizations. The overall mitigation planning process encompasses the following steps (FEMA, 2005, p. vii):

- Identification of resources to improve the planning team's capability for incorporating historic properties into the hazard mitigation plan;
- Assessment of the risks for identification and prioritisation of those historic properties which are potentially exposed to hazards;
- Evaluation of mitigation measures through the cost-benefit analysis and other decision-making tools; and
- Implementation of a hazard mitigation plan and monitoring its progress.

The FEMA's risk assessment is central to the overall mitigation planning, and it consists of the following steps (FEMA, 2005, p. 2-1):

- Step 1. Identification of the hazards that may potentially affect a site;
- Step 2. Profiling hazards and identifying hazard-prone zones;
- Step 3. Identification of the historic properties vulnerable to the hazards; assessing their vulnerability and values to the community; and
- Step 4. Estimation of the potential losses (Figure 3-5, left).



**Figure 3-5** *left: Risk assessment procedure (FEMA, 2005), right: Disaster Risk Management cycle (UNESCO WHC et al., 2010)*

The FEMA's systematic risk assessment procedure provides ranking criteria and practical worksheets for analysis of the elements of risk. It recommends establishing a GIS database while

overlaying the map of identified hazards with the inventory map of historic properties to determine the properties which are situated in hazard-prone zones.

### 3.5.3 UNESCO's disaster risk management cycle

A comprehensive risk management guideline specific to World Heritage sites has been prepared in 2010 by UNESCO WHC in cooperation with the three Advisory Bodies of the World Heritage Convention (i.e. ICOMOS, ICCROM, and IUCN). The UNESCO's manual on disaster risk management underscores the importance of a holistic view to evaluating risk factors and cause-effect relationships while considering the Outstanding Universal Values (OUV), authenticity, and integrity in the procedure. Within the three major phases of DRM (Figure 3-5, right), the following steps are proposed for the preparation of a DRM plan (UNESCO WHC et al., 2010, p. 16):

- Identification and assessment of disaster risk;
- Prevention and mitigation of disaster risks;
- Emergency preparedness and response plan;
- Recovery plan; and
- Implementation and monitoring of the DRM plan.

Within the step of risk assessment, three main components need to be analysed: probability of a particular disaster scenario, severity of the consequences of the disaster scenario, and consequence in terms of 'loss of value' represented by the relative impact on those attributes conveying the values. To appropriately assess the above-mentioned elements, the manual indicates the following factors that need to be identified and analysed (UNESCO WHC et al., 2010, p. 23):

- Listing all the natural and human-induced hazards that the property may be exposed to them;
- Evaluation of the performance of existing disaster preparedness and management systems;
- Analysis of the potential adverse impacts of existing damage and deterioration patterns;
- Examination of the underlying risk factors linked to the surrounding environment that may increase the property's vulnerability (e.g. physical, social, and institutional factors);
- Analysis of the potential adverse effect of previous improper restoration; and
- Evaluation of the 'cause-effect' relationships between various primary hazards and underlying risk factors, including secondary hazards, that increase the property's vulnerability (Figure 3-6).



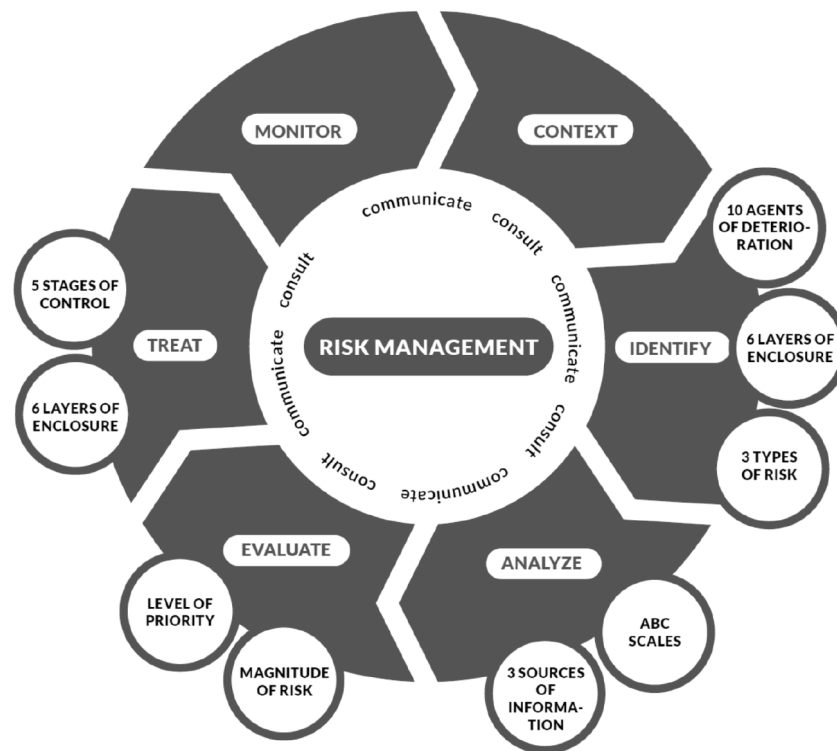
**Figure 3-6 Risk Analysis procedure (UNESCO WHC et al., 2010)**

Furthermore, the manual suggests developing disaster scenarios to predict the likely disaster situation at the property and its setting. "Scenarios are constructed on the basis of assumptions derived from information about the current and the proposed activities and projects in the area, the management systems in place, and the vulnerability of the property to various hazards that has been previously assessed" (UNESCO WHC et al., 2010, p. 27). The output of the risk evaluation will facilitate the prioritisation of risk reduction measures in the next steps.

### 3.5.4 ICCROM & CCI's approach to risk assessment and management

ICCROM and Canadian Conservation Institute (CCI) have developed a simplified DRM for cultural heritage sites and museums in 2016 to assist the responsible organisations and staff with the protection of cultural assets from multiple sudden-onset hazards and agents of gradual deterioration (Figure 3-7). The risk assessment procedure follows the general risk assessment steps of ISO 31000, and adapts it to the specific requirements of cultural heritage, as below (ICCROM and CCI, 2016, p. 15):

- Identification of risks: to find the appropriate tools, to survey the heritage asset and to make a photographic record, and to identify specific risks;
- Analysis of risks: to quantify each specific risk, to split or combine specific risks, and to review and refine the analyses; and
- Evaluation of risks: to compare risks to each other, to criteria, to expectations, to evaluate the sensitivity of prioritization to changes in the value pie, and to evaluate uncertainty, constraints, and opportunities.



**Figure 3-7 Risk management Cycle (ICROM and CCI, 2016)**

The manual further develops a risk analysis tool, which was previously introduced in the ICCROM's workshops, UNESCO's manual on disaster risk management (2010), and was applied to the Petra archaeological site in Jordan (2012). Based upon numeric scales, the so-called ABC method consists of three components: A. frequency of the damaging event or the rate of occurrence of a process; B. fraction of value lost in each affected item; and C. percentage or fraction of the heritage asset value (ICCROM & CCI, 2016). After scoring the three above-mentioned components, risk will be measured by adding the scores of the components. The level of risk priority will be further determined by using colour codes corresponding to the overall risk scores.

### 3.6 Global practices of DRA and DRM for cultural heritage

There are only few examples of cultural properties for which an integrated earthquake risk assessment have been developed. Most of the current examples have mainly concentrated on technical and structural features or the whole cycle of DRM without providing a detailed risk assessment procedure. Furthermore, the contribution of non-structural factors (e.g. the coping capacity of the management system) and heritage values to the risk assessment and risk mapping need further development.

#### 3.6.1 Risk management for the Petra archaeological park in Jordan

Petra is an archaeological site situated in Jordan, between the Red Sea and the Dead Sea and occupied since prehistoric times (UNESCO WHC's Website, 2015). The property has been inscribed on the UNESCO World Heritage List in 1985 under criteria i, iii, and iv (ibid). Petra can be considered as a WH site with almost the same typology with the case of Bam because both properties convey heritage values associated with archaeological remains and architectural monuments from prehistoric times, historic public and religious places, ingenious water management system. The property is threatened by natural hazards (e.g. earthquakes and floods) and human-induced hazards.

As mentioned earlier, the CCI-ICN & ICCROM approach has been applied to Petra World Heritage site in 2012. The procedure was based on two assessment methods of assessing and reducing risks to collections and artefacts (adapted from *Waller's Cultural Property Risk Analysis Model, 2003*) and the *Risk Management Australian/New Zealand Standard* (Standards Australia/Standards New Zealand, 2004) (Paolini et al., 2012, p. 19). In respect to the importance of risk management for heritage conservation, Paolini et al. say "the risk management methodology is an integral part of the management plan, with the aims of improving site conservation and tourism management, and strengthening the involvement of the local community".

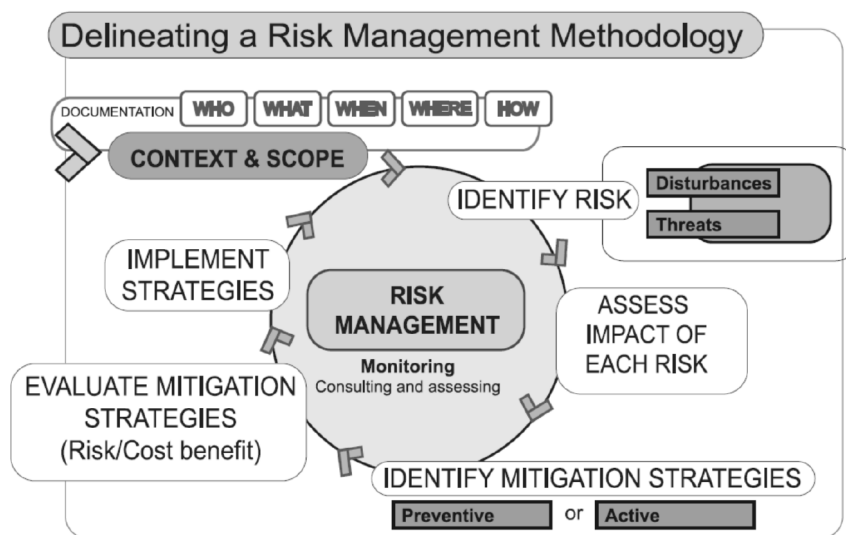


Figure 3-8 Risk management approach for Petra (Paolini et al., 2012)

Figure 3-8 shows the Petra risk management cycle and its respective components. The procedure comprises the following steps (ibid, p.18):

- Establishment of the context and scope, including the documentation review, the value assessment, and the condition assessment;
- Identification of risks;
- Assessment of the impact of each risk;

- Identification of possible mitigation strategies;
- Evaluation of risks and mitigation strategies based on cost-benefit analysis; and
- Implementation of the strategies (preventively or actively) to treat risks.

The methodology offers qualitative and quantitative approaches for the risk analysis phase. In the qualitative approach, rate of risk is measured based on the severity of impact (mild, severe, and catastrophic) and frequency and probability of the damage occurring (rare, sporadic, and continuous). Accordingly, the following three levels of risks can be determined (ibid, p.29):

- Catastrophic and rare;
- Medium and sporadic; and
- Mild and constant.

The quantitative risk assessment method proposed by CCI-ICN & ICCROM, known as the ABC method (Table 3-3), is based on measuring the following three criteria (ibid, p.30):

- Probability or extent of damage happening (A);
- Degree of loss of value and integrity as a result of the impact (B); and
- Fraction of the assessed area susceptible to the threat, and the extent of its vulnerability (C).

**Table 3-3 Calculation of the risk magnitude for Petra, using the ABC method (Paolini et al., 2012)**

Threat	Agent of deterioration	A	B	C	$\Sigma$ Risk magnitude	Magnitude of risk
2205: Road/path running through precinct	Physical forces: AG04.1: On surface. Impact human activities: AG09.5: Physical developments.	4.5	4	1.5	10	High
2404: Earthquake	Physical forces: AG04.1: On body. AG04.2: dynamic Dissociation: AG08.1: Physical dissociation. AG10: Risk for users.	1	4.5	5	10.5	High

For analysing each component, particular ranking criteria are defined. Afterwards, the magnitude of risk is calculated by summing up the components as: “A (probability) + B (loss in value) + C (fraction susceptible)” (ibid). The scores will fall into different class ranges defined in the project, and will be interpreted qualitatively and quantitatively in order to provide risk management strategies with the required information.

### 3.6.2 Disaster risk management of cultural heritage following the Great Hanshin earthquake

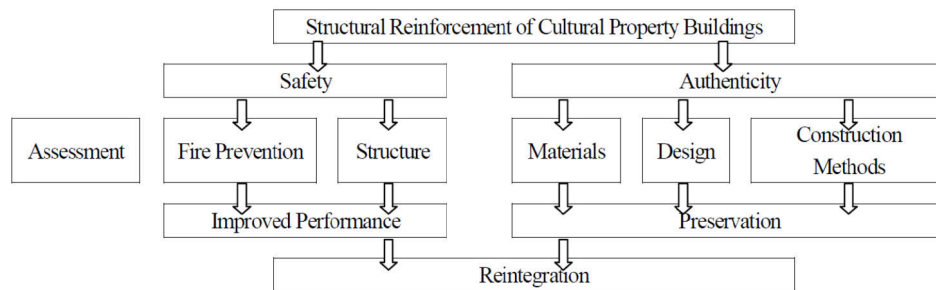
The magnitude 6.8 (USGS) Great Hanshin earthquake or Kobe earthquake occurred on January 1995 in the Hyogo prefecture in Japan, and caused a tragic loss of life and destruction of the buildings and infrastructure. Following the earthquake in 2005, *the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters (HFA)* was adopted by the governments around the world.

The earthquake caused widespread damages and the collapse of the cultural properties. In Hyogo Prefecture, 46 national cultural sites, 54 prefectural-designated cultural sites, and 43 municipally-designated cultural sites suffer severe damages (Murakami, 2006). In the recovery process, one of the main challenges was retaining a balance between authenticities and safety. Figure 3-9 shows the overall approach to the structural reinforcement of heritage buildings following the Kobe earthquake.



In the post-earthquake recovery project of cultural heritage, the following options have been proposed, in order of priority, for the structural reinforcement (ibid, p. 17):

- Additions using traditional techniques and traditional materials (e.g. strengthening the foundation joint with a fishplate splice which is the traditional good joint system);
- Additions using traditional techniques and techniques derived from them, and traditional and modern materials (e.g. covering the traditional joint by wrapping the post with carbon fibre threads);
- Additions using modern techniques and modern materials (e.g. adding a steel frame in order to reduce the load on the existing structural materials); and
- Replacements using modern techniques and modern materials (e.g. adding reinforcement to the existing structural system, could involve the introduction of something like anti-vibration apparatus as a replacement for part of the existing structural system).



**Figure 3-9 Overall approach to the structural reinforcement of cultural properties after the Kobe earthquake (Murakami, 2006)**

Following the establishment of the theoretical options, a condition assessment was conducted for each damaged property to recognise the appropriate reinforcement option. Apart from the structural measures, considerable efforts have been devoted to building the coping capacity of the risk management system. The non-structural strategies involved the establishment of an inventory system, increasing awareness of the need for disaster prevention, developing comprehensive and systematic disaster prevention for cultural properties, and human resource development (ibid).

### 3.6.3 Risk mapping for cultural heritage in Italy

The *Risk Map of Cultural Heritage* was a project aimed to develop tools and methods for maintenance and restoration of architectural and archaeological properties and artefacts in Italy against the environmental and human-related threats. The project has been carried out by the Istituto Centrale per il Restauro (ICR). The risk mapping procedure comprises the following three major phases (Baldi et al., 1995):

**Phase 1:** “Gathering and analysing information about the environmental harshness to which cultural items are subjected”; this phase includes the following thematic maps (ibid):

- “Thematic Maps of Environmental Danger Factors”: using the computer-based Geographical Information System (GIS), three thematic maps regarding three different danger factors and their spatial distribution on the Italian territory were produced:
  - “Static-structural danger: e.g. earthquakes, hydro-geological risks, and volcanism”;
  - “Environmental air-danger: e.g. air pollution, climate, and sea aerosol”;
  - “Human danger: e.g. theft, hooliganism, and tourist pressure”;

- “Thematic Maps of Cultural Heritage”: this database involves information from a bibliographic source regarding the distribution and consistency of cultural heritage properties at the municipal level.

The above two thematic maps were overlaid in order to identify the properties which are exposed to the identified risk factors.

**Phase 2:** “A survey, on two different levels, of the condition, and therefore of real vulnerability, of cultural items”; two cataloguing activities were carried out in this phase, depending on the requirements of the project (ibid). Accordingly, for evaluating the physical condition and conservation problems, data was gathered in different formats (e.g. alphanumeric, graphics, and images) and was recorded on magnetic and optical disks. The technology of ‘Iconometric Model’ was used in the photography of the buildings in order to provide the elements with the necessary details for further actions. Furthermore, a vulnerability index was developed in order to analyse the actual condition of each property. In some cases, there was a need for a more accurate assessment of the material decay, as below (ibid):

- Studying stone materials: samples of stone materials were exposed to the air and then examined for the deposit of dust and chemical and petrographic analysis.
- Controlling environmental pollution: through a mobile survey station, data regarding dispersed particles (e.g. black smoke and nitrogen oxides) was gathered to help establish the extent of atmospheric threats.
- Controlling climate: climate data was gathered and processed to establish its influence on global environmental threats.

**Phase 3:** “A computer-based synthesis of quantitative data concerning the distribution and real vulnerability of items, and of the presence of danger factors”. In this final phase, the above-mentioned maps and information need to be combined in order to provide the items with their corresponding risk levels. In the GIS environment, the above-mentioned thematic maps, information from cataloguing, and vulnerability indices have been aggregated to generate a risk map (ibid).

## 3.7 Impacts of earthquakes on cultural heritage properties<sup>12</sup>

### 3.7.1 Conservation challenges for seismic protection of cultural properties

Past experience reveals that a number of historic constructions have survived from earthquakes although they had been supposed to be totally destroyed based on the current structural engineering knowledge (Ferrigni, 2005; Langenbach, 2008). In the case of Arg-e Bam in Iran, which has been partially destroyed by the 2003 earthquake, investigations (Langenbach, 2008) demonstrated that most seismic damages occurred in the restored parts of the citadel, while those parts that had not been repaired for a long time remained almost intact. Importantly, the original part of the property played a key role in verifying the authenticity of Bam and its Cultural Landscape during its WH inscription process.

Improper intervention without understanding the behaviour of original structures, whether in the pre- or post-disaster phase, apart from posing risks to the values and authenticity, may increase

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<sup>12</sup> This section is based on two papers published by the author (Ravankhah, Schmidt, and Will, 2017a; Ravankhah and Schmidt, 2016)

susceptibility to future earthquakes. Regarding the interventions to the historic structures, Feilden and Jokilehto (1998, p. 68) state that

“The aim of treatment is to prolong the lifespan of original materials and structures, to keep them in their original position in the construction and on the site (in situ), (...). It can be acceptable within the limits of potential unity if it is vital for the survival of the remaining original structure”.

Historic masonry buildings demonstrate different seismic behaviour in comparison to modern constructions. Lagomarsino (2008, p. 135) indicates the low tensile strength of masonry and states that “(...) masonry buildings were proportioned to bear vertical loads and the static horizontal thrusts of arches and vaults”. A masonry construction may survive a few seismic shocks of high intensity; however, the vibration of long duration will cause cracks that divide the structure to some parts with different dynamic characteristics leading to widespread damages (Feilden, 1987).

In respect to the susceptibility of earthen constructions, Tolles et al. (1996) state that because adobe is a low-strength material, during an earthquake, the stress in the adobe material may easily exceed its tensile strength and cracks or collapse will occur. Some scholars (e.g. Houben and Guillaud, 2008, p. 73) believe that “many practitioners of systematic stabilisation do not know, or do not appreciate the original characteristics of soil, and start about stabilising soil with undue haste when it is not particularly useful”. On the other hand, “a survey of historic adobe buildings damaged in the 1994 Northridge earthquake showed that retrofitted adobe buildings performed significantly better than those that had not been upgraded” (Tolles et al. 2002, p. xii). Such statements and evidence may seem to contradict each other. However, understanding of the traditional construction, the stabilisation methods, and the materials used for structural reinforcement play a significant role in the effectiveness of the structural seismic performance.

Stabilisation and retrofitting measures may pose additional impacts on structural integrity and heritage values. Regarding the issue, Tolles, Kimbro, and Ginell (2002, p. 73) point out three major alternatives: “minimum levels of intervention, moderate levels of security and intervention, and high levels of security and damage control”. These options can be applied according to the nature of an earthquake and the structural and architectural characteristics of earthen monuments in a particular place. However, the challenge still remains: to what extent it is acceptable to make intervention while considering not only the potential hazard-dependent damages, but also those risks that may be imposed to the current status of a property through human activities.

Structural reinforcement and retrofitting might be challenging when it comes to improving the seismic performance of historic buildings. Retrofitting entails “reinforcement or upgrading of existing structures to become more resistant and resilient to the damaging effects of hazards” (UNISDR, 2009). “Retrofitting of historic structures can be highly intrusive because of the risk of removing character-defining design elements, or having them obscured with incompatible modern materials” (FEMA, 2005, p. 3-10).

It is important to understand the adobe structures and earthen construction techniques with respect to its history and environment to evaluate various risks which may occur during seismic events. This first principle of conservation is somehow the basis of two other principles: ‘minimal intervention’ and ‘reversibility’ (Tolles et al. 2002), to prevent intervention-related risks to earthen architectures during seismic events. In an address to an international conference devoted to seismic strengthening of cultural monuments, Jokilehto states that “the principle [of historic architecture conservation] is to define the architectural typology of the buildings, to define the historical parameters in deciding what is the substance that conserves the historic value of the fabric, and where changes can be proposed” (cited in Tolles et al. 2002, p. xii).

Comparing traditional and modern conservation methods, Will and Meier (2008, p. 10) point out two opposing retrofitting attitudes in heritage conservation philosophy. They emphasise that traditional methods tend to “plan more limited protective measures for buildings whose vulnerability is evident than for those whose builders quite obviously had in mind for them to withstand great dangers”, while “with its emphasis on cultural heritage as historical documents take the opposite course and award special protection precisely to these vulnerable works (...)”. Ferrigni (2005, p. 185), reconsidering the conventional wisdom of traditional methods, suggests that “if occupants can be safely evacuated, a lesser degree of strengthening allowing limited damage should be permissible and is preferable from the conservation point of view”. In fact, heritage conservation principles play a vital role in formulating adequate disaster mitigation strategies to keep a balance between structural stability and heritage values. In a more holistic view, Worthing and Bond (2008, p. 95) indicate that “minimum intervention does not just refer to the fabric, it refers to all actions in the place, including additions, new buildings and changes in use (...) to ensure that any changes protect and enhance cultural significance”.

Extreme concentration on technical reinforcement rather than promoting disaster resilience of cultural heritage and its setting has raised another serious concern for safeguarding heritage. In the context of World Heritage, disaster resilience might be perceived as the capacity to retain the OUV, as well as the authenticity and integrity of the key components conveying the OUV. Most current seismic-retrofitting measures predominantly focus on technical and standardized solutions to enhance structural strength to potential quakes. Admittedly, adequate risk treatment of historic constructions requires additional indicators beyond merely structural parameters. Worthing and Bond (2008, p. 181) emphasise the role of values in DRM and states that “in order for risk management to be translated into a useful management tool for the maintenance of historic buildings, the development and use of assessments of cultural significance through a conservation management plan becomes critical”. The following section explores the disaster risk identification framework for cultural heritage and its setting that needs to be framed in a holistic approach to multiple risks.

### **3.7.2 An integrated approach to earthquake impact identification**

The complexity of an emergency during and after an earthquake, due to the potential consequential hazards and threats, underscores the need for an integrated view to impact identification. Such a multi-hazard context may comprise diverse individual hazards with different characteristics in a region and/or one specific hazard that may trigger other hazards and threats. In other words, concentrating on ‘disaster’ resulting from an earthquake rather than only on the quake itself will provide a more integrated impact identification framework.

“Disasters are systems problems – a failure in one sector often has cascading repercussions in other sectors; the extent to which the system can respond to and recover from a disaster is dependent on technical, societal, economic, and governmental strengths and vulnerabilities” (Petak and Tubbesing, 2008, p. 1). A system-based approach to disasters stresses a need for an interdisciplinary analysis of disasters from earthquakes (e.g. in the field of structural engineering, disaster management, heritage conservation, and urban planning) in a multiple risk context. Such an integrated view, by stressing ‘earthquake disaster risk’ instead of ‘earthquake risk’ aims to illuminate the significance of secondary hazards, potential human-induced hazards and human errors in the impact identification process, due to the fact that while a disaster may begin with an earthquake, its full scope is triggered by a combination of all the above-mentioned threats.

UNESCO WHC et al. (2010, p. 26) emphasises analysing the “cause-effect” relations between primary hazards and secondary threats, and suggest preparing a disaster scenario that should be “(...) as narratives as progressive sequences of events affecting each other, thereby unfolding a particular

situation”. In regard to different types of potential impacts, Schmidt et al. (2010, p. 98) emphasises that the “adequate assessment methods can be directly linked to crosses made in a significance assessment matrix; and therefore, criteria for the selection of adequate methods depend on the significance and nature of impacts, such as qualitative assessment for categories of non-tangible impacts”. An example of the impact identification and analysis matrix for cultural heritage have been prepared by Schmidt and Rudolff (2014) to assess the climate change impacts in the Republic of Macedonia.

In the impact identification process in this research, potential natural hazards and human-induced threats following earthquakes are considered to be addressed in the risk treatment strategies. Accordingly, the following sections explore the three categories of potential impacts on cultural heritage properties, as below:

- Potential direct impacts of earthquakes on cultural heritage properties;
- Potential indirect impacts on cultural heritage properties by secondary hazards following earthquakes; and
- Potential indirect impacts on cultural heritage properties by human-induced threats following earthquakes.

### **3.7.3 Potential direct impacts of earthquakes**

The most destructive primary effects of earthquakes are associated with ground shaking, surface faulting, and soil failures. Direct seismic damages, apart from the characteristics of earthquakes (e.g. its magnitude, epicentre distance, and local ground condition), rely heavily on the susceptibility of historic fabric and its settings. Below, potential direct impacts of earthquakes on cultural heritage sites are outlined.

#### **3.7.3.1 Loss of fabric, collections, and archives**

Lateral forces of earthquakes may extremely damage un-reinforced masonry buildings, especially the foundations and the weak points such as roofs, doors, and windows. Technically, the structural susceptibility of historic constructions can be influenced by the quality of masonry, compatibility of materials, type of construction, and architectural shape. Vatandoust et al. (2008a, p. 314), in respect to the massive impact of the 2003 earthquake on the adobe architecture of Arg-e Bam in Iran, recognise significant factors that increased the seismic susceptibility of the property. Some factors include improper former interventions within the citadel resulting in changes to the original plans, termite attacks to adobe materials, and seasonal winds and sandstorms. Inappropriate pre-disaster interventions (e.g. incompatibility between primary and added materials) may result in reducing the seismic performance of the whole construction.

In contrast to the case of Bam, historic buildings in the central city of Christchurch survived the 2010 earthquake of magnitude 7.1 with minor damages, mainly due to appropriate seismic reinforcements over the last three decades (Riddett, 2010, p. 42). Renovation of 55 Window Palace in Bhaktapur Durbar in Kathmandu before the M7.8 Nepal Earthquake in April 2015 is another good practice not only because of enhancement in its seismic performance, but for applying traditional techniques to maintain its authenticity (Maskey, 2015, p. 288). Following an accurate structural assessment of the palace, the renovation was carried out based on traditional seismic strengthening details using brick masonry, timber ties, and stone (ibid). The 55 Window Palace survived the earthquake with only minor damage (Lizundia et al., 2016). The above examples highlight the role of adequate conservation approaches and structural interventions in enhancing the seismic capacity of heritage properties.

Apart from structural components, movable cultural heritage such as collections, furniture and archives, which are conveying significant socio-cultural values associated with communities, are exposed to seismic risks. Movable objects, especially those lacking appropriate fixing techniques, might fall down or be seriously damaged by other falling installations and objects. Sungay et al. (2004) regarding the seismic vulnerability of museums in Istanbul, for instance, mention some potential earthquake impacts to collections including damage by broken glass such as showcases, dropping of free-standing objects such as humidity controllers and air conditions, and falling ceiling parts or decorative elements that might hit the valuable objects. Since collections and furniture might be seriously damaged by collapsed structural and non-structural elements as well, potential impacts should be identified through a more detailed cause-effect relationship.

Documents including architectural, structural, and historical surveys, detailed architectural drawings, audio and video records, apart from being part of the heritage, play a key role in the truthfulness of post-disaster treatment. Venice Charter (ICOMOS, 1964, Article 9) emphasises the importance of authentic documents in the recovery of values and indicates that “the process of restoration is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is based on respect for the original material and authentic documents (...)”. Documents and records are crucial for damage assessment and restoration activities in order to prevent possible additional risks to cultural values. However, documents might be seriously damaged by secondary hazards of fires and flooding in the emergency phase, rather than by the earthquake itself. Hence, they should be kept in a safe place far from the disaster-prone boundary, as Feilden (1987, p. 72) says “storage in a bank vault is not good enough-if the bank is in the same disaster-prone area as the institution”.

### **3.7.3.2 Loss of the OUV, authenticity, and integrity**

Natural hazards may threaten heritage values associated with tangible as well as intangible attributes, such as construction technique, building typologies, and traditional knowledge. Values of a site may not simply be reversible via physical restoration or reconstruction. According to the Burra Charter (Australia ICOMOS, 2013, Article 1) “cultural significance is embodied in the place itself, its fabric, setting, use, associations, meanings, records, related places and related objects” that have evolved in the particular socio-cultural circumstances of a site’s history. Despite this, “because of the difficulty of putting a value on the non-market nature of many cultural heritage objects or because of the absence of a replacement price for them, important historic buildings, characterised by their uniqueness and often by the vulnerability of their materials, are ranked in terms of their insurance damage assessment beneath mere material property such as industrial complexes or consumer goods” (Will, 2012).

In the context of World Heritage, seismic damage to those attributes conveying the OUV may lead to a considerable loss in its universal significance and authenticity. The Operational Guidelines (UNESCO WHC, 2017, para. 80) in respect to ‘authenticity’ indicates that “the ability to understand the value attributed to the heritage depends on the degree to which information sources about this value may be understood as credible or truthful”. Although earthquakes may largely affect the qualifying condition of originality, the adequate degree of authenticity relies essentially on the extent to which key attributes of a heritage site are considered sufficient to pass on the OUV. In this regard, Stovel (2007, p. 30) states that “authenticity is not an absolute qualifier (...). Authenticity is a relative concept, and must always be used in relation to the ability of particular attributes to express clearly the nature of key recognized values”. In the case of Arg-e Bam, even though the earthquake caused massive destruction, the property passed the test of authenticity because the original parts of the citadel that survived with minimal damage have been representing its universal values.

Properties nominated to the World Heritage List, according to UNESCO WHC (2017, para. 87), should also meet the conditions of integrity. The term ‘Integrity’ is defined as “a measure of the wholeness and intactness of the natural and/or cultural heritage and its attributes” (ibid, para. 88). Since verification of integrity depends on the presence of the key elements carrying the OUV, seismic damages to each component might be considered as a serious loss of integrity, particularly in case of cultural landscapes and urban settlements.

### **3.7.4 Potential indirect impacts of subsequent hazards following earthquakes**

Installations and infrastructures damaged by quakes, whether within the core zone or buffer zone of a site, can cause disastrous secondary hazards that might be more destructive than the primary hazard. Seismic damages to lifeline networks (e.g. roads, drainage systems, water supply, gas and electricity lines, and other installations) may lead to additional risks to already affected but survived structures and collections. For instance, damage to water and power lines may result in secondary hazards of floods and fires, respectively. Stovel (1998, p. 57) points out that damage to property alarm, early warning and communication systems may result in slowing effective response and coordination among engaged agencies. Similarly, blocked roads by collapsed fragments in the buffer zone may weaken the efficiency of emergency response in the core zone of a property. Below, the most typical quake-induced secondary hazards and their corresponding impacts are discussed.

#### **3.7.4.1 Fires and explosions**

Following earthquakes, broken power or gas lines, electrical equipment and installations, or laboratories’ material and chemicals might induce explosions and fires. It takes a fire to entirely destroy valuable collections, libraries, and archival documents that have survived from seismic activities. Lack of appropriate fire precautionary measures, especially in the case of the timber structures and organic materials, can lead to a serious loss of heritage values in design, material, and techniques. Moreover, fire-induced high temperature and smoke can reduce structural performance and damage archival records. Apart from the fire itself, Feilden (1987, p. 56) points out the activation of water sprinkler systems due to fire that results in additional impacts to art collections.

#### **3.7.4.2 Flooding and rising groundwater**

It is very likely that quakes are followed by water-related risks through damaging water pipes, drainage systems, fire suppression systems, and hydro-electric installations. Furthermore, the failure of hydrological infrastructures, such as dams and levees, as a result of seismic activities surrounding a heritage site may cause large-scale flooding. Dampness from flooding may damage porous historic materials and collections that might be already cracked or broken by earthquakes; and post-flooding drying may cause the growth of micro-organisms such as fungi. Moisture further may cause additional damages, such as “(...) dissolution of finishes, paints and surfaces; erosion of masonry mortars and deposition of waterborne impurities in the pores of masonry units; warping, splitting and cracking of wood and organic materials, and increased susceptibility to rot” (Stovel, 1998, p. 74). Rising groundwater is another quake-induced threat, which changes soil pH. It is worth mentioning that “archaeological evidence is preserved in the ground because it has reached a balance with the hydrological, chemical and biological processes of the soil” (Colette, 2007, p. 23). Consequently, archaeological objects might be irreversibly deteriorated by dampness and soil pH changes following the seismic events.

### **3.7.4.3 Meteorological threats**

Diurnal and seasonal weather events, such as intense rainfall, snow, wind-driven rain and sandstorm, following an earthquake may cause cumulative impacts on remaining structures and interior collections. In particular, those buildings that have already lost their ceilings or suffer from the improper drainage system might be more at risk. For instance, the rise of moisture into mud structures as a result of rising groundwater level or rainfall can weaken additionally strength of affected buildings and make them more vulnerable to potential aftershocks or future earthquakes. Such a situation may result in increasing biological attack of insects, fungi, moulds, as well as the growth of vegetation on masonry structures and organic materials. According to the *Heritage@Risk* report 2000 (ICOMOS, pp. 115–121), following the 2009 earthquake in L’Aquila in Italy, “salt crystallisation as the result of damp walls, vegetation that is not removed and thus breaks up the walls, as well as microbiological infestation from algae, fungi and lichen” were reported as secondary agents of risks associated with the quakes. In a quake-affected museum that partially lost its windows and roofs, collections (e.g. textiles, paintings, and sculptures) might be exposed to methodological hazards, including temperature and humidity changes. In such a situation, immediate salvage and stabilisation measures should be determined within a multiple risk context while considering the climate and biological parameters of the region.

## **3.7.5 Potential indirect impacts of human-induced threats following earthquakes**

### **3.7.5.1 Potential human-induced hazards and threats**

A number of human-associated threats might threaten heritage properties after a disaster, depending on the socio-political circumstance of a region and its coping capacity to respond to disasters. Affected historic sites may consist of valuable damaged fragments and movable objects that are exposed to serious threats such as theft and illicit trafficking. Furthermore, sensitive political and religious documents and records of institutions in historic buildings might be at risk of looting; this may also lead to additional structural damages. Hazardous supplies containing explosive, pollutant, and poisonous materials in the setting of a site are sources of further risks, particularly intentional explosions. Additionally, disrupted communication networks, massive traffic, and high density of buildings and populations surrounding WH sites in urban areas may cause additional safety and security issues.

### **3.7.5.2 Potential response-related threats**

During the emergency phase, which generally takes 72 hours following the earthquake hazard, new risks might emerge due to a lack of appropriate coordination between heritage organisations and emergency departments. Emergency teams and volunteers, if not familiar with heritage conservation, may cause additional risks to cultural significance of remaining materials. During fire control, objects and artefacts that have withstood the quake might be exposed to water or dry chemicals used in fire extinguishers. Even activities by staff or experts may cause additional serious impacts to the OUV-conveying elements during damage assessment.

Earthquakes may reveal primary and original materials, ruin archaeological objects, and traditional construction techniques. Distinguishing newly emerged historical levels and valuable materials from debris is a highly specialised task to avoid potential threats to the added-value attributes. It is crucial, therefore, to raise awareness of municipalities, emergency response services and volunteers about specific requirements of cultural heritage. Movable cultural heritage needs special considerations during damage assessment, salvage and triage, and displacement process to avoid additional risks. The stabilisation of movable objects is a very sensitive work including “surface cleaning, rinsing,



and controlled drying or making customized supports” and therefore “treatments should be carefully recorded and condition of the object before and after the treatment should be documented” (ICCROM and Smithsonian Institution, 2016, p. 9).

### 3.7.5.3 Potential recovery-related threats

During post-disaster restoration and reconstruction, additional impacts related to improper interventions, illegal constructions, and land-use changes may occur. Introducing modern materials or applying new seismic-retrofitting methods to historic structures are common challenges to the heritage values and authenticity when it comes to structural reinforcement. The test of authenticity becomes even more complicated when traces of a disaster needs to be truthfully visible in the lifespan of the property. In this regard, Thomson (2008, p. 7) categorises authenticity of post-disaster reconstruction into three major categories: “authenticity of connection” to represent the pre-disaster socio-cultural and environmental continuity; “authenticity of renewal” in terms of new construction; and “authenticity of experience” to reflect damage induced by hazards and express a traumatic episode. Even though the mentioned challenge was not directly caused by quakes, disaster contains such consequential risks mainly with respect to retaining heritage values that may last a long time following the hazard.

When it comes to cultural landscapes and urban heritage, pressure of unauthorised developments and land use changes within a heritage site or its setting may threaten the site during the recovery process. Modern materials and architectural styles may threaten townscape, craftsmanship, and lifestyle of the societies who are seeking more seismic-resistant settlements. The impact of post-disaster constructions on the visual integrity of historic sites is another example of new emerging risks. Although post-disaster change is essential and inevitable, it should be run in a sustainable way with minimal impact on cultural values. In a holistic view, Stovel (2004, p. 26) believes that “preparedness planning in historic settlements and towns needs to reflect the different legal, social and economic contexts (...) and particular ownership and responsibility patterns, traditions and mechanisms which are already in place”.

Admittedly, reconstruction is not only addressing the physical aspects but also reviving socio-cultural and economic values that have evolved based on the inhabitants’ needs during the history of a settlement. Jigyasu (2001, p. 2) states that “most of the existing practices for earthquake mitigation and planning are rather shaped by ‘techno-centric’ and externally operated ‘instrumental’ paradigm based on objectivist, positivist, determinist and reductionist assumptions of logical empiricism”. Similarly, Oliver-Smith (2006, p. 23) criticises those disaster housing and settlement designs which “endanger the connection that people have with their built environment, violating cultural norms of space and place, inhibiting the re-weaving of social networks and delaying or stopping the re-emergence of community identity”. Cultural properties and associated communities are socio-culturally and economically interdependent; there might be a large loss of living heritage if such correlations are neglected or underestimated during the rehabilitation and recovery process.

Replacement versus reconstruction on the original site is another major dilemma in the post-disaster recovery (Aysan and Davis, 1993). For several reasons, such as economic opportunities, cultural traditions, and specific lifestyles associated with the geographical conditions, communities may not intend to move even to a safer place. In fact, “the benefits of the original site may outweigh the risks; Cultural, symbolic and historical value of the damaged site to the nation or the inhabitants cannot be easily transferable to a new site” (Aysan and Davis, 1993, p. 38). Rejection of relocation of quake-affected villages in Dhamar, Yemen, in 1982 by local communities is an example of such a failed replacement project in which cultural, economic, and environmental dimensions were neglected in so-called “contractor built reconstruction” of the new site (Barakat, 1993). The consequential socio-

cultural risk of natural hazards, particularly associated with intangible heritage, needs to be adequately integrated into the DRM strategies in historic areas.

### 3.8 Summary

A review of the current conceptual and analytical frameworks and procedures of the risk assessment and management in general (e.g. ISO 31000, 2009; AEMC, 2010; Birkmann and Welle, 2015) and those specific to cultural heritage (e.g. Stovel, 1998; FEMA, 2005; UNESCO WHC et al., 2010; and ICROM and CCI, 2016) demonstrates that cultural heritage still suffers from the lack of the integrated and event-specific risk assessment methodologies. Furthermore, an analysis of some relevant concrete cases affected by natural hazards (e.g. Paolini et al., 2012; Baldi et al., 1995) has been carried out. Most of the current methodologies for cultural heritage have mainly concentrated on technical and structural features or the whole cycle of DRM without providing a detailed risk assessment procedure. Furthermore, the contribution of the non-structural factors (e.g. the coping capacity of the management system) and heritage values to the risk assessment and risk mapping need to be adequately taken into account.

Through an extensive review of the literature and past earthquake examples, an integrated framework for disaster impact identification has been proposed. The framework does not only focus on the primary hazard of the earthquake, but it addresses the secondary natural hazards and human-induced threats which may occur following an earthquake. Overall, this chapter provides *Chapter 4-Methodology* with a theoretical background to develop a risk assessment methodology for cultural heritage, and in particular for the study area.

# **CHAPTER 4**

## **METHODOLOGY**

## 4.1 Introduction

This chapter describes the overall methodological framework of the research. Firstly, the research methodology selected for data collection and analysis in the study area is discussed. Activities undertaken regarding the primary data collection, including site observation and expert interview, are explained in detail; and then, different methods and tools that will be applied to the analyses of data are outlined.

In the second part, this chapter develops a risk assessment methodology for cultural heritage, in particular for the case of Bam and its Cultural Landscape. The current approaches and methods that have been reviewed in *Chapter 3-Literature Review* are considered in the development of the risk assessment methodology. Furthermore, this chapter elaborates how the selected data collection and analysis methods will be applied in the different steps of the proposed risk assessment procedure. The procedure of deriving indicators in the risk assessment is outlined while considering the existing theoretical and conceptual frameworks regarding the analysis of risk and its components.

## 4.2 Overall methodological approach of research

Different scientific disciplines may apply different methodological approaches in response to their own theoretical and empirical research requirements. However, when it comes to interdisciplinary research, a specific methodological standard of a particular discipline may not fulfil the complex nature of a research problem. To address the statement of the problem and to fulfil the sub-objectives of this thesis, an interdisciplinary approach needs to be considered within its overall methodological framework. Such an approach can incorporate the risk assessment standards and approaches into the methodologies while addressing the principles and qualitative aspects of heritage conservation.

Hence, constructing a methodological procedure for risk assessment applied to the case of Bam should address the interdisciplinary nature of the thesis. Accordingly, the overall methodological approach of the research is a triangulation of qualitative and semi-quantitative methods in the data collection and analysis process in order to promote the quality of the measurements and results. The semi-quantitative methodology has been increasingly applied in the area of natural hazards and risk management, such as in *Realising European ReSILience for Critical InfraStructure* project (RESILENS, 2016), using the numerical ranking scales to evaluate parameters corresponding to the coping capacity of a system.

“Triangulation as a keyword is used to name the combination of different methods, study groups, local and temporal settings, and different theoretical perspectives in dealing with a phenomenon” (Flick, 2009, p. 444). According to Denzin (1989), a methodological triangulation can be carried out by applying additional methods, such as two qualitative methods and/or by adding a quantitative method. Below, the complementary methods that have been applied for gathering and analysing data are provided.

### 4.2.1 Primary data collection

This step includes collecting data at the case of Bam and its Cultural Landscape to find about what happened during and after earthquake 2003 in Bam and also the current situation of Bam concerning risk preparedness measures for potential earthquakes. In this phase, the following methods will be applied:

#### 4.2.1.1 Fieldwork via site observation

In addition to the identification of the elements of the property, the site observation has been conducted in order to provide the structural susceptibility assessment with the required data. A qualitative structural susceptibility assessment “(...) is based on accurate on site observation of a number of parameters that are known to qualify the seismic performance of historic masonry buildings, leading to an expert judgment of the expected building vulnerability” (D’Ayala et al., 2008).

Accordingly, in-situ photography of the heritage properties within the core zone of Bam and its Cultural Landscape was done to purposively grasp their particular attributes. This condition assessment of the property included the structural elements and building materials, construction techniques, current damages and deterioration patterns, as well as the post-earthquake stabilisation and restoration measures. It has been followed by the office activities to sort the data and prepare the useful fieldwork information to be integrated into the different steps of the risk assessment, particularly the vulnerability assessment. The data were also cross-checked with the information extracted from the document analysis.

#### 4.2.1.2 Expert interview via a structured questionnaire

In a structured interview, interviewees are asked a list of particular questions designed according to the information required in the process of fulfilling the research objectives. For instance, the data required for conducting the coping capacity analysis in this research was mainly provided by specialists and organisations engaged in the conservation, post-disaster recovery, and management of Bam and its Cultural Landscape. “The goal of the structured interview is for the interviewing of respondents to be standardised so that differences between interviews in any research project are minimized” (Bryman, 2008, p. 192).

Depending on the nature of a research project, various target groups might be selected for the structured interview. Flick (2009) emphasises that the experts are integrated into the investigation not as a single case but as representing a group. In this research, the target groups include specialists with the required knowledge and experience in the case of Bam, and staff members of the cultural heritage organisation in charge of the management of the property. As Table 4-1 shows, the experts are selected from different disciplines engaged in the risk management of the case of Bam in order to address the diverse angles of the study.

**Table 4-1 The list of national and international experts who were interviewed**

Experts	Affiliation
Dr. Masoud Ghamari	Research and technical centre of World Heritage site of Bam and its Cultural Landscape; Iranian Cultural Heritage, Handicrafts and Tourism Organization (ICHHTO)
Dr. Sorna Khakzad	Cultural heritage specialist; Former chief architect and landscape designer at Bam Recovery Project
Dr. Shirin Shad	Civil Engineer and Heritage Designer in the conservation/recovery of Bam and its cultural landscape
Dr. Farnaz Arefian	Director of a private sector consultancy company and project director for post-disaster housing reconstruction programme, and post-disaster urban design project in Bam & Baravat
Prof. Randolph Langenbach	International Consultant & Assist. Professor (Emeritus) and Retired Disaster Recovery Expert; former consultant to FEMA and UNESCO; worked on damage assessment of Arg-e Bam after the earthquake

Expert interviews may also encounter some problems, such as identifying the right specialists, difficulty to convince them to give an interview, and the problem of confidentiality regarding some issues in the organisations (ibid). This research experienced somehow the mentioned difficulties; however, because of the familiarity of the author with the target groups and his previous experience at the site, appropriate experts representing different disciplines or organisations engaged in the management of the property have been identified. Flick (2009, p.169) also believes that “the exclusive focus on the knowledge of a specific target group may be too narrow”. Thus, this research does not rely only on the survey, but also on other complementary methods such as observation and document/report analysis in order to improve the credibility and confirmability of the research.

The expert questionnaire aimed at gathering data about multiple impacts of Bam earthquake 2003 on the elements of Bam and its Cultural Landscape as well as the status of the risk assessment and management of the property before and after the earthquake. The questions correspond to the criteria or indicators derived in the risk assessment methodology while considering the theoretical framework and cases study. The structured questionnaire provides the author with standardised responses to facilitate the data analysis process. The questionnaire is divided into the following three main sections (please see Appendix 1 for more information):

**Part 1. Bam and its Cultural Landscape before the Bam earthquake 2003:** this part explored the pre-earthquake status of the property with respect to the following aspects:

- Attributes of Bam included in the conservation plan of Arg-e Bam before the earthquake 2003; and
- Status of disaster risk management in the pre-disaster conservation of the property.

**Part 2. Impact of the Earthquake 2003 on Bam and Its Cultural landscape:** this part supported the hazard assessment and susceptibility analysis through obtaining data regarding the following issues:

- Potential secondary hazards and environmental factors after the 2003 earthquake;
- Possible human-induced threats following the earthquake 2003 to the property;
- Overall impact of the earthquake 2003 to different attributes of Bam and its Cultural Landscape; and
- Overall impact on the OUV and on the condition of authenticity and integrity of the property.

**Part 3. Recovery project of Bam and its Cultural Landscape after the earthquake 2003:** this part provides data for analysing the existing risk management system and evaluating the coping capacity of the property and its management system to future earthquakes as below:

- Tangible and intangible attributes of the property included in the post-disaster recovery;
- Consideration of the structural and non-structural risk reduction measures in the post-disaster conservation and management;
- Consideration of the authenticity and integrity in the damage assessment and recovery project; and
- Existing risk mitigation and preparedness plan and/or measures against future earthquakes.

Table 4-2 presents the qualitative and semi-quantitative rating scales used in the different question categories of the questionnaire. According to the table, five rating scales from 1 to 5 were used as semi-quantitative values in the questions. Besides, qualitative scales were defined for different categories of questions. For example ‘impact level’ in questions 5 and 6; ‘level of relevance/consideration’ in questions 3 and 7; and ‘quality level of plan/measures’ in questions 11 and 12 (please see Appendix 1). The data extracted from the questionnaire together with the data

coming from the fieldwork and secondary sources provide the research with the information required to identify and analyse disaster risks of potential earthquakes to the property.

**Table 4-2 Ranking Scale used in the expert questionnaire**

Qualitative rating scales			Semi-quantitative rating scales
Impact level	Level of relevance/consideration	Quality level of plan/measures	
Catastrophic	Very high	Very well-developed	5
Major	High	Well-developed	4
Moderate	Medium	Acceptable	3
Minor	Low	Poorly-developed	2
Insignificant	Not relevant/considered	Nothing exists	1
No data is provided by the responders (N/D)			
The data provided by the responder is not applicable to the scope of the question (N/A)			

#### 4.2.2 Secondary data collection

A review of the existing documents has been also conducted to obtain information on the history of the elements of the property, past earthquake events, the pre and post-earthquake interventions, and the status of the existing management system. Apart from providing some phases of the risk assessment process for which no data was available, the secondary data helped cross-check the responses coming from the questionnaire survey.

The sources from which the information was obtained include the scientific literature and papers regarding the pre and post-earthquake condition of Bam, official records of the Bam recovery process, and visual materials. In the section of vulnerability assessment, for instance, the *Annual Report of Arg-e Bam Research Foundation* (ICHHTO, 2008b) and the *Comprehensive Management Plan for Bam and its Cultural landscape 2008-2017* (ICHHTO, 2008a) were used for the analysis of the corresponding indicators.

#### 4.2.3 Data analysis methods

According to ISO 31010 (2009, p. 13), risk analysis methods can be generally classified into qualitative, semi-quantitative, and quantitative methods, depending on “the particular application, the availability of reliable data and the decision-making needs of the organization” as below:

- Qualitative methods that define consequence, probability and level of risk by significance levels such as “high”, “medium” and “low”, may combine consequence and probability, and evaluates the resultant level of risk against qualitative criteria.
- Semi-quantitative methods that use numerical rating scales for consequence and probability and combine them to produce a level of risk using a formula. Scales may be linear or logarithmic, or have some other relationship; formulae used can also vary.
- Quantitative methods that estimate practical values for consequences and their probabilities, and produces values of the level of risk in specific units defined when developing the context. Full quantitative analysis may not always be possible or desirable due to insufficient information about the system or activity being analysed, lack of data, influence of human factors, etc. or because the effort of quantitative analysis is not warranted or required.

As mentioned before, a semi-quantitative method will be applied to the data analysis in order to make the calculation process more reliable. However, qualitative ranking scales are also used to make the results more understandable for a wide range of potential stakeholders. According to the Australian Government Resources (2017), “semi-quantitative approaches to risk assessment are currently widely used in an effort to overcome some of the shortcomings associated with qualitative approaches (...) [because they] are intended to provide a more detailed prioritisation of risks than the outcome of qualitative risk assessments (...)”. “Semi-quantitative risk analysis seeks to categorise risks by comparative scores rather than by explicit probability and financial or other measurable consequences. It is thus more rigorous than a purely qualitative approach but falls short of a full comprehensive” (Poljanšek et al., 2017, p. 49).

In different steps of the risk assessment procedure in the case of Bam, particular data analysis methods have been applied as below:

- Significance assessment matrix to analyse the significance of the heritage elements;
- Indicator-based vulnerability assessment index;
- Risk index for calculating the level of risks to the heritage elements;
- Risk map based on the aggregation of the risk components in ArcGIS; and
- ALARP (As Low As Reasonably Practicable) principle for evaluating the risks.

An overall methodological framework of the research is presented in *Section 4.3* (Figure 4-1), which demonstrates the data collection and analysis methods applied to the different steps of the risk assessment procedure.

### **4.3 Developing a methodology of earthquake disaster risk assessment**

This section develops a systematic methodology of earthquake risk assessment specific to WCH sites while considering the existing approaches and methods reviewed in *Chapter 3-Literature review*. Flick (2009, p.134) emphasise that “the target of conducting case studies is not only the precise description or to make statements regarding the concrete case, but because it is a typical or particularly instructive example of similar cases with the same problem”. Although the overall proposed procedure could be applied to different typologies of cultural heritage, the indicators defined in each step may vary based on the specific characteristics of heritage properties and their geographical settings. For the purpose of practicality and applicability, particular characteristics of the earthen constructions and Bam Citadel have been taken into account for deriving the indicators in the assessment procedure.

According to ISO 31000 (2009, p.11), “Risk assessment is the overall process of risk identification, risk analysis and risk evaluation”. Looking at the risk assessment methods explained in *Section 3.4-Current approaches and methods of risk assessment*, this research applies the risk index method within the overall semi-quantitative approach of the research. “Risk indices are essentially a qualitative approach to ranking and comparing risks. While numbers are used, this is simply to allow for manipulation” (ISO 31010, 2009, p. 81). Thus, risk indices are considered as a semi-quantitative measure of risk using a scoring approach to categorise risk (ibid).

According to ISO 31010 (2009), the strengths of this method is to allow multiple components and factors that may influence the risk level to be integrated into a numerical scoring system. This advantage gives flexibility to the interdisciplinary nature of this thesis dealing with factors associated with earthquake hazard and cultural heritage. Hence, it provides a practical instrument to measure and categorise different risks to heritage assets in a cultural heritage site. In comparison to the consequence-probability matrix methods, risk indices allow for the contribution of more components which may affect the risk level. Furthermore, risk indices provide a detailed analysis of the risk



components and their aggregation that reduces the ambiguity of rapid ranking of risk in the qualitative risk matrices.

However, the risk index method has few limitations that need to be addressed within the assessment process. According to ISO 31010 (2009), because the result of the process is a numerical value, it might be misinterpreted or misused. Applying the ALARP principle in the risk evaluation is an appropriate strategy for adequate interpretation of risk index outputs. Another limitation is the lack of a general model to aggregate the components (ibid). This limitation can be overcome by defining a particular scaling system for the analysis of the components and specific equations for calculating vulnerability and risk levels. The author applied a risk index method to cultural heritage exposed to multiple hazards and climate change threats in a European project entitled STORM (Safeguarding Cultural Heritage through Technical and Organisational Resources Management). In this thesis, the risk index is applied to the specific hazard of the earthquake and the case of Bam while deriving their corresponding indicators.

The earthquake risk assessment methodology for cultural heritage in this section was developed based on the existing risk assessment and management approaches and standards (e.g. ISO 31000, 2009; FEMA, 2005; UNESCO World Heritage Center et al., 2010), which have been reviewed in *Chapter 3-Literature review*. According to *Section 3.4.2-Risk components and risk analysis approaches*, the three main components of risk that will be incorporated into the risk index in this research are ‘hazard’, ‘exposure’, and ‘vulnerability’. The proposed risk assessment procedure for the earthquake hazard comprises seven major steps, as follows:

1. Assessing earthquake hazard:
  - Analysing primary hazard (earthquakes);
  - Identifying potential natural and human-induced hazards following the earthquake;
2. Assessing exposure (significance assessment of heritage elements at risk):
  - Identifying elements of the site exposed to earthquakes;
  - Assessing the significance of the elements;
  - Mapping the elements and their associated significance;
3. Assessing the seismic vulnerability of the elements of the site:
  - Analysing the seismic susceptibility;
  - Analysing the coping capacity of the management system;
4. Identifying potential impacts of earthquake-induced disasters on the site;
5. Analysing risks and building a risk index for the elements of the site;
6. Generating an earthquake risk map; and
7. Evaluating risks to the elements of the site.

Before starting the risk assessment procedure the context of overall risk management cycle needs to be established. “By establishing the context for the management of risks, the basic parameters within which risks shall be managed are defined” (AEMC, 2010, p. 10). The context may comprise defining the objectives, determining the scope of the work, identifying the stakeholders, defining the risk assessment criteria and so on. In this thesis, such basic requirements have been mentioned in *Chapter 1-Introduction* and *Chapter 2- Study area*.

Figure 4-1 presents the research design of the thesis. This overall methodological framework encompasses the procedure of risk assessment within the risk management cycle while outlining the data collection and analysis methods applied to each step. Furthermore, it illuminates the final output of each step and the links between the different components to fulfil the risk analysis and evaluation. Although the procedure portrays different stages sequentially to make it a systematic process to follow, it is not a linear process; conducting each stage may need review and modification of the previous steps. A detailed description of the assessment steps and their corresponding indicators are provided in the next sections.

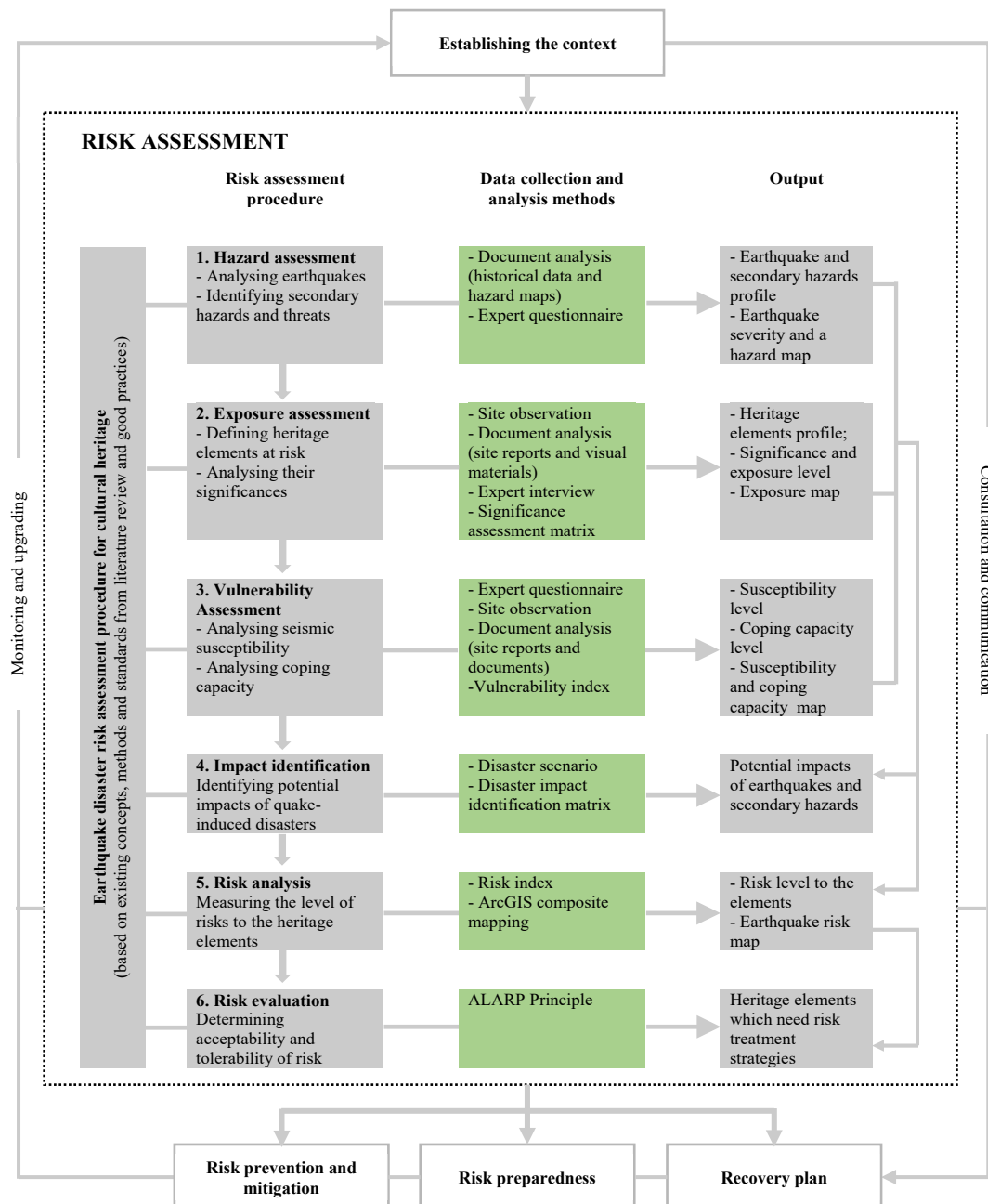


Figure 4-1 Research design: the overall methodological framework of the research, the risk assessment procedure, and the methods of data collection and analysis

### 4.3.1 Assessing earthquake hazard

The first step in identifying risk is to find sources of the risk. In this study, the primary source of potential impacts is the earthquake hazard. The hazard assessment comprises the following steps:

- Identifying the seismic characteristics of the region;
- Analysing the earthquakes in terms of likelihood and severity; and
- Identifying potential natural and human-induced threats following the earthquake.

A preliminary earthquake profile needs to be prepared to gather basic data regarding the historical frequency and severity of the earthquake in a region, including the information regarding the geological (e.g. type of soil, seismic faults, and water table) and hydro-meteorological (e.g. surface water and related infrastructure, precipitation, and wind) characteristics. Some other factors need to be considered within the profile are mentioned in *Section 3.2.2- Characteristics of earthquake hazard*.

“The level of severity of natural hazards can be quantified in terms of the magnitude of the occurrence as a whole (event parameter) or in terms of the effect the occurrence would have at a particular location (site parameter)” (Coburn et al., 1994, p. 35). While the magnitude of an earthquake can be expressed by the Richter scale or the moment magnitude scale (MMS), the intensity is expressed by the Modified Mercalli scale (please see *Section 3.2.2- Characteristics of earthquake hazard*). Table 4-3 shows how earthquakes with different magnitudes can be interpreted in terms of the intensity and their potential consequences. A semi-quantitative ranking scales corresponding to the earthquake magnitudes are added to Table 4-3 to facilitate the measurement of the severity of hazard and its further integration into the risk index.

**Table 4-3 Estimated severity of earthquakes (adapted from USGS, 2012)**

<b>Magnitude</b>	<b>Mercalli intensity</b>	<b>Description</b>	<b>Average earthquake effects</b>	<b>Severity of hazard</b> <i>(ranking scales based on the author's interpretation)</i>
1.0–1.9	I	Micro	Micro-earthquakes, not felt, or felt rarely. Recorded by seismographs.	Very Low (1)
2.0–2.9	I to II	Minor	Felt slightly by some people. No damage to buildings.	
3.0–3.9	III to IV		Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	
4.0–4.9	IV to VI	Light	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	Low (2)
5.0–5.9	VI to VII	Moderate	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone.	Medium (3)
6.0–6.9	VIII to X	Strong	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in	High (4)

Magnitude	Mercalli intensity	Description	Average earthquake effects	Severity of hazard (ranking scales based on the author's interpretation)
			wider areas; up to hundreds of miles/ kilometres from the epicentre. Strong to violent shaking in epicentral area.	
7.0–7.9	X or greater	Major	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicentre.	Very High (5)
8.0–8.9		Great	Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions.	
9.0 and greater			At or near total destruction – severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography.	

Likelihood of a hazard is another important factor in expressing its significance in the risk assessment. “In risk management terminology, the word “likelihood” is used to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively (...)” (ISO 31000, 2009). The likelihood is based on probability and can be presented in various ways (Table 4-4), such as recurrence intervals, exceedance probabilities, return periods, and frequencies (AEMC, 2015, p. 38).

**Table 4-4 Likelihood level (adapted from AEMC, 2015, p. 39)**

Likelihood	Annual Exceedance Probability (AEP)	Frequency
Almost certain	63% per year or more	Once or more per year
Likely	10% to <63% per year	Once per 10 years
Possible	1% to <10% per year	Once per 100 years
Rare	0.1% to <1% per year	Once per 1000 years
Very rare	0.01% to <0.1% per year	Once per 10,000 years

Spatial distribution of hazards within a heritage site can be mapped through GIS spatial analysis, depending on the size of the site and the availability of data regarding the contributing factors. In respect to heritage properties, there might not be any alteration of hazard probability or severity in the different areas of the site. Consequently, exposure and vulnerability contribute considerably to the level of risk.

Although this research focuses mainly on the earthquake hazard, other possible natural hazards and human-induced threats following an earthquake are also addressed in the impact identification step. Such potential threats were discussed in *Section 3.7.4-Potential indirect impacts of subsequent natural hazards* and *Section 3.7.5-Potential indirect impacts of human-induced threats following an earthquake*. Accordingly, potential natural hazards may include tsunamis, fires, flooding, rising groundwater, and meteorological threats. Human-induced threats might be associated with looting

and illicit trafficking of collections, illegal urban development, and improper interventions. Those secondary hazards relevant to the case of Bam were incorporated to the expert questionnaire (please see *Section 5.3.2-Identifying potential secondary hazards following the earthquake*) in order to provide the impact identification matrix with the additional risk agents.

#### 4.3.2 Assessing exposure (significance assessment of heritage elements at risk)

The term ‘Exposure’ is defined by UNISDR (2009) as “People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses”. “The term exposure is frequently used in the field of insurance where the total value at risk (exposure) is determined, e.g. the value of buildings, and next the vulnerability of the considered value at risk under a certain stress (e.g. a defined type of flooding) is analysed” (EC, 2010, p. 16). In this research, the elements of a heritage site and their associated significances are considered as the elements at risk. Thus, the exposure assessment is conducted as follows:

- Identifying elements of the heritage site exposed to earthquakes; and
- Assessing the significance of the heritage elements.

Following the identification of elements of a heritage site, which can be conducted through site observation and document analysis, the significance of the elements needs to be assessed. The term ‘cultural significance’ is now commonly used to refer to the collection of the various values associated with a place which together identify why it is important” (Worthing and Bond, 2008, p. 47). The Burra Charter (Australia ICOMOS, 2013, Article 1) emphasises that “Cultural significance is embodied in the place itself, its fabric, setting, use, associations, meanings, records, related places and related objects”. ICOMOS (2011, p. 8) suggests “the value of heritage attributes is assessed in relation to statutory designations, international or national, and priorities or recommendations set out in national research agendas, and ascribed values”. It also emphasises the importance of the qualitative analysis using professional judgement in the values assessment process.

In respect to the World Heritage sites, each heritage asset may contribute to the overall Outstanding Universal Value; thus, assigning different values to the site components is a challenging task. “While the statement of significance sets out in general terms the nature and level of significance of a place, the assessment of individual elements provides the flexibility necessary for the management of future change” (Kerr, 2013, p. 19). In this study, the significance of different components of the site needs to be individually determined in order to provide more accurate data for the exposure assessment and further risk analysis and mapping. There are different approaches to the categories of heritage values (e.g. Feilden and Jokilehto, 1998; De la Torre and the Getty Conservation Institute, 2002; Drury and McPherson, 2008). For the purpose of the risk assessment in this study, the following criteria are adapted to assess the significance of heritage assets:

- **Architectural and technological significance:** “architectural value is concerned with innovation, development and perhaps pinnacles of achievement (as in ‘the finest example of...’) in relation to architectural ideas and movements, and also in the work of individuals” (Worthing and Bond, 2008, p. 63).
- **Aesthetic significance:** “aesthetic value refers to the sensory and perceptual experience of a place” (...) and may express the “special compositional or uncommonly attractive qualities involving combinations of colour, textures, spaces, massing, detail, movement, unity, sounds, scents” (Australia ICOMOS, 2013). “In a sense, we are essentially talking about character and what makes a ‘sense of place’” (Worthing and Bond, 2008, p. 62).

- **Historical significance:** “a place may have historic value because it has influenced, or has been influenced by, a historic event, phase, movement or activity, person or group of people” (Australia ICOMOS, 2013).
- **Social significance:** “social value refers to the associations that a place has for a particular community or cultural group and the social or cultural meanings that it holds for them” (Australia ICOMOS, 2013). “It refers to the benefits of social cohesion and group identity” (Worthing and Bond 2008, p. 66).
- **Economic importance:** “this can be seen at a very simple level as pertaining to the quantification of how much money is generated by heritage places, either directly through admissions and sales of services and goods at the site, or indirectly in the sense of visitors to a place purchasing goods and services in the wider area. It is also associated with the “(...) direct and indirect investment and employment opportunities and realities” (Worthing and Bond 2008, p. 65).
- **Functional importance:** it is related to “(...) the continuity of the original type of function or the initiation of a compatible use of a building or an area. In a ruined structure, the original functional value is lost, but a new one has been found in serving programmatic requirements for resource interpretation, or as a venue for activities such as the visual and performing arts” (Feilden and Jokilehto, 1993, p. 20).
- **Environmental importance:** “landscapes can have environmental value ... a park in a city can also provide important environmental value to the local community, not least by acting as a ‘green lung’ to reduce pollution” (Worthing and Bond, 2008, p. 62).
- **Degree of integrity:** it represents the ‘wholeness and intactness’ (UNESCO World Heritage Centre, 2017, para. 87) of the elements of the property to convey the aforementioned significances in the current condition of a heritage property.

The significance assessment can be performed through document analysis and/or professional judgement. According to Table 4-5, the relative significance assigned to heritage assets may fall in one of the ranking scales of Unknown (1), Limited (2), Some (3), Considerable (4), and Exceptional (5), respectively. The overall significance of each heritage asset can be measured by applying the arithmetic mean. To calculate the level of exposure, the overall significance scores may fall in five equal-sized classes to provide a comparative exposure analysis among the elements of the site; the classes are interpreted as Very low (1), Low (2), Medium (3), High (4), and Very high (5) level of exposure. Then, the elements of the site and their associated significance can be mapped in GIS or other available formats.

**Table 4-5 A hierarchical system for the levels of significance of heritage assets (adapted from Kerr, 2004; cited in Worthing and Bond, 2008)**

Ranking scales		Description
Exceptional	5	Features of exceptional/international significance or which contain elements with a significance beyond national boundaries
Considerable	4	Features of considerable/national significance, possibly reflected in statutory designations such as Scheduled Ancient Monument, Listed Building or equivalent nationally graded sites (including those of ecological and nature conservation value)
Some	3	Features of some significance, important at regional level either individually or for group value
Limited	2	Features of limited/local significance
Unknown	1	Features of unknown significance resulting from a lack of sufficient information on which to base sound analysis of its value

### 4.3.3 Assessing seismic vulnerability of cultural heritage

Scientific communities and international organisations engaged in disaster management and climate change adaptation have defined the term ‘vulnerability’ slightly different; however, the main difference is the components that are incorporated into the vulnerability calculation. UNISDR (2009) defines vulnerability as “the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.” Birkmann (2013a, p. 9) emphasises that “despite differences in the interpretation of the concept of vulnerability, it has, however, become an essential element to underscore the importance of social factors and societal structures in the construction of risk and of adaptation options.”

Apart from the structural susceptibility of a system, a significant factor which may influence vulnerability, and consequently, the risk is the capacity of the existing risk management system. UNISDR (2009) defines coping capacity as “the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters”. Looking at *Section 3.4.2- Risk components and risk analysis approaches*, the concept of vulnerability in this research comprises two components of susceptibility and coping capacity to adequately address both structural and non-structural features of a system. “The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during crises or adverse conditions” (UNISDR, 2009). This approach fits the nature of earthquake hazard which may lead to a sudden-onset disaster.

An indicator-based vulnerability assessment is applied to the risk assessment procedure in order to adequately analyse the vulnerability components. Indicators are variables (not 'values') which act as an operational representation of an attribute, such as quality, characteristic, and property of a system (Gallopín, 1997, p.14). An indicator could be either a qualitative (nominal) variable, a rank (ordinal) variable, or a quantitative variable (ibid). The vulnerability should be measured via a forward-looking perspective; however, the past event data has to be used to derive sound indicators to estimate vulnerability (Birkmann, 2013b, p.97). The data required for measuring the indicators of vulnerability can be gathered through the expert questionnaire and the in-situ observation of elements of heritage properties.

#### 4.3.3.1 Deriving indicators for susceptibility analysis

Seismic susceptibility of a heritage property represents the weakness of its structural and material features to withstand the earthquake forces. Depending on the disciplines and the focus of investigations, there are different approaches to seismic susceptibility indicators. Tolles et al. (1996) point out the configuration of the adobe walls, roof, floors, openings, and foundation systems, the effectiveness of seismic retrofit measures, and the condition of the building as the factors influencing the earthquake potential damages to the adobe structures. D’Ayala et al. (2008), from the structural engineering perspective, propose the analysis of factors such as the relationship with adjacent buildings, geometric characteristics of the building, structural system, mass irregularity, architectural features, and general conditions for the seismic vulnerability assessment. Lagomarsino (2008, p. 135) links the vulnerability of historical buildings to the quality of masonry, the architectural shape, and the dimensions and the presence of aseismic reinforcements.

Because of the diverse typologies of cultural heritage and their construction techniques, the susceptibility indicators should be defined according to the particular characteristics of a heritage property. The following four indicators for susceptibility analysis of Bam, as an earthen construction, were defined based on *Section 3.7.3-Potential direct impacts of earthquakes on cultural heritage properties* and the post-earthquake reports of Bam regarding the factors contributing to the structural damages.

- **Quality of structure/material:** the type and condition of the structural system are fundamental factors contributing to the seismic performance of buildings during earthquakes. Bam Citadel is an adobe masonry construction in which sun-dried mud bricks combined with mud layers have been applied to walls, vaulted and domed structures. Because the current condition of the citadel is incorporated into the assessment, the structural interventions related to the post-earthquake stabilisation needs to be considered as well. Some stabilisation activities performed after the earthquake are as follows (Vatandoust et al., 2008a, p. 315):
  - Injection grouting of cracks less than 2 cm wide, such as those found in the Sistani House and the Stable;
  - Applying tension elements such as glass and palm fibres used prior to the injection process;
  - Installation of centre cores and other vertical and horizontal reinforcements deep into the walls (vertical elements are inserted into the soil beneath the structure to a depth of 1.5 m along the walls); and
  - Applying adobes reinforced with palm fibres to increase the ductility of the structure.
- **Type of foundation/ground:** the quality of foundation and the type of the ground are other key factors contributing to the extent of earthquakes damage. Through the foundations, seismic shocks are transferred to the walls (Feilden, 1987). In Arg-e Bam, most of the buildings lack foundations and built on soft soil, except the Governor’s quarter that is built on a rock bed. In the post-earthquake stabilisation, some structures (e.g. in the Sistani House or the Payambar Mosque) were connected to the ground with tension elements (cables) made of artificial fibres to increase the lateral resistance of the structure (Vatandoust et al., 2008a, p. 315).
- **Cracks and detachments:** current structural cracks and detachments in the adobe walls and roofs are additional parameters which affect the structural integrity and reduce the seismic performance of the whole building. In the citadel, past natural hazards, improper interventions and material incompatibility, and climate factors are the main causes of the structural damages.
- **Material losses:** gradual deterioration and climate factors (e.g. sand storms) may result in loss of adobe materials of the mud bricks (Khesht) and mud layers (Chineh) as well as the clay-straw mortars. Loss of the cohesion of adobe materials not only affect the structural stability, but provide a ground for biological threats, such as termites.
- **Biological infestations (Termites’ damage):** apart from the above-mentioned parameters, termite-related damages was another significant factor in the high level of damage (Langenbach, 2005; Vatandoust et al., 2008a). Termites consume straw, which is used in the sun-dried bricks and clay mortars to enhance the strength of the adobe materials.

Table 4-6 shows the above-mentioned indicators and their associated ranking criteria for susceptibility analysis of Bam and its Cultural Landscape. For each indicator, a set of ranking criteria was defined to facilitate ranking the indicators. The susceptibility scores may fall into one of the ranking scales of Low (1), Medium (2), and High (3). Due to the difficulty to obtain sufficient data regarding the material and structural analysis, only three ranking scales have been used in this step. However, the overall susceptibility scores assigned to each heritage elements will be reclassified to be integrated into the risk index.



**Table 4-6 Indicators and ranking criteria for susceptibility analysis of the case of Bam**

Indicators	Ranking criteria	Susceptibility score
<b>Quality of structure/material</b>	Good quality mud layers and mud bricks structure; Appropriately repaired/reinforced	1 (low)
	Medium quality mud layers and mud bricks structure; Poorly repaired/reinforced	2 (medium)
	Heavily damaged mud structures	3 (high)
<b>Type of foundation/ground</b>	Properly constructed foundation tied to the structure	1 (low)
	Connected structure to the ground with tension elements; or No foundation, built on a rock bed	2 (medium)
	lack of foundation, built on a bed of soft soil	3 (high)
<b>Cracks and detachments</b>	Appropriately repaired/reinforced	1 (low)
	Some deteriorated areas, poorly repaired/reinforced	2 (medium)
	Many deteriorated areas	3 (high)
<b>Material losses</b>	Appropriately repaired/reinforced	1 (low)
	Some deteriorated areas, poorly repaired/reinforced	2 (medium)
	Many deteriorated areas	3 (high)
<b>Biological infestations (Termites' damage)</b>	Appropriately repaired/reinforced	1 (low)
	Some deteriorated areas, poorly repaired/reinforced	2 (medium)
	Many deteriorated areas	3 (high)

### Weighting the susceptibility indicators

The above-mentioned indicators are not considered equally important in the overall susceptibility calculation. For instance, structural parameters and foundations have a key role in seismic performance. Thus, the indicators were weighted by applying the Analytic Hierarchy Process (AHP). The Analytic Hierarchy Process (AHP), developed by Saaty and Kearns (1985), is a tool for weighting the assessment criteria in a decision-making process. In order to conduct a comparison among the susceptibility indicators, a particular ranking scale needs to be used. Table 4-7 (adapted from Saaty and Kearns, 1985) shows the nine-point ranking scale applied for the subjective pairwise comparison of the importance of indicators. Accordingly, it needs to be determined in a matrix how much one indicator is more important than another one so that all indicators can be priorities for the purpose of determining their relative weights in a multi-indicator analysis.

**Table 4-7 Ranking scale for pairwise comparison of the importance of indicators (adapted from Saaty and Kearns, 1985)**

Intensity of relative importance	Explanation
1	Two indicators are equally important
3	One indicator is slightly more important than another one
5	One indicator is more important than another one
7	One indicator is strongly more important than another one
9	One indicator is extremely more important than another one

Table 4-8 presents the procedure of weighting the indicators contributing to the overall seismic susceptibility. For example, the importance of ‘quality of structure’ relative to ‘material losses’ is 5, as it is inserted in the corresponding cell. For the reverse comparison, the relative importance is 1/5 or 0.20, as it is entered in the corresponding cell. The relative significance of the parameters in the overall seismic susceptibility of the case of Bam was determined based on the factors contributing to the structural damages in *Section 2.4.3-The 2003 Bam earthquake and its impacts*, *Section 2.5.5-Construction technique and building material*, and *Section 3.7-Impacts of earthquakes on cultural heritage properties*. Accordingly, the ‘quality of structure’ and ‘quality of foundation’ are the most important indicators, which directly influence the seismic structural behavior. ‘Cracks and detachments’ is the next important indicator as it will weaken the seismic performance of structure and material to the lateral forces of earthquakes. ‘Material losses’ and ‘biological infestations’ are additional factors that can contribute to the stability of earthen material.

Once the matrix is filled in with the relative importance scores, the weight of each indicator needs to be calculated. For this purpose, each indicator is normalised in its corresponding column; and then, the average of each row will be the weight of its corresponding indicator (Saaty and Kearns, 1985). There are alternative ways to calculate the relative weight of criteria or indicators. Below one alternative (corresponding to Table 4-8) with four steps is provided. For each step, there is an example for the indicator ‘quality of structure’ (SIs), the second row of Table.

- Step 1: calculate the sum of each column:

*The column of ‘quality of structure/ material’:*  $1 + 1 + 0.33 + 0.20 + 0.20 = 2.73$

*The column of ‘type of foundation/ ground’:*  $1 + 1 + 0.33 + 0.20 + 0.20 = 2.73$

*The column of ‘cracks and detachments’:*  $3 + 3 + 1 + 0.33 + 0.33 = 7.66$

*The column of ‘material losses’:*  $5 + 5 + 3 + 1 + 1 = 15$

*The column of ‘Termites’ damage’:*  $5 + 5 + 3 + 1 + 1 = 15$

- Step 2: normalize the elements in each column:

*An example for the second row of Table, ‘quality of structure’ (SIs):*

*The column of ‘quality of structure/ material’:*  $1 \div 2.73 = 0.37$

*The column of ‘type of foundation/ ground’:*  $1 \div 2.73 = 0.37$

*The column of ‘cracks and detachments’:*  $3 \div 7.66 = 0.39$

*The column of ‘material losses’:*  $5 \div 15 = 0.33$

*The column of ‘termites’ damage’:*  $5 \div 15 = 0.33$

- Step 3: add the normalized elements in each row:

*An example for the second row of Table, ‘quality of structure’ (SIs):*  $0.37 + 0.37 + 0.39 + 0.33 + 0.33 = 1.79$

- Step 4: divide the row totals (step 3) by the number of indicator:

*The relative weight of the indicator ‘quality of structure’ (SIs):*  $1.79 \div 5 = \mathbf{0.36}$

**Table 4-8 Weighting the susceptibility indicators for the case of Bam, by applying the AHP**

Susceptibility assessment indicators		Quality of structure/material	Type of foundation/ground	Cracks and detachments	Material losses	Termites' damage	Weights (W)
Quality of structure	SIs	1	1	3	5	5	<b>0.36</b>
Quality of foundation	SIf	1	1	3	5	5	<b>0.36</b>
Cracks and detachments	SIc	0.33	0.33	1	3	3	<b>0.16</b>
Material losses	SI <sub>m</sub>	0.20	0.20	0.33	1	1	<b>0.06</b>
Biological infestations (Termites' damage)	SI <sub>b</sub>	0.20	0.20	0.33	1	1	<b>0.06</b>
Sum		2.73	2.73	7.66	15	15	1

#### Computing the overall susceptibility

Each indicator is multiplied by its corresponding weight; and then, the results will be added to compute the overall seismic susceptibility as below:

$$S_{Earthquake} = (SIs \times Ws) + (SI_m \times Wm) + (SI_i \times Wi) + (SIc \times Wc) \quad (4-1)$$

Where

S = overall susceptibility

SI = susceptibility indicators

W = weights (Ws, Wf, Wc, Wm, and Wb are the weights corresponding to SIs, SIf, SIc, SI<sub>m</sub>, and SI<sub>b</sub>, respectively)

According to the weights of indicators, obtained in

Table 4-8, the following equation is applied to the case of Bam for calculating the susceptibility:

$$S_{Earthquake} = (SIs \times 0.36) + (SI_f \times 0.36) + (SIc \times 0.16) + (SI_m \times 0.06) + (SI_b \times 0.06) \quad (4-2)$$

#### 4.3.3.2 Deriving indicators for coping capacity analysis

The degree of capacity to mitigate, respond to and recover from disasters significantly contributes to the level of potential impacts. Coping capacity relies heavily on the institutional and management system of heritage sites, and in a broader context, on the urban and regional planning engaged in the protection of cultural heritage from natural hazards. The capacity building encompasses a variety of concepts and factors, depending on the system in question. In the context of World Heritage, Stovel (1998) mentions some factors within the preparation of emergency response and recovery plan that are applicable to the capacity analysis. Some of the most significant factors are training activities,

earthquake-response drills and simulation, adequate documentation, storage and salvation conservation facility, availability of experienced professionals, and security and fire alarm systems (ibid).

In this research, the capacity analysis was conducted based on particular indicators incorporated into the experts' questionnaire. The indicators were derived according to the literature review conducted in *Section 3.3.2-Heritage and disaster resilience and Section 3.7- Impacts of earthquakes on cultural heritage properties* as well as *Section 2.6-Conservation and management status*. The indicators for the analysis of coping capacity are as follows:

- **Information and communication system:** it represents the status of the current heritage information system (e.g. inventory of the heritage assets); the risk information system and maps (e.g. GIS database); and the directory of emergency-related contacts (including heritage and risk experts) for a heritage site.
- **Risk awareness:** it embodies the local staff awareness regarding impacts of earthquakes on a property as well as the awareness of the local residents regarding impacts of earthquakes on the property and its indirect effects on its setting.
- **Risk mitigation strategies/actions:** risk mitigation includes the pre-disaster risk treatment measures aiming at reducing the potential damages of disasters. The plan should address the monitoring and maintenance of structures; the structural risk mitigation while applying the traditional earthen construction technique for instance, and modern reinforcement methods; and consideration of the OUV, authenticity, and integrity in the past restoration and stabilisation measures.
- **Risk preparedness strategies/actions** (including emergency response and recovery plan): risk preparedness mainly aims to facilitate emergency response activities. The plan should address the first aid measures, such as, salvage, triage, and stabilization of movable and immovable heritage; the emergency response services (e.g. equipment and supplies); early warning system (e.g. for fires); the disaster drills and field exercises within the site; the emergency evacuation plan for staff and tourists in the citadel; and the risk compensation mechanism and insurance coverage after disasters. According to the questionnaire conducted in this thesis, there was no adequate risk mitigation and preparedness plan for Bam Citadel before the earthquake 2013; this could be mentioned as a significant factor contributing to the high level of damage.
- **Institutional framework:** it represents the status of the legal framework for conservation and management of the property, including its protection from earthquakes; the cooperation between heritage organisations, disaster management, environmental bodies, and civil protection; and integration of the property in urban and regional disaster risk management.

Table 4-9 presents the indicators and their associated sub-indicators for analysis of coping capacity. The scores assigned to the indicators fall into one of the ranking scales of Very low (1), Low (2), Medium (3), High (4), and Very high (5). Following the analysis of the capacity indicators, the arithmetic mean is applied to measure the overall coping capacity of the system. In order to integrate this component into the risk index, the 'lack of coping capacity' needs to be considered. The reason is that because the components of risk are multiplied to measure risk, they need to be of the same nature regarding their influence on the level of risk. The overall score of coping capacity may fall into one of the classes of 1-1.8, 1.8-2.6, 2.6-3.4, 3.4- 4.2, and 4.2-5. It should be noted that the min-max values in the classes are 1-less than 1.8, 1.8-less than 2.6, etc. The mentioned classes are respectively interpreted as Very high (5), High (4), Medium (3), Low (2), and Very low (1) level of lack of coping capacity (Table 4-10).

**Table 4-9 Indicators and sub-indicators for coping capacity analysis while considering the case of Bam**

Indicators	Sub-indicators
<b>Information and communication system</b>	Heritage information system (e.g. inventory of heritage assets)
	Risk information system and maps (e.g. GIS database)
	Directory of emergency-related contacts (e.g. heritage and disaster experts)
<b>Risk awareness</b>	Staff awareness regarding impacts of earthquakes on the property
	Local people awareness regarding impacts of earthquakes on the property and its indirect effects
<b>Risk mitigation strategies/actions</b>	Monitoring and maintenance of structures
	Structural risk mitigation (e.g. seismic structural reinforcement) including post-earthquakes stabilisation
	Traditional knowledge and technique of earthen construction
	Modern methods of restoration and retrofitting
	Consideration of the OUV, authenticity, and integrity in the restoration and mitigation measures
<b>Risk preparedness strategies/actions (including emergency response and recovery)</b>	first aid measures (e.g. salvage, triage, and stabilization of movable and immovable heritage)
	Emergency response services (e.g. equipment and supplies)
	Early warning system (e.g. for fires)
	Disaster drills and field exercises within the site
	Emergency evacuation plan for staff and tourists in the citadel
	Risk compensation mechanism and insurance coverage
<b>Institutional framework</b>	Legal framework for conservation and management of the property, including protection of the property from earthquakes
	Cooperation between heritage organisations and disaster management, environmental bodies, and civil protection
	Integration of the property in disaster risk management of the city of Bam

**Table 4-10 Determining the level of ‘lack of coping capacity’**

Overall coping capacity score	Quality level of plan/measures	level of ‘coping capacity’	level of ‘lack of coping capacity’
1-1.8	Very poor	Very low (1)	Very high (5)
1.8-2.6	Poorly-developed	Low (2)	High (4)
2.6-3.4	Acceptable	Medium (3)	Medium (3)
3.4- 4.2	Well-developed	High (4)	Low (2)
4.2-5	Very well-developed	Very high (5)	Very low (1)

#### 4.3.3.3 Calculating the vulnerability

To measure the overall vulnerability, it should be noted that susceptibility and coping capacity are opposing components; the higher degree of susceptibility increases the overall vulnerability while the higher degree of coping capacity reduces the overall vulnerability. Thus, the ‘lack of coping capacity’ is applied to measure vulnerability. The vulnerability is calculated by applying the geometric mean aggregation as follows:

$$\text{Vulnerability} = \sqrt{\text{Susceptibility} \times \text{Lack of coping capacity}} \quad (4-3)$$

### 4.3.4 Identifying potential impacts of disasters

Following the identification and analysis of the risk elements (i.e. hazard, exposure, and vulnerability), potential impacts of earthquake-induced disasters on elements of a heritage site need to be identified. Although only earthquake hazard is incorporated into the risk index within the scope of this thesis, other potential secondary hazards are addressed in the impact identification matrix. This provides a more comprehensive list of direct and indirect impacts during and after a disaster. To identify the potential impacts, the following two steps are conducted:

- Defining an earthquake disaster scenario; and
- Developing an impact identification matrix.

#### 4.3.4.1 Defining an earthquake disaster scenario

Disaster scenario is a prediction of the disaster situation that should comprise defining primary hazards, exploring natural hazards and human-induced threats triggered by the primary hazards, and identifying their associated potential impacts. “Scenarios are constructed on the basis of assumptions derived from information about the current and the proposed activities and projects in the area, the management systems in place, and the vulnerability of the property to various hazards that has been previously assessed” (UNESCO WHC et al., 2010, p. 27). The scenario facilitates the identification of potential direct and indirect impacts while linking the hazards, elements at risk, and vulnerability factors to build the emergency situation.

#### 4.3.4.2 Developing an impact identification matrix<sup>13</sup>

As mentioned in *Section 3.7.2-An integrated approach to earthquake impact identification*, potential natural hazards and human-induced threats following earthquakes are considered to be addressed in the risk treatment strategies. In order to conduct the procedure of identifying the impacts of the mentioned multiple hazards to cultural heritage in a more systematic manner, an impact identification matrix is proposed. The matrix (Table 4-11) comprises possible threats of/from earthquakes (i.e., its primary effects, secondary hazards, and human-induced threats) on one axis, and tangible and intangible attributes of cultural properties exposed to disasters on the other axis. The potential secondary hazards and threats have been identified according to *Section 3.7.4-Potential indirect impacts of subsequent natural hazards* and *Section 3.7.5-Potential indirect impacts of human-induced threats following an earthquake* while considering the relevance of hazards to the case of Bam. The matrix, while looking at the above-mentioned disaster scenario, aims to identify the potential impacts which may occur during and after a disaster. In fact, each potential impact is determined based on a specific source and receptor of the impact.

In the case of secondary disasters to structural elements, a potential impact could be, for example: there is a potential that rising groundwater resulting from an earthquake causes dampness entering into porous historic materials and collections that might be already cracked or broken by the earthquake; and post-dampness drying may cause growth of micro-organisms such as fungi. The impact can be written in the matrix by particular keywords expressing the sources and damages. It should be noted that the status of existing coping capacity (e.g. risk mitigation and preparedness plan) needs to be considered while potential impacts are being predicted.

In the context of World Heritage, loss of value is directly linked to the impacts on tangible and intangible attributes that are conveying the OUV. Furthermore, loss of authenticity, such as the impact on the authenticity of material, function, and design (UNESCO, 2017) as well as loss of

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<sup>13</sup> This section is based on a paper published by the author (Ravankhah, Schmidt, and Will, 2017a)

integrity, such as the impact on the visual, structural, and functional integrity (Jokilehto, 2006) need to be addressed. Impact on authenticity and integrity might occur directly by earthquakes and its secondary hazards or indirectly by human errors. Overall, the matrix provides a list of multiple impacts which may occur during, and after a quake-induced disaster in order to facilitate determining site-specific mitigation and preparedness strategies.

**Table 4-11 Impact identification matrix for earthquake-induced disasters, with a focus on the case of Bam**

Attributes of Bam and its Cultural Landscape		Potential primary and secondary hazards and threats								
		Potential primary effects			Potential secondary hazards and climate factors			Potential human-induced threats		
		Ground shaking	Landslide	Liquefactions	Fires & Explosions	Precipitation & surface runoff	Wind-driven sand/rain & Sandstorms	Looting	Illegal urban development	Improper emergency response
Tangible attributes										
Physical elements	Structural elements	<i>e.g. structural cracks and deformation</i>			<i>e.g. washing away of archaeological remains</i>					<i>e.g. applying incompatible structural techniques or materials during restoration and stabilisation</i>
	Materials and Mortars									
	Decorative elements				<i>e.g. penetration of water and wind into motives and finishes</i>					
	Collections and Archives									
Natural elements	e.g. elements of cultural landscape									
Setting	e.g. archaeological remains									
Intangible attributes ( <i>adapted from UNESCO, 2003</i> )										
Oral traditions and expressions										
Performing arts										
Social practices, rituals and festive events		<i>e.g. loss of religious rituals or ceremonies</i>								
Knowledge and practices										
Traditional craftsmanship										
Skills and knowledge										

Specific considerations for WH properties ( <i>based on the above tangible and intangible attributes conveying the values</i> )	Potential primary and secondary hazards and threats									
	Potential primary effects			Potential secondary hazards and climate factors			Potential human-induced threats			
	Ground shaking	Landslide	Liquefactions	Fires & Explosions	Precipitation & surface runoff	Wind-driven sand/rain & Sandstorms	Looting	Illegal urban development	Improper emergency response	Improper interventions & reconstruction
Outstanding Universal values (OUV)							<i>e.g. loss of the OUV due to potential improper emergency response, salvage, stabilisation, and restoration</i>			
Authenticity							<i>e.g. loss of authenticity due to neglecting adobe construction technique or overuse of modern retrofitting techniques</i>			
Integrity	<i>e.g. loss of visual integrity due to damage/collapse of particular architectural elements contributing to the visual values</i>									

#### 4.3.5 Analysing the earthquake risks: risk index and risk map

As mentioned before, the risk index method is applied to measure the level of risk to the elements of a heritage site. The components of risk, which have been analysed in the above procedure of risk assessment, are integrated into the risk index to calculate the level of vulnerability and risk. The risk components have been measured as follows:

- **Hazard:** according to the historical data of earthquake events in the region and its spatial distribution using the GIS modelling, the severity of an earthquake can be classified as Very low (1), Low (2), Medium (3), High (4), or Very high (5) level.
- **Exposure:** following an analysis of the significance of elements of a heritage site, the arithmetic mean is applied to measure the overall significance scores. The overall scores are interpreted as Very low (1), Low (2), Medium (3), High (4), or Very high (5) level of exposure.
- **Vulnerability:** an indicator-based procedure is applied to assess the components of seismic vulnerability as follows:
  - **Susceptibility:** seismic susceptibility is analysed by deriving some particular indicators relevant to the case of Bam. The ‘Analytic Hierarchy Process’ method is also applied to weight the indicators. In order to keep the consistency of the number of classes in the risk index, the scores were reclassified and interpreted as Very low (1), Low (2), Medium (3), High (4), or Very high (5) susceptibility level;
  - **Coping capacity:** capacity analysis is conducted based on an indicator-based assessment using the expert questionnaire and document analysis. The arithmetic mean is applied to measure the overall coping capacity scores. Because susceptibility and coping capacity are opposing components, the ‘Lack of coping capacity’ needs to be integrated into the risk index. The reason is that because the components of risk are multiplied to measure risk, they need to be of the same nature regarding their influence on the level of risk. The



level of lack of coping capacity may fall in one of the regions of Very high (5), High (4), Medium (3), Low (2), or Very low (1).

Following the analysis of the risk components, vulnerability and risk need to be calculated by defining a specific equation. There are different aggregation approaches on combining the risk components, depending on the requirements and characteristics of a system for which risk assessment is performed. Importantly, the scores for each part of the system have to be internally consistent and maintain their linkage; scores might be added, subtracted, multiplied and/or divided (ISO 31010, 2009). In the concept of the *World Risk Index* project (Birkmann and Welle, 2015), in which hazard and exposure are considered as one component, vulnerability is calculated by using the arithmetic mean; and risk is computed by multiplication of the components. In the *INFORM Index for Risk Management* project (Marin-Ferrer et al., 2017), a multiplicative equation using the geometric mean is developed to combine the elements of risk. In terms of vulnerability of archaeological sites to climate change, Cathy Daly (2014) calculates vulnerability through an additive/subtractive equation.

In this research, vulnerability (*as mentioned in Section 4.3.3.3*) and risk are calculated by applying the geometric mean aggregation method through the following equations:

$$\text{Vulnerability} = \sqrt{\text{Susceptibility} \times \text{Lack of coping capacity}}$$

$$\text{Risk} = \sqrt[3]{\text{Hazard} \times \text{Exposure} \times \text{Vulnerability}} \quad (4-4)$$

The geometric mean, which specifies the central tendency of the risk components, retains the range of classes as it is defined for the risk components in this chapter. Thus, the same qualitative and semi-quantitative ranking scales will be applicable to the vulnerability and risk scores. Another reason is that multiplicative equation, compared to additive, gives a better interpretation of risk; for instance, if one of the components (e.g. hazard) is zero, the risk equals zero. The vulnerability and risk score may fall in one of the 5 equal-sized classes with class ranges of 1-1.8, 1.8-2.6, 2.6-3.4, 3.4- 4.2, and 4.2-5. It should be noted that the min-max values in the classes are 1-less than 1.8, 1.8-less than 2.6, etc. They are respectively interpreted by numbers and colour codes as Very low (1, dark green), Low (2, light green), Medium (3, yellow), High (4, orange), and Very high (5, red) level in the risk index and risk map.

A risk map can be created based on the aggregation of the risk components in risk index and their visualisation in ArcGIS. The different layers that need to be overlapped are exposure layer (which presents the spatial distribution of heritage elements), earthquake hazard layer (which shows the spatial distribution of potential earthquake and its severity), and vulnerability layer (which includes structural susceptibility layer and the layer of lack of coping capacity). The risk map provides multiple sectors engaged in the risk management of cultural heritage with a shared understanding of the potential disaster situation in the different areas of a site by showing the elements at risk of earthquakes and the level of their related risks.

#### 4.3.6 Evaluating the risks

Risk evaluation, as the output of the risk assessment, provides decision-making process with essential information related to those heritage assets that need risk reduction strategies. Furthermore, it helps prioritise the elements for the risk management plan. The ALARP (As Low As Reasonably Practicable) principle is applied in this study to evaluate risk. The ALARP principle helps define boundaries between disaster risks which might be intolerable, tolerable or broadly acceptable (AEMC, 2010). Accordingly, risks may fall into one of the following regions (AEMC, 2010):

- Intolerable region: risks require risk treatment measures to derive them at least to the tolerable region.
- Tolerable region: risks are subject to ALARP and should be treated to drive them to the acceptable region.
- Acceptable region: risks do not need additional risk treatment measures, and should be managed by existing management systems.

Before defining the risk evaluation table, ‘uncertainty’ should be addressed. The level of ‘confidence’ in the risk assessment procedure is applied to indicate the robustness of the approach and address uncertainty; confidence assessment is also a proxy for analysis of ‘sensitivity’ (AEMC, 2010). Within the three confidence level (low, medium, and high), a medium-confidence level was chosen to be applied to the risk evaluation for the case of Bam. This is considered based upon the criteria of the availability of data/information (e.g. data extracted from the fieldwork and document analysis) and the level of agreement between the experts (e.g. in the expert questionnaire). In this model, the risks with ‘Very high’ and ‘High’ levels are placed in the intolerable region to be fully integrated into the risk treatment plan. Accordingly, the following risk evaluation model (Table 4-12) is applied to Bam in the next chapter.

**Table 4-12 Risk evaluation table (with a moderate confidence level) for the case of Bam (adapted from AEMC, 2010)**

Risk level	Tolerability	Further step
Very high	Intolerable region	Risks require risk treatment measures to derive them at least to the tolerable region.
High		
Medium	Tolerable region	Risks are subject to ALARP and should be treated to drive them to the acceptable region.
Low	Acceptable region	Risks do not need additional risk treatment options and should be managed by existing management systems.
Very low		

Table 4-12 provides the decision-making process with the information regarding those risks that need to be incorporated into the risk treatment plan and on which level. Furthermore, the above procedure of risk assessment for a heritage site will give a clear perception of the risk elements to determine site-specific risk reduction strategies mainly through reducing the seismic structural susceptibility, enhancing the coping capacity of the heritage management system, and increasing the effectiveness of emergency response using the GIS earthquake risk maps.

#### 4.4 Summary

The overall methodological framework of the thesis has been described in detail in this chapter. The chapter provided an explanation of the primary data collection (e.g. in-situ observation of the property and the expert questionnaire) and the secondary data collection (e.g. extracted from the report and document analysis) to cross-check the primary data. In different steps of the risk assessment procedure, particular data analysis methods, such as significance assessment matrix, indicator-based vulnerability assessment index, risk index, and risk mapping in ArcGIS have been applied. As mentioned before, a semi-quantitative method was applied for analysing the data in order to make the calculation process more reliable. However, qualitative ranking scales are also used to make the results more perceptible for the site managers and potential stakeholders.

In the second part of the chapter, a Cultural Heritage Risk Index was proposed to measure the level of risk based on the aggregation of the components of ‘hazard’ (earthquakes), ‘exposure’

(significance of the site elements), and ‘vulnerability’ (susceptibility and coping capacity). Moreover, an impact identification matrix was developed to provide the risk treatment strategies with the multiple impacts associated with primary effects of earthquakes as well as with secondary hazards and human-induced threats following the earthquakes.

**CHAPTER 5**  
**APPLICATION OF THE RISK**  
**ASSESSMENT TO THE STUDY**  
**AREA**

## 5.1 Introduction

In *Chapter 4-Methodology*, the overall methodology of risk assessment for cultural properties in the seismic areas, with a focus on the case of Bam, has been developed. In this chapter, the methodology is applied to the case of Bam and its Cultural Landscape.

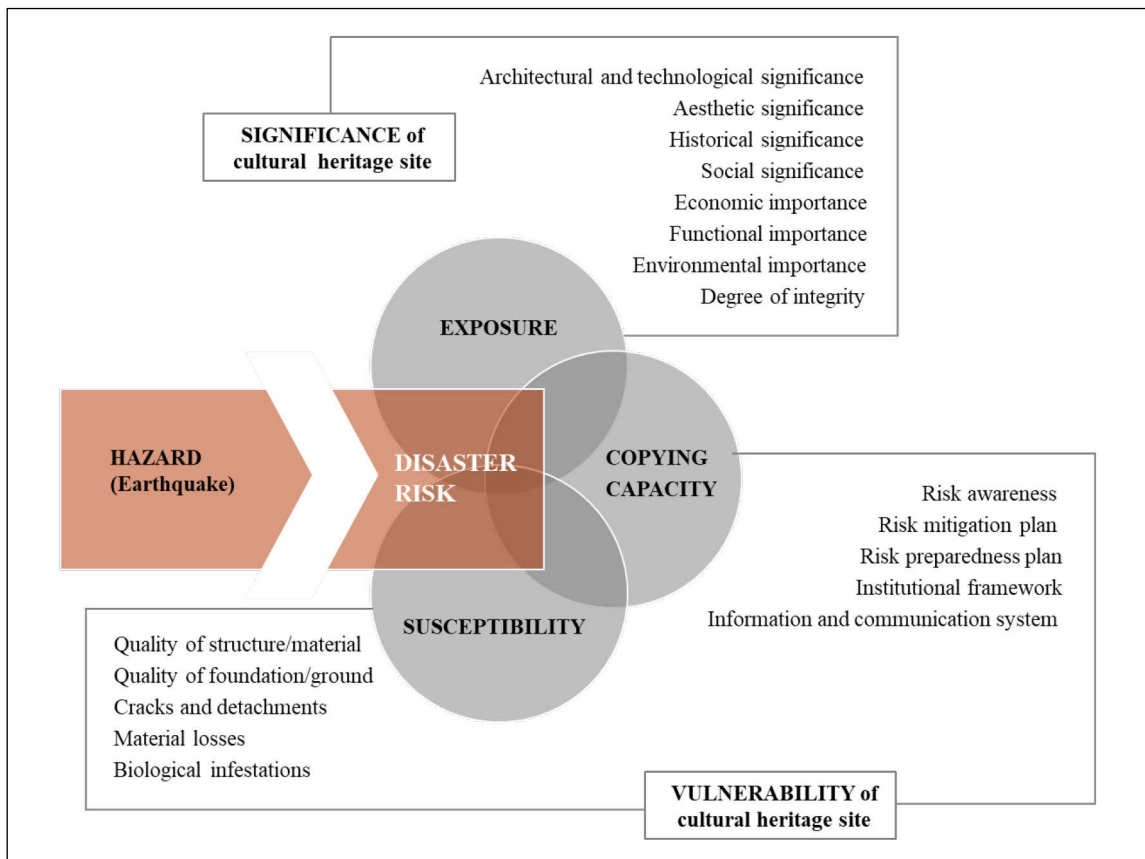
The earthquake hazard in Bam is analysed according to the historical data and the seismic maps. A detailed description of the elements of Bam is provided according to the fieldwork and document analysis; and subsequently, the significance of the elements is assessed to explore the exposure patterns. According to the vulnerability index, the level of seismic susceptibility and coping capacity are measured. Then, the components of risk are incorporated into the risk index for measuring the level of risks to the elements of Bam. Accordingly, an earthquake risk map of the property is generated by applying ArcGIS. Finally, the risks will be evaluated to determine which elements of Bam need risk treatment strategies in the mitigation and preparedness plans.

## 5.2 Risk assessment procedure for the case of Bam

According to Chapter 4-methodology, the following disaster risk assessment procedure is applied to the case of Bam and its Cultural Landscape:

1. Assessing earthquake hazard in Bam:
  - Analysing primary hazard of the earthquake;
  - Identifying potential natural and human-induced hazards following the earthquake;
2. Assessing exposure (significance assessment of heritage elements at risk):
  - Identifying elements of Bam exposed to earthquakes;
  - Assessing the relative significance of the elements;
  - Mapping the elements and their associated significance;
3. Assessing the seismic vulnerability of the elements of Bam:
  - Analysing the seismic susceptibility;
  - Analysing the coping capacity of the management system;
4. Identifying potential impacts of earthquake-induced disasters on the site;
5. Analysing risks and building a risk index for the elements of Bam;
6. Generating an earthquake risk map; and
7. Evaluating risks to the elements of Bam.

While conducting the above procedure, the components of risk and their corresponding indicators that have been defined for the case of Bam, are analysed in order to calculate the risk. Figure 5-1 shows the components of risk and their related indicators for developing a Cultural Heritage Risk Index for Bam and its Cultural Landscape.



**Figure 5-1 Components of risk and related indicators to build a Cultural Heritage Risk Index for Bam and its Cultural Landscape**

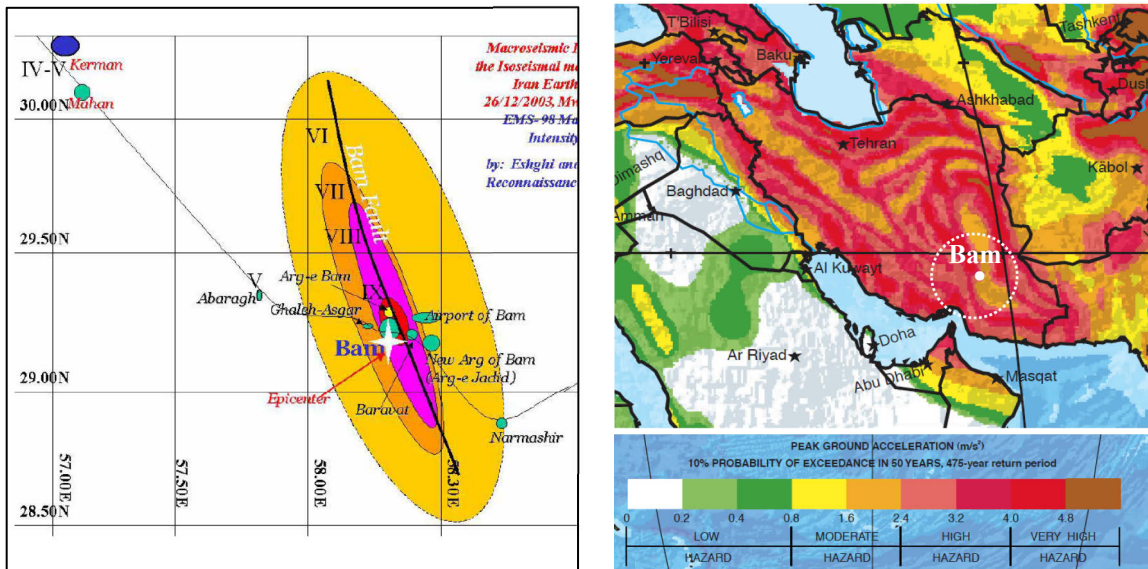
### 5.3 Assessing earthquake hazard in Bam

#### 5.3.1 Analysing primary hazard of the earthquake

In respect to the historical seismicity of the region, before the earthquake of 2003, no damaging earthquakes in Bam have been recorded (Berberian, 2005; Manafpour, 2003; Nadim, 2004). Berberian (2005), however, believes that this assumption that no major earthquakes over the past 2,000 to 2,500 years occurred in Bam is incorrect. He says this assumption is according to the mistaken belief that the present Arg-e Bam is between 2,000 and 2,500 years old without considering that the citadel was restored several times before 1900 possibly due to gradual erosion, invasions and earthquakes.

Since 1900, some earthquakes have been recorded in the northwest of Bam and within a range of 150km, such as, the Sirch-Hassan-abad earthquake (1877, Ms 5.6) about 130km Northwest of Bam; the Laleh Zar earthquake (1923, Ms 6.7); the Golbaf earthquake (1949, Ms 6.0), and the Golbaf Earthquake (1981, Mw 6.6) (Manafpour, 2003, p. 6). “The major faults in this region include the Nayband fault with a North-South trend, the Kuh Banan fault which trends Northwest-Southeast and the Gowk fault that starts at the junction of the two aforementioned faults and trends in a North-South direction towards the Jebal Barez mountains in the Southwest of Bam” (Manafpour, 2003, p. 6).

According to the *International Institute of Earthquake Engineering and Seismology* (Eshaghi and Zare, 2003), the epicentre of the earthquake of magnitude  $M_w=6.6$  was located in the city of Bam at the coordination of 29.04N and 58.33E; based on the field investigations, the earthquake intensity was assessed to be roughly IX in the city of Bam (Figure 5-2, left). The exact effects of potential earthquakes are difficult to predict. In the Bam earthquake, the capacity of local soil, the relationship between ground acceleration and the resonant frequency of a structure, the three-dimensional force of the ground motions, and the relatively long duration of the earthquake (almost 13 sec) were mentioned as factors contributing to the high level of damages (Vatandoust et al., 2008a, p. 313).



**Figure 5-2 left: Macro seismic intensity and the isoseismic map of the Bam earthquake 2003 (Eshaghi and Zare, 2003), right: Seismic Hazard Zoning Map of Iran, extracted from Global Seismic Hazard map (Giardini et al., 2003)**

According to Figure 5-2 (right), which is based on a 10% probability of exceedance in 50 years, the city of Bam is located in a high seismic zone. Based on the historical data of earthquake events in the whole region, an earthquake with a magnitude of 6.0–6.9 can be expected. Based on the U.S. Geological Survey, this can be a strong earthquake with the intensity of VIII to X that may cause moderate to severe damage to the non-earthquake-resistant structures; it is felt in wider areas up to hundreds of kilometres from the epicentre. According to Table 5-1, a high-severity earthquake can be estimated.

**Table 5-1 Estimated severity of earthquakes (adapted from USGS, 2012)**

Magnitude	Mercalli intensity	Severity of hazard
1.0–1.9	I	Very Low (1)
2.0–2.9	I to II	
3.0–3.9	III to IV	
4.0–4.9	IV to VI	Low (2)
5.0–5.9	VI to VII	Medium (3)
6.0–6.9	VIII to X	High (4)
7.0–7.9	X or greater	Very High (5)
8.0–8.9		
9.0 and greater		

As described in *Section 3.2.2- Characteristics of earthquake hazard*, liquefaction and landslides are among the major primary effects of earthquakes. Although Bam has a high proportion of loose sand and silt deposits, the level of groundwater in the region is low (Manafpour, 2003, p. 8). According to the post-earthquake reports and the expert's opinion in the questionnaire, no evidence of landslides or liquefaction has been reported within the Bam Citadel or its immediate surrounding.

### 5.3.2 Identifying potential secondary hazards following the earthquake

As stated in *Chapter 3-Literature review*, apart from the primary hazard of the earthquake, subsequent hazards and threats may cause additional impacts during and after the disasters. The following potential hazards and threats have been extracted from *Chapter 2-Study area*, as well as, *Section 3.7.4-Potential indirect impacts of subsequent natural hazards* and *Section 3.7.5-Potential indirect impacts of human-induced threats following an earthquake* and the Bam post-earthquake reports; and subsequently, they are integrated into the expert questionnaire.

- **Flooding:** in the northern part of the citadel, there is a seasonal river called 'Posht-e Rud'. The river is dry most of the year (Manafpour, 2003). There has been no evidence of flooding associated with the river that may affect the citadel.
- **Rising groundwater:** as mentioned above, the level of groundwater in most parts of the region is low.
- **Fires and explosion:** there could be a potential for fires induced by quake-damaged electricity lines, electrical equipment and installations within the citadel or damaged infrastructure in its surrounding. Furthermore, fire-induced high temperature and smoke can reduce structural performance and damage movable collections.
- **Rainfall and snowfall:** according to the Bam Meteorological Centre, the average annual precipitation in Bam is 58.8 mm and the maximum record is reported 147 mm. However, diurnal and seasonal weather events following an earthquake may cause cumulative impacts on remaining structures and interior collections, particularly those buildings that have already lost protective roofs or suffer from the improper drainage system.
- **Wind-driven sand and Wind-driven rain:** wind-related climate factors are considered as the gradual cause of the adobe deterioration in the Bam Citadel. According to the Bam Meteorological Centre, the maximum recorded wind was 133 km/hr; (sand) storms are reported mainly in the end of winters and beginning of springs. The quake-induced damaged structures and materials are particularly susceptible to water penetration and wind erosion.
- **Looting and illicit trafficking of collections:** emergency situation and lack of security in the quake-affected sites may pose serious threats, such as theft and illicit trafficking, to the valuable damaged fragments and movable objects.
- **Encroachment and illegal urban development:** as mentioned in *Chapter 2-Study area*, some evidence of the industrial and residential development pressure has been reported adjacent to the core zone of the property after the 2003 earthquakes.
- **Improper response, damage assessment, and interventions:** potential human errors during the emergency response and recovery process may contribute to causing additional effects following earthquakes. Emergency teams and volunteers, if not familiar with heritage assets and conservation principles, may cause further risks to the already damaged structures and survived collections.



Table 5-2 shows the result of the expert questionnaire regarding the above-mentioned potential secondary hazards that may affect the property following future earthquakes. For predicting the potential occurrence of the hazards, the worst-case scenario based on the experts' opinion is considered in order to address the potential indirect impacts in the step of impact identification. The results are cross-checked with the above-mentioned description of the secondary hazards, which are based on the Bam post-disaster reports.

**Table 5-2 Identification of potential hazards and threats following the earthquake**

Potential natural and human-induced hazards following the earthquake	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Potential occurrence (based on the worst-case scenario)
<b>Potential secondary hazards and environmental factors</b>						
Flooding	2	2	2	0	N/D	Low (2)
Rising ground water	0	0	1	0	N/D	Very low (1)
Fire and explosion	3	0	1	0	N/D	Medium (3)
Rainfall and snowfall	2	2	4	0	N/D	High (4)
Wind-driven sand	4	0	4	3	N/D	High (4)
Wind-driven rain	4	0	4	0	N/D	High (4)
<b>Potential human-induced threats</b>						
Looting and illicit trafficking of collections	3	3	4	3	N/D	High (4)
Encroachment and illegal urban development	4	1	4	2	N/D	High (4)
Improper response, damage assessment, and interventions	0	4	4	3	N/D	High (4)

Since this study focuses on earthquake hazard, the above secondary hazards and threats are not considered as primary hazards and they are not directly incorporated into the earthquake risk analysis. According to Table 5-2, the following secondary hazards and threats should be considered in the identification of the potential indirect impacts following earthquakes to support determining additional risk mitigation and preparedness strategies. Accordingly, the potential hazards and threats following an earthquake in Bam could be as follows:

- Potential secondary hazards and environmental factors: fire and explosion, rainfall and snowfall, wind-driven sand, wind-driven rain; and
- Potential human-induced threats: looting and illicit trafficking of collections, encroachment and illegal urban development, improper response, inappropriate damage assessment, and incompatible interventions.

## 5.4 Assessing exposure (significant assessment of heritage elements at risk)

According to the expert questionnaire, in comparison with the conservation plan before the earthquake, there has been a more integrated approach in the post-earthquake recovery to include the different attributes of Bam, such as Qanat irrigation system and earthen architectural structures and know-how. In this study, different elements of Bam and its Cultural Landscape and their associated significance are considered in the exposure assessment procedure, as follows:

- Identifying elements of the heritage site exposed to earthquakes; and
- Assessing the significance of the heritage elements.

### 5.4.1 Identifying elements of Bam exposed to the earthquakes

The elements of the core zone of the property were identified through site observation and document analysis. The description and characteristics of the elements are not only used for the significance assessment, but they are incorporated into the susceptibility analysis and the final risk index. Although all key elements of the core zone are included into the significant assessment, there are few architectural remains outside of the Bam Citadel that two of them have been involved due to the lack of data availability.

#### 5.4.1.1 Inside Arg-e Bam (Bam Citadel)

As mentioned, **Arg-e Bam (Bam Citadel)** is the origin of the current city of Bam; according to the archaeological evidence, the citadel dates back to the Achaemenid period between the 6<sup>th</sup> and 4<sup>th</sup> centuries BC (ICHO, 2004). The unique settlement of the citadel comprises the Governor's quarter, and a residential area that includes a bazaar, school, mosque, and other structures. Below, the elements within the citadel are outlined.

**Fortification walls and towers:** the fortification wall and its 52 watchtowers (ICHHTO, 2008a) are the most visible component of the Bam Citadel. The main gate is situated on the south side of the fortification. The wall is surrounded by a moat, probably for defensive purposes. Its construction technique is based on mud brick and mud layers. The wall and its watchtowers, in particular the upper parts, have been seriously destroyed by the earthquake. Reinforced mud bricks by using the existing debris and palm fibres are applied for the reinforcement of the structure (Figure 5-3).



Figure 5-3 Western fortification wall during the post-earthquake recovery (Author, 2013)

**Main gate:** the main gate is located in the Southern part of the citadel. Its construction is based on mud brick, mud layer and straw plaster. The gate was extremely demolished by the earthquake and has been recently restored (Figure 5-4).



**Figure 5-4** *left:* Main gate after the earthquake (Author, 2013), *right:* Main gate after the post-earthquake restoration (Sasan Alirezaei, 2018, taken for the author)

**Governor’s quarter (Hākemneshin):** the Governor’s quarter is built on a rocky hill in the northern part of the citadel. The complex consists of different structures, including the governor’s residence dating back to the Safavid period (16th–18th centuries). The unique architecture of the Hakemneshin was adapted to the topographical characteristics of the hill while applying the local construction technique of sun-dried mud-brick in combination with mud layer (Figure 5-5). The quarter, including its watchtower, was destroyed by the earthquake.



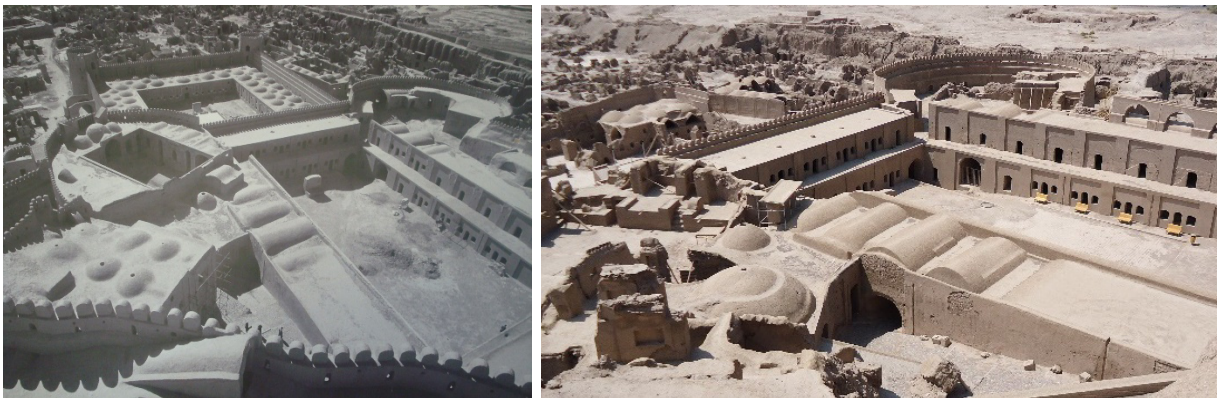
**Figure 5-5** View from bazaar to the Governor’s quarter, after the earthquake (Author, 2013)

**Stables:** the stables building is located in the north-eastern part of the citadel. Its construction technique is based on earthen walls and dome roofs using mud brick, mud layer, straw plaster, and gypsum decoration. “The most well-known historic events related to the citadel occurred in the Stables. It was in this very stables that the arrest of the romantic Lotf-‘Ali Khān, the last Zand pretender to the Persian throne, took place in late autumn 1794 (ICHO, 2004, p.14)”. There is a water reservoir in the centre of stables courtyard that has survived the earthquake, probably because of its underground structure, which behaves like a foundation. Stables, which has been destroyed by the earthquake, partially restored following through stabilization of walls, ceilings, and vaults using a mesh made of artificial fibres (Vatandoust et al. 2008a) (Figure 5-6).



**Figure 5- 7** *left: Stables after the earthquake (Author, 2008), right: Stables after the post-earthquake recovery (Felicitas Ernst, 2018, taken for the author)*

**Barracks:** this rectangular brick paved area is surrounded by two stories of rooms that were partially damaged by the earthquake despite the pre-earthquake restoration (ICHHTO, 2008a). Its construction technique is based on the earthen walls and dome roofs using mud brick, mud layer and straw plaster. Barracks has been restored following the earthquake by applying the traditional adobe materials (Figure 5-7).



**Figure 5- 6** *left: Barracks and Stables before the earthquake (ICHHTO: Bam Local Office), right: Barracks after the post-earthquake recovery (Author, 2013)*

**Residential quarter:** the main part of the residential area is located on the southern side of the Governor’s quarter. The residential quarter comprises different parts such as houses, theatre, Madreseh and a bazaar, which connects the main gate to the Governor’s part. Below, the main elements of the residential quarter are described.

**Sistani house:** the Sistani house is a typical house, including a private area known as Andarooni and a public area known as Birooni, located in the middle of the residential area. Two rooms of the house were selected for the stabilisation project. Stabilization was done by using mud bricks reinforced with palm fibres, injection grouting of cracks, and connection of the structure to the ground with tension elements (Vatandoust et al. 2008a) (Figure 5-8).



Figure 5-8 *left*: Sistani house after the post-earthquake restoration (Author 2013), *right*: The post-earthquake reinforcement in Sistani house (Author 2013)

**Payambar mosque:** the Payambar mosque is situated in the western part of the citadel and the north-west of the bazaar. The mosque was destroyed by the earthquake and has been fully restored in response to the needs of the local community (Figure 5-9). The earthen structures were connected to the ground with tension elements to increase the seismic performance of the whole building (Vatandoust et al. 2008a).



Figure 5-9 A view from the Governor's quarter to the residential quarter, including a bazaar, Payambar mosque, and Sistani house during the post-earthquake recovery (Author 2013)

**Mirzā Na'im ensemble:** this complex, which is located in the middle of the citadel, comprises a religious theatre (Tekiyeh) and a religious school (Madreseh) that date back to the 18th century AD (ICHO, 2004). Its construction technique is based on the mud bricks and mud layers. The religious theatre has an open courtyard used for the religious ceremony of Ta'zieh. Despite the earthquake has extensively damaged the ensemble, it has been partially restored and has continued its function for religious ceremonies as well as for the meetings and workshops.

**Jameh mosque (Masjed-e Jom'eh):** the mosque is located in the south-eastern side of the citadel. It dates back to the 8th century AD, and it has been said that it was one of the oldest mosques ever built in Iran; the mosque had a courtyard surrounded by three prayer hall and Eyvāns (ICHO, 2004). Its construction technique is based on earthen walls and domes using mud brick, mud layer, and straw plaster. It was destroyed by the earthquake. Currently, the earthquake debris was removed and the restoration plan is under progress. The mosque and the nearby well so-called 'Chāh-e Sāheb-e Zamān' have played an important role in the religious rituals of the local residents.

**Tekiyeh:** the religious theatre so-called ‘Tekiyeh’ is situated in the intersection of the bazaar’s main row of shops and the paths that lead to the mosque. It involves an open courtyard, where religious ceremonies took place, flanked by rooms and two-storeyed galleries (ICHO, 2004). Its construction technique is based on earthen walls and dome roofs using mud brick, mud layer, and straw plaster. The building was destroyed by the earthquake (Figure 5-10, left) and restoration work is currently being carried out to continue its function (Figure 5-10, right).



**Figure 5-10** left: Tekiyeh after the earthquake (ICHO, 2004), right: Tekiyeh after the post-earthquake restoration (Felicitas Ernst, 2018, taken for the author)

**Bazaar:** a dome roof construction, on a north-south axis, connects the main gate to the Governor’s quarter. It was a marketplace, the so-called ‘bazaar’, for exchanging and selling goods such as silk and cotton garments. Its construction technique is based on earthen walls and dome roofs using mud brick, mud layer, and straw plaster. The bazaar was destroyed by the earthquake and currently, has been restored and reinforced by applying mesh made of artificial fibres for reinforcing its domes and arcs (Figure 5-11).



**Figure 5-11** bazaar during the post-earthquake recovery (Author, 2013)

**Residential remains:** those areas that consist mainly of remaining structures in the residential quarter, such as houses, public spaces, and Konāri quarter (Figure 5-12), are considered as the residential remains in the exposure assessment phase. Apart from the earthquake, this area has suffered from decay and deterioration due to the environmental factors, such as wind-driven sand.



Figure 5-12 *left*: View to residential remains (south-west of citadel) after the earthquake (Author, 2013), *right*: View to the residential quarter (south-east of citadel) after the earthquake (Author, 2013)

#### 5.4.1.2 Surrounding the Bam citadel<sup>14</sup>

**Icehouse:** in the north-eastern part of the citadel, there is a unique dome roof construction using mud bricks that is called icehouse (Yakhchāl) (Figure 5-13, left). In order to supply cold water for the summertime, a vast shallow pool shaded by a long adobe wall was used during the long winter nights to make ice; then, the ice was removed from the pool at dawn and was restored in a large tank under the large dome of the Icehouse to be used during the hot summer days (ICHO, 2004). The icehouse had been restored before the earthquake and transformed into an auditorium (ibid). The Icehouse, and particularly its large dome, was extremely damaged by the earthquake and it is currently under the restoration work (Figure 5-13, right).



Figure 5-13 *left*: Icehouse before the earthquake (ICHO, 2004), *right*: Icehouse after the earthquake (Author, 2013)

**Qanats:** the survival of the Bam old settlement in the arid region relied heavily on an ancient underground irrigation system called Qanat, dating back to 2.500 years ago. It is an example of environmental resilience and the sustainable interaction of nature and human-kind. Qanat, which consists of a gradually sloping underground channel and vertical shafts, is a method of supplying groundwater that transfers water from an aquifer to a human settlement in arid and semi-arid regions.

<sup>14</sup> This section is based on a paper published by the author (Ravankhah et al., 2017b).



**Figure 5-14 Cultural Landscape in the northern part of the citadel after the earthquake (Author, 2013)**

Qanat is vital for continuity of the cultivation and irrigation of date palms in Bam (Figure 5-14). According to the *State of Conservation* of the property in 20102, “in Bam city, there are 125 Qanats. During the earthquake, 64 of those Qanats were destroyed. 80% of the gardens around the city are irrigated by the Qanats, which means 8.000 hectares. 306 km have been used as channels for caring the water. 125 of the Qanats have been restored and cleaned” (UNESCO WHC’s website, 2016).

**Date palm orchards:** date palm orchards are another significant element of Bam’s cultural landscape, highly dependent on the Qanat system. Sabri et al. (2006, p. 50), in describing the ‘garden city’ of Bam as a ‘micro-ecosystem’, state that “it is a network of gardens mixed into the urban fabric which extend to the outskirts of the town” and stress the understanding of this model in the reconstruction of the city of Bam (Figure 5-15). Many date palms survived the earthquake and are still considered as the main source of agricultural production. For the local residents, date orchards are not just a source of income but a part of family identity (Fallahi, 2007). The gardens represent a traditional agricultural land-use adapted to a desert area that, combined with the Qanat system, reflects ecosystem management that takes full advantage of locally available resources.



**Figure 5-15 left: View from the citadel to the date palm orchards in the northern part (Author, 2013), right: Date palm orchards and water streams in Bam (Author, 2008)**



### 5.4.1.3 Intangible attributes linked to the property<sup>15</sup>

It should be mentioned that intangible attributes of Bam and its Cultural Landscape cannot be separated from the tangible elements and each relies on the other for conveying the meaning and functional continuity among the local community. In the exposure assessment, intangible attributes are also considered to emphasise their role in linking the property to the Bam community. Below, the main intangible attributes of Bam are mentioned.

**Religious rituals and ceremonies:** as mentioned earlier, local religious rituals and ceremonies (e.g. Ashura ceremony so-called 'Ta'zieh' in the courtyard of Tekiyyeh) take place in the Jameh mosque, the Tekiyyeh, and in the Payambar mosque in the citadel. Ta'zieh has been inscribed on the *Representative List of the UNESCO Intangible Cultural Heritage of Humanity* in 2010. "Ta'zīye (or Ta'azyeh) is a ritual dramatic art that recounts religious events, historical and mythical stories and folk tales" (Intergovernmental Committee for the Safeguarding of the Intangible Cultural Heritage, 2010). There is also an annual ceremony linked to the Persian New Year so-called 'Nowruz' in the Governor's quarter. Such ceremonies have been an enabler for retaining the sense of identity and belonging to the property among local inhabitants for many years and can be considered as a positive factor in the post-disaster socio-cultural rehabilitation of the city.

**Traditional knowledge and technique of earthen architecture:** Arg-e Bam is a well-known earthen construction worldwide based on the locally available materials and the technique of mud layer (Chineh) combined with mud bricks (Khesht). According to the *Bam Declaration and Recommendations* (ICHO et al., 2004b, p.5), "The impact of the earthquake on the built heritage of Bam and its infrastructures demonstrated that it was the quality of construction and engineering of the buildings that was the main cause of damage rather than the construction materials themselves". Applying the earthen construction technique in the pre and post-disaster conservation and reinforcement strategies need to be adequately taken into account.

**Traditional management system linked to the Qanat:** the distribution and maintenance of the Qanat water require a social structure and traditional management system that can have a great potential for improving risk communication and awareness-raising among the local inhabitants. Although the system was partially damaged by the earthquake, it continues to irrigate Bam's gardens and supply drinking water. Since the Qanat system is owned by local inhabitants, communal meetings take place to dedicate the required funds for annual repair and cleaning of the system in a socially cooperative manner (Ward English, 1998), in order to ensure the supply of water to all dwellings and gardens. Such a linkage between traditional environmental management and social structure can be also viewed as a positive factor for promoting disaster resilience in Bam.

### 5.4.2 Assessing the relative significance of the elements

As mentioned in *Chapter 2-Study area*, Bam and its Cultural Landscape has been inscribed on the WH List under the following criteria (UNESCO WHC's website, 2012):

- **Criterion (ii):** the interaction of the various influences at the crossroads of important trade routes at the southern side of the Iranian high plateau;
- **Criterion (iii):** development of a trading settlement in the desert environment of the Central Asian region;
- **Criterion (iv):** a fortified settlement and citadel in the Central Asian region, based on the use mud layer technique (Chineh) combined with mud bricks (Khesht); and

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<sup>15</sup> This section is based on a paper published by the author (Ravankhah et al., 2017b).

- **Criterion (v):** the interaction of man and nature in a desert environment, using the Qanats.

When it comes to the OUV of the property, the different elements are the integral part of the Bam's cultural landscape for conveying the above criteria. Therefore, they cannot be independently judged and prioritised in the context of the OUV. However, in order to conduct exposure assessment and further risk assessment procedure, the significance of the elements need to be weighed while using specific indicators. The defined indicators are proposed in order to facilitate the risk assessment procedure and its further prioritisation purposes; they do not necessarily represent the value of the elements. The indicators for the significance analysis, as described in *Chapter 4-Methodology*, are as follows:

- **Architectural and technological significance:** it represents the architectural and technical achievement in applying the traditional knowledge and technique of earthen architecture, which is based on the locally available materials and the construction technique of mud bricks (Khesht) and mud layer (Chineh).
- **Aesthetic significance:** it characterizes the form, scale, and materials of the earthen walls, arcs, and dome roofs using mud brick, mud layer, and straw plaster.
- **Historical significance:** it represents the evolution of the citadel. According to the archaeological evidence, it dates back to the Achaemenid period between the 6th and 4th centuries BC. The old settlement was situated on the crossroads of important trade routes linked to the Silk Road.
- **Social significance:** it is associated with the social structure and identity of the local community, including the traditional management system of Qanat water distribution and local religious rituals and ceremonies (e.g. Ashura ceremony so-called 'Ta'zieh' in the courtyard of Tekiyyeh).
- **Economic importance:** it represents the significance of the property in the tourism industry and in providing employment opportunities for Bam residents. Furthermore, the local economy relies heavily on the elements of the cultural landscape such as date palm orchards and Qanat irrigation system.
- **Functional importance:** it is associated with the current use of the elements, for instance, religious rituals and ceremonies taking place in Jameh mosque, Tekiyyeh, and Peyambar mosque in the citadel.
- **Environmental importance:** it embodies the environmental significances of the cultural landscape in respect to the local earthen materials, the Bam settlement in the semi-arid regions, ecosystem management and the cultivation and irrigation of date palms using the Qanat system.
- **Degree of integrity:** it represents the "wholeness" and "intactness" (UNESCO WHC, 2017, para. 88) of the elements of the property to convey the aforementioned significances in the current condition of the property.

Table 5-3 presents the significance assessment of the components of Bam and its Cultural Landscape according to the above-mentioned indicators. The measurement of indicators was conducted based on the current information mentioned in *Chapter 2-Study area* and in *Section 5.4.1- Identifying elements of Bam exposed to the earthquakes*. The expert opinion has been also considered through consulting with Dr. Eskandar Mokhtari, the former director of the Bam recovery project. The significance scores assigned to the elements fall in one of the ranking scales of Unknown (1), Limited (2), Some (3), Considerable (4), and Exceptional (5). In case an indicator is not applicable to an element or data is not available, it is shown by 'N/A' and 'N/D', respectively.

Table 5-3 Assessing the significance of the elements of Bam and its Cultural Landscape

Elements of Bam and its Cultural Landscape	Indicators for significance analysis								Significance score	Overall level of significance
	Architectural and technological significance	Aesthetic significance	Historical significance	Social significance	Economic importance	Functional importance	Environmental importance	Degree of integrity		
Fortification walls and towers	4	4	5	3	4	3	3	3	3.6	Some (3)
Governor's quarter	5	5	5	4	4	2	3	3	3.8	Considerable (4)
Barracks	5	5	5	4	4	3	3	3	4	Considerable (4)
Stables	4	5	5	4	4	2	3	3	3.7	Some (3)
Main gate	3	5	5	3	4	4	3	2	3.6	Some (3)
Bazaar	4	5	5	5	4	2	3	3	3.9	Considerable (4)
Tekiyeh	4	5	5	4	4	4	3	3	4	Considerable (4)
Sistani house	4	4	5	3	4	4	3	4	3.9	Considerable (4)
Peyambar mosque	3	4	5	4	4	4	3	3	3.7	Some (3)
Jaame mosque	3	3	5	4	4	4	3	3	3.6	Some (3)
Mirzā Na'im Ensemble	4	4	5	4	4	2	3	3	3.6	Some (3)
Residential remains	3	2	5	3	4	2	3	2	3	Limited (2)
Surrounding structure (Icehouse)	4	3	5	4	4	2	4	3	3.6	Some (3)
Qanat	5	3	5	5	5	5	5	3	4.5	Exceptional (5)
Date palm orchards	N/A	N/A	5	3	5	5	5	3	4.3	Considerable (4)

Following the analysis of the significance of the elements of Bam, the arithmetic mean is applied to the above indicators to measure the overall significance scores. In order to keep the consistency of the number of classes in the further risk index, the scores are reclassified to divide the range of scores into five equal-sized classes with class ranges of 2.0-2.6, 2.6-3.2, 3.2-3.8, 3.8-4.4, and 4.4-5.0. The class calculation is based on the lowest and highest significance scores assigned to the elements to conduct a comparison between the elements. To calculate the level of exposure, the above-mentioned classes are respectively interpreted as Very low (1), Low (2), Medium (3), High (4), and Very high (5) level of exposure.

### 5.4.3 Mapping the elements and their associated significance

Figure 5-16 shows the exposure map of the property that was generated according to the above significant assessment matrix for the elements of Bam and its Cultural Landscape.

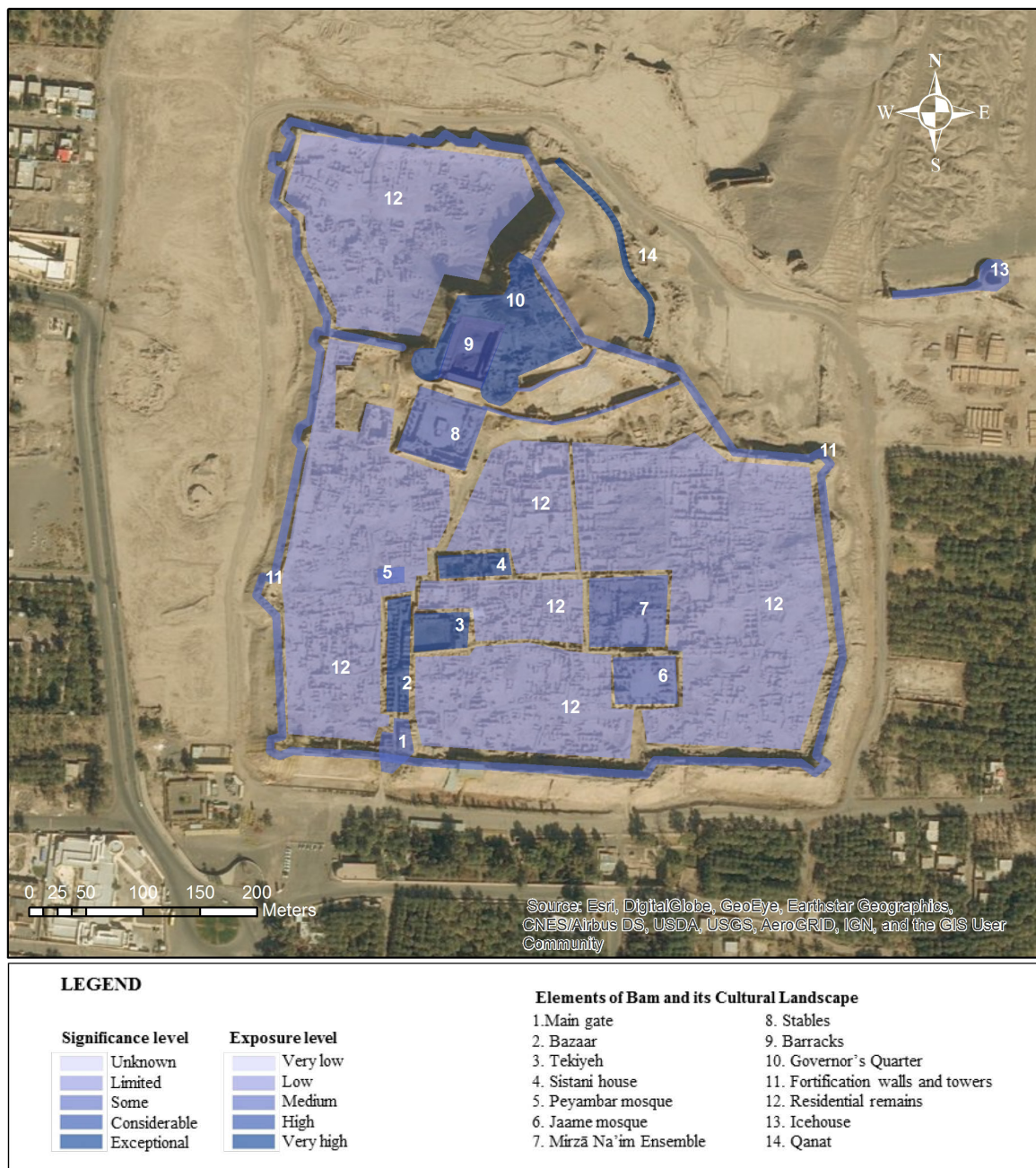


Figure 5-16 Exposure (significance) map of the elements of Bam (with a focus on Arg-e Bam and its immediate surrounding)

### 5.5 Assessing the seismic vulnerability of the elements of Bam

Apart from the severity of earthquakes, the structural characteristics of a site and the status of existing management systems are key factors contributing to the level of potential impacts on the property. Such factors represent ‘vulnerability’ of the site to potential disasters. As it is mentioned in *Chapter 4-Methodology*, the seismic vulnerability of the property is analysed based on the two components of ‘susceptibility’ and ‘coping capacity’ while measuring their corresponding indicators. The data

required for the vulnerability assessment was gathered through the expert questionnaire and the in-situ observation while cross-checked by the post-earthquake reports and documents.

### 5.5.1 Analysing seismic susceptibility

Seismic susceptibility of a heritage property represents the weakness of its structural and material features to withstand the earthquake forces. Susceptibility analysis for Bam is an approximate semi-quantitative assessment procedure based on the particular indicators derived in the methodology, *Section 4.3.3.1- Deriving indicators for susceptibility analysis*. The indicators were analysed based on the fieldwork to observe current condition of earthen materials and structures (please see the pre and post-earthquake photos provided in *Section 5.4.1- Identifying elements of Bam exposed to the earthquakes*) and the post-earthquake restoration and reinforcement activities as well as analysis of the relevant reports and documents. The indicators for the analysis of susceptibility are as follows:

- Quality of structure/material;
- Type of foundation/ground;
- Cracks and detachments;
- Material losses; and
- Termites' damage.

Table 5-4 shows the susceptibility analysis of the components of Bam and its Cultural Landscape according to the above-mentioned indicators. The measurement of indicators is conducted according to the ranking criteria, defined in *Chapter 4-Methodology*. The ranking scores assigned to the susceptibility indicators are Low (1), Medium (2), or High (3) susceptibility. In case an indicator is not applicable to an element or data is not available, it is shown by 'N/A' and 'N/D', respectively.

**Table 5-4 Analysing seismic susceptibility of the elements of Bam and its Cultural Landscape**

Elements of Bam and its Cultural Landscape	Quality of structure/material	Type of foundation/ground	Cracks and detachments	Material losses	Termites damage	Susceptibility score	Susceptibility level
	<i>SI<sub>s</sub></i> ( <i>W<sub>s</sub></i> =0.36)	<i>SI<sub>f</sub></i> ( <i>W<sub>f</sub></i> =0.36)	<i>SI<sub>c</sub></i> ( <i>W<sub>c</sub></i> =0.16)	<i>SI<sub>m</sub></i> ( <i>W<sub>m</sub></i> =0.06)	<i>SI<sub>b</sub></i> ( <i>W<sub>b</sub></i> =0.06)		
<b>Fortification walls and towers</b>	Heavily damaged mud structures, (3)	lack of foundation, built on a bed of soft soil, (3)	Many deteriorated areas, (3)	Many deteriorated areas, (3)	Some deteriorated areas, under restoration, (2)	2.9	Very high (5)
<b>Governor's quarter</b>	Heavily damaged mud structures, (3)	Built on a rock bed, (2)	Many deteriorated areas, (3)	Many deteriorated areas, (3)	Many deteriorated areas, (3)	2.6	Very high (5)
<b>Barracks</b>	Good quality mud layers and mud bricks, appropriately repaired/reinforced, (1)	Built on a rock bed, (2)	Some deteriorated areas, under restoration, (2)	Appropriately repaired/reinforced, (1)	Appropriately repaired/reinforced, (1)	1.5	Low (2)

Elements of Bam and its Cultural Landscape	Quality of structure/ material	Type of foundation/ ground	Cracks and detachments	Material losses	Termies damage	Susceptibility score	Susceptibility level
	<i>SIs (Ws=0.36)</i>	<i>SIf (Wf=0.36)</i>	<i>Sic (Wc=0.16)</i>	<i>SIm (Wm=0.06)</i>	<i>Sib (Wb=0.06)</i>		
<b>Stables</b>	<i>Damaged mud structures, partly reinforced, (2)</i>	<i>Built on a rock bed, (2)</i>	<i>Some deteriorated areas, under restoration, (2)</i>	<i>Some deteriorated areas, under restoration, (2)</i>	<i>Some deteriorated areas, under restoration, (2)</i>	2.0	Medium (3)
<b>Main gate</b>	<i>Good quality mud layers and mud bricks, appropriately repaired/reinforced, (1)</i>	<i>lack of foundation, built on a bed of soft soil, (3)</i>	<i>Appropriately repaired/reinforced, (1)</i>	<i>Appropriately repaired/reinforced, (1)</i>	<i>Appropriately repaired/reinforced, (1)</i>	1.7	Low (2)
<b>Bazaar</b>	<i>Good quality mud layers and mud bricks appropriately repaired/reinforced, (1)</i>	<i>lack of foundation, built on a bed of soft soil, (3)</i>	<i>Appropriately repaired/reinforced, (1)</i>	<i>Appropriately repaired/reinforced, (1)</i>	<i>Appropriately repaired/reinforced, (1)</i>	1.7	Low (2)
<b>Tekiyeh</b>	<i>Good quality mud layers and mud bricks, appropriately repaired/reinforced, (1)</i>	<i>lack of foundation, built on a bed of soft soil, (3)</i>	<i>Appropriately repaired/reinforced, (1)</i>	<i>Appropriately repaired/reinforced, (1)</i>	<i>Appropriately repaired/reinforced, (1)</i>	1.7	Low (2)
<b>Sistani house</b>	<i>Damaged mud structure, partly reinforced, (2)</i>	<i>Connection of the structure to the ground with tension elements, built on a bed of soft soil, (2)</i>	<i>Some deteriorated areas, under restoration, (2)</i>	<i>Some deteriorated areas, under restoration, (2)</i>	<i>Appropriately repaired/reinforced, (1)</i>	1.9	Medium (3)
<b>Peyambar mosque</b>	<i>Good quality mud layers and mud bricks, appropriately repaired/reinforced, (1)</i>	<i>Connection of the structure to the ground with tension elements, built on a bed of soft soil, (2)</i>	<i>Some deteriorated areas, under restoration, (2)</i>	<i>Appropriately repaired/reinforced, (1)</i>	<i>Appropriately repaired/reinforced, (1)</i>	1.5	Low (2)
<b>Jaame mosque</b>	<i>Heavily damaged mud structures, (3)</i>	<i>lack of foundation, built on a bed of soft soil, (3)</i>	<i>Many deteriorated areas, (3)</i>	<i>Many deteriorated areas, (3)</i>	<i>Some deteriorated areas, under restoration, (2)</i>	2.9	Very high (5)

Elements of Bam and its Cultural Landscape	Quality of structure/ material	Type of foundation/ ground	Cracks and detachments	Material losses	Termites damage	Susceptibility score	Susceptibility level
	<i>SIs (Ws=0.36)</i>	<i>SIf (Wf=0.36)</i>	<i>SIc (Wc=0.16)</i>	<i>SI<sub>m</sub> (W<sub>m</sub>=0.06)</i>	<i>SI<sub>b</sub> (W<sub>b</sub>=0.06)</i>		
<b>Mirzā Na'im ensemble</b>	Heavily damaged mud structures, (3)	lack of foundation, built on a bed of soft soil, (3)	Many deteriorated areas, (3)	Many deteriorated areas, (3)	Some deteriorated areas, under restoration, (2)	2.9	Very high (5)
<b>Residential remains</b>	Heavily damaged mud structures, (3)	lack of foundation, built on a bed of soft soil, (3)	Many deteriorated areas, (3)	Many deteriorated areas, (3)	Some deteriorated areas, under restoration, (2)	2.9	Very high (5)
<b>Surrounding structure (Icehouse)</b>	Heavily damaged mud structure, (3)	lack of foundation, built on a bed of soft soil, (3)	Many deteriorated areas, (3)	Many deteriorated areas, (3)	Some deteriorated areas, under restoration, (2)	2.9	Very high (5)
<b>Qanat</b>	Heavily damaged mud structures, (3)	Underground structure, (2)	Many deteriorated areas, (3)	Many deteriorated areas, (3)	Some deteriorated areas, under restoration, (2)	2.6	High (4)

Subsequently, the susceptibility of the elements to earthquakes is computed (according to the weights obtained in *Section 4.3.3.1- Deriving indicators for susceptibility analysis*) through the following equation:

$$S_{Earthquake} = (SI_s \times 0.36) + (SI_f \times 0.36) + (SI_c \times 0.16) + (SI_m \times 0.06) + (SI_b \times 0.06)$$

Where

S = overall susceptibility;

SI = susceptibility indicators; and

W = weights (Ws, Wf, Wc, Wm, and Wb are the weights corresponding to SIs, SIf, SIc, SI<sub>m</sub>, and SI<sub>b</sub>, respectively).

In order to keep the consistency of the number of classes in the further risk index, the susceptibility scores are reclassified to divide the range of scores into 5 equal-sized classes with class ranges of 1-1.4, 1.4-1.8, 1.8-2.2, 2.2-2.6, and 2.6-3. They are respectively interpreted as Very low (1), Low (2), Medium (3), High (4), and Very high (5) susceptibility level.

### 5.5.2 Mapping the susceptibility of the elements

Figure 5-17 shows the seismic susceptibility map of the property that was generated according to the above susceptibility analysis of the elements of Bam and its Cultural Landscape.

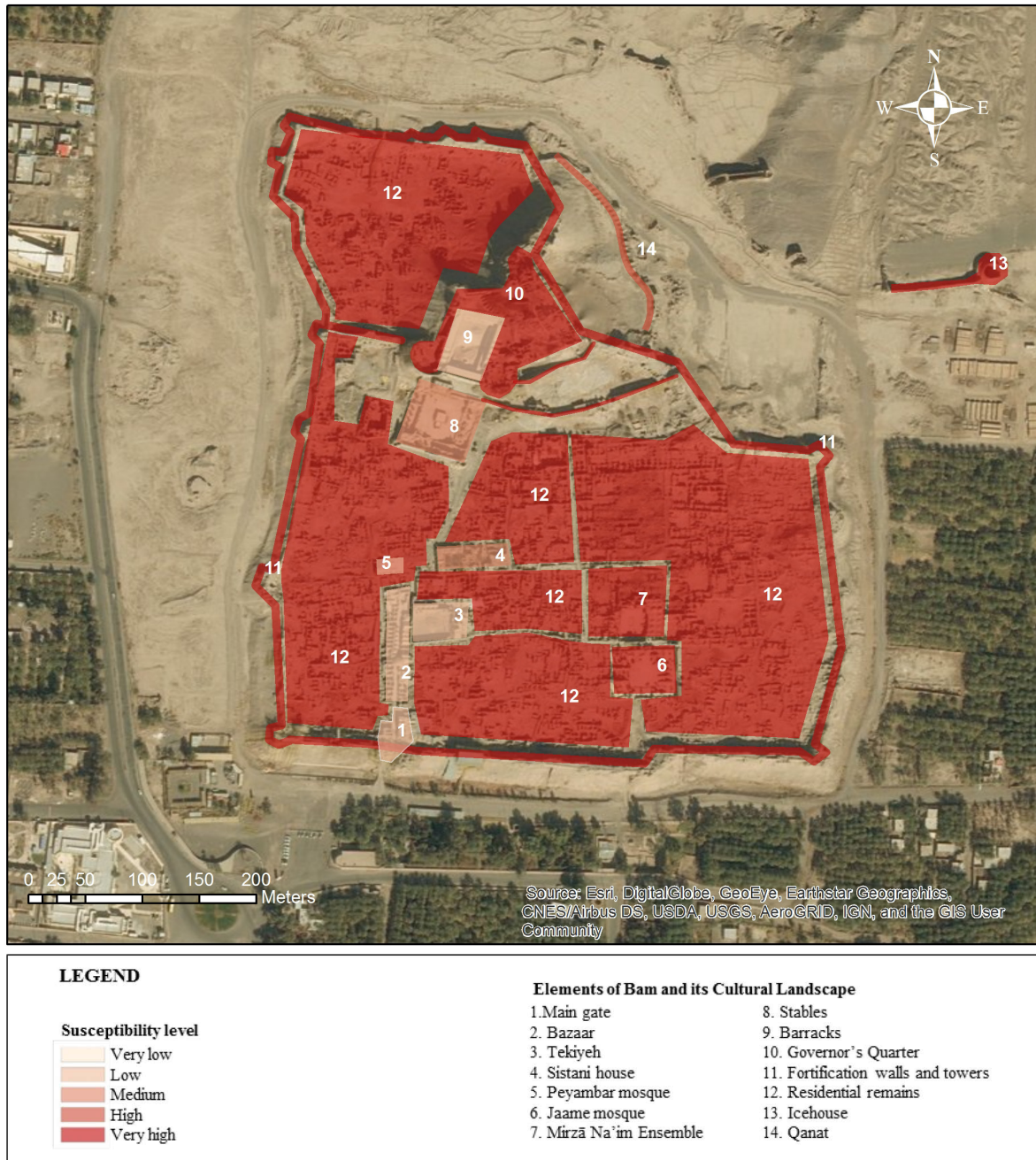


Figure 5-17 Susceptibility map of the elements of Bam (with a focus on Arg-e Bam and its immediate surrounding)

### 5.5.3 Analysing the coping capacity of the management system

Coping capacity relies heavily on the heritage management system, and in a broader context, on the urban and regional planning engaged in the protection of cultural heritage from disasters. In this research, the capacity analysis was conducted based on particular indicators incorporated into the experts' questionnaire. In respect to some indicators, only those experts who work in the responsible agencies can answer the corresponding questions. The experts' responses are cross-checked with the post-earthquake reports and documents, such as *Annual Report of Arg-e Bam Research Foundation* (ICHHTO, 2008b) and *Comprehensive Management Plan for Bam and its Cultural landscape 2008-*



2017 (ICHHTO, 2008a), to ensure the accuracy of responses. According to *Section 4.3.3.2-Deriving indicators for coping and adaptive capacity analysis*, the indicators for the analysis of coping capacity are as follows:

- Information and communication system;
- Risk awareness;
- Risk mitigation strategies/actions;
- Risk preparedness strategies/actions (including emergency response and recovery plan); and
- Institutional framework.

Table 5-5 shows the coping capacity analysis of the components of Bam and its Cultural Landscape according to the above-mentioned indicators. The indicators are measured based on the ranking scales, defined in *Chapter 4-Methodology*. Accordingly, the ranking scores assigned to the capacity indicators are Very low (1), Low (2), Medium (3), High (4), and Very high (5). These scores are respectively corresponding to the quality level of plan/measures in the expert questionnaire as ‘Nothing exists’, ‘Poorly-developed’, ‘Acceptable’, ‘Well-developed’, and ‘Very well-developed’. In case the expert’s response is not applicable or data is not available, it is shown by ‘N/A’ and ‘N/D’, respectively.

**Table 5-5 Analysing the coping capacity of the management system**

Coping capacity indicators /sub-indicators		Expert 1	Expert 2	Expert 3,4,5	Document analysis (based on the post-earthquake reports and documents in Bam Local Office)	Score
Information and communication system	Heritage information system (e.g. inventory of heritage assets)	4	4	N/D	<i>According to the Annual Report of Arg-e Bam Research Foundation (ICHHTO, 2008b)</i>	4
	Risk information system and maps (e.g. GIS database)	1	1	N/D	<i>According to the Annual Report of Arg-e Bam Research Foundation (ICHHTO,2008b); and Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a)</i>	1
	Directory of emergency-related contacts (including heritage and disaster experts)	4	2	N/D	<i>Considering the opinion of the expert 1, who is based on the Research and technical centre of the World Heritage site of Bam and its Cultural Landscape</i>	4
Risk awareness	Staff awareness regarding impacts of earthquakes on the property	-	-	-	<i>According to the staff interview at local office during the fieldwork</i>	3
	Local people awareness regarding impacts of earthquakes on the property and its indirect effects	-	-	-	<i>According to An Interdisciplinary Analytical Study on the Risk Preparedness of Bam and Its Cultural Landscape (Fallahi, 2008)</i>	3

Coping capacity indicators /sub-indicators		Expert 1	Expert 2	Expert 3,4,5	Document analysis (based on the post-earthquake reports and documents in Bam Local Office)	Score	
Risk mitigation strategies/actions	Monitoring and maintenance of structures	1	2	N/D	Considering the opinion of the expert 1, who is based on the Research and technical centre of the World Heritage site of Bam and its Cultural Landscape	1	
	Structural risk mitigation (e.g. seismic structural reinforcement) including post-earthquakes stabilisation	4	4	N/D	According to the Annual Report of Arg-e Bam Research Foundation (ICHHTO, 2008b)	4	4
	Traditional knowledge and technique of earthen construction	3	3	N/D	According to the Annual Report of Arg-e Bam Research Foundation (ICHHTO, 2008b)	3	3
	Modern methods of restoration and reinforcement	3	2	N/D	According to the Annual Report of Arg-e Bam Research Foundation (ICHHTO, 2008b)	3	3
	Consideration of the OUV, authenticity, and integrity in the restoration and mitigation measures	4	4	N/D	According to the Annual Report of Arg-e Bam Research Foundation (ICHHTO, 2008b)	4	4
Risk preparedness strategies/actions (including emergency response and recovery)	first aid measures (e.g. salvage, triage, and stabilization of movable and immovable heritage)	1	1	N/D	According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'risk preparedness and disaster mitigation'	1	1
	Emergency response services (e.g. equipment and supplies)	3	1	N/D	Considering the opinion of the expert 1, who is based on the Research and technical centre of the World Heritage site of Bam and its Cultural Landscape	3	
	Early warning system (e.g. for fires)	1	1	N/D	According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'risk preparedness and disaster mitigation'	1	1
	Disaster drills and field exercises within the site	-	-	-	According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'risk preparedness and disaster mitigation'	2	2
	Emergency evacuation plan for staff and tourists in the citadel	1	1	N/D	According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'risk preparedness and disaster mitigation'	1	1

Coping capacity indicators /sub-indicators		Expert 1	Expert 2	Expert 3,4,5	Document analysis (based on the post-earthquake reports and documents in Bam Local Office)	Score	
	Risk compensation mechanism and insurance coverage	1	N/D	N/D	<i>According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'risk preparedness and disaster mitigation'</i>	1	1
Institutional framework	Legal framework for conservation and management of the property, including protection of the property from earthquakes	-	-	-	<i>According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'institutional framework'. Compared to local/national heritage, the legal framework for WH properties is better developed.</i>	3	3
	Cooperation between heritage organisations and disaster management, environmental bodies, and civil protection	-	-	-	<i>According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'stakeholders and engaged agencies'</i>	3	3
	Integration of the property in disaster risk management of the city of Bam	2	3	N/D	<i>According to Comprehensive Management Plan for Bam and its Cultural Landscape 2008-2017 (ICHHTO, 2008a); Section 'urban and regional planning'</i>	3	3
<b>Overall coping capacity score</b>						<b>2.50</b>	

Following the analysis of the capacity indicators, the arithmetic mean aggregation method is applied to them to measure the overall coping capacity of the system. The overall score of coping capacity falls into one of the classes of 1-1.8, 1.8-2.6, 2.6-3.4, 3.4- 4.2, and 4.2-5. As mentioned in the *Chapter 4-Methodology*, to be able to integrate this component into the risk index, the 'lack of coping capacity' needs to be considered. The reason is that because the components of risk are multiplied to measure risk, they need to be of the same nature regarding their influence on the level of risk. To calculate the lack of coping capacity, the mentioned classes are respectively interpreted as Very high (5), High (4), Medium (3), Low (2), and Very low (1) level of lack of coping capacity. For instance, if 'coping capacity' is very low and its score falls into 1-1.8, the 'lack of coping capacity' will be very high. In the case of Bam, the overall coping capacity score is 2.50 (please see Table 5-5) that falls into the second class (1.8-2.6); accordingly, the level of lack of coping capacity is 'High' (4).

The vulnerability is calculated by multiplying 'susceptibility' by 'lack of coping capacity' while applying a specific equation defined in *Section 4.3.3.3-Calculating the vulnerability*. The level of vulnerability of the elements of Bam to earthquakes is calculated in *Section 5.7-Risk analysis and building a risk index for the elements of Bam* while conducting the Bam risk index.

## 5.6 Identifying potential impacts of earthquake-induced disasters

According to the expert questionnaire, the earthquake 2003 had a high impact level on the physical elements of Bam, and consequently, it caused a significant loss of the values associated with the earthen construction know-how and religious rituals in the citadel. In the post-earthquake damage assessment and recovery project, the structural authenticity and visual integrity have been

particularly taken into account to retain the OUV of the property. An example of such activities is the application of palm fibres to the adobe materials to improve their seismic performance while ensuring the material compatibility and retaining authenticity. The palm fibre is a locally-available material with high resistance to termites. Before performing an impact identification matrix for the case of Bam, a preliminary disaster scenario is defined in order to frame the multiple emergency situations to explore the nature of potential impacts in advance.

### 5.6.1 Defining an earthquake disaster scenario in Bam

According to the seismic data and maps in the region, there is a possibility of **an earthquake** with high severity in the city of Bam in the next 500 years. It can be a strong earthquake with the intensity of VIII to X, which may cause moderate to severe damage to the non-earthquake-resistant structures. The earthquake will probably cause serious damages to the WH site of **Bam and its Cultural Landscape**; to its **tangible elements** (e.g. Bam Citadel, Qanat system, and archaeological remains) as well as **intangible attributes** (e.g. earthen construction know-how and religious rituals).

The earthquake may seriously damage the **adobe structure** since it is highly vulnerable to seismic lateral forces. The level of impact might be higher in those parts of the property that have lost their structural integrity; have not been adequately stabilized after the earthquake 2003 or **inappropriately restored or reinforced**; and have lost the material cohesion due to the **climate factors and termites**. The situation may lead to the loss of **earthen architecture knowledge** and technique as well as the loss of socio-cultural values associated with the **religious rituals** in the citadel. The disaster may damage the **Qanat** irrigation system leading to a serious **shortage of water** that is vital for the irrigation of **date palms** as the main source of the economy in the city of Bam.

There is a probability that the earthquake cause **liquefaction** because of the soft soil specifically around Qanat, and cause cracks in the earthen walls and block the **shafts of the Qanat**. The quake-damaged gas and electricity lines around the citadel may cause explosions and fires, which can particularly impact date palm orchards. Furthermore, there is a potential that **rainfall** causes **dampness** into porous mud materials and collections that might be already cracked or collapsed. Post-dampness drying in adobe materials may cause the growth of **micro-organisms** such as fungi. **Wind-driven rain and sandstorm** may cause additional damages and erosion of already affected adobe materials, in particular in those buildings that have already lost protective roofs.

The collapsed buildings and materials may cause loss of life and injuries to local people, site staff, and tourists. The **routes may be blocked** that disrupt **emergency evacuation** and firefighting activities. The situation will be more challenging due to the **lack of an appropriate risk preparedness** plan for the property. **Lack of security and safety** in the property and city will further affect the **tourism-related industry** that leads to an **economic loss** in the city.

During the emergency, Arg-e Bam may be exposed to the **looting of materials and collections** due to the lack of security. During the emergency response, volunteers, fire and rescue team, and even site staff may cause **additional risk** to the property resulting in a loss of the **OUV, authenticity, and integrity**. During the recovery process, **improper interventions** might increase the vulnerability of the property to further hazards, and also may affect the authenticity and integrity of the property. **Illegal development** and encroachment may also occur adjacent to the core zone and threaten the integrity of the property.

### 5.6.2 Developing an impact identification matrix

According to the expert questionnaire, the earthquake 2003 highly damaged the citadel and its associated elements such as surrounding earthen structures and Qanat irrigation system. Partial

destruction of some key attributes caused a loss of the OUV, authenticity of structure and design, and structural and visual integrity of the property. As described in Section 4.3.4.2- *Developing an impact identification matrix*, an impact identification matrix is developed to link the potential sources of risk to the receptors of impact during and after a disaster. The earthquake-induced disaster in the matrix comprises the following three categories of risk sources:

- Primary effects that are liquefaction, landslides, and ground shaking.
- Secondary hazards and climate factors that include wind-driven sand/rain and sandstorms, precipitation and surface runoff, and fires and explosions.
- Human-induced threats that might be associated with improper interventions and reconstruction, improper emergency response, illegal urban development, and looting.

The attributes of Bam and its Cultural Landscape that might be affected by the above-mentioned hazards and threats are as follows:

- Tangible attributes that encompass Bam Citadel (including adobe structure, adobe material and mortar, decorative elements and finishing, and collections and archives), and Bam's cultural landscape (including adobe structure, Qanat system, and date palm orchards).
- Intangible attributes that are associated with earthen architecture knowledge, religious rituals and ceremonies in the citadel, and the traditional management system in Bam.

Furthermore, the matrix predicts the potential loss of the OUV according to the impacts on tangible and intangible attributes that are conveying the OUV. The potential loss of authenticity, such as impact on the authenticity of material, design, and setting (UNESCO, 2017) as well as the loss of integrity, such as impact on the visual and structural integrity (Jokilehto, 2006) were determined based upon the identified impacts on the attributes of the property. Potential impacts of the secondary hazards and human-induced threats following earthquakes need to be addressed in the risk treatment strategies for Bam and its Cultural Landscape.

Table 5-6 Disaster impact identification matrix for the elements of Bam and its Cultural Landscape

Attributes of Bam and its Cultural Landscape	Potential primary and secondary hazards and threats					
	Potential primary effects			Potential secondary hazards and climate factors		
	Ground shaking	Landslide	Liquefactions	Fires & Explosions	Precipitation & surface runoff	Wind-driven sand/rain & Sandstorms
<b>Tangible attributes</b> <b>Arg-e Bam (Bam citadel)</b>	Structural cracks and deformation; Damage to masonry joints and connections; Collapse of building components (e.g. protective roofs) or entire structures	Cracks and material detachments	Cracks and layer detachments	Reduced stability by burning organic materials (e.g. straw); Damage from heat and smoke to bricks	Increased loading pressure on adobe structure; Damage to archaeological sites by sand and dust; Washing away of archaeological remains	Penetration of water and wind into porous/cracked materials; Erosion of adobe by wind and rain
	Adobe structure ( <i>mud bricks combined with mud layers</i> )	Material ( <i>mud bricks</i> ) & Mortar ( <i>clay and straw</i> )	Decorative elements & Finishing ( <i>straw plaster 'Kah-gel'</i> )	Damage from heat and smoke to interior finishes	Theft of damaged/collapsed fragments	Theft of damaged/collapsed fragments
	Cracks and layer detachments	Cracks and layer detachments	Cracks and layer detachments	Damage from heat and smoke to interior finishes	Penetration of water and wind into motives and finishes; Damage due to humidity changes; Biological contamination	Theft of damaged/collapsed fragments
	Falling down of freestanding items; Damage due to collapsed walls and ceilings; potential loss of archaeological objects	Cracks and layer detachments	Cracks and layer detachments	Damage from heat and smoke to objects; Burning of documents/archives	Damage to survived collections by humidity and wind-blown dust; Biological contamination	Theft of valuable objects and documents
						<b>Illegal urban development</b> <b>Improper emergency response</b> <b>Improper interventions &amp; reconstruction</b>
						Damage from water or dry chemicals used by firefighters; Potential damage by volunteers or rescue teams; Confusion due to lack of coordination and preparedness; Additional loss during salvage, triage, stabilization and displacement; Potential impacts on newly-revealed archaeological objects Applying incompatible structural techniques or materials during restoration and retrofitting Development pressure (e.g. high-rise buildings, extensive agricultural and mining activities, and widening of roads)



		Potential primary and secondary hazards and threats					
		Potential primary effects			Potential secondary hazards and climate factors		
		Ground shaking	Landslide	Liquefactions	Fires & Explosions	Precipitation & surface runoff	Wind-driven sand/rain & Sandstorms
<b>Specific considerations for WH properties</b>							
<b>Outstanding Universal values (OUV)</b>							
<b>Authenticity</b>							
<b>Integrity</b>							



## 5.7 Risk analysis and building a risk index for the elements of Bam

As mentioned in *Chapter 4-Methodology*, risk index method is applied to measure the level of risk to the elements of Bam and its Cultural Landscape. The components of risk, which have been analysed in the above procedure of risk assessment, are integrated into the risk index (Table 5-7) to calculate the level of vulnerability and risk. The risk components have been measured as follows:

- **Hazard:** according to the Seismic Hazard Zoning Map of Iran (Giardini et al., 2003) (please see Figure 5-2), the city of Bam is located in a high seismic zone. Based on the historical data of earthquake events in the region, an earthquake with a magnitude of 6.0–6.9 can be expected, which can be a strong earthquake with high severity. Accordingly, the level of earthquake hazard in the property is considered High (4).
- **Exposure:** the elements of Bam and its Cultural Landscape and their associated significance are exposed to potential earthquakes. Following the analysis of the significance of the elements of Bam, the arithmetic mean was applied to the indicators to measure the overall significance scores. In order to keep the consistency of the number of classes in the further risk index, the scores were reclassified and interpreted as Very low (1), Low (2), Medium (3), High (4), or Very high (5) level of exposure.
- **Vulnerability:** an indicator-based procedure is applied to assess the components of vulnerability as follows:
  - **Susceptibility:** susceptibility analysis for Bam is an indicator-based assessment procedure, based on the fieldwork to observe the current condition of earthen materials and structures. The susceptibility of the elements to earthquakes was computed by applying the Analytic Hierarchy Process method. In order to keep the consistency of the number of classes in the risk index, the scores were reclassified and interpreted as Very low (1), Low (2), Medium (3), High (4), or Very high (5) susceptibility level.
  - **Coping capacity:** capacity analysis is conducted based on an indicator-based assessment using the expert questionnaire and document analysis. The arithmetic mean aggregation is applied to measure the overall coping capacity scores. To be able to integrate this component into the risk index, the ‘lack of coping capacity’ needs to be considered. The reason is that because the components of risk are multiplied to measure risk, they need to be of the same nature regarding their influence on the level of risk. The level of lack of coping capacity may fall in one of the regions of Very high (5), High (4), Medium (3), Low (2), and Very low (1). In the case of Bam, the level of lack of coping capacity is High (4).

**Table 5-7 Risk index for Bam and its Cultural Landscape**

Elements of Bam and its Cultural Landscape	Risk No.	Hazard	Exposure	Susceptibility	Lack of Coping Capacity	Vulnerability		Risk	
						Score	Level	Score	Level
Fortification walls and towers	R.1	High (4)	Medium (3)	Very high (5)	High (4)	4.47	Very high (5)	3.9	High (4)
Governor's quarter	R.2	High (4)	High (4)	Very high (5)	High (4)	4.47	Very high (5)	4.3	Very high (5)
Barracks	R.3	High (4)	High (4)	Low (2)	High (4)	2.83	Medium (3)	3.6	High (4)

Elements of Bam and its Cultural Landscape	Risk No.	Hazard	Exposure	Susceptibility	Lack of Coping Capacity	Vulnerability		Risk	
						Score	Level	Score	Level
Stables	R.4	High (4)	Medium (3)	Medium (3)	High (4)	3.46	High (4)	3.6	High (4)
Main gate	R.5	High (4)	Medium (3)	Low (2)	High (4)	2.83	Medium (3)	3.3	Medium (3)
Bazaar	R.6	High (4)	High (4)	Low (2)	High (4)	2.83	Medium (3)	3.6	High (4)
Tekiyeh	R.7	High (4)	High (4)	Low (2)	High (4)	2.83	Medium (3)	3.6	High (4)
Sistani house	R.8	High (4)	High (4)	Medium (3)	High (4)	3.46	High (4)	4.00	High (4)
Peyambar mosque	R.9	High (4)	Medium (3)	Low (2)	High (4)	2.83	Medium (3)	3.3	Medium (3)
Jaame mosque	R.10	High (4)	Medium (3)	Very high (5)	High (4)	4.47	Very high (5)	3.9	High (4)
Mirzā Na'im ensemble	R.11	High (4)	Medium (3)	Very high (5)	High (4)	4.47	Very high (5)	3.9	High (4)
Residential remains	R.12	High (4)	Low (1)	Very high (5)	High (4)	4.47	Very high (5)	2.7	Medium (3)
Icehouse	R.13	High (4)	Medium (3)	Very high (5)	High (4)	4.47	Very high (5)	3.9	High (4)
Qanat	R.14	High (4)	Very high (5)	High (4)	High (4)	4.00	High (4)	4.3	Very high (5)
Date palm orchards	R.15	High (4)	High (4)	Very low (1)	High (4)	2.00	Low (2)	3.2	Medium (3)

Following the analysis of the risk components, vulnerability and risk are calculated by the following equations (please see *Section 4.3.5-Analysing the earthquake risks: risk index*):

$$\text{Vulnerability} = \sqrt{\text{Susceptibility} \times \text{Lack of coping capacity}}$$

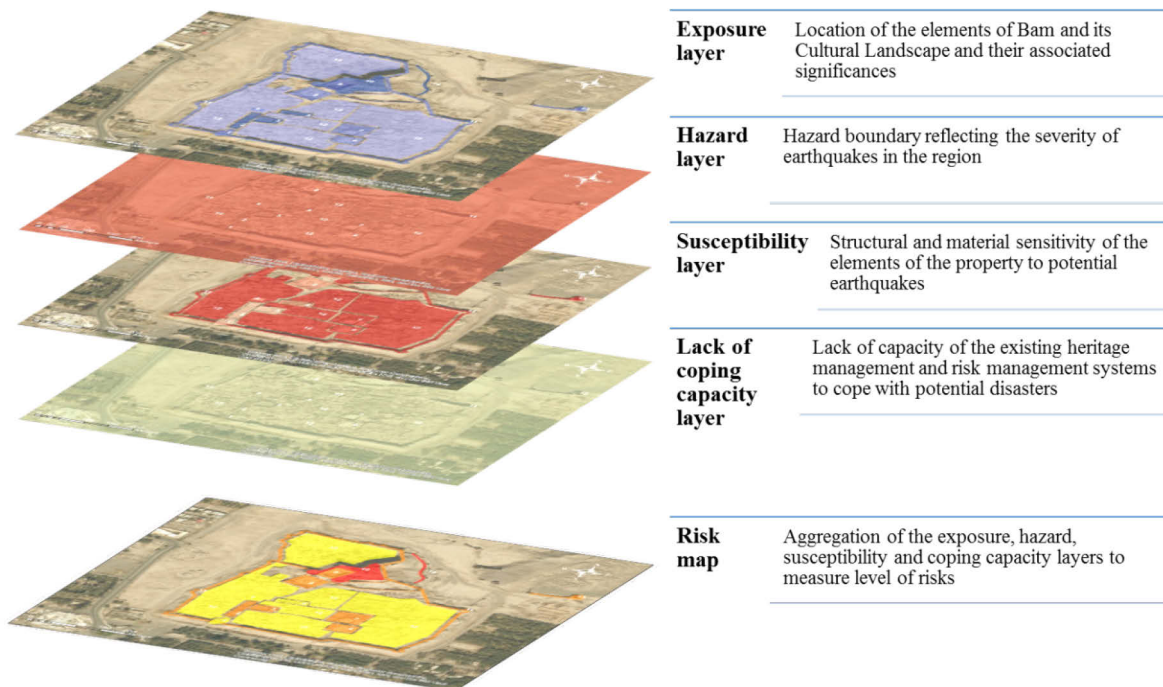
$$\text{Risk} = \sqrt[3]{\text{Hazard} \times \text{Exposure} \times \text{Vulnerability}}$$

The vulnerability and risk score may fall in one of the 5 equal-sized classes with class ranges of 1-1.8, 1.8-2.6, 2.6-3.4, 3.4- 4.2, and 4.2-5. They are respectively interpreted by numbers and colour codes as Very low (1, dark green), Low (2, light green), Medium (3, yellow), High (4, orange), and Very high (5, red).

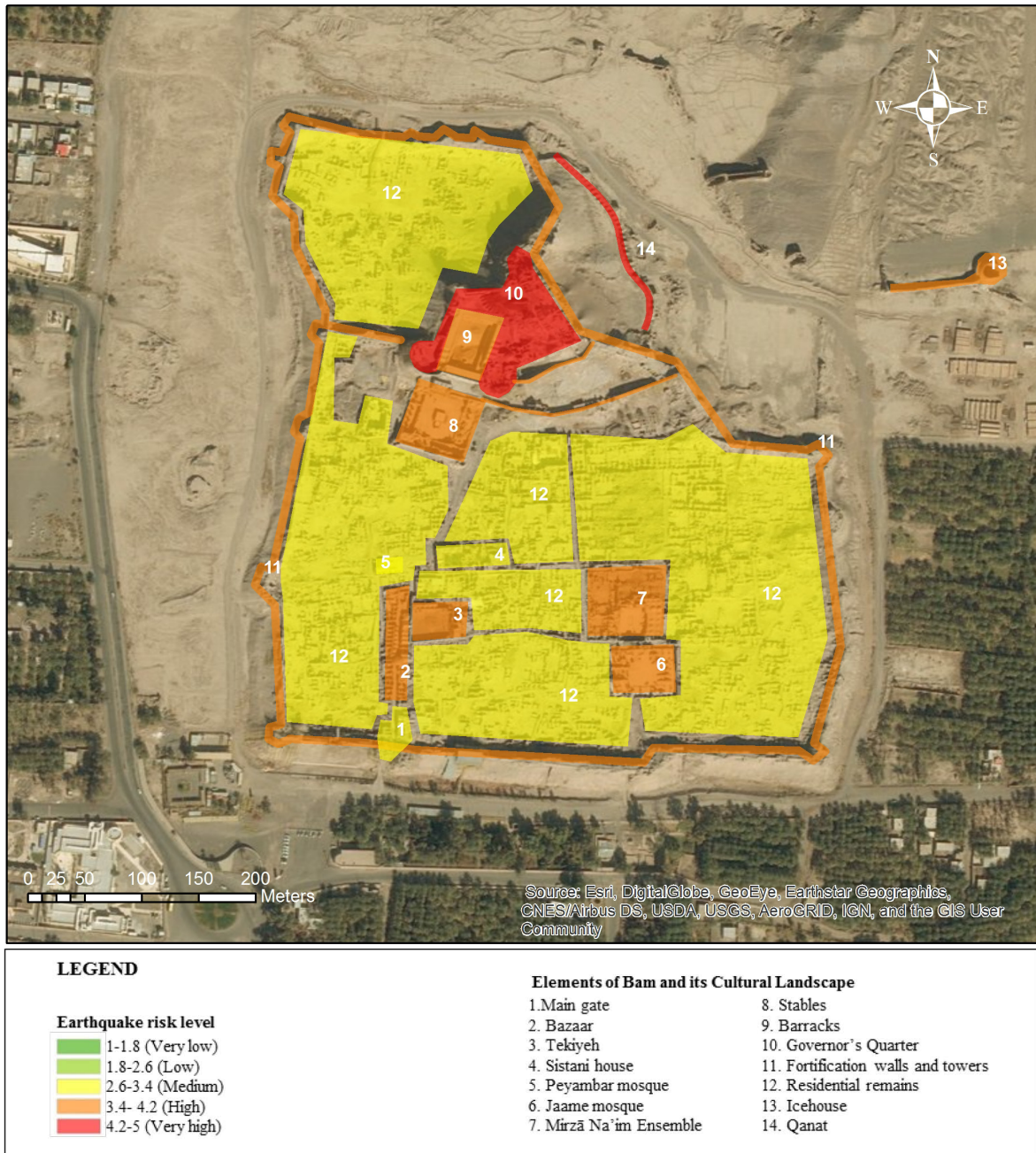
## 5.8 Generating an earthquake risk map

Figure 5-18 illustrates the concept of the risk map, which is based on the aggregation of the risk components in the risk index and their visualisation in ArcGIS.

- Exposure layer that presents the spatial distribution of the elements of Bam and their associated significances.
- Earthquake hazard layer that shows the spatial distribution of potential earthquakes in the region and its expected severity.
- Vulnerability layer that comprises the two following layers:
  - Susceptibility layer, presenting the level of structural and material susceptibility of the elements;
  - The layer of lack of coping capacity, demonstrating the lack of capacity of the existing risk management system to cope with the potential impacts of earthquakes.



**Figure 5-18** Concept of the risk map, based on the aggregation of the risk components



**Figure 5-19 Earthquake risk map of the elements of Bam (with a focus on Arg-e Bam and its immediate surrounding)**

Figure 5-19 shows a risk map for the site that is generated according to the risk index (Table 5-7) and the risk concept (Figure 5-18). It demonstrates which of the elements are at risk of the earthquake and on which level. The risk map provides the assessment team and stakeholders with a shared understanding of the potential disaster situation in the different areas of the site.

## 5.9 Risk evaluation for the elements of Bam

Risk evaluation is the output of the risk assessment to provide the decision-making process with essential information related to those elements of Bam that need risk treatment strategies. Furthermore, it helps prioritise the elements of Bam in the risk management plan. According to *Section 4.3.6-Evaluating the risks*, ALARP (As Low As Reasonably Practicable) principle is applied for evaluating the risks to the elements of Bam. Table 5-8 shows which elements of the property and on which level of priority need risk treatment strategies.

**Table 5-8 Risk evaluation table (with a moderate confidence level) for Bam and its Cultural Landscape**

Risk level	Risk No.	Elements which need risk treatment strategies	Further step
Very high (Intolerable region)	R.2	Governor's quarter	Risks require risk treatment measures to derive them at least to the tolerable region.
	R.14	Qanat	
High (Intolerable region)	R.1	Fortification walls/towers	
	R.3	Barracks	
	R.4	Stables	
	R.6	Bazaar	
	R.7	Tekiyeh	
	R.8	Sistani house	
	R.10	Jaame mosque	
	R.11	Mirzā Na'im ensemble	
Medium (Tolerable region)	R.5	Main gate	Risks are subject to ALARP and should be treated to drive them to the acceptable region.
	R.9	Peyambar mosque	
	R.12	Residential remains	
	R.15	Date palm orchards	
Low (Acceptable region)	-	-	Risks do not need additional risk treatment options and should be managed by the existing management system.
Very low (Acceptable region)	-	-	

According to Table 5-8, the elements of Bam may fall in one of the three following regions:

- **Intolerable region (high priority for the risk treatment):** Governor's quarter and Qanat are placed in an intolerable region with a 'Very high' level of risk that means the highest priority should be given to these two elements. Some elements such as Barracks, Tekiyeh, and Sistani house that are exposed to a 'High' level of earthquake risk fall also in this region. Every element placed in the intolerable region requires risk treatment measures to derive them to the tolerable and later on to the acceptable region.
- **Tolerable region (medium priority for the risk treatment):** Main gate and Peyambar mosque, due to the recent adequate reinforcement, have low seismic susceptibility compared to some other elements. The elements placed in the tolerable zone are subject to the ALARP principle. ISO 31000 (2009) suggests some criteria such as cost-benefit analysis and considerations of the values and perceptions of stakeholders to evaluate the risk treatment strategies that are applicable to the tolerable region. It should be determined to what extent

the proposed strategies and measures are beneficial and/or effective compared to the cost of the planning and implementation.

- **Acceptable region (low priority for the risk treatment):** no elements have been placed in this region. In the acceptable region, the elements do not need specific risk treatment measures, but should be managed by existing heritage management systems such as by periodic monitoring and maintenance.

## 5.10 Summary

The methodology of risk assessment, which was developed in *Chapter 4-Methodology*, has been applied to the case of Bam and its Cultural Landscape in this chapter. A Cultural Heritage Risk Index for Bam was developed to provide a detailed analysis of the earthquake hazard in Bam, the exposure (significance) of the elements of Bam, the seismic susceptibility of the elements, and the coping capacity of the existing management system. Then, the components of risk were incorporated into the risk index for measuring the level of risk to the elements of Bam. Accordingly, an earthquake risk map of the property was generated in ArcGIS. Finally, the risks were evaluated to determine which elements of Bam and on which level of priorities need risk treatment strategies in the risk mitigation and preparedness plans.

A disaster scenario for the case of Bam was developed to frame the multiple emergency situations and to explore the nature of potential impacts in advance. Through a multiple impact identification matrix, the potential damages that might be caused by earthquakes and secondary natural and human-induced threats have been determined. Furthermore, the matrix predicted the potential loss of the OUV, authenticity, and integrity, according to the impacts on tangible and intangible attributes of the property.

It should be noted that not only the final output of the risks assessment procedure, but each step of the assessment procedure corresponding to the risk components will contribute to the risk management strategies. This will be discussed in *Chapter 6-Discussion and conclusion*.

# **CHAPTER 6**

## **DISCUSSION AND CONCLUSIONS**

## 6.1 Introduction

This chapter provides a summary of the research process, and outlines how the objectives of the research have been fulfilled. The findings of the risk assessment procedure are discussed to underscore the key results and their contribution to risk management and heritage conservation. The quality of the research is evaluated through particular criteria. The chapter outlines how the research process and findings can be applied in theory and practice, and suggests future research directions.

## 6.2 Summary of the research

### **CHAPTER 1: Introduction**

- The state of the problem and the need for developing risk assessment for cultural heritage;
- A brief review of the current state of the art; and
- The objectives of the study as well as the methods to fulfil the objectives.

### **CHAPTER 2: Description of the study area**

- Building composite maps of WCH properties and Earthen WH properties in the seismic zones;
- Description of the earthquake 2003 and inscription of ‘Bam and its Cultural Landscape’ on the WH List; and
- Description of the construction technique, pre-disaster interventions, post-disaster recovery, and the conservation and management status of the property.

### **CHAPTER 3: Building a theoretical background**

- Review of the conceptual and analytical frameworks and procedures of the risk assessment and management;
- Review of some relevant concrete cases affected by natural hazards; and
- Proposing an integrated framework for disaster impact identification of primary effects of earthquakes as well as secondary natural hazards and human-induced threats.

### **CHAPTER 4: The overall methodological framework**

- Description of the primary data collection (in-situ observation of the property and the expert questionnaire) and the secondary data collection (report and document analysis);
- Description of the data analysis methods: significance assessment matrix, indicator-based vulnerability assessment index, risk index, and risk mapping in ArcGIS;
- Developing a Cultural Heritage Risk Index based on the aggregation of the risk components: hazard, exposure, and vulnerability; and
- Proposing a multiple impact identification matrix to consider secondary natural hazards and human-induced threats following earthquakes.

### **CHAPTER 5: Cultural Heritage Risk Index for Bam**

- Analysing the earthquake hazard in Bam, the exposure (significance) of the elements of Bam, the seismic susceptibility of the elements, and the coping capacity of the existing management system;
- Determining the level of risks to the elements of Bam according to the risk index;
- Generating an earthquake risk map of the property in ArcGIS; and
- Evaluating the risks to determine which elements of Bam need risk treatment strategies.

### **CHAPTER 6: Discussion and conclusions**

- Achievement of the research objectives;
- Discussion of results and their contribution to risk management;
- Credibility and confirmability of the research; and
- Implication of the research and suggested further research.



### 6.3 Achievement of the research objectives

The research objectives stated in *Chapter 1-Introduction* built a sequence of tracks in the core zone of the thesis. The aim of the research was **to develop an integrated and systematic methodology of earthquake disaster risk assessment for the World Heritage site of Bam and its Cultural Landscape**. According to *Chapter 4-Methodology*, the risk assessment procedure for Bam and its Cultural Landscape follows a **systematic** procedure, as follows. The procedure portrays particular stages sequentially to analyse the different components of risk through deriving particular indicators, proposing data analysis methods, and building a composite map (see also *Section 4.3: Figure 4.1*).

1. Assessing earthquake hazard in Bam:
  - Analysing primary hazard of the earthquake;
  - Identifying potential natural and human-induced hazards following the earthquake;
2. Assessing exposure (significance assessment of heritage elements at risk):
  - Identifying elements of Bam exposed to earthquakes;
  - Assessing the relative significance of the elements;
  - Mapping the elements and their associated significance;
3. Assessing the seismic vulnerability of the elements of Bam:
  - Analysing the seismic susceptibility;
  - Analysing the coping capacity of the management system;
4. Identifying potential impacts of earthquake-induced disasters on the site;
5. Analysing risks and building a risk index for the elements of Bam;
6. Generating an earthquake risk map; and
7. Evaluating risks to the elements of Bam.

To build an **integrated** framework, the methodology adopted the principles and methods of risk assessment and management on one side, and incorporated the specific considerations of WCH properties (e.g. the OUV and associated conditions of authenticity and integrity) in the procedure, on the other. Furthermore, both structural (e.g. sensitivity of materials and structures) and non-structural (e.g. heritage values and coping capacity of the management system) criteria have been incorporated into the assessment procedure. The characteristics of seismic events and the key attributes of the World Heritage site of Bam and its Cultural Landscape have been particularly taken into account to develop a site- and event-specific method for Bam. Below, this section outlines the procedures and findings of the research corresponding to the defined objectives of the thesis.

#### 6.3.1 Objective 1: To develop a systematic assessment procedure for cultural heritage through deriving specific criteria and indicators for analysing the components of risk

According to *Chapter 4-methodology*, the three main components of risk within the assessment procedure in this research are: hazard, exposure, and vulnerability. The risk components have been analysed through deriving particular criteria and indicators, as follows:

**Hazard:** according to the historical data and maps of earthquake events in the region and its spatial distribution using GIS modelling, the severity of an earthquake can be classified. The following three phases were incorporated into the hazard assessment:

- Analysing the primary hazard of the earthquake;
- Identifying potential secondary hazards and environmental factors; and

- Identifying potential human-induced threats.

**Exposure:** to analyse the exposure of the elements at risk, the significance of the elements was assessed according to the following criteria. For the purpose of significance assessment, the criteria were adapted from Worthing and Bond (2008), Australia ICOMOS: Burra Charter (2013), and Feilden and Jokilehto (1993).

- Architectural and technological significance;
- Aesthetic significance;
- Historical significance;
- Social significance;
- Economic importance;
- Functional importance;
- Environmental importance; and
- Degree of integrity.

**Vulnerability:** an indicator-based procedure was applied to assess the components of seismic vulnerability through analysing the following two sub-components:

- **Susceptibility:** the indicators for analysing seismic susceptibility were derived in *Section 4.3.3.1-Deriving indicators for susceptibility analysis* and the post-earthquake reports of Bam regarding the factors contributing to the structural damages. The seismic susceptibility indicators relevant to the case of Bam are as follows:
  - Quality of structure/material;
  - Type of foundation/ground;
  - Cracks and detachments;
  - Material losses; and
  - Biological infestations (Termites' damage).
- **Coping capacity:** capacity analysis was conducted based on the expert questionnaire and document analysis. The indicators were derived in *Section 4.3.3.2- Deriving indicators for coping capacity analysis*. The indicators for the analysis of coping capacity in Bam are as follows:
  - Information and communication system;
  - Risk awareness;
  - Risk mitigation strategies/actions;
  - Risk preparedness strategies/actions (including emergency response and recovery plan); and
  - Institutional framework.

For each of the coping capacity indicator, a set of sub-indicators has been defined (please see Table 4-9) to facilitate the assessment process and questionnaire design.

### **6.3.2 Objective 2: To identify the potential impacts of earthquake-induced disasters on Bam and its Cultural Landscape, including its OUV, and associated conditions of authenticity and integrity**

In *Section 5.6-Identifying potential impacts of earthquake-induced disasters*, an impact identification matrix, which has been developed within the methodology framework, was applied to the case of Bam. In the impact identification process, potential natural hazards and human-induced threats following earthquakes were considered to be addressed in the risk treatment strategies of the property. The matrix links the potential sources of risk to the receptors of impact during and after a disaster. The earthquake-induced disaster defined in the matrix targets the following three categories of risk sources:

- Primary effects that are liquefaction, landslides, and ground shaking.
- Secondary hazards and climate factors that include wind-driven sand/rain and sandstorms, precipitation and surface runoff, and fires and explosions.
- Human-induced threats that might be associated with improper interventions and reconstruction, improper emergency response, illegal urban development, and looting.

The attributes of Bam and its Cultural Landscape that might be affected by the above-mentioned hazards and threats are as follows:

- Tangible attributes that involve Bam Citadel (including adobe structure, adobe material and mortar, decorative elements and finishing, and collections and archives), and Bam's cultural landscape (including adobe structures, Qanat system, and date palm orchards).
- Intangible attributes that are associated with earthen architecture knowledge, religious rituals and ceremonies in the citadel, and the traditional management system in Bam.

The potential impacts of the above-mentioned hazard and threat on the attributes of the property were identified in the matrix (please see Table 5-6). The matrix also predicted the potential loss of the OUV, authenticity, and integrity in the case of Bam according to the impacts on tangible and intangible attributes that are conveying the OUV. The potential loss of the OUV could be, for instance, impact on fortified town layout of the citadel and archaeological sites, impact on earthen construction technique (sun-dried mud-brick combined with mud layer), and impact on Bam's cultural landscape (e.g. the Qanat system). Moreover, following the earthquakes, potential improper emergency response, salvage, stabilisation, and restoration might also affect the heritage values.

The potential loss of the authenticity could be due to damage to particular characteristics (e.g. adobe arcs and domes) and the citadel layout, loss of traditional mud-brick and mud layer construction, and damage to cultural landscape (e.g. to Icehouse and Qanat). Post-earthquake interventions may also affect the authenticity of the property due to neglecting adobe construction technique and overuse of the modern retrofitting techniques.

The potential loss of the integrity might be associated with loss of structural integrity due to the destruction of earthen elements in diverse integrated parts of Bam Citadel and loss of visual integrity due to damage or collapse of particular architectural elements in the citadel (e.g. watchtowers). In the post-disaster phase, the integrity of the property might be also affected by neglecting key elements of the core zone in the recovery project and potential changes in the form and layout of the cultural landscape.

### 6.3.3 Objective 3: To develop a Cultural Heritage Risk Index for Bam in order to measure the seismic vulnerability and risk to the elements of Bam and its Cultural Landscape

In *Section 5.7-Risk analysis and building a risk index for the elements of Bam*, the components of risk, which had been analysed in the assessment procedure, were integrated into the risk index (Please see Table 5-7) to calculate the level of vulnerability and risk. The risk components have been measured as follows:

- **Hazard:** based on the seismic zoning maps and the historical data of earthquake events in the region, an earthquake with a high severity can be expected in Bam. Accordingly, the level of earthquake hazard in the property was considered High (4).
- **Exposure:** the elements of Bam and its Cultural Landscape and their associated significance are exposed to potential earthquakes. Following the analysis of the significance of the elements of Bam, the arithmetic mean was applied to the indicators to measure the overall significance scores.
- **Vulnerability:** an indicator-based procedure was applied to assess the components of vulnerability as follows:
  - **Susceptibility:** susceptibility analysis for Bam was performed based on the fieldwork to observe the current condition of earthen materials and structures. Susceptibility of the elements to earthquakes was computed by applying the ‘Analytic Hierarchy Process’ method.
  - **Coping capacity:** capacity analysis was conducted based on the expert questionnaire and document analysis. The arithmetic mean aggregation was applied to measure the overall coping capacity scores. To be able to integrate this component into the risk index, the ‘lack of coping capacity’ was measured.

Following the analysis of the risk components, vulnerability and risk are calculated (Please see Table 5-7) by applying the geometric mean aggregation method through the following equations:

$$\text{Vulnerability} = \sqrt{\text{Susceptibility} \times \text{Lack of coping capacity}}$$

$$\text{Risk} = \sqrt[3]{\text{Hazard} \times \text{Exposure} \times \text{Vulnerability}}$$

### 6.3.4 Objective 4: To generate an earthquake risk map for the elements of Bam and its Cultural Landscape

In *Section 5.8-Generating an earthquake risk map*, Figure 5-18 illustrates the concept of risk map based on the aggregation of the risk components and their visualisation in ArcGIS.

- Exposure layer (the spatial distribution of the elements of Bam and their associated significances);
- Earthquake hazard layer (the spatial distribution of potential earthquakes in the region and its expected severity); and
- Vulnerability layer that comprises the two following layers:
  - Susceptibility layer (the level of structural and material susceptibility of the elements);
  - The layer of lack of coping capacity (the lack of capacity of the existing risk management system to cope with the potential impacts of earthquakes).

The earthquake risk map for the elements of Bam (please see Figure 5-19) was generated according to the risk index (Table 5-7) and the risk concept. The risk map provides information regarding those elements of the property which might be affected by earthquakes at the different risk levels.

### 6.3.5 Objective 5: To evaluate the risks to the elements of Bam and its Cultural Landscape in order to determine which elements and on which level of priority need risk treatment strategies

While applying the ALARP principle, the output of the risk assessment for Bam provides decision-making process with essential information related to those elements of Bam that need risk treatment strategies (please see Table 5.8). Besides, it helps prioritise the elements of Bam for the further risk management plan. Accordingly, each element of the property was placed in one of the following regions:

- Intolerable region: risks require risk treatment measures to derive them at least to the tolerable region.
- Tolerable region: risks are subject to ALARP and should be treated to drive them to the acceptable region.
- Acceptable region: risks do not need additional risk treatment measures, and should be managed by existing management systems.

It should be noted that not only the final output of the risks assessment procedure, but each step of the assessment procedure will contribute to the risk management strategies. This will be discussed in the next section.

## 6.4 Discussion of results and their contribution to risk management

The level of vulnerability and risks corresponding to the elements of Bam and its Cultural Landscape have been determined in *Section 5.7-Risk analysis and building a risk index for the elements of Bam* and *Section 5.9- Risk evaluation for the elements of Bam*. As mentioned, not only the final output of the risks assessment procedure, but the information related to the risk components will contribute to the risk management strategies. This section discusses the findings within the risk assessment procedure and outlines their contribution to risk management.

Figure 6.1, which is built based on the Bam risk index, demonstrates how the level of risk to the elements of Bam is influenced by the risk components. Accordingly, because the elements shared the same level of hazard, the significance (exposure) and vulnerability of the elements are the main determinants of the relative level of risk. This means the risk treatment strategies should be predominantly focused on exposure, and more importantly, vulnerability reduction to future earthquakes. The risk assessment, in general, can provide risk management with the following strategies to avoid or reduce the risks.

**Avoiding or reducing the hazard:** depending on the nature and characteristics of a sudden-onset hazard, there might be a possibility to reduce its likelihood or severity. In the context of this research, earthquake hazard, unlike some other natural hazards, cannot be eliminated or mitigated. Other options, such as the early warning system, are not sufficiently effective in the case of seismic events mainly due to the unpredictability of the exact occurrence time and place. Nevertheless, in some cases, foreshocks may help to announce the potential occurrence of an earthquake.

With respect to the secondary hazards and threats, monitoring of hazards and early warning system can help to reduce the hazards. In the case of Bam, the following hazards and threats need to be addressed within the risk treatment strategies:

- Potential secondary hazards and environmental factors: fire and explosion, rainfall and snowfall, wind-driven sand, wind-driven rain; and
- Potential human-induced threats: looting and illicit trafficking of collections, encroachment and illegal urban development, improper response, damage assessment, and interventions.

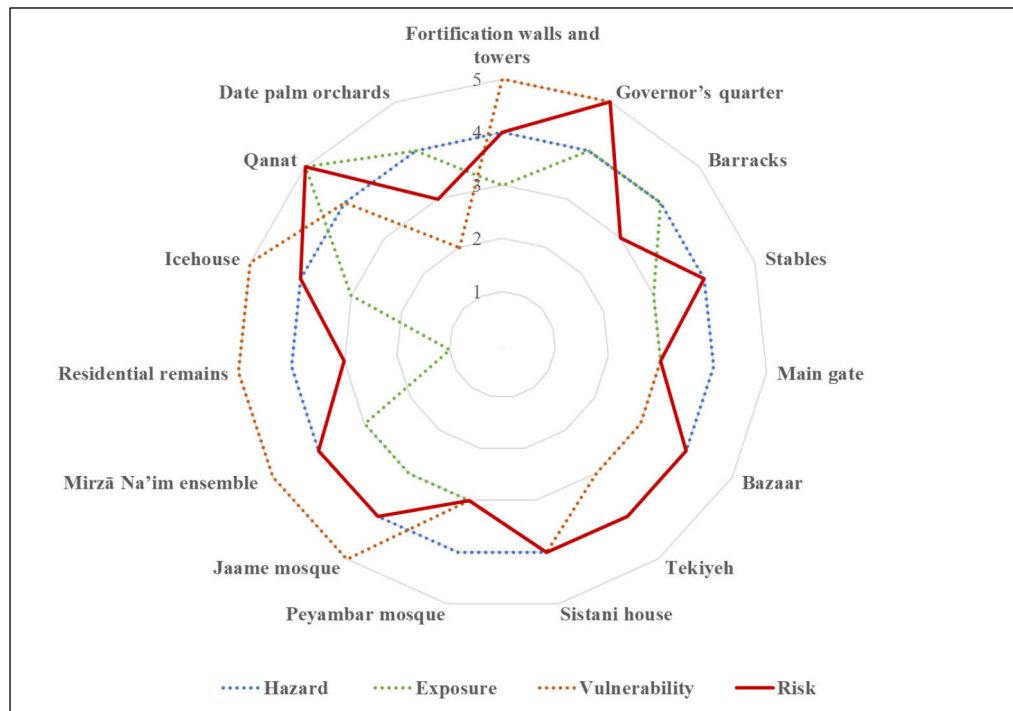


Figure 6-1 Influence of hazard, exposure, and vulnerability on the risk level in Bam

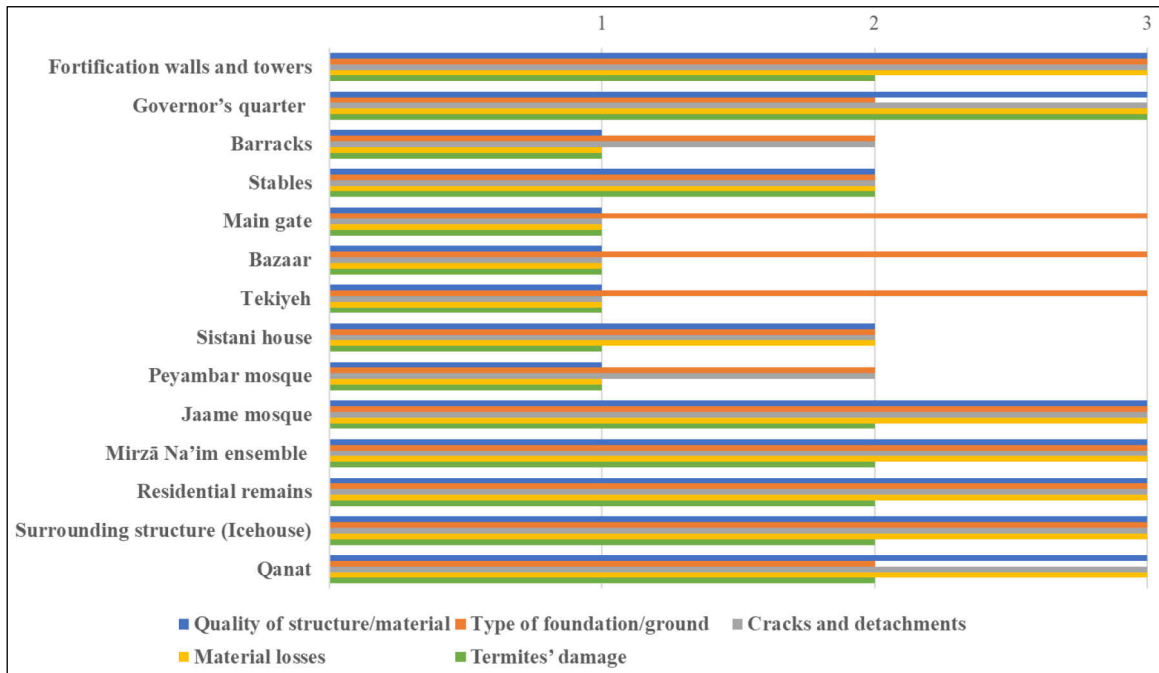
**Reducing the exposure:** as mentioned in *Section 5.4- Assessing exposure (significant assessment of heritage elements at risk)*, the location and significance of the elements of Bam and its Cultural Landscape have the main role in the exposure assessment. One option to reduce the exposure is to relocate the elements outside the earthquake-prone areas. However, this is not a desirable strategy considering the heritage principles because it affects the sense of place and integrity of the property. In the case of movable objects (e.g. potential objects from archaeological excavations), relocation of the objects to the safe place outside of the hazard boundary could be discussed within the decision-making process.

**Reducing the seismic vulnerability:** the indicator-based vulnerability assessment provides site-specific information regarding the structural and non-structural weaknesses of the site, through the following strategies.

**Reducing the seismic susceptibility:** the seismic performance of historic buildings can be improved through different reinforcement options. Some traditional and modern measures applied to Arg-e Bam have been discussed in this research. However, particular attention needs to be given to avoid additional impacts on the authenticity and integrity of the property. Incompatibility of material and design in the pre- and post-earthquake interventions have been discussed in *Section 3.7.2- An integrated approach to earthquake impact identification*. Stovel (1998) emphasises some essential criteria in the seismic reinforcement activities, such as an adequate understanding of a building condition and its structural system, the history of its evolution and conservation, and its heritage values that need to be carefully considered in the risk mitigation measures.

Figure 6.2 shows an interpretation of the seismic susceptibility analysis according to *Section 5.5.1- Analysing seismic susceptibility*. The ranking scores assigned to the susceptibility indicators are Low (1), Medium (2), or High (3) susceptibility. The information provided in this chart assists risk

management to recognise those susceptibility features of each element that need more concentration in the seismic reinforcement and restoration. According to the chart, in the main gate, bazaar, and Tekiyeh, reinforcement measures need to particularly address the strengthening of foundation or connecting the structures to the ground.



**Figure 6-2 Interpretation of the seismic susceptibility analysis for the risk management strategies**

**Enhancing the coping capacity of the management system:** capacity improvement, apart from the non-structural risk mitigation, is closely linked to the risk preparedness and recovery plan. Figure 6.3 is built based on *Section 5.5.3-Analysing coping capacity of the management system* to provide an interpretation of the coping capacity analysis. The ranking scores assigned to the capacity indicators are Very low (1), Low (2), Medium (3), High (4), and Very high (5). These scores are respectively corresponding to the quality level of plan/measures in the expert questionnaire as ‘Nothing exists’, ‘Poorly-developed’, ‘Acceptable’, ‘Well-developed’, and ‘Very well-developed’. Those areas that need specific consideration for improvement are highlighted in yellow.

According to the chart, there is a significant lack in the existing ‘risk information system and map’ within the management of the property. This can be enhanced through generating an earthquake information system (e.g. GIS database) and developing vulnerability and risk maps and their corresponding datasets that play a key role in the emergency response. Another example is the cultural first aid within the risk preparedness plan. A multi-stakeholder emergency response plan needs to be prepared to provide a guide for salvage, triage, and stabilization of movable and immovable heritage after an earthquake. The plan should also ensure the earthquake drills and training programmes to promote the capacity building at the local level. The indicators should be discussed within the multiple agencies engaged in the safeguarding of the property as well as within the broader civil protection and risk management at the urban and regional levels.

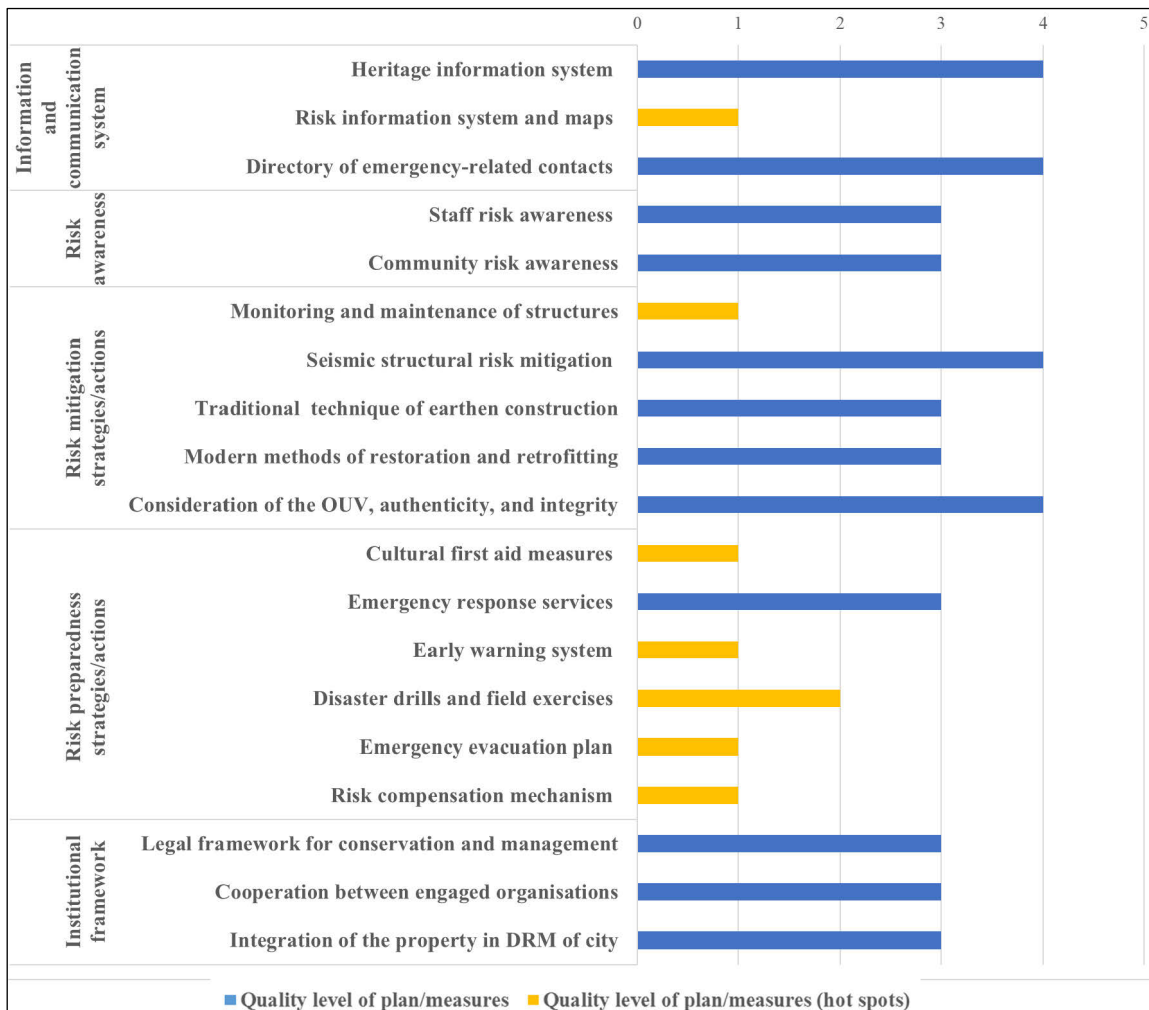


Figure 6-3 Interpretation of the coping capacity analysis for further risk management strategies

## 6.5 Credibility and confirmability of the research

In quantitative research, ‘reliability’ and ‘validity’ are two significant criteria for assessing the quality of research projects. While reliability is associated with the consistency of the processes and measures to allow for repeatability of the results and findings, validity relies on the integrity of the conclusions with regard to the research procedure (Bryman, 2008). However, recent investigations suggest that qualitative research, in comparison to quantitative research, cannot be adequately judged by applying the mentioned criteria.

To assess the quality of qualitative research, Lincoln and Guba (1985) suggest alternative criteria for judging the ‘trustworthiness’ of research that are equivalent to the reliability and validity. The criteria comprise credibility, transferability, dependability, and confirmability. Shenton (2004, p.73) looking at the Lincoln’s and Guba’s trustworthiness concept, has developed strategies to fulfil the trustworthiness in qualitative research projects, as follows:

- **Credibility:** activities such as triangulation of methods and theories, adaptation of appropriate research methods, description of background and qualifications of the researcher, review of previous research to establish frameworks can enhance the credibility of the research.
- **Transferability:** in terms of applying the procedures and/or findings to the other context, background data should be established and detailed description of the phenomenon in question needs to be provided.



- **Dependability:** in respect to employing the procedures and/or findings in the future research projects, the methodology and processes need to be described in detail.
- **Confirmability:** this criterion can be improved by using triangulation to reduce potential effects of researcher bias, recognising limitations of the methods, in-depth description of the methodology, and demonstrating ‘audit trail’ to allow the reader to follow the research steps through a diagram.

Lincoln and Guba (1985) also suggest that the trustworthiness of research can be promoted through communicative validation and evaluations with the professionals in the area of the research.

### 6.5.1 Credibility of the research

**Triangulation of methods:** to enhance the quality of the measurements and findings, a triangulation of qualitative and semi-quantitative methods was applied to the data collection and analysis. According to Denzin (1989), a triangulation of different methods applied to gather data is required for the risk assessment procedure. As it is described in *Chapter 4-Methodology*, in-situ observation of the elements of the property was carried out to purposively grasp their particular attributes. An expert questionnaire was conducted to evaluate the status of the risk management and coping capacity of the system. The primary data was cross-checked with the information extracted from the official reports and records of the Bam recovery process. In the different steps of the risk assessment procedure, specific data analysis methods, such as indicator-based vulnerability assessment index, risk index, and risk mapping in ArcGIS have been applied.

**Review of previous research to establish frameworks:** in order to establish a theoretical background to develop a risk assessment methodology for the study area, the conceptual and analytical frameworks and procedures of risk assessment and management have been reviewed in *Chapter 3- Literature review*. Moreover, the existing risk assessment methods for cultural heritage as well as some concrete cases have been reviewed in order to incorporate the recent development of the field into the proposed methodology.

**Background and qualifications of the researcher and communicative validation:** in order to promote the credibility and value of the thesis, several publications and presentations have been carried out that include peer-reviewed journal articles and book chapters (Ravankhah and Schmidt, 2016; Ravankhah et al., 2017a; Ravankhah et al., 2017b) and peer-reviewed conference papers (Ravankhah and Schmidt, 2014; Ravankhah, 2015).

The author’s educational backgrounds of Bachelor’s degree in Architectural Engineering, Master’s degree in Post-disaster Reconstruction, and an ongoing PhD in Heritage Studies helped to conduct such interdisciplinary research. Furthermore, his academic experience through his teaching and research activities in the Chair of Environmental Planning at Brandenburg University of Technology Cottbus-Senftenberg and the Institute of Spatial and Regional Planning at the University of Stuttgart played an important role in improving the quality of the research.

Throughout his PhD programme, the author awarded two certificates through attendance in the *10th UNESCO International Training Course (ITC) on Disaster Risk Management of Cultural Heritage* in Kyoto in 2015 and the *Residential Doctoral School incorporating the 4th International Conference on Building Resilience* in the UK in 2014. During the mentioned events, feedback from intentionally-recognised professionals in the area of risk management and heritage conservation had a significant role in enhancing the overall methodological framework of the thesis.

### 6.5.2 Transferability of the research

As mentioned by Shenton (2004), in order to apply the procedures and/or findings to the other context, the background data should be established and the phenomenon in question needs to be adequately described. The seismological and historical overview of the study area was mentioned in *Chapter 2-Study area*. A description of the construction technique and building material, pre-disaster interventions, post-disaster recovery process, and the conservation and management status of the property has been also provided. Through the fieldwork and document analysis (please see *Chapter 5-Application of the risk assessment to the study area*), particular characteristics of the elements of Bam have been identified and incorporated into the methodological framework.

For the reasons of clarity and applicability, the focus of the research is on World Cultural Heritage sites to address their specific characteristics. Even though the overall methodological framework and risk assessment procedure can be applicable to other heritage sites (e.g. adobe constructions), the indicators (e.g. susceptibility indicators) need to be adapted considering the specific characteristics of a new case. To apply the methodology to other typologies of heritage or even similar cases, the criteria and indicators may need to be modified according to the structural and non-structural attributes of the case and its setting, geological and socio-cultural background, and the institutional and management systems.

### 6.5.3 Dependability of the research

In order to enable the risk assessment procedures and/or findings to be employed in the future research projects, the theoretical methodology has been described in detail in *Chapter 4-Methodology* and applied to the case of Bam in the empirical part in *Chapter 5-Application of the risk assessment to the study area*. Transparency of the conceptual frameworks, data collection and analysis, and the measurements in the different phases of the procedure has been particularly taken into account.

### 6.5.4 Confirmability of the research

**Triangulation to reduce potential effects of researcher bias:** as described above, the triangulation of different methods has been applied to the data collection and analysis in the case of Bam. The primary data (e.g. in susceptibility and capacity analysis) has been cross-checked with the secondary data from the report and document analysis to reduce the potential contribution of the research bias in the analysis.

**An in-depth description of the methodology:** as mentioned above, a detailed description of the theoretical methodology has been developed in *Chapter 4-Methodology* to provide the readers with the conceptual frameworks, data collection and analysis methods, and the equations applied to measure the vulnerability and risk. The criteria and indicators for analysing the components of risks have been described in a systematic way in the methodological framework.

**Demonstrating ‘audit trail’ to allow the reader to follow the research steps through a diagram:** the following diagrams have been developed in the research process to illuminate the sequence of the research tracks:

- Visual outline of thesis structure (Figure 1.1) that provides the contents of each chapter and the interrelations between different chapters in building the theoretical background and methodological framework.
- Research design (Figure 4.1) that provides the overall methodological framework of the research, the risk assessment procedure, and methods of data collection and analysis

applied to each step. The diagram illuminates the final output of each assessment step and the links between the different components to fulfil the risk analysis and evaluation.

- Components of risk and related indicators (Figure 5.1) that outlines the indicators needed for developing a Cultural Heritage Risk Index for Bam and its Cultural Landscape.

### 6.5.5 Limitations of the research

There are two types of limitations encountered in the research, as follows:

**Lack of data availability and/or accessibility:** in general, the governmental agencies and authorities in the study area were reluctant to provide the data in the digital format, such as GIS database, hazard zoning, and city maps. Hence, it is difficult to recognise if such data is simply not available or not accessible. However, the author through applying different methods (e.g. site observation, risk mapping in ArcGIS, and document analysis) has provided the assessment procedure with required data and information.

**Limitations regarding the expert questionnaire:** although the author is familiar with the study area and multiple experts engaged in the post-earthquake conservation of the property, it was difficult to convince the specialists to attend the interview. This has partly affected the number of interviewees. However, a number of right experts representing different disciplines or organisations engaged in the management of the property were involved in the expert questionnaire. Another limitation was regarding those questions that only the local and regional authorities may have the right information, such as those related to the analysis of the coping capacity of the management system in Bam. For such questions, the scores assigned by the Expert 1 (who is from the *Research and technical centre of the World Heritage site of Bam and its Cultural Landscape*) have been mainly considered. However, the other complementary methods such as document and report analysis were used to cross-check the primary data.

## 6.6 Implication of the research findings

The contribution of the risk assessment procedure and findings in the area of risk management and heritage conservation are as follows:

**Contribution of the risk assessment to the existing management plan of Bam:** the findings of the empirical parts of this research (e.g. vulnerability assessment of the elements of the property, risk assessment of the elements, and earthquake risk map) can be integrated into the management plan of the property. This will help the ongoing conservation to adequately address the earthquake risks and the potential impacts. The findings highlight those areas of susceptibility and coping capacity that need specific considerations in the vulnerability reduction. Moreover, the output of risk evaluation provides the risk management of Bam and its Cultural Landscape with a prioritisation of the elements for risk treatment options.

**Contribution to the WCH nomination and management plans:** in general, the research plays an essential role in establishing risk management frameworks to protect cultural heritage from natural hazards. In the context of WH, the proposed risk assessment procedure can contribute to the preparation of the WH nomination, in “Section 4b-Natural disasters and risk preparedness (earthquakes, floods, fires, etc.)” (UNESCO WHC, 2017) to provide an integrated hazard identification and risk assessment for cultural heritage exposed to natural hazards. The properties placed on the World Heritage List in Danger and those applying for the Emergency Assistance Funds may benefit from the risk index and impact identification matrix. Within the WH management plans,

the risk assessment procedure will provide site-specific risk management strategies to ensure retraining the OUV and associated conditions of authenticity and integrity.

**Contribution to the implementation of the SDGs and the UN’s Sendai Framework for Disaster Risk Reduction (2015-2030):** as mentioned, the Goal 11 of the SDGs – “make cities and human settlements inclusive, safe, resilient and sustainable” – highlights the protection of heritage in target 11.4: “strengthen efforts to protect and safeguard the world’s cultural and natural heritage” (UN, 2015, p. 18). The integration of ‘cultural heritage’ in disaster resilience has been also emphasised in the *Sendai Framework for Disaster Risk Reduction (2015-2030)*, particularly in the Priority for Action 1 “Understanding disaster risk and Priority” (UNISDR, 2015b, p. 14). The proposed risk assessment in this thesis and its contribution to the risk management will assist the authorities and engaged organisations to adequately incorporate the cultural heritage considerations into the resilience planning. The risk mapping provides multiple stakeholders with a common understanding of risk at site, which can promote the efficiency of the emergency response.

## 6.7 Suggested further research

**Integrating Bam’s cultural heritage into the urban resilience planning:** challenges and opportunities regarding the integration of cultural heritage into the broader resilience planning are discussed in a paper published by the author (Ravankhah et al., 2017b). Even though the city of Bam appeared to be highly vulnerable in the 2003 earthquake, particularly in terms of loss of life and structural collapse, Bam’s Cultural Landscape had a vital role in the rehabilitation and recovery of the city. The multi-dimensional values of the site, associated with traditional agricultural land-use, Qanat distribution system, and the unique architectural and archaeological attributes, made a significant contribution to the socio-cultural, environmental and economic recovery of the city.

Multi-stakeholder cooperation in the protection of the property led to a *comprehensive management plan for Bam and its Cultural Landscape 2008-2017* (ICHHTO, 2008a). In 2010, the management plan was approved by the Iranian Higher Council for Architecture and Urban Planning as an annexe to the existing Bam Spatial Structural Master Plan for Bam City (UNESCO WHC’s website, 2016). Despite this valuable progress, a further step is necessary. It is recommended that Bam’s heritage is fully integrated (as an integral part of the city, not as a separate fragment) into the urban planning and disaster management process to reconsider heritage and non-heritage in the same context within the future disaster resilience and development planning.

To address the challenge, interdisciplinary research needs to be carried out to incorporate the heritage considerations into the regional pre-disaster DRM policies (e.g. risk assessment, mitigation and preparedness) as well as into the post-disaster plans (e.g. emergency response and recovery plan), while evaluating their potential direct and consequential impacts on heritage values. The effectiveness of the integration relies heavily on the multi-sectoral cooperation mechanisms, while taking into account the existing legal system, between the heritage sector and civil protection agencies. This should go beyond the simple preservation of heritage sites, and seek for including heritage as an integral part of resilience planning within the broader urban and regional context, while transferring the role of heritage values and traditional knowledge in coping capacities to other sectors.

**An indicator-based disaster resilience framework for cultural heritage:** apart from the lack of a systematic risk assessment procedure within the overall risk management cycle for cultural heritage, an integrated disaster resilience framework has not been adequately addressed in the theory and practice. Such a framework might be developed while applying an event-specific or a multi-hazard approach. An integrated approach to the risk associated with both sudden-onset and slow-onset hazards may need a complex set of indicators for the risk components, such as susceptibility. While

a site-specific indicator-based assessment facilitates determining the effective strategies at the local level, an overall resilience framework can assist the protection of heritage sites at the regional and national levels. Although such a framework can considerably facilitate the safeguarding of cultural heritage, it might pose a number of challenges associated with disciplinary boundaries, competing priorities at the urban and regional levels, and eventually multi-sectoral institutional arrangements. However, the challenges and opportunities need to be discussed through interdisciplinary research to provide a scientific ground in the area of heritage disaster resilience.

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# APPENDICES

## Appendix 1. Expert questionnaire

### PhD thesis topic: Earthquake Disaster Risk Assessment for Cultural World Heritage Sites: The case of Bam and its Cultural Landscape in Iran

#### About the questionnaire:

The aim of this questionnaire is to gather information about multiple impacts of Bam earthquake 2003 on the World Heritage site of Bam and its Cultural Landscape and to assess the status of risk assessment and management of the property before and after the earthquake. The information will help the author to identify and evaluate disaster risks of potential earthquakes to the property. Please send the questionnaire back to the email address provided.

Personal information	
Name	
Title/expertise	
Role in the conservation/recovery of Bam and its Cultural Landscape	
E-mail	

#### Part 1. Bam and its Cultural Landscape before the Bam earthquake 2003

1. To what extent did the conservation plan of Arg-e Bam, before the earthquake of 2003, comprises the following attributes of Bam?

Attributes of the property	Level of consideration					
	Very high	High	Medium	Low	Not considered	N/D
Arg-e Bam (Bam Citadel)						
Qanat (underground irrigation system)						
Earthen architectural structures surrounding the citadel, in the core zone						
Archaeological sites in the core zone						
Date palm orchards						
Valuable collections and documents in the citadel						
Earthen construction know-how						
Religious rituals and ceremonies in the citadel						
Traditional water management linked to Qanat						
➤ Additional comments						

2. To what extent did the pre-disaster conservation and management of the property involve the following essential requirements of a disaster risk management (DRM)?

Disaster risk management	Level of consideration					
	Very high	High	Medium	Low	Not considered	N/D
Risk identification/assessment						
Risk mitigation <sup>16</sup> measures						
Risk preparedness <sup>17</sup> plan						
Seismic-resistance and reinforcement						
➤ Additional comments						

## Part 2. Impact of the Earthquake 2003 on Bam and Its Cultural landscape

3. How much do you rate the role of the following secondary hazards and environmental factors on posing additional damage to the property after the earthquake 2003?

Secondary hazards/ environmental factors	Level of relevance					
	Very high	High	Medium	Low	Not relevant	N/D
Liquefaction						
Flooding						
Rising groundwater						
Fire and explosion						
Rainfall and snowfall						
Wind-driven sand						
Wind-driven rain						
➤ Additional comments						

4. How much do you rate the role of the following potential human-induced threats on posing additional damage to the property after the earthquake 2003?

Potential human-induced threats	Level of relevance					
	Very high	High	Medium	Low	Not relevant	N/D
Man-made hazards (e.g. Looting and illicit trafficking of collections)						
Improper emergency response activities (e.g. By firefighters and volunteers)						
Improper damage assessment/interventions						
Lack of coordination among engaged agencies						
Encroachment and illegal urban development and land use change adjust to the core zone						
➤ Additional comments						

<sup>16</sup> Risk mitigation refers to the measures to reduce the risk of earthquakes to the property.

<sup>17</sup> Risk preparedness refers to planning for emergency response and recovery.

5. How much do you rate, in overall, the impact of the earthquake 2003 to different attributes of Bam and its Cultural landscape?

Attributes of the property	Level of impact					
	Catastrophic	Major	Moderate	Minor	Insignificant	N/D
Arg-e Bam (Bam Citadel)						
Qanat (underground irrigation system)						
Earthen architectural structures surrounding the citadel, in the core zone						
Archaeological sites in the core zone						
Date palm orchards						
Valuable collections and documents in the citadel						
Earthen construction know-how						
Religious rituals and ceremonies in the citadel						
Traditional water management linked to Qanat						
➤ Additional comments						

6. To what extent did the earthquake directly affect the Outstanding Universal Values (OUV) and the condition of authenticity and integrity of the property?

The OUV, authenticity, and integrity	Level of impact					
	Catastrophic	Major	Moderate	Minor	Insignificant	N/D
Loss of the OUV						
Loss of authenticity of structure and material						
Loss of authenticity of form and design						
Loss of authenticity of function						
Loss of integrity of structure and material						
Impact on visual integrity						
➤ Additional comments						

### Part 3. Recovery project of Bam and its Cultural Landscape after the earthquake 2003

7. To what extent has the Bam recovery project comprised the following tangible and intangible attributes of the property?

Attributes of the property	Level of consideration					
	Very high	High	Medium	Low	Not considered	N/D
Arg-e Bam (Bam Citadel)						
Qanat (underground irrigation system)						
Earthen architectural structures surrounding the citadel, in the core zone						
Archaeological sites in the core zone						
Date palm orchards						
Valuable collections and documents in the citadel						

Earthen construction know-how						
Religious rituals and ceremonies in the citadel						
Traditional water management linked to Qanat						
➤ Additional comments						

8. To what extent has the post-disaster conservation/management of the property involved the following requirements of a disaster risk management against potential earthquakes?

Disaster risk management (DRM)	Level of consideration					
	Very high	High	Medium	Low	Not considered	N/D
Risk identification/assessment						
Risk mitigation measures (including seismic-resistance and reinforcement)						
Risk preparedness (including emergency response and recovery plan)						
Risk identification/assessment						
➤ Additional comments						

9. How would you rate the following requirements of a disaster risk assessment in the risk preparedness of Bam and its Cultural Landscape after the earthquake 2003?

Attributes of the property	Level of relevance					
	Very high	High	Medium	Low	Not relevant	N/D
Geological studies (e.g. Soil, fault lines, water tables)						
Hazard analysis (nature, probability and severity of possible seismic events)						
Vulnerability assessment (including exposure, sensitivity, and coping capacity analysis)						
Value assessment (for both tangible and intangible attributes of the property)						
Generating a vulnerability/ risk map (GIS or another format)						
Disaster risk identification (based on a disaster scenario and including identification of multiple risks)						
Disaster risk analysis and evaluation (including structural and functional loss estimation)						
➤ Additional comments						

10. To what extent have the damage assessment and recovery project in the core zone considered the OUV, authenticity and integrity of the property?

The OUV, authenticity, and integrity	Level of consideration					
	Very high	High	Medium	Low	Not considered	N/D
The OUV						
Authenticity of structure and material						
Authenticity of form and design						
Authenticity of function						
Integrity of structure and material						
Visual integrity						
➤ Additional comments						

11. How would you rate the following measures potentially carried out during the damage assessment and recovery of Bam and its Cultural landscape?

Measures in Bam recovery project	Quality level of the plan/measures					
	Very well-developed	Well-developed	Acceptable	Poorly-developed	Nothing exists	N/D
Salvage, triage and stabilisation for moveable objects						
Triage and in-situ stabilisation for immovable heritage						
Full damage assessment						
Integration of the property in the overall disaster risk management of the city of bam						
Traditional knowledge and technique of earthen construction						
Modern methods of restoration and reinforcement						
Generating a map (GIS format or others) of valuable and vulnerable elements in the core zone						
Revival of local rituals and ceremonies in the citadel						
Providing temporary facilities in the citadel for tourists						
➤ Additional comments						

12. How do you rate the existing disaster risk management system of the property in regard to the following criteria?

DRM of Bam and its cultural landscape	Quality level of the plan/measures					
	Very well-developed	Well-developed	Acceptable	Poorly-developed	Nothing exists	N/D
Directory of responsible agencies and specialists available and their responsibilities during and after future disasters						
Emergency and security equipment (e.g. Fire hydrant)						
Emergency evacuation plan for staff and tourists in the citadel						
First aid kit including salvage, triage, and stabilization of movable and immovable heritage						
Early warning system						
Inventory and map of valuable and vulnerable properties within the core zone						
Maintenance and monitoring system						

Potentials pre and post-disaster national and international funds						
Risk compensation mechanism and insurance coverage						
➤ Additional comments						

**Thank you for taking the time to answer this questionnaire. Your cooperation is greatly appreciated.**

Mohammad Ravankhah

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## Appendix 2. The Bam Declaration and Recommendations



Shared Legacy, Common Responsibility

### ***International Workshop for the Recovery of Bam's Cultural Heritage***

*Bam City, Kerman Province, Islamic Republic of Iran  
17-20 April 2004*

### ***Declaration and Concluding Recommendations of the international workshop***

*Organized by the Iranian Cultural Heritage Organization  
UNESCO World Heritage Centre  
International Council on Monuments and Sites (ICOMOS)  
UNESCO Tehran Cluster Office,  
Hosted by the Province of Kerman and City of Bam  
With the support of the Government of Japan, the World Bank, and  
UNESCO World Heritage Fund*

**International Workshop on the Recovery of Bam's Cultural Heritage  
(17-20 April 2004, Bam, I.R. of Iran)**

**The BAM Declaration and Recommendations**

**Preamble**

The devastating earthquake of 26 December 2003 in the historic desert city of Bam, Islamic Republic of Iran, caused the tragic loss of many lives and the destruction of an overwhelming part of its cultural heritage. This natural disaster stirred a strong sense of solidarity in the international community for the people of Bam. This wish to aid was also particularly strong amongst institutions and professionals in the conservation of cultural heritage.

On the occasion of the International Day of Monuments and Sites (18 April), the Iranian Cultural Heritage Organization (ICHO), the United Nations Educational, Scientific, and Cultural Organization (UNESCO), and International Council of Monuments and Sites (ICOMOS) organized an International Workshop for the Recovery of Bam's Cultural Heritage between 17-20 April 2004 in Bam. 38 international and 23 Iranian expert participants and representatives of local and national authorities, and 31 ICHO members, gathered from Canada, France, Germany, Iran, Italy, Japan, Peru, Spain, the United Kingdom and the United States of America, as well as representatives the Governments of France and Italy, International Centre for Earth Construction – Ecole d'Architecture de Grenoble - (CRATerre-EAG, France), the Getty Conservation Institute, World Monuments Fund, the International Centre for the Study of the Preservation and the Restoration of Cultural Property (ICCROM), ICOMOS, the World Bank, and UNESCO.

The workshop participants examined and reflected on the impact of the earthquake on Bam's heritage, notably Arg-e Bam and its related properties, the architecture and heritage assets which characterize this unique city, strategically located on the fringe of the desert;

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**Drawing** from lessons learnt from previous natural disasters which affected built heritage in urban settings, such as the 1995 Kobe earthquake in Japan, and various earthquakes in India, Morocco, Turkey, and countries in North and South America,

**Recognizing** the universal nature of the ancient but still used earthen architecture as a living tradition adapted to desert environments, such as in Bam,

**Noting with concern** that human and natural threats continue to endanger Bam's heritage and realising the need for both urgent and long-term preventive considerations, which demand full co-ordination between all stakeholders,

**Stressing** the need to promote continued utilization of earth as a traditional building material for new constructions, thereby retaining and expanding the specialist skills and employment opportunities,

**Emphasising** the fact that wisdom, knowledge and correct engineering principles must combine to create the required conditions for safe building, and it is not necessarily the implementation of material such as adobe which contributes to the failure of structures,

**Recognizing** the heroic and successful efforts by the authorities and professionals of Iran, in particular, the Iranian Cultural Heritage Organization, to effectively respond to the post-earthquake emergency needs of Bam's cultural heritage,

**Noting** that the crisis-response experience for Bam's cultural heritage could serve as a valuable and useful model at an international level after future disasters,

**Calling upon** all national and international partners and stakeholders to actively participate in the recovery process of Bam,

**Recalling** existing international conventions, recommendations, charters, and declarations favouring the integration of heritage conservation within the overall development process,

**Adopted the following Declaration and Recommendations**, for improved planning and conservation of Bam's heritage as an integral part of the recovery process and sustainable development process after the cataclysm, and called upon the Iranian authorities, ICOMOS and UNESCO to mobilize further co-operation at both national and international level to ensure that adequate steps are taken in the short, mid and long term, to provide further guidelines for preventive measures applicable to buildings, living settlements, archaeological sites of earthen architecture and cultural landscapes in Iran and around the world, and to encourage co-operation in the fields of research, education and training in relevant disciplines.

### **1. Conserving the full significance of Arg-e Bam and its setting**

1. Arg-e Bam, whose strategic location was chosen for agricultural, economic and defensive reasons, is the cultural and spiritual landmark of the city of Bam and a dominant feature of its landscape. It is also a highly significant and exceptional record of many archaeological layers and historical periods, representing the long and rich civilization of this city, contributed to the evolution of earthen architecture and cultural development.
2. The earthquake caused major structural damage to Arg-e Bam and affected the visual and functional nature of its relation to the city and its traditions. It also exposed some of the archaeological features. A full understanding of the impact of the earthquake from a conservation and archaeological point of view is necessary to provide a comprehensive basis for specific interventions either to conserve the site, or to re-establish some of its pre-earthquake condition in concurrence with international conventions and charters.
3. The exceptional work achieved since the day of the earthquake by ICHO has taken into account the complex character of Bam's heritage, including the spiritual role of Arg-e Bam and its related properties in the life of the citizens of Bam. In particular, the Workshop participants took note of the rapid establishment of the access path within Arg-e Bam, which was planned with care and sensitivity, and of the other related facilities and safety measures.
4. The conservation and protection of Arg-e Bam requires a balanced approach with reference to scientific and cultural data to understand its place in the living culture and its contribution to the specific identity of Bam and the nature of its archaeological site. In this sense, archaeological research work and conservation should be considered as concurrent and complementary activities to be carried out on the property.
5. The significance of Arg-e Bam and its related properties, and the consequences of the earthquake both call for the establishment of a permanent centre dedicated to research and conservation. The elaboration of long term conservation strategies and time-restricted comprehensive management plans will contribute to the protection of Arg-e Bam, which the Government of Iran is presently proposing to be recognized as World Heritage property.

## 2. Conserving the character and the heritage of the city and landscape

1. The diverse tangible and intangible heritage resources of Bam express values associated with the long and complex history of the city. The heritage of Bam and its surrounding area are a cultural landscape composed of the desert environment, ingenious water use, management and distribution systems, (e.g. Qanats), agricultural land use, gardens, and built environment.
2. In the urgent recovery process of Bam city, the cultural, social, economic, and physical aspects must be addressed simultaneously with the conservation of Arg-e Bam. The absence of detailed and in-depth studies of the various cultural, social-economic and physical aspects of the city should not prevent recovery actions from taking place. Nevertheless they should be planned and implemented in a sensitive manner, in constant consultation with the heritage managers. Meanwhile, mid to long term planning and implementation to conserve the heritage of Bam, its character and cultural landscape should be undertaken. As part of this effort, an inventory of buildings, building elements and landscape features, should be prepared. All these efforts will provide information to implement awareness and social programmes for the people of Bam, and develop their understanding and appreciation of their earthen heritage.
3. Recovery planning and implementation should both refer to and be the subject to an integrated documentation programme. Considering the diversity of Bam's heritage and the challenges to the revitalization of Bam's cultural landscape, the techniques and media used for documentation should be appropriate to the objectives of the specified tasks at hand. All information should be incorporated into the information system of the larger management plan.
4. The foundation of Bam's strong identity is composed of gardens and plantations, monuments of religious and civil uses, traditional houses, public facilities and water systems, and such features as the walls of different types of earth constructions, for example "chiné", and all the manifestations of intangible heritage. The conservation, wherever possible, should be preferred and their reconstruction should be seen as a chance to perpetuate the living identity of Bam. Thus, through its urban landscape, there is an opportunity for real improvement in building technologies, and a reduction in vulnerability to natural forces, such as future earthquakes.

## 3. Integrating heritage in the recovery process and the future development of Bam

1. The conservation and revitalization of intangible and tangible heritage of Bam must be integrated within the General Master Plan which should be revised, as well as complementary support programmes and special projects contributing to the recovery process of post-earthquake Bam, in order to ensure that the unique identity and cultural character of Bam are retained and fully contribute to the restoration of the life of its citizens.
2. The cultural heritage, in particular the site of Arg-e Bam and the overall character of the city also constitute primary but non-renewable resources for the future social and economic development of the city, through tourism and other related activities. As such, their conservation and adequate management, including the perpetuation of skills and traditional know-how are to be considered as resources for the city's future development.
3. The recent development of tourism and its likely future expansion are not incompatible with the scientific and cultural objectives associated with the conservation and protection of Bam's cultural heritage and should be seen as complementary.

While tourism infrastructures should be planned and developed so as to limit or eliminate their potentially negative visual or physical impacts on cultural heritage, the benefits of tourism should be shared with the local economy and contribute to the conservation of the cultural resources. Finally, the interpretation or presentation of the sites should include reference to the earthquake and its consequences for the local population.

#### **4. Preserving and enriching the tradition of earthen architecture**

1. The impact of the earthquake on the built heritage of Bam and its infrastructures demonstrated that it was the quality of construction and engineering of the buildings that was the main cause of damage rather than the construction materials themselves. This also demonstrates the need to document and understand building and material performance properly. This is particularly important in the development of seismic earthen architecture technology for future use in Bam and elsewhere in Iran.
2. It is important to upgrade the social image of vernacular architecture among the local people, without which this kind of architecture will be inevitably lost due to the loss of the relevant traditional skills and know-how.

#### **5. Protecting and preventing damage to earthen heritage in seismic areas**

1. The collapse of structures and the debris resulting from earthquakes are serious risks to human life and to cultural heritage. It is now recognized that protection against such cataclysms must be considered both for historic and contemporary structures. In light of this, it should be the practice in heritage environments to go beyond the confines of standard present-day engineering analysis and design techniques. This should include a full understanding and possible use of the earthquake performance characteristics of traditional anti-seismic construction practices of the regions and nations involved.
2. To facilitate the protection and prevention of damage to earthen heritage, it is essential to:
  - a. Increase understanding of the complete behaviour and performance of the earth material, structure, and construction in seismic areas;
  - b. Document the traditional cultures and architectures where earth is the principle building material, paying special attention to their specific responses and relationships to the needs of the inhabitants, and environments;
  - c. Document the different types of existing earthen materials and building systems, to understand and develop a glossary for the processes of decay;
  - d. Maintain and monitor all types of earthen structures;
  - e. Ensure that a full understanding and appreciation of earthen architecture, building materials and structures is integrated into the documentation used by all involved in conservation activities.

#### **6. Sustaining co-operation to realize the conservation goals**

1. The diversity of cultural, scientific, educational and management issues of Bam and the effects of the earthquake call for sustained co-operation at different levels, the sharing of concerns and knowledge in order to increase the capacity required for the realisation of specific projects.

2. At the local level, the recovery of Bam's cultural heritage requires the development of an integrated approach that is transparent and open towards the population. Basing itself on information and the processes of education, consultation, and participation, this approach should take into account the perspective of the local population, acknowledging the specific responsibilities of the institutions and professionals entrusted with the care, maintenance and accessibility of Arg-e Bam and other elements of Bam's cultural heritage.
3. Co-operation among governmental and non-governmental institutions and associations, at the national and international levels is essential to carry on specific tasks, such as the development of a comprehensive information system. Moreover, an interdisciplinary approach is necessary to address the various scientific, educational and conservation needs of Bam's cultural heritage. The setting up of appropriate tools and mechanisms to facilitate and sustain such national and international co-operation is required and must be implemented.
4. Co-operation must be developed with other organizations, especially those usually involved in restoration, archaeology and conservation of heritage, as well as those working in the fields of urban planning, housing, tourism and funding activities.

## 7. Recommendations

1. Recommendations for immediate action:
  - a. Document, identify and analyse initial risks and implement emergency stabilisation treatments.
  - b. Secure and stabilise the parts of Arg-e Bam which are vulnerable to aftershocks.
  - c. Provide adequate, sensitively designed and safe access to conservation professionals, the general public, and to the citizens of Bam who will continue to utilize the Arg-e Bam for traditional and religious activities.
2. Recommendations for short-term actions (2004-2005):
  - a. Define criteria and procedures for managing debris, taking into full consideration, on a case by case basis, the structural implications any interventions may cause on the heritage resources.
  - b. Continue with rigour the consultation process between ICHO and the relevant authorities in ensuring that the Master Plan for the Reconstruction of Bam City respects the heritage areas of Bam, as defined within the core and buffer zones, which are being proposed for World Heritage inscription. In addition, the panoramic views and cultural landscape surrounding Arg-e Bam and its related properties must be taken into account within the Master Plan.
  - c. Strengthen and continue the comprehensive management planning process in a short to medium time frame, for Arg-e Bam and its surrounding areas.
  - d. Develop plans for visitor access and orientation, including exhibition of pre and post-earthquake events and heritage assets.
3. Recommendations for mid-term actions (2004-2010):
  - a. Develop and implement a site management plan for Arg-e Bam and its surrounding areas. The plan must address and establish policies for conservation, archaeological researches, rehabilitation, cultural landscape protection, site interpretation, access, circulation and safety. Furthermore, the plan should guarantee compatibility with the General Master Plan being developed for Bam's reconstruction.
  - b. Develop a conservation programme, which includes a comprehensive analysis resulting in interventions based on the identification of the complete range of values in accordance with international charters.

- c. Implement an open information management system to ensure access to information and to prevent wastes of effort. To this end, standard criteria for data collection, classification and entry must be established. These standards must take into consideration the needs of multiple disciplines.

4. Recommendations for long-term actions (2004-2015):

- 1. Assess the objectives of the site management plan of Arg-e Bam, the effectiveness of the policies within the management plan, and the compatibility with the expected outcomes from the General Master Plan.
- 2. Conduct scientific investigations to address issues related to the long term conservation of earthen architecture in Arg-e Bam. This could contribute, in a broader national and international context, to the development of adapted use of earthen architecture techniques for seismic areas and for contemporary needs.

**8. Sustaining the momentum and focus to implement the present Declaration and Recommendations**

- 1. Establish a permanent research centre for Arg-e Bam in particular, and on earthen architecture in general, which may also promote the use of Arg-e Bam as a training and research centre of national significance.
- 2. To provide Bam and its heritage with the necessary support, the participants agreed that it would be essential for ICHO, ICOMOS and UNESCO to continue their co-operation to ensure the results of this workshop are effectively responded to. The documentation resources drawn from the information management system of Bam's heritage should comprise the foundation for sustainable conservation work. Special attention to the development of user interface design appropriate to professional communities, public outreach programmes, and pedagogical usage should be given priority. The appropriate cultural contexts and technological infrastructures can be instrumental in the dissemination strategies in this stage of implementation.
- 3. The urgent creation of a fund by UNESCO for streamlining assistance to Bam's heritage was recommended.

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Finally, the participants of the Workshop expressed their deep appreciation to the Iranian Cultural Heritage Organization and the Iranian authorities, ICOMOS and UNESCO for jointly hosting and organizing this timely and important Workshop. Furthermore, gratitude was expressed to the Government of Japan, UNESCO and its World Heritage Committee, and the World Bank, for their generous technical and financial assistance to realize this Workshop, and to the Governments of Canada, France and Italy, the Getty Conservation Institute, and the World Monuments Fund for their technical co-operation.

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