Chapter 1
Introduction

Abstract This chapter is an introduction to indicate the prominent function and necessity of resilience in different dimensions of a community against natural and manmade hazards by highlighting some examples of recent natural and manmade disasters. It is presented a broad definition of resilience concepts in different sciences by means of an extensive literature review. Different frameworks available in literature are described and compared. Finally, the concept of Resilience-Based design is presented as an extension of Performance-Based Design.

1.1 Motivations

Although substantial progress has been made in technology towards improved performance of the built environment, natural disasters, acts of terrorism, technological failures, wars, market collapses etc. have been responsible for loss of life, disruption of commerce and financial networks, damaged property loss of business continuity and essential services during the last two decades. Many facilities and infrastructures are vulnerable to natural hazards as well as manmade hazards, and the risk of damage due to hazardous events all over the world continues to increase as proven by recent events.

Some recent examples are provided to highlight the fragility of European communities and the world, specifically in the context of critical infrastructure failure and hazards (Caverzan and Solomos 2014). They have been grouped according to the hazard distinguishing between *natural* and *manmade hazard*, including in this category accidental human actions and terrorist attacks.

This classification is arguable, because there is a common opinion that all disasters can be seen as being human-made, because they are the result of human failure to introduce appropriate *disaster management measures*. Furthermore a specific disaster can initiate other disasters (e.g. earthquake causing tsunami causing coastal flooding etc.).

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1.1.1 Disasters Caused by Natural Hazard

A natural disaster is a sudden event not caused by human being that generates widespread damage with loss of life. Natural disasters might be caused by

- earthquakes,
- flooding,
- volcanic eruption,
- landslide,
- hurricanes,
- wildfire, bushfire,
- tornadoes,
- avalanches,
- tropical cyclone,
- etc.

Although Europe is assumed relatively safe from severe natural hazards, significant risks do exist and can be extreme, especially due to the high density of population in the region. The European Environmental Agency (EEA 2011) recorded the highest number of fatalities from natural events to be caused by heat waves, while floods and storms caused the greatest economic loss, during the period of 1998–2009. These two are not the only categories of natural hazards which are prevalent. In April 2010, the eruption of the Eyjafjallajökull volcano in Iceland compromised European air traffic for weeks. This result exemplifies how an unexpected phenomenon can influence critical infrastructures, even if they are not directly hit (Figs. 1.1 and 1.2).

Obviously, Europe has been subject to and is prone to hazards just like any other country, such as the United States. For the U.S. in particular, two natural disastrous events significantly influenced the development of resilience concepts: Hurricane

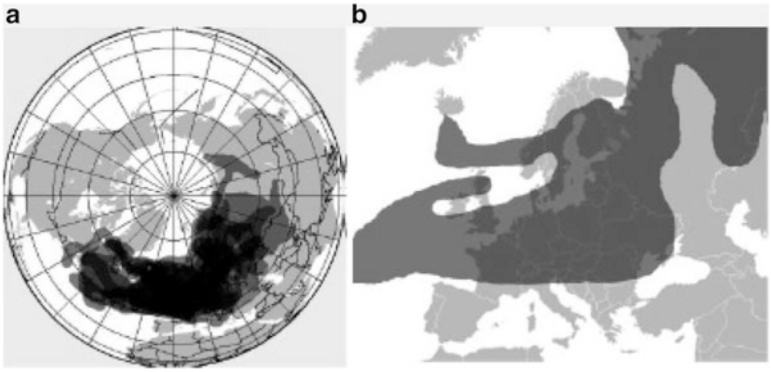


Fig. 1.1 Composite map of the volcanic ash cloud spanning in 14–25 April 2010 for the Eyjafjallajökull eruption (source http://en.wikipedia.org)

Fig. 1.2 Aerial image from Eyjafjallajökull volcano eruption. Ash cloud on April 17th, 2010 (source: http://en.wikipedia.org)

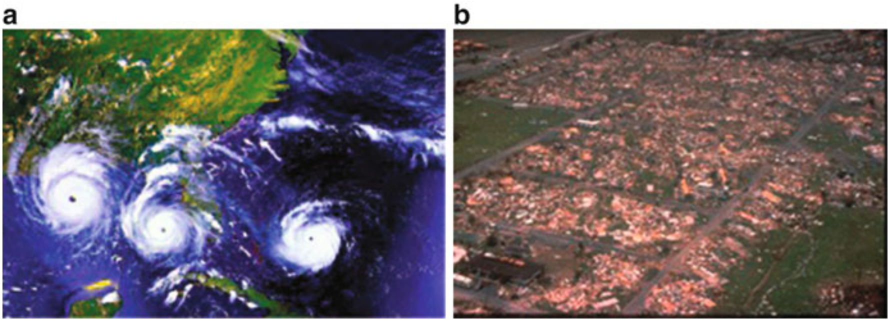


Fig. 1.3 Hurricane Andrew, (**a**) three views of Andrew on 23, 24 and 25 August 1992 as the hurricane moves from East to West (source http://earthsky.org Image credit: NASA), (**b**) An aerial view of Dade County, Florida, showing damage was hit by Hurricane Andrew (source: http://en.wikipedia.org image credited: FEMA)

Andrew in 1992 and Hurricane Katrina in 2005 (McAllister 2013). When Hurricane Andrew struck Dade County on August 24th, the storm devastated the area. It caused an estimated 25 billion dollars in damage and destroyed approximately 49,000 homes (Fig. 1.3).

Hurricane Katrina struck the Gulf Coast region in August of 2005 and rapidly escalated to a Category 5 with maximum sustained winds of 78 m/s. Storm surge and associated wave action caused breaches in the flood protection system in New Orleans, resulting in substantial structural damage to residences in the immediate vicinity of breaches and approximately three-quarters of the city became flooded (Fig. 1.4). Bridges were damaged by the uplift and lateral loads imparted by storm surge and associated wave action. An additional problem was the damage sustained by industrial facilities such as seaports, petrochemical facilities due to storm surge and flooding (NIST 2006). The extensive, multi-state destruction caused by Hurricane Katrina in 2005 serves as a reminder that natural disasters remain a significant threat to our livelihood. The unprecedented state of emergency brought

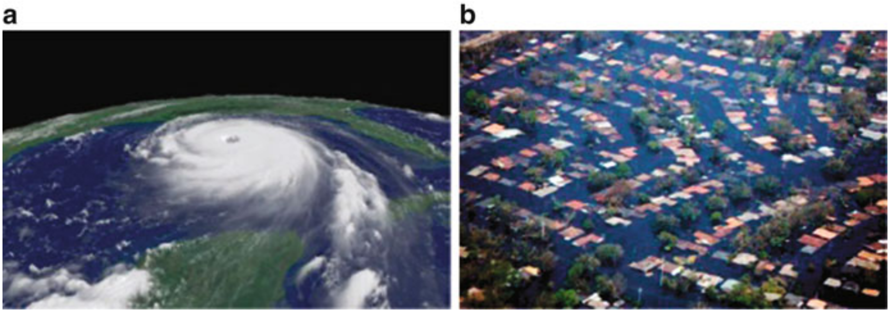


Fig. 1.4 Hurricane Katrina: (**a**) satellite image of the hurricane (source: image credited by NOAA); (**b**) flooding caused by Hurricane Katrina in the New Orleans area, August 31st, 2005 (source: http://de.wikipedia.org)

Fig. 1.5 Indian Ocean (Jan. 2, 2005) – A village near the coast of Sumatra lays in ruin after the Tsunami that struck South East Asia – (source: http://en.wikipedia.org)

renewed focus on the need to address protection from the threat of natural disasters, in addition to manmade hazards. As a result, the scientific community has been compelled to investigate the concept of resilience.

In the world, many other types of disasters happened in the last decade. The Indian Ocean earthquake which occurred on December 26th, 2004 with an epicentre off the west coast of Sumatra, in Indonesia was the third-largest earthquake ever recorded on a seismograph with a magnitude Mw between 9.1 and 9.3. The earthquake and the following tsunami (Fig. 1.5) killed 230,000 people in 14 countries, and inundating coastal communities with waves up to 30 m.

Fig. 1.6 An aerial view of the Sendai region with black smoke coming from the Nippon Oil refinery – (source: http://en.wikipedia.org)

The Great East Japan earthquake happened off the Pacific coast of Tohoku and was a magnitude 9.0 (Mw) undersea megathrust earthquake off the coast of Japan that occurred at 14:46 JST (05:46 UTC) on Friday 11 March 2011 (Fig. 1.6). The two Earth's tectonic plates collide in what is called a subduction zone, so East of Japan (the Pacific plate) slides beneath the overriding Eurasian plate. The total damages from the earthquake and tsunami are estimated at $300 billion dollars (about 25 trillion yen), according to the Japanese government, while the number of confirmed deaths is 15,891 as of April 10, 2015. The tsunami caused a cooling system failure at the Fukushima Daiichi Nuclear Power Plant, which resulted in a level-7 nuclear meltdown and release of radioactive materials. The electrical power and backup generators were overwhelmed by the tsunami and the plant lost its cooling capabilities.

1.1.2 Disasters Caused by Human Action (Manmade Disasters)

Manmade disasters are those caused directly or indirectly by human action or inaction. They belong to this category:

- terrorism,
- civil disorders,
- criminality,
- wars,
- industrial and engineering accidents,

- waste disposal,
- fire,
- nuclear explosions/radiation,
- transport accidents,
- power outage,
- etc.

Below are reported some examples of disasters belonging to this category occurring in the last decade.

A key example is the Italian electrical blackout of September 2003 (Bacher et al. 2003). The origin of the blackout was two power lines in Switzerland which had flashed over in an alpine storm, causing the Italian grid to increase its demand and overload other lines that brought power to France, this subsequently caused blackouts across the entire Italian grid as well as failures in Switzerland. Another example is the 2003 Northeast blackout in US, a widespread power outage that occurred throughout parts of the Northeastern and Midwestern United States and the Canadian province of Ontario on Thursday, August 14, 2003 (Fig. 1.7). Power was restored within 7 h, but many others did not get their power back until two days later or even a week after in more remote areas. A software bug in the alarm system at a control room of the First Energy Corporation in Ohio was the blackout's primary cause. A lack of alarm left operators unaware of the need to re-distribute power after overloaded transmission lines hit unpruned foliage, which triggered a race condition in the control software.

This is not the only example of a failure involving the electrical grid. In fact, in 2006 another power outage occurred when a power line across the River Ems in Germany was switched off to allow a cruise ship to pass safely (Fig. 1.8). This outage unintentionally triggered blackouts that spread to France, Italy, Spain and

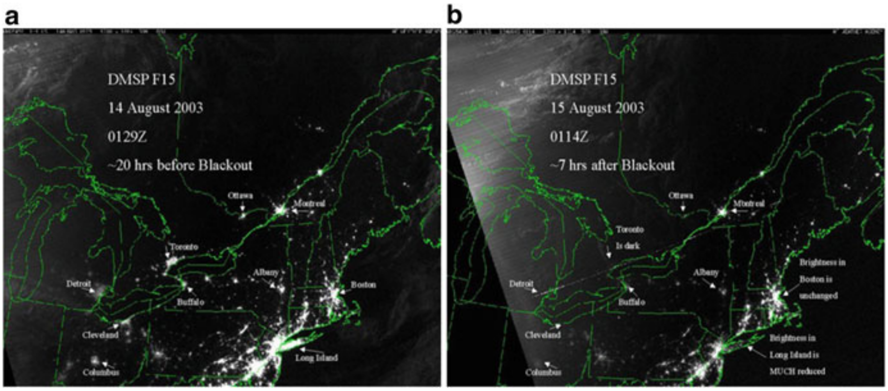


Fig. 1.7 Satellite images of the Northeastern United States blackout of August, 2003 which plunged millions of people into darkness (**a**) night Lights satellite image before the blackout, (**b**) night Lights satellite image after the blackout (source: NOAA credited by Air Force Weather Agency)

Fig. 1.8 Norwegian Pearl ship in the Papenburg, Germany, shipyard in November 2006. The ship indirectly caused a two-hour power outage on the evening of November 4, 2006 (source http://news.nationalgeographic.com)

Fig. 1.9 Aftermath of the fierce fire that claimed 39 lives in the Mont Blanc tunnel (source http://www.tunneltalk.com)

Portugal. Power system elements were also tripped in Austria, Hungary, Croatia, Bosnia, Ukraine, Romania and Morocco (UCTE 2007).

Tunnels are another example of important components of the transportation network. Many of the main cross-border routes in Europe are characterized by critical road and rail tunnels. Tunnels are vulnerable mainly to explosion and fire. Examples of disasters related to this component are the Mont Blanc and Tauern Tunnel fires (UN 2001), Figs. 1.9 and 1.10 and the Channel Tunnel fires of 1996 (Fig. 1.11), 2006 and 2008 (CTSA 1997; RAIB 2007; BEA-TT and RAIB 2010).

Fig. 1.10 The Tauern Tunnel fire. The main site in the rear burned at over 1000°C. A thick coat of foam covers the ground and parts of the roof hanging down against the fiery background (source http://www.landroverclub.net)

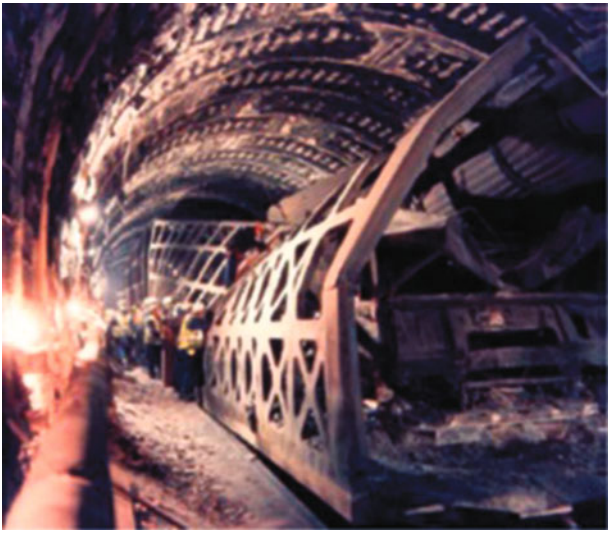


Fig. 1.11 Damage caused by the 1996 freight shuttle train fire in the Channel Tunnel (source http://www.tunneltalk.com)

When the protection of critical infrastructure is considered, *terrorism* remains a major concern. Europol (2012) recorded 316 attacks in the EU in 2009, 249 in 2010 and 174 in 2011 and an increase in the use of improvised explosive devices (IEDs) by terrorists of various affiliations. The components required for the construction of IEDs are easy to obtain, their production requires expertise that is available through open source information, and the chemical precursors can be obtained legally in EU Member States. In October 2011, improvised devices similar to incendiary devices (IIDs) were used in a coordinated attack targeting railway infrastructures in Germany.

Fig. 1.12 Terroristic attacks in rail transport system in Europe. (**a**) Madrid, 2004 (source http://www.telegraph.co.uk), (**b**) London, 2005 (source http://www.dailymail.co.uk)

Railway infrastructures and their occupants have been the target of terrorist attacks in major cities such as London and Madrid. Three days before the Spanish election, during the peak of Madrid morning rush hour on Thursday March 11th, 2004, ten explosions occurred on board of four commuter trains (Fig. 1.12a). All the target trains were traveling between Alcalá de Henares and the Atocha station in Madrid in the same direction.

There were three bombs which exploded in the Atocha station, two bombs in different carriages in the El Pozo del Tío Raimundo Station, one other explosion occurred in the Santa Eugenia Station and the last one exploded in different coaches of the train-approximately 800 m from Atocha Station. The explosions killed 191 people and wounded 1.800. One year after Madrid's attacks, on July 7th, 2005, a series of coordinated suicide attacks in central London were conducted by four terrorists (Fig. 1.12b). The attacks targeted civilians using the public transport system during the morning rush hour. Two attacks were conducted on Circle line sub-surface trains, while the third one targeted a Piccadilly line deep-level underground train traveling southbound from King's Cross-St. Pancras and Russell Square, and also damaged the surrounding tunnel. A final bomb was detonated on the top deck of a double-decker bus, 1 h after the first attack. Naturally these incidents caused serious disruptions in the rail transport system of both cities, and it took several days to regain full capacity.

Recently in France on November 13, 2015, a series of coordinated terrorist attacks occurred in Paris and Saint-Denis (Fig. 1.13). Three suicide bombers struck near the Stade de France in Sanit-Denis, followed by suicide bombings and mass shootings at cafés, restaurant and a music venue. 130 people were killed (89 only at the Bataclan theatre), while 368 people were injured. Seven of the attackers died. This has been the deadliest attack in the European Union since the Madrid train bombing in 2004. The Islamic State of Iraq and the Levant (ISIL) claimed the attacks, saying it was in retaliation for the French airstrikes on ISIL targets in Syria and Iraq.

Fig. 1.13 Paris Shootings – The day after (Maya-Anais Yataghene [CC BY 2.0 http://creativecommons.org/licenses/by/2.0]) (via Wikimedia)

Fig. 1.14 Police officers, emergency vehicles, and journalists at the scene 2 h after the shooting ("Charlie-Hebdo-2015-11" by Thierry Caro / Jérémie Hartmann – Own work. Licensed under CC BY-SA 4.0 via Commons – https://commons.wikimedia.org/wiki/File:Charlie-Hebdo-2015-11.JPG/media/File:Charlie-Hebdo-2015-11.JPG)

These attacks were anticipated by the Charlie Hebdo shooting on January 7, 2015 when two brothers, Saïd and Chérif Kouachi, forced their way into the offices of the French satirical weekly newspaper Charlie Hebdo in Paris. Armed with assault rifles, submachine guns and grenades, they killed 12 people and injured 11 others in the building (Fig. 1.14). Charlie Hebdo had attracted attention for its controversial depictions of Mohammed. Hatred for Charlie Hebdo's cartoons, which made jokes about Islamic leaders as well as Mohammed, is considered to be the principal motive for the massacre.

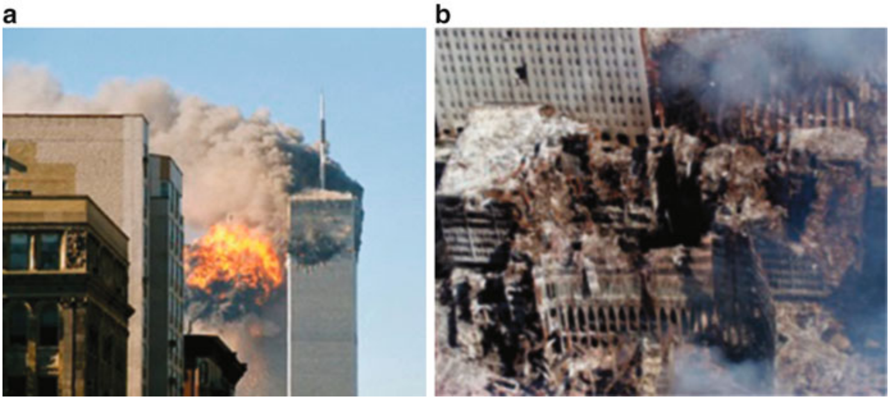


Fig. 1.15 The World Trade Center attack: (**a**) 9th September 2001, Flight 175 crashes into 2 WTC (source: http://en.wikipedia.org); (**b**) the remains of 6 World Trade Center, 7 World Trade Center, and 1 World Trade Center on September 17, 2001 (source http://en.wikipedia.org)

Outside of Europe, the most known terrorist attack happened in USA on September 11, 2001, when three large passenger aircrafts flew into the World Trade Center buildings and the Pentagon (Fig. 1.15). The fires following the impact caused the collapse of both the WTC 1 and WTC 2 buildings in less than 1.5 h. Once the buildings collapsed, the fire spread to the WTC 7 building where the emergency Operations Centre was located (Kendra and Wachtendorf 2003). The collapse of WTC buildings led to major damage of the surrounding buildings and the loss of power, communication and water in lower Manhattan as well as the interruption of financial markets. The loss of life by occupants and responders, and the damages to the surrounding buildings and infrastructure systems raised concern about how the destruction of a building can affect the entire built community around it NIST (2008).

Another example in US is the Boston marathon terrorist attack which occurred on April 15th, 2013. The bombs exploded 12 s and 190 m apart near the marathon finish line, killing 3 people and injured 264 who were treated in 27 local hospitals. The terrorists were two Chechen brothers: Dzhokhar Tsarnaev and Tamerlan Tsarnaev, which motivated by extremist Islamist beliefs and the wars in Iraq and Afghanistan. Units from Boston EMS, the Boston Police Department, and the Boston Fire Department were dispatched to assist emergency responders already on-scene (rescue workers and medical personnel) to assist runners and bystanders (Fig. 1.16).

The aftermath of these tragic events and the natural realization by researchers of the importance of considering resilience in their analyses, caused the shift in attention from vulnerability and risk assessment to new design and evaluation approaches based on resilience assessment, which involve many different disciplines: economics, political science, engineering, environmental planning, social science, etc. The evolution towards resilience thinking is far from trivial. "Resilience as a concept is more dynamic, it is non-linear and cross-linked, complex because it

Fig. 1.16 The area of the first blast a few minutes after the explosion

considers many factors and embraces uncertainty" (Stumpp 2013). Current work in the field of resilience is the product of theoretical and practical constructs that have seen refining and reshaping of the disaster paradigm over the past three decades. This has led to multiple definitions and the need for new terminology and/or metrics that will be harmonized. For this reason, various definitions are presented and discussed in the next section in order to establish the basic familiarity needed to develop further research in the field of critical infrastructure resilience.

1.2 Milestones for Preparedness Throughout History

The concepts of resilience and emergency response are not new or unique to recent history; they have actually been commonly practiced for human and organizational life around the world dating back to ancient times. Humans have been subjected to the adverse effects of disasters since the dawn of their existence and attempted to minimize their hazard vulnerability and exposure. Regardless of the actions that were taken, they have all had a similar purpose – to manage emergencies. Below is a list of some of the first examples of emergency authorities in the world, progressing to the recent ones.

- During the ancient Persian Achaemenid Empire (559–300BC), strategic, public and emergency management were well organized and efficient. They had already developed an alert system against flooding, disaster management programs following earthquakes and other types of disasters (e.g. robust shelters against extreme weather conditions were available at that time).

- Amenemhet III was a pharaoh of the Twelfth Dynasty of Egypt (ruled from c.1860 BC to c.1814 BC). He created a substantial river control project using a system of over 200 water wheels that diverted Nile floodwaters and allowed significant land reclamation.
- In AD 79, when the volcano Vesuvius began erupting, two towns in its shadow, Herculaneum and Pompeii, faced an impending catastrophe. Herculaneum, which was at the foot of the volcano and therefore directly in the path of its lava flow, was buried almost immediately. Conversely, the majority of Pompeiis population survived because the citizens of Pompeii had several hours before the volcano covered their city in ash, and the cities leaders organized a mass evacuation.
- St. Florian lived in the time of the Roman emperors Diocletian and Maximian. He was the commander of the imperial army in the Roman province of Noricum. In addition to his military duties, he was also responsible for organizing firefighting brigades in AD 303. He organized and trained an elite group of soldiers whose sole duty was to fight fires.
- Several Medieval cities were often set on fire during wars and natural disasters. For this reason, in 1254 AD by royal decree, King Saint Louis II of France created the guet bourgeois (“burgess watch”), an organization of private citizens who patrolled the streets in order to prevent crimes and fires.
- The Inca Empire was the largest empire in pre-Columbian America, expanding throughout the Andes Mountains in South America (during the thirteenth to fifteenth centuries). They built their cities on the peaks of rugged, though easily defensible, mountains, in order to prevent hostile attacks. In doing so, they placed themselves in a zone of high natural hazard risk (from landslides), which they maintained through land terracing.
- Kaifeng is the region located on the south bank of the Yellow River in China prone to devastating floods throughout its history. After the 1642 Yellow River flood caused about 300,000 life losses, Kangxi Emperor made the city as a rural backwater city of much less importance. They moved the people and thus they decreased the vulnerability against future floods.
- London suffered a devastating fire in 1666 which caused damages in area of about two square miles of the city. Before that, the city had no fire protection network. Subsequent of this event, private firefighting units were established by the insurance companies to extinguish fires in their clients property.
- After the fire of 1802 in New Hampshire, the U.S. Congress provided financial assistance to the city to rebuild it. This is one of the first examples of U.S. government investment in the emergency management and recovery functions.
- Nagoya city in Japan suffered severe damages after the 1891 Nobi earthquake of magnitude 8. Afterwards, an Earthquake Disaster Prevention Investigation Council was formed in 1892 by the Japan government to focus on the earthquake disasters and to develop damage mitigation plans.
- The Flood Control Act of 1934 in United States is one of the significant steps toward emergency management in this country and reflects this believe that natural disasters could be controlled by humans. After this act, design and

construction of flood control systems were investigated more by the U.S. Army Corps of Engineers to eliminate the risk of floods.
- In response to the damaging consequences brought about by major disastrous events, individuals and societies have attempted to minimize their hazard vulnerability by developing mitigation plans. This effort resulted in a number of guidance documents and tools to use for assessing hazards and for developing approaches to reduce or eliminate those vulnerabilities. For example the United States Federal Emergency Management Agency (FEMA), which grew out of the Federal Civil Defense Act of 1950, has produced a series of frameworks to address the spectrum of prevention, protection, mitigation, response, and recovery. Canadas Office of Critical Infrastructure Preparedness and Emergency Preparedness (OCIPEP), and Great Britains disaster management agency are the other efforts which form the basis for modern disaster and emergency management. On October 23rd, 2001 the EU Council established the Community Mechanism for Emergency authority, which is a tool to enhance community cooperation in civil protection matters. A recast of this Council Decision was adopted on November 8th, 2007.

This list of early milestones of *Preparedness* and *Resilience* all over the world show that these are key concepts and have recently been spreading within the engineering community.

The following sections of this chapter provide general information on the state-of-practice in resilience-based design (RBD) and current frameworks available. Then is illustrated the transition from performance-based design (PBD) towards resilience-based design (RBD). The main aspects of the resilience-based design framework that might prove useful in the development of resilience-based guidelines are identified.

1.3 What Is Disaster Resilience?

Latest disasters all over the world have shown clearly that not all threats can be averted. The natural and manmade disasters over the past years with which the human society had to cope with had stressed the necessity to be prepared and to be able to recover in a short time from a sudden and unexpected change in the communities technical, organizational, social and economical condition. The concepts of “risk reduction”, “vulnerability”, “recovery”, and “resilience” have become keywords when dealing with hazardous events. Modern societies as States are trying to enhance their resilience against extreme events of any kind, after realizing that they cannot prevent every risk from being realized, but rather they must manage risks and adapt by minimizing the impact on human beings and other systems. When a disaster strikes, the community affected requires immediate help to survive, resources, and efforts to recover in a short time. In other words, the community needs to be “prepared” and less “vulnerable”, in order to achieve a high “resilience”.

Resilience, according to the dictionary, means "the ability to recover from (or to resist being affected by) some shock, insult or disturbance". Resilience in general is defined as the ability of systems to rebound after severe disturbances, or disasters. The concept of resilience has several definitions, because of its broad utilization in ecology, social and political sciences, economy, and engineering fields with different meanings and implications.

In earlier work by the authors, resilience was defined including technical, organizational, social and economic aspects (Bruneau and Reinhorn 2004). Various attempts have been made to provide a comprehensive definition, but recent literature review collected by Manyena (2006) points out that the current definition is too vague to be useful in the field of disaster risk reduction. In his research, Manyena reviews the concept of resilience in terms of definitional issues, its relationship with the concept of vulnerability, its application in the field of disaster management and risk deduction. Manyena (2006) evaluating all the possible definitions provided from the 90 to nowadays, suggests that Resilience could be viewed as the "intrinsic capacity of a system, community or society predisposed to a shock or stress to adapt and survive by changing its non-essential attributes and rebuilding itself". As regards its relationship with the concept of vulnerability, it can be accepted that the latter is closely associated to the level of resilience, but it is a complementary aspect of the community preparedness.

As Klein et al. (2003), the term derives from the Latin word "*resilio*" that means "*to jump back*". The field in which the term was first used is in psychology and psychiatry in the 1940s, and it is mainly accredited to Norman Garmezy, Emmy Werner and Ruth Smith.

In physics and engineering, the term resilience describes the property of a material to absorb energy when it is elastically deformed and then, when unloaded, to recover energy. Later, the concept of resilience was established in the field of ecology by Holling (1973), who stated that the resilience of an ecological system is "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables. Stability represents the ability of a system to return to an equilibrium state after a temporary disturbance; the more rapidly it returns to equilibrium and the less it fluctuates, the more stable it would be".

The researchers in resilience have continued to study it deeper and in a wider way. An extended literature review has elaborated upon resilience for years (Table 1.1), each contribution has added new nuances. Primarily, resilience has been defined in the context of the speed of systems going towards equilibrium (Adger 2000), capability to cope and bounce back, ability to adapt to new situations (Comfort 1999), to be inherently strong and flexible and adaptive (Tierney and Bruneau 2007), and to withstand external impacts and recover with least outside interferences (Mileti 1999). After the original definition of resilience in ecological systems, the word's meaning was expanded to *engineering*, *social*, and *economical* fields.

In the engineering field, resilience is defined as the capability of a system to maintain its functionality and to degrade gracefully in the face of internal and external changes (Allenby and Fink 2005). The main difference in defining

Table 1.1 Literature review about resilience definitions

Author	Definition
Holling (1973)	Ecological systems resilience is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables
Wildavsky (1991)	Resilience is the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back
Horne and Orr (1998)	Resilience is the ability of a system to withstand stresses of environmental loading…[it is] a fundamental quality found in individuals, groups, organizations, and systems as a whole
Haimes (1998)	Resilience is the ability of system to return to its optimal condition in a short period of time. Considering resilience one of four strategies for hardening a system, together with security, redundancy and robustness
Mileti (1999)	Local resiliency with regard to disasters means that a locale is able to withstand an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life and without a large amount of assistance from outside the community
Comfort (1999)	Resilience is the capacity to adapt existing resources and skills to new situations and operating conditions
Adger (2000)	Social resilience is the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change
Gunderson et al. (2002)	Engineering resilience is the speed of return to the steady state following a perturbation ecological resilience is measured by the magnitude of disturbance that can be absorbed before the system is restructured
Fiksel (2003)	Resilience is the essence of sustainability the ability to resist disorder
Bruneau et al. (2003)	Resilience is defined in terms of three stages: the ability of a system to reduce the probability of an adverse event, to absorb the shock if the adverse event occurs, and to quickly re-establish normal operating conditions. So resilience thus encompasses the four characteristics of robustness, redundancy, resourcefulness, and rapidity. Are considered four types of resilience: technical; organizational; economic; and social
Allenby and Fink (2005)	Resiliency is defined as the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must
Rose and Liao (2005)	Regional economic resilience is the inherent ability and adaptive response that enables firms and regions to avoid maximum potential losses
Hollnagel (2006)	Resilience is defined as the intrinsic ability of an organization (system) to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap and/or in the presence of a continuous stress
Manyena (2006)	Evaluating all the possible definitions provided from the 1990s to nowadays, resilience could be viewed as the intrinsic capacity of a system, community or society predisposed to a shock or stress to adapt and survive by changing its non essential attributes and rebuilding itself

(continued)

Table 1.1 (continued)

Author	Definition
Woods (2006)	Resilience is defined as the ability of systems to anticipate and adapt to the potential for surprise and failure
Holmgren (2007)	Resilience is the ability of the system to return to a stable condition after a disruption. Distinguishing robustness and resilience, using robustness to imply that the system will remain (nearly) unchanged even in the face of disruption
Tierney and Bruneau (2007)	Resilience is both the inherent strength and ability to be flexible and adaptable after environmental shocks and disruptive events
DHS-RSC (2008)	Resilience is the ability of systems, infrastructures, government, business, and citizenry to resist, absorb, recover from, or adapt to an adverse occurrence that may cause harm, destruction, or loss of national significance
Haimes (2009)	Resilience is defined as the ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite costs and risk
Vugrin et al. (2010)	Given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is the ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels

resilience arises between the engineering approach where resilience occurs by moving towards the previous stable state (Bruneau et al. 2003), and the ecological approach where resilience is achieved moving towards a different system state (Handmer and Dovers 1996).

Social resilience is the ability of groups or societies to cope with external stresses and disturbances as a result of social, political, and environmental change (Adger 2000). Economic resilience is the inherent ability and adaptive response that enables firms and regions to avoid maximum potential losses (Rose and Liao 2005). It has mainly been studied in the context of seismic response and recovery (Tierney 1997), community behavior (Chang and Shinozuka 2004) and disaster hazard analysis (Rose 2004).

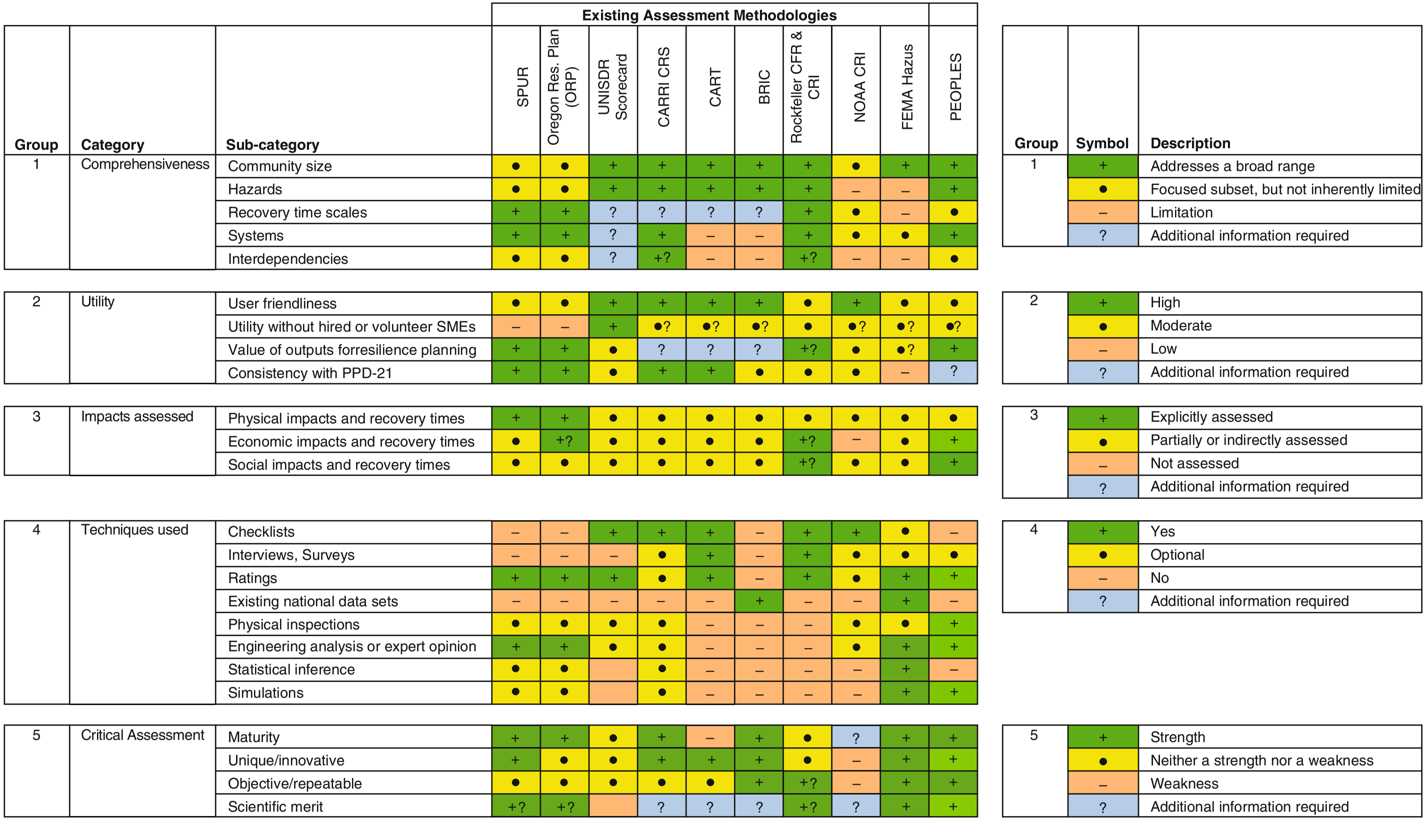
The outcomes of the 2005 World Conference on Disaster Reduction (WCDR) confirmed the importance of the entrance of the term resilience into disaster discourse and gave birth to a new culture of disaster response. Among the experts in disasters, however, the definitions of resilience are various and sometimes contrasting. Resilience can be considered as a desired outcome or, in a broader way, as a process leading to a desired outcome. Reducing resilience to an outcome does not take into account the performance of the process itself, or the effort to reach a certain result.

The definition of the resilience for the NIST framework (National Institute of Standards and Technology) is contained in Presidential Policy Directive 21 (PPD 2013) and withstand and recover rapidly form disruption" (PPD 2013). The first phrase "the ability to prepare for and adapt to changing conditions" according to the NIST disaster resilience framework (2015) refers to "preparing for conditions that are likely to occur within the lifetime of a facility or infrastructure system, such as a hazard event, and hazard intensities or physical conditions that may change over time. Changing conditions include the effects of aging infrastructure systems and climate change, such as sea level rise in coastal areas. Changing conditions also include changes in our use of infrastructure systems". The second part "withstand and recovers rapidly from disruptions must be examined for the anticipated range of possible hazard event. In a resilient community, a hazard event at the design level should cause only local disruptions that the community can tolerate without long term detrimental effects. If an unanticipated or extreme event occurs, the resilience planning and preparation should reduce the extent of disruption and recovery time. Additionally, communities that have a well-developed resilience plan are prepared to recover in a way that improves sustainability and resilience". As related to the built environment, resilience means "the ability of identified buildings and infrastructure systems to return to full occupancy and function, as soon as they are needed, to support a well-planned and expedited recovery". Under this definition resilience includes "activities already conducted by some communities, such as disaster preparedness, hazard mitigation, code adoption and enforcement, and emergency response" (NIST 2015).

On the other hand, *disaster resilience* can be viewed as a deliberate process (leading to desired outcomes), which is comprised of a series of events, actions, or changes to augment the capacity of the affected community, places emphasis on the human role in disasters. Disaster resilience is considered a quality, characteristic, or result that is generated or developed by the processes that foster or promote it.

1.4 State of Art of Existing Resilience Frameworks

Several frameworks are currently available in literature and a compact comparison of them is given in Fig. 1.17 in term of features and applicability. The frameworks were evaluated on the basis of five broad categories, including: comprehensiveness, utility, impacts assessed, techniques used, and overall merit (with respect to the maturity, innovativeness, objectivity, and scientific merit). The criteria were assessed in the context of community resilience planning and assessment, particularly concerning the built environment. Below is given a brief description of existing framework which are grouped according to the spatial dimension in *City, State* and *National* level.



Group	Category	Sub-category	Existing Assessment Methodologies									
			SPUR	Oregon Res. Plan (ORP)	UNISDR Scorecard	CARRI CRS	CART	BRIC	Rockfeller CFR & CRI	NOAA CRI	FEMA Hazus	PEOPLES
1	Comprehensiveness	Community size	●	●	+	+	+	+	+	●	+	+
		Hazards	●	●	+	+	+	+	+	–	–	+
		Recovery time scales	+	+	?	?	?	?	+	●	–	●
		Systems	+	+	?	+	–	–	+	●	●	+
		Interdependencies	●	●	?	+?	–	–	+?	–	–	●
2	Utility	User friendliness	●	●	+	+	+	+	●	+	●	●
		Utility without hired or volunteer SMEs	–	–	+	●?	●?	●?	●	●?	●?	●?
		Value of outputs forresilience planning	+	+	●	?	?	?	+?	●	●?	+
		Consistency with PPD-21	+	+	●	+	+	●	●	●	–	?
3	Impacts assessed	Physical impacts and recovery times	+	+	●	●	●	●	●	●	●	●
		Economic impacts and recovery times	●	+?	●	●	●	●	+?	–	●	+
		Social impacts and recovery times	●	●	●	●	●	●	+?	●	●	+
4	Techniques used	Checklists	–	–	+	+	+	–	+	+	●	–
		Interviews, Surveys	–	–	–	●	+	–	+	●	●	●
		Ratings	+	+	+	●	+	–	+	●	+	+
		Existing national data sets	–	–	–	–	–	+	–	–	+	–
		Physical inspections	●	●	●	●	–	–	–	●	●	+
		Engineering analysis or expert opinion	+	+	●	●	–	–	–	●	+	+
		Statistical inference	●	●		●	–	–	–	–	+	–
		Simulations	●	●		●	–	–	–	–	+	+
5	Critical Assessment	Maturity	+	+	●	+	–	+	●	?	+	+
		Unique/innovative	+	●	●	+	+	+	●	–	+	+
		Objective/repeatable	●	●	●	●	●	+	+?	–	+	+
		Scientific merit	+?	+?		?	?	?	+?	?	+	+

Group	Symbol	Description
1	+	Addresses a broad range
	●	Focused subset, but not inherently limited
	–	Limitation
	?	Additional information required
2	+	High
	●	Moderate
	–	Low
	?	Additional information required
3	+	Explicitly assessed
	●	Partially or indirectly assessed
	–	Not assessed
	?	Additional information required
4	+	Yes
	●	Optional
	–	No
	?	Additional information required
5	+	Strength
	●	Neither a strength nor a weakness
	–	Weakness
	?	Additional information required

Fig. 1.17 Evaluation matrix of ten different resilience frameworks (Adapted from NIST 2015)

1.4.1 City Level Resilience Framework

NIST framework (National Institute of Standards and Technology, 2015) Among the most recent ongoing projects which need to be mention is the NIST (National Institute of Standards and Technology) Community Resilience Program NIST (2015) which aims to evaluate the existing resilience frameworks on the basis of a comprehensive list of community parameters. The program aims to develop a new framework, which will assemble the potentialities of all available methods and assimilate new concepts surrounding resilience that have been explored in the latest research. In particular, NIST gives a summary of available guidance, metrics, and tools for the assessment of community resilience under a variety of natural and manmade hazards with considering the different levels of hazard intensity or magnitude for each. Furthermore, it presents three types of metrics that can be used by a community to measure improvements through the understanding and implementation of proactive planning: (i) *recovery times* for the restoration of function of building and infrastructure systems, (ii) *economic metrics* to represent business, tax base, income, local services and amenities as well as sustained growth, and finally (iii) *social metrics* representing survival, safety and security, sense of belonging, and growth and achievement to reflect the hierarchy of human needs (Maslow's Hierarchy of Needs, 1943).

Despite of comprehensiveness in concepts, the NIST does not provide a systematic and theoretical framework to evaluate resilience, but it provides a sort of guidelines of what a framework should look like. However several parts of these guidelines are not fully developed and there is no a specified description on how to apply these concepts in practice and to assess the performance of critical infrastructures and their interdependencies for example. Although this framework is not limited inherently, it is developed specifically for communities within the United States and it is cannot be considered as an international guideline.

San Francisco Planning and Research Association (SPUR) Framework Among the frameworks at the city level, it is necessary to mention the San Francisco Planning and Research Association (SPUR) Framework.

The SPUR framework aims to make San Francisco become a Disaster Resilient City through seismic mitigation policies. The policy recommendations and mitigation plans are focused on community demands before, during and after responding to hazard events. In general the stated goals of the SPUR report (2009) are summarized as:

- Define resilience concept in the context of disaster planning;
- Establish performance goals for the "expected" earthquake that supports the concepts of resilience;
- Development of real performance tools that help to reach the specified performance goals;
- Suggest next steps for San Franciscos new buildings, existing buildings and lifelines.

The SPUR methodology concentrates on defining performance goals for several clusters of buildings (i.e., groups of buildings that provide a community service, such as critical response facilities, emergency housing, or neighborhood services) and defining target recovery time for a specified earthquake scenario in the San Francisco Bay area. SPUR does not directly address both the economic and social dimensions of resilience for the city of San Francisco. Whilst the economic and social impacts and the consequences effects in the estimation of the recovery time are the key questions for community leaders, stakeholders, investors, or governments, this methodology does not provide a direct performance metrics to quantify them. On the other hand SPUR focuses on earthquakes as the primary hazard in San Francisco and it does not provide a comprehensive methodology that can also be used against other natural or manmade hazard events. In addition, SPUR restricts the size of the community to the city of San Francisco and therefore its framework can not be applied or extended to any other community.

UNISDR Disaster Resilience Scorecard for Cities The United Nations International Strategy for Disaster Risk Reduction (UNISDR) Disaster Resilience Scorecard for Cities "provides a set of assessments that will allow cities to understand how resilient they are to natural disasters." The Scorecard is "intended to enable cities to establish a baseline measurement of their current level of disaster resilience, to identify priorities for investment and action, and to track their progress in improving their disaster resilience over time." This framework catalogues different evaluation criteria in research, organization, infrastructure, response capability, environment and recovery. Each evaluation criterion is broken down according to the measured resilience dimension, the measurement scale and evaluated through a formal checklist. The tool does not offer a theoretical framework which clearly explains how to apply these methods in practice. Additional information is needed to evaluate the performance of critical infrastructures and their interdependencies. Furthermore there is not any specific approach and metric tool to assess the recovery times considering all community dimension such as economical and social parameters.

1.4.2 State Level Resilience Framework

Oregon Resilience Plan The Oregon Seismic Safety Policy Advisory Commission (OSSPAC) was managed by House Resolution 3 in 2011 in order "to lead and coordinate preparation of an Oregon Resilience Plan that reviews policy options, summarizes relevant reports and studies by state agencies, and makes recommendations on policy direction to protect lives and keep commerce flowing during and after a Cascadia earthquake and tsunami." The Oregon Resilience Plan (2013) was built upon the SPUR methodology and the Resilient Washington State initiative in order to produce a statewide projection of the impacts of a single earthquake and tsunami scenario. Immediate impacts include lives losses, buildings destroyed or damaged, and households displaced.

A particular statewide vulnerability identified during the study was the Oregon's liquid fuel supply and the resulting cascade effects induced by a long-term disruption of the liquid fuel supply.

The OSSPAC has suggested eight task groups:

1. earthquake and tsunami scenario,
2. business and work force continuity,
3. coastal communities,
4. critical buildings,
5. transportation,
6. energy,
7. information and communications,
8. water and wastewater.

The framework determines the likely impacts of magnitude 9.0 Cascadia earthquake and tsunami and proposes a method to estimate the recovery time after such a hazard event. It also describes an acceptable time frame for each critical infrastructure classification to fulfill the expected resilience performance. When analyzing in detail, the Oregon resilience plan does not offer a unique and novel approach to make communities resilient, but it follows mostly SPUR methodology. In fact, Oregon resilience plan when compared with the SPUR framework provides a methodology to evaluate the economic dimension of resilience while the performance metrics to quantify the social aspects after hazard events are still missing. In addition there is not any specific tool or indicator to assess the resilience of a community against the manmade hazard events such as the terrorist attacks etc.

1.4.3 National Level Resilience Framework

FEMA Hazus Methodology The Federal Emergency Management Agency's (FEMA) Hazus methodology (Hazus 2014) "is a nationally applicable standardized methodology that contains models for estimating potential losses due to earthquakes, floods and hurricanes. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquakes, hurricanes and floods. Users can visualize the spatial relationships between populations and other fixed geographic assets or resources for the specific hazard being modeled – a crucial function in the pre-disaster planning process."

The Hazus methodology and data sets cover the entire United States, and the study region (i.e., community) can be defined as any combination of the US Census tracts. The framework considers immediate physical, economic and social impacts and leads to outputs on expected damage losses of different infrastructures. Estimated repair time is explicitly considered in economic loss estimates produced by the model, but the economic outputs are not tabulated or viewable as a function of time.

There are limitations in the framework that will not allow to apply the software to evaluate resilience indicators. First, all the performances are indicated or normalized to economic costs. Second, Hazus can be used to assess the losses that can be avoided through mitigation measures, but it does not estimate the mitigation costs and therefore does not estimates the return on investments. Third, all the losses are considered independent each other and therefore the cascading effects and all interdependencies following a hazard event are neglected in the framework. Finally, Hazus is an hazard specific framework that cover only three types of hazard, and although it has been tried to be extended to other nations as well, it is made to be applied in USA.

PEOPLE framework The PEOPLES framework has been developed at MCEER in 2009 and it was the result of 1 year project sponsored by NIST (Cimellaro et al. 2016). According to the summary given in Fig. 6.1, the PEOPLES framework is not hazard specific and it is multidimensional, so it can be applied to different spatial (City, State and National level) and temporal dimensions, while taking into account interdependencies between different components. However some improvements should be envisioned in the techniques used to enhance its ability to evaluate the community resilience index. More detail about the PEOPLES framework are provided in Chap. 6.

1.5 From Performance-Based Design to Resilience-Based Design

1.5.1 PEER Performance Assessment Methodology

In the last decades, researchers at the Pacific Earthquake Engineering Research (PEER) Center have developed a seismic performance assessment methodology based on an equation framework, which incorporates various sources of uncertainty using the concepts of conditional probability and total probability theorem. Nowadays, seismic standards provide a set of prescriptive rules with the goal of human safety. Recent research suggests quantifying structural performance in more useful terms to simplify stakeholders' decisions. Therefore, PEER has suggested that *economic losses (dollars), downtime*, and *number of fatalities (deaths)* are the indicators that should be used to evaluate building performances and they have developed a probabilistic framework that uses the results from seismic hazard analysis and response simulations to estimate damages and monetary losses incurred during earthquakes. The above-mentioned methodology is divided into four steps:

- The first step uses probabilistic seismic hazard analysis to generate a seismic hazard curve, which quantifies the frequency of exceeding a ground motion intensity measure (IM) for the site being considered.

- The second step involves using structural response analysis to compute engineering demand parameters (EDPs), and the collapse capacity of the structure being considered.
- The third step produces damage measures (DMs) using fragility functions, which are cumulative distribution functions relating EDPs to the probability of being or exceeding particular levels of damage.
- The fourth and final step determines decision variables (DVs), such as the economic losses, based on repair and replacement costs of damaged building components, which can be used by stakeholders to make more informed design decisions.

1.5.2 History of the Development of the PEER Integral

Initially, it was proposed that the following three sources of uncertainty should be considered for a probabilistic estimation of DVs:

- Uncertainty corresponding to the ground motion intensity,
- Uncertainty corresponding to the structural response,
- Uncertainty corresponding to the decision variable.

These kinds of uncertainties were taken into account in the PEER model by defining a random variable associated with that source of uncertainty. The uncertainty in estimating the seismic hazard at the site has been modeled by considering a ground motion intensity measure (IM, e.g. PGA, PGV, I, $S_a(T)$) as a random variable and estimating the mean annual frequency of exceedance of the seismic hazard at the site, $\upsilon(IM > im)$, by performing a Probabilistic Seismic Hazard Analysis (PSHA). The uncertainty in estimating the intensity of the structural response is incorporated by considering a vector of engineering demand parameters (EDP's) and estimating the conditional probability of the engineering demand parameter exceeding a certain intensity, edp, at different levels of ground motion intensity, $P(EDP > edp|IM = im)$. The uncertainty in estimating decision variables, DV's, is incorporated using the conditional probabilities of exceeding a certain level of dv at a level of edp, $P(DV > dv|EDP = edp)$. The original first version of the PEER framing equation was introduced to estimate the mean annual frequency of exceedance of a decision variable, $\upsilon(DV > dv)$, as follows (Cornell and Krawinkler 2000):

$$\upsilon_{DV}(DV > dv) = \iint P(DV > dv|DM = dm).dP \\ (DM > dm|EDP = edp).d\upsilon(IM > im)| \qquad (1.1)$$

In a second version, it was proposed that a more realistic estimation of the decision variable can be achieved by estimating the decision variable as a function of the level of damage experienced in the facility instead of estimating the decision variable as a function of the level of deformation.

A new random variable, which corresponds to the level of damage that can be experienced in a facility, was introduced into the PEER framework and in PEER's terminology has been called damage measure, DM. Consequently, the PEER framework Eq. (1.1), has been modified as follows (Krawinkler and Miranda 2004):

$$\upsilon_{DV}(DV > dv) = \iiint P(DV > dv|DM = dm)dP(DM > dm|EDP = edp).dP \\ (EDP > edp|IM = im).d\upsilon(IM > im) \tag{1.2}$$

where P is the probability of exceedance of the decision variable, DV, conditioned to as DM, and $P(DM > dm|EDP > edp)$ is the probability of a damage state, DM, exceeding dm, when the engineering demand parameter, EDP, is equal to edp. For certain measures of seismic performance such as economic losses in individual building components, it is more appropriate to assume that damage measures are discrete. Therefore, it was proposed that economic losses in individual components are computed from the need to apply discrete repair and replacement actions that is triggered at discrete damage states (Miranda and Aslani 2003; Krawinkler and Miranda 2004).

1.6 Towards Resilience-Based Design (RBD)

Although the above described methodology is rapidly spreading, there are fundamental parts that the Performance based design (PBD) does not cover. This method can be applied to describe of a single building or structure, while does not provide an assessment of both the portfolio and community. Today, designer and engineers approach a structure as if it stands alone, without considering the interaction with the community. The performance of an individual structure is not governed by its own performance, but it interacts heavily with the performance of other entities within the same community.

Hospitals are clear examples of these interdependencies between the building and the community. Despite recent codes are considering more stringent criteria in design of this occupancy (e.g. occupancy category III, per ICC IBC, 2012), there are hospitals which are not able to remain functional without electricity and water even if the structure has no structural damage. Another example of the limitations of PBD is given by 2009 L'Aquila earthquake (Cimellaro et al. 2010), during which the small town of Castelnuovo was completely destroyed, except a single housing unit that was standing after the earthquake and suffered minor damage. According to the PBD the building was ok, because there were no damage to the structure, but from the resilience point of view the building was not functional, because the entire city around the building was destroyed and abandoned. Resilience based design (RBD) is a new fundamental way of looking at the problem, because interdependencies exists between the analyzed system and other structural and infrastructural systems. In this methodology, the building is not considered alone, but as a group of buildings using the "Portfolio Approach" which will allow regional loss analysis. So it will be moved from the concept of "housing units" to the concept of "housing block". More details on RBD are provided in Chap. 2.

1.7 Summary and Remarks

Some examples of recent natural and manmade disasters are provided to show the necessity to develop resilient communities. The definition of seismic resilience combines information from technical and organizational fields, from seismology and earthquake engineering to social science and economy. Different frameworks available in literature are described and compared. The Pacific Earthquake Engineering Research (PEER) has established a probabilistic framework to estimate damage and monetary losses incurred during earthquakes which is based on Performance-Based Design. In the evaluation of seismic performance, it's required to introduce Decision Variables, incorporating various sources of uncertainty such as those corresponding to the damage measures, the structural response and the ground motion intensity. However the PBD approach works well for single buildings, while when building blocks or entire communities are considered it is necessary to adopt Resilience-Based Design concepts.

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