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## 2.4

# Recording disaster losses for improving risk modelling capacities

**Scira Menoni, Costanza Bonadonna, Mariano García-Fernández, Reimund Schwarze**

### 2.4.1 Relationship between pre-event risk modelling and post-disaster loss data

Pre-event risk assessment and post-event damage estimation are more linked than is generally thought. As shown in Figure 2.14, either probabilistic or deterministic damage forecasts are appraised in pre-event risk assessment, whilst in the aftermath of the event, the scenario that occurred is analysed. Both modelled and estimated damage can regard one or few exposed items or multiple sectors ranging from businesses to lifelines (available in fewer cases). Damage can be expressed as physical damage to items and/or monetary costs of repair or as loss to individual economic sectors or to a given economy and society as a whole.

In the case of the pre-event assess-

ment, hazard, exposure and vulnerability are the components that need to be evaluated and combined in order to obtain a risk assessment. In the post-event analysis, the estimated damage must be described on the basis of the observed hazard features, on the configuration of exposed systems and on their vulnerability at the time of the event.

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*Pre- and post-damage assessment have more in common than generally perceived; in both cases there is a need to understand the relative contribution of hazard, exposure and vulnerability factors on the overall damage.*

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There is still a debate on the meaning of damage and losses and which

types should be considered; here, an interpretation based on previous EU projects and available literature is proposed (Merz et al., 2010; Meyers et al., 2015; Van der Veen and Logtmeijer, 2005). As can be seen in Figure 2.15, damage due to natural hazards is generally divided into damage to tangible objects and assets, meaning those for which a monetary assessment is easily obtained and not controversial, and damage to intangibles, meaning values such as human life, historic heritage or natural assets for which monetisation is either extremely difficult or controversial. Damage to both tangibles and intangibles can be direct, meaning the damage provoked by the hazardous stressor, or indirect, which is consequent upon the direct damage (e.g. production loss due to damaged machinery) or upon ripple effects due to the interdependency of economic systems, both forward and backward linkages. Whilst direct damage generally occurs locally, indirect damage can develop over much greater time and space scales, also far from the event's 'epicentre' and long

after the event has occurred. In some methodologies, damage and losses are distinct: the first term refers to affected infrastructure and buildings, whilst the second refers to economic losses (GFDRR, 2013). In the following sections, the link between pre- and post-event damage and loss assessment is discussed, showing the contribution that enhanced post-disaster analysis can make in terms of knowledge and information to improve the quality and comprehensiveness of pre-event risk models.

Examples will be taken from three distinct hazard domains, such as earthquakes, floods and volcanic eruptions,

in order to provide evidence for more theoretical assumptions. These natural disasters were chosen because of their diversity, the difference in terms of types and the extent of damage they produce. However, their use is just paradigmatic. Experts in other fields will be able to find correspondences to the hazard risk they are more familiar with.

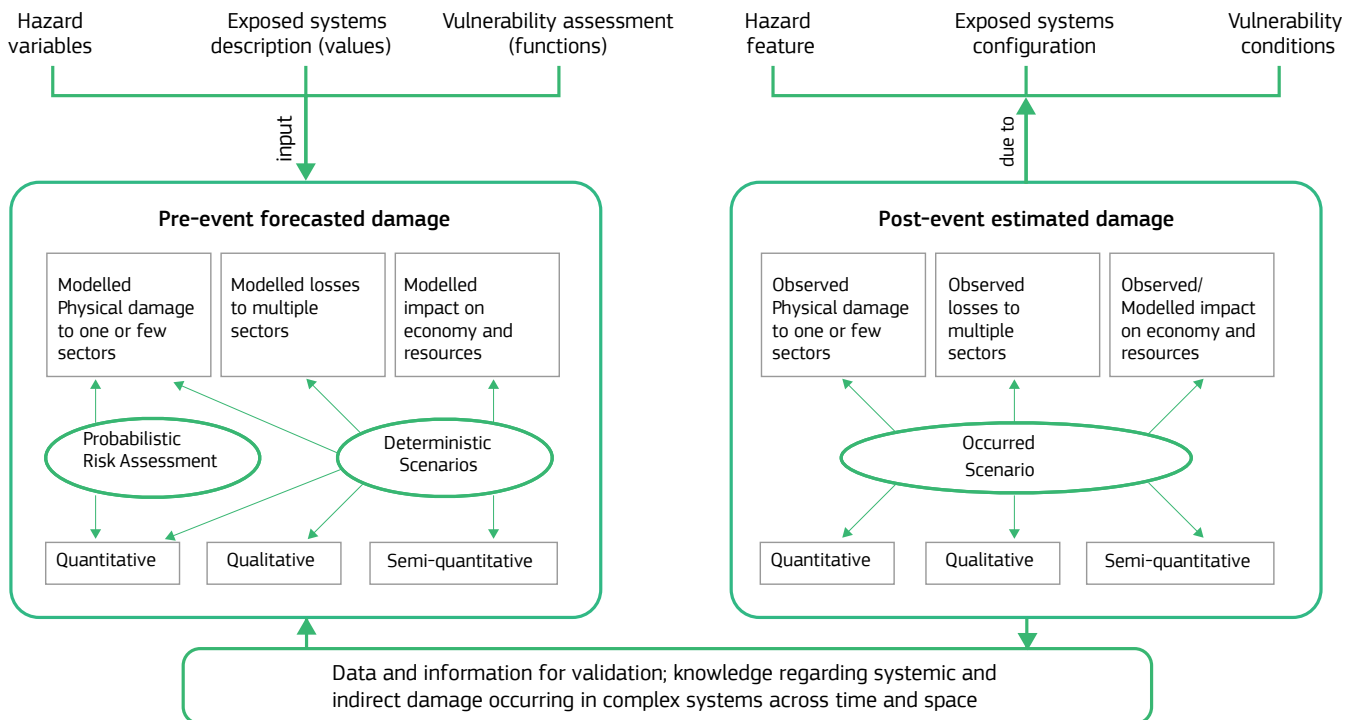
## 2.4.2 How post-disaster damage has been used to develop risk models: state of the art in a nutshell

### 2.4.2.1 State of the art of risk models

Expected damage can be assessed using quantitative, qualitative and semi-quantitative risk models (Figure 2.14, see also Chapter 2.1). Quantitative risk assessments dominate in

FIGURE 2.14

Pre - and post - disaster damage assessments  
Source: courtesy of authors



scientific journals; however, they generally consider quite a limited number and type of variables. More complex understandings of risk, which also comprise the consequences on the social, economic and environmental systems as well as on complex built systems such as critical infrastructures, are inevitably covered by a mixture of quantitative and qualitative appraisals (OECD, 2012; Theocharidou and Giannopoulos, 2015; Menoni et al., 2007). In the more widely accepted definition, risk is measured in terms of expected damage (probability of expected damage or deterministic damage scenarios) and is obtained as a function of hazard, exposure (see

also Chapter 2.2) and vulnerability (see also Chapter 2.3). Whilst the first two aspects are provided in quantitative terms, the last one is often assessed through more qualitative or semi-qualitative approaches (Turner et al., 2003; Petrini, 1996). In the past, risk assessments were actually mainly hazard analyses, whereas in more recent times, quantitative appraisals of exposure have been increasingly included in risk assessment. Besides exposed people and assets, more realistic evaluations take into consideration their relative vulnerability as well, intended as the susceptibility to damage, which is an intrinsic measure of weakness and fragility (Mc Entire,

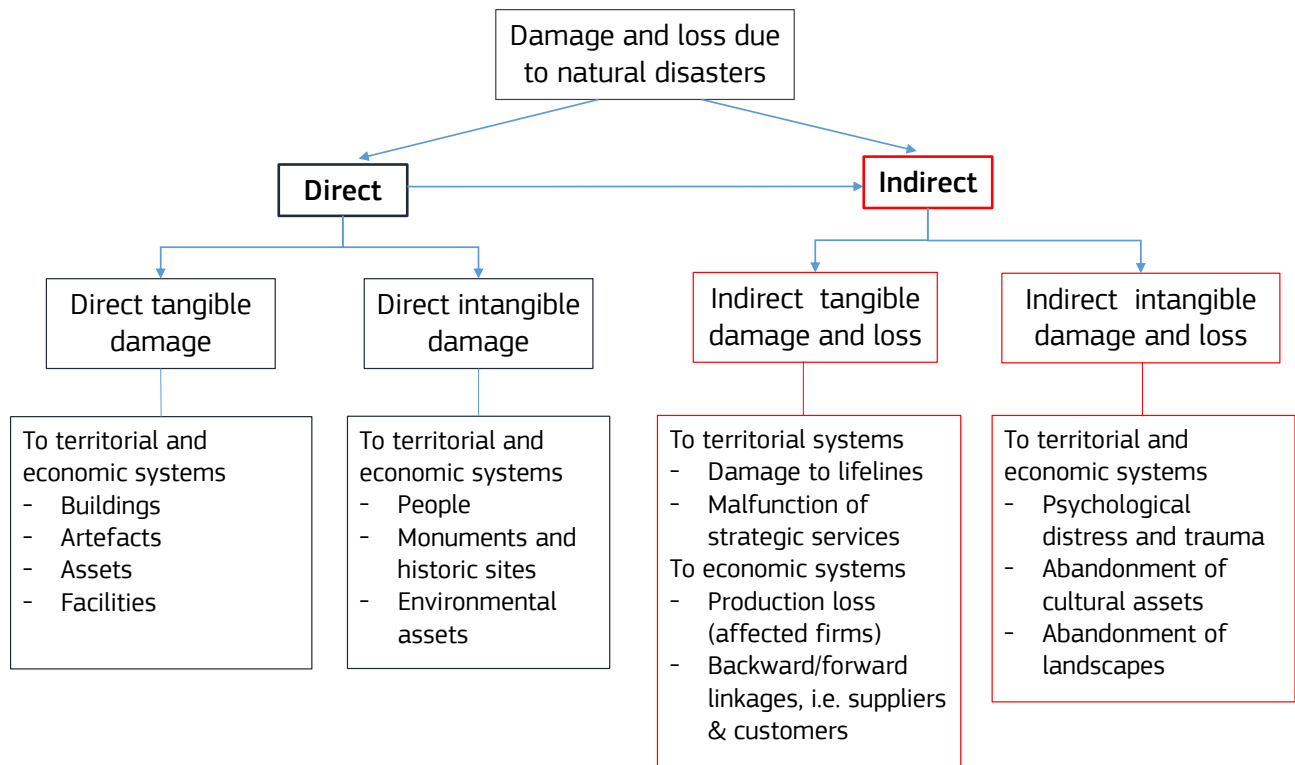
2005; Scawthorn, 2008).

*Vulnerability and damage functions have been the most widely used tools, especially by engineers, to deal with pre-event damage assessment fed by post-disaster statistical data.*

The capacity to assess the latter is more recent and restricted to some exposed elements and systems, with

FIGURE 2.15

Definition of direct and indirect damage  
Source: Merz et al. (2010)



the obvious difficulty of constructing a comprehensive and coherent picture of what the total effect of a disaster in a given area may be (Barbat et al., 2010).

In the following section, the state of the art in vulnerability or damage functions in the field of seismic, volcanic and flood hazards are provided, highlighting similarities and differences. Vulnerability or damage functions are used to correlate hazard indicators (such as acceleration or water depth) with damage (such as damage index or monetary cost of repair and recovery).

### 2.4.2.1.1 How vulnerability/damage curves have been developed for seismic risk

Seismic engineers have started developing vulnerability curves long before

colleagues in other natural hazards fields, coherent with the fact that the only possible protection measure against earthquakes is reducing buildings' vulnerability. Early seismic vulnerability methods were proposed in the seventies in Japan and the United States, and were being developed during the eighties in Europe (Coranago, 1991; Senouci et al., 2013). Main European seismic vulnerability methods include GNDT (Benedetti et al. 1988), Risk-UE (Lagomarsino and Giovinazzi, 2006) and Vulneralp (Guéguen et al., 2007). Thus, the seismic field set the floor for a general methodology that was followed in other fields as well; it can also be considered as having general relevance. First, damage after earthquakes was observed in a very large number of cases and in structures differing in their layout, material, typology, age, resistant systems, etc. Two relevant results were achieved: on the one hand,

a very large database with hundreds of failure cases was developed, and on the other hand, the specific factors determining buildings' response to earthquakes were identified. Such factors have been translated into parameters, as in the example provided in Table 2.2 (Zonno et al., 1998). In the practical application of the latter, the vulnerability of buildings is obtained from the weighed sum of the score assigned to each parameter, ranging from A (no vulnerability) to D (very high vulnerability), and multiplied by a weight expressing the relative relevance of the parameter.

Second, vulnerability curves are compiled by plotting seismic severity (on the horizontal x axis), expressed, for example, as acceleration, versus the percentage of damage or a damage index between 0 and 1 (on the vertical y axis). At maximal stress, any building is expected to collapse, whereas at no stress no building is expected to be damaged; anything in between, the intrinsic vulnerability of buildings is likely to produce differential damage. As a third step, a comparison between modelled damage based on vulnerability curves and post-event observed damage should be carried out as discussed in Chapter 2.3.

### 2.4.2.1.2 How vulnerability/damage curves have been developed for volcanic risk

Vulnerability curves in volcanology have been developed much more recently and are available only for some of the hazards that may be triggered by an explosive eruption. More specifically, vulnerability curves describing the collapse of roofs are available for

TABLE 2.2

Indicators to assess seismic risk  
Source: Zonno et al. (1998)

	PARAMETERS	VULNERABILITY CLASS				WEIGHT
		A	B	C	D	
1	Organization of resistant elements	0	5	20	45	1
2	Quality of resistant elements	0	5	25	45	0.25
3	Conventional Strength	0	5	25	45	1.5
4	Building position and foundations	0	5	25	45	0.75
5	Floors	0	5	15	45	var
6	Plan Shape	0	5	20	45	0.5
7	Elevation Shape	0	5	20	45	var
8	Maximum distance between walls	0	5	20	45	0.25
9	Roof	0	15	20	45	var
10	Non structural elements	0	0	20	45	0.25
11	Maintenance conditions	0	5	20	45	1

tephra fallout (e.g. Figure 2.16), while initial curves have been proposed for ballistic and pyroclastic flows in EU funded project MIAVITA (n.d.) (see also in Chapter 3.2 for the description and definition of volcanic hazards). The lack of vulnerability data for other hazards includes the unfeasibility of building constructions that are able to stand the stress due to lava or pyroclastic flows. Exposure, i.e. the location of constructions, becomes more important. In addition, given the relative low frequency of large volcanic eruptions affecting largely inhabited places, damage to modern structures could be observed only in a limited number of cases and mostly related to the collapse of roofs under

tephra load. This is why vulnerability curves have been developed only for the damage to building roofs due to tephra fallout (Figure 2.16). The effect of tephra on other exposed elements, e.g. agriculture and infrastructures, have also recently been attempted (Wilson et al., 2014; Craig et al., 2016).

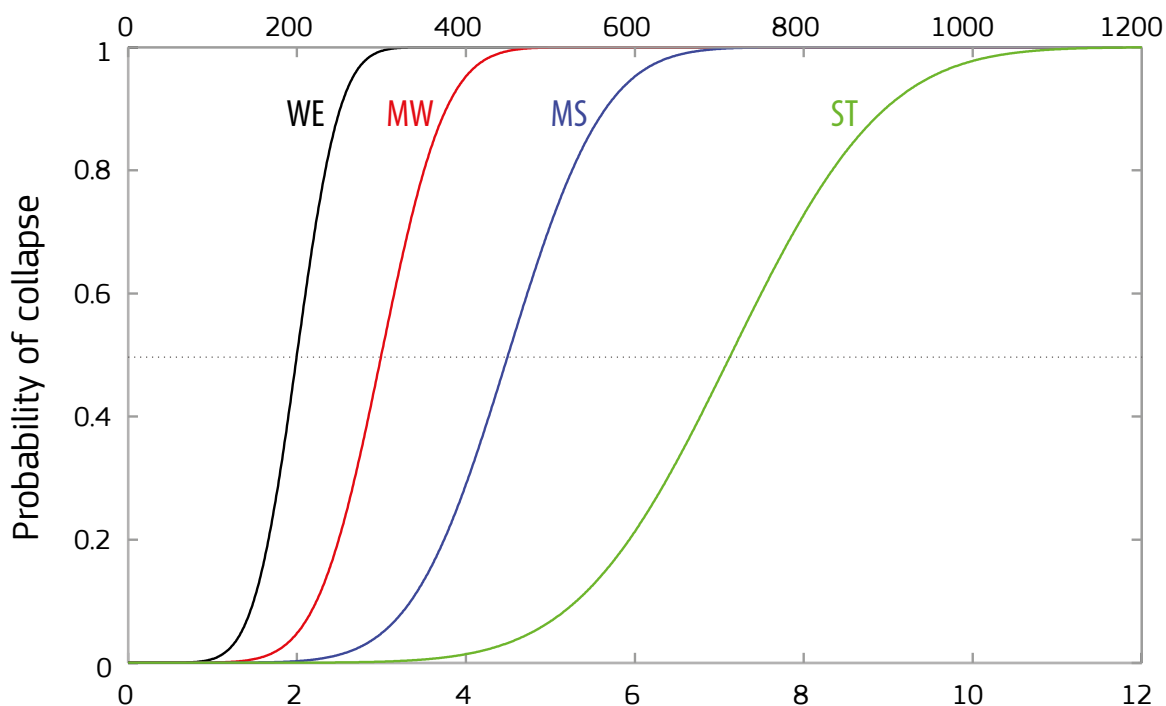
### 2.4.2.1.3 How vulnerability/damage curves have been developed for flood risk

It should be highlighted that in the flood case, scholars refer to damage rather than vulnerability curves, even though the followed method is very similar. Curves are plotted on a plane

with an x axis that generally reports water depth and a y axis where damage is reported as costs of repair. Curves represent types of buildings differing for the number of floors, material, presence of basement or not and occupation of the first level. For a comprehensive overview of such curves, one may refer to the work of Jongman et al. (2012) and Thieken et al. (2008). Both recognise the limitations of current methods that neglect hazard severity variables such as velocity or sediment transport, which may be more relevant than water depth as a damage cause, especially in the case of flash floods.

FIGURE 2.16

Damage curves for collapse of roofs associated with tephra fallout  
Source: Biass et al. (2016)



### 2.4.2.2 Key aspects of currently used vulnerability and damage curves

The brief discussion of the three domains permits to highlight some commonalities: first, the philosophy according to which vulnerability is represented by curves that depend on the intrinsic characteristics of different types of structures; second, the need of a statistically meaningful population of observed damaged buildings to develop vulnerability or damage curves; and third, vulnerability or damage curves are available for a limited set of structures and a limited number of sectors. They are largely available for residential buildings, far less for industrial facilities and even less for infrastructures. This restricts the capacity to construct comprehensive quantitative risk assessment for all assets and sectors. Furthermore, whilst vulnerability curves are derived from the observation of individual objects, risk assessment is developed for an area or a region. Therefore, risk assessment is based on the hypothesis that assets in a given region can be averaged in terms of their vulnerability features.

Another factor limiting the possibility to transfer such curves from one geographic area to another derives from the fact that the observed damage and relative vulnerability factors are highly context dependent, as they are linked to the types of buildings and structures that have been surveyed. This is the reason why consulting firms that provide insurance and reinsurance companies with immediate figures of loss due to a recent calamity

carry out post-disaster surveys. The rapid evolution of information technology information technology has given an important impulse to the use of risk assessment scenarios by means of very large datasets comprising information on land uses and basic built stock characteristics that can be digested in a rather short time. However, feedback from real events is crucial to increasing the reliability

of their modelling capacity (Marsh, 2015).

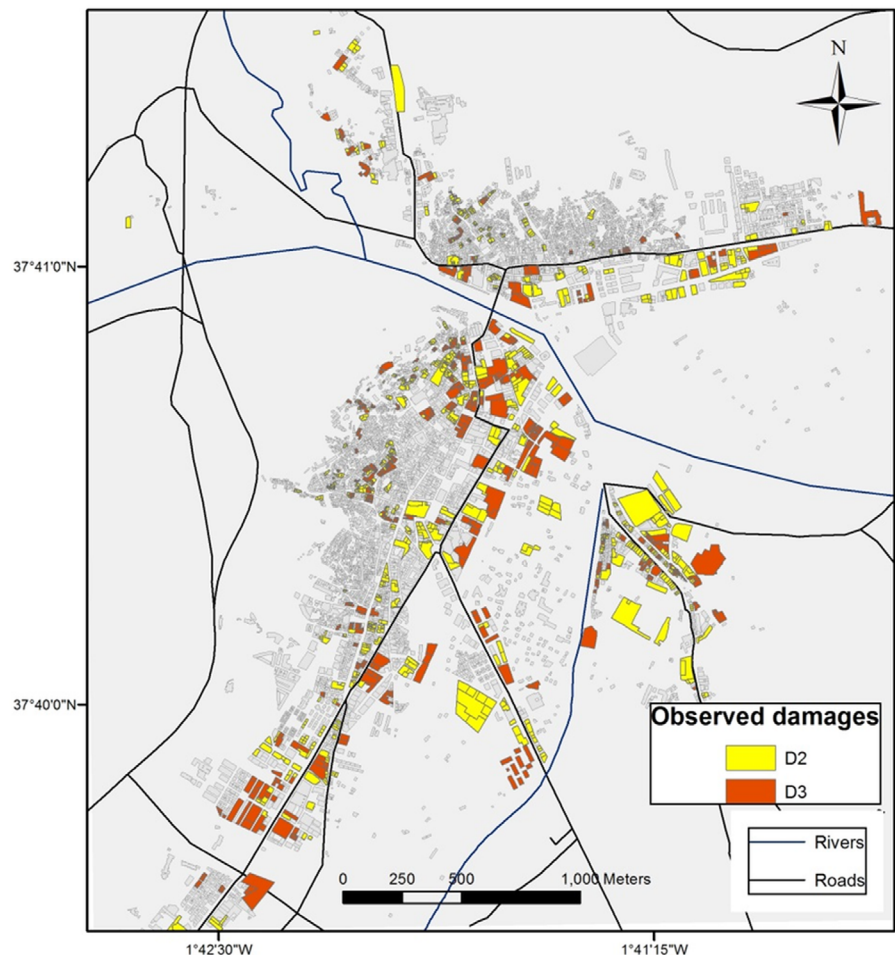
### 2.4.2.3 Use of post-event damage data for evaluating the reliability of risk models results

Even though separate events that have occurred cannot provide a com-

**FIGURE 2.17**

**Observed building damage in the city of Lorca in terms of mean damage grade (D1: slight, D2: moderate, D3: heavy and D4: partial collapse) for the Mw5.2 earthquake on 11 May 2011**

Source: DG Citizen Security and Emergencies of the Region of Murcia



prehensive validation for risk models, they can be used to assess the discrepancies between the model forecasts and observations.

Here the comparison between pre- and post-damage assessments conducted for the city of Lorca in Spain

is provided. Figure 4 shows the actual observed damage in the most affected suburbs in Lorca as a consequence of the earthquake that occurred on 11 May 2011. Figure 2.18 represents the modelled damage using Risk-EU approach (Lagomarsino and Giovinazzi, 2006), considering the seismic load by

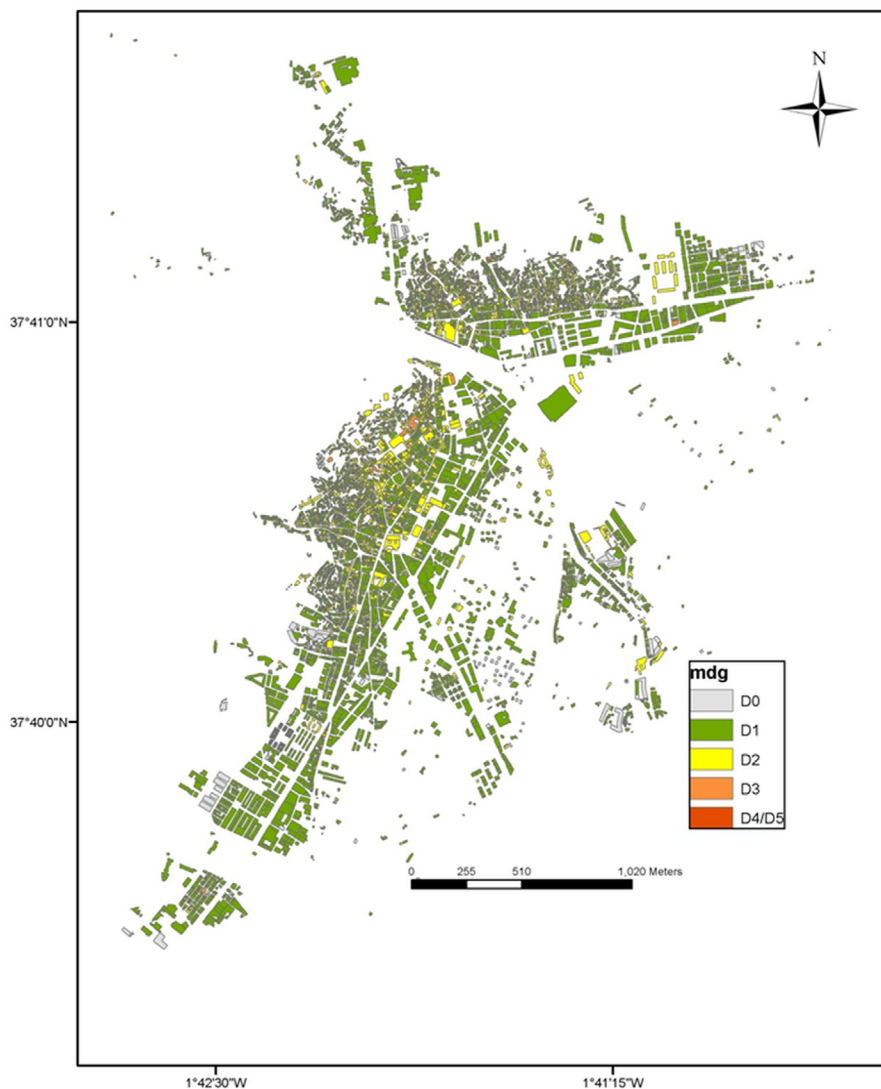
the observed European macroseismic scale (EMS-98) intensity and the vulnerability index by building typology, age and number of floors.

The comparison between Figure 2.17 and Figure 2.18 shows that the modelled scenario underestimates the damage, particularly for the highest damage levels. This suggests the need to consider additional vulnerability factors such as the state of preservation, orientation, discontinuities, soft story buildings, plan/vertical irregularities, openings and quality of construction that were missing in the pre-event vulnerability appraisals. Also, in this specific case, there could be possible previous effects from a M4.5 foreshock.

**FIGURE 2.18**

**Simulation of physical damage to buildings in the city of Lorca using the direct approach.**

Source: courtesy of authors



### 2.4.3 Damage and losses to multiple sectors: relevance for more comprehensive risk assessments

Exercises similar to the one briefly shown in Chapter 2.4.2.3 are very important to evaluate the consistency of risk models; however, they are often limited to a restricted number of assets and to direct physical damage. In the following, the state of the art in risk assessments and damage estimations by sectors will be shortly discussed, distinguishing between tangible and intangible exposed assets. Needs in terms of future damage data provision are also discussed.

## 2.4.3.1 Damage to tangibles

### 2.4.3.1.1 Agriculture

As suggested by Brémond et al. (2013), damage to agriculture should comprise different elements: crops, soil, infrastructures and storage facilities, which are differently exposed and vulnerable to various hazards such as earthquakes, volcanic eruptions and floods (FAO, 2015).

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*Post-event damage assessment can provide a more comprehensive understanding of damage to multiple sectors including agriculture, infrastructure, services and industrial and commercial activities, overcoming the narrow approach taken so far.*

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Earthquakes have usually been associated with potential damage to storage facilities for animals or machinery; not much thought has been given to infrastructures used in agriculture. Nonetheless, the 2012 earthquake in Italy proved to be devastating for hydraulic infrastructures needed for irrigation that was halted for several days with heavy consequences for production.

Damage due to volcanic hazard, in

particular gas and tephra, is associated with animals, crops, irrigation water and soil that can be devastated for a long time (Craig et al., 2016).

Floods may affect all above mentioned components differently, but as mentioned by Brémond et al. (2013), this is not reflected in currently available damage curves.

### 2.4.3.1.2 Industries and commercial businesses

Industries and commercial businesses are often treated as buildings, even though they differ from the latter in many regards. A first difference is the large space usually necessary for activities that make these facilities more vulnerable to earthquakes. Secondly, potential damage to machinery and raw and finished products may be more relevant than damage to structures, particularly in the case of floods, where damage to structures is generally low.

Thirdly, businesses present a very large combination of buildings, machinery, activities and processes that make it hard to standardise vulnerability assessment. Information on damage suffered by industries and factors that make them vulnerable are available for flood risk and earthquakes (Suzuki, 2008; Krausman, 2010). Damage to business can sometimes turn into a severe secondary hazard (risk cascade), when dangerous plants are affected by natural hazards producing the so called Natech hazards (Cozzani et al., 2010; Ministère chargé de l'environnement, 2005; see also Chapter 3.14).

## 2.4.3.2 Damage to intangibles

Damage to intangibles is that which affects people and artefacts that are considered of incommensurable value, i.e. it is very difficult or controversial to monetise. Consideration in this paper will be limited to three examples, one for each hazard.

### 2.4.3.2.1 Loss of cultural heritage due to earthquakes

Earthquakes occurring in historic towns often affect ancient buildings and monuments more permanently and dramatically. Their vulnerability is due to several factors including construction material, type of resistant technology, lack of maintenance and poor or totally lacking seismic retrofitting. Furthermore, historic centres in Mediterranean areas, e.g. Greece, Spain, southern France, Italy and Slovenia, are characterised by complex urban blocks. The vulnerability of these blocks is exacerbated by the presence of shared structural components between adjacent buildings, topographic layout and the recent introduction of infrastructures, without taking seismic risk into sufficient consideration. From a cultural perspective, it is very difficult to assess the value of lost heritage. Methods are available but evaluations are always heavily loaded with societal and emotional concerns that are hard to represent in formalised quantitative terms.

### 2.4.3.2.2 Loss of natural assets and soil as a consequence of floods

Floods may damage, for example, parks and natural preserves in different ways (Gautak and Van der Hoek, 2003): light structures used for visiting such areas may be destroyed and contamination due to toxic and dangerous substances carried out by inundating waters may occur with different degrees of severity, while fauna and flora may also be affected. When a post-flood damage assessment was conducted it was observed that certain species of birds abandoned the area due to the loss of nutrients in the soil and water (Menoni et al., 2017). Time is required in order to assess whether or not such damage is permanent and whether or not eventual substituting species are as rich in biodiversity as those they have substituted. Similar considerations may regard the soil itself for agricultural purposes. Salinisation resulting from coastal inundations and loss of fertile soil may be more or less permanent. Those observations should lead to enhanced risk models that provide an output to show not only the immediate damage due to the event, but also its evolution and dynamic over time, which may require years to appraise the real, longer-term effects.

### 2.4.3.3 Historical examples of permanent relocation

Loss of social capital as a result of temporary or long-term relocation is an issue that should be considered whenever such a measure is exam-

ined. Sometimes during volcanic crises, such a decision is inevitable to safeguard people's life. Examples of past relocations such as those associated with the 1982 El Chichón eruption in Mexico (Marrero et al., 2013), the 1991 Pinatubo eruption in the Philippines (Newhall and Punongbayan, 1997), the 1991 Hudson volcano eruption in Chile (Wilson et al., 2012) and the 2010 Merapi eruption in Indonesia (Mei et al., 2013) suggest that without careful planning, communities can be largely disrupted. In all these examples, people were detached from their source of income and from the territory that is often a fundamental component of their livelihood and identity.

## 2.4.4 The relevance of indirect damage and losses to account for the complexity of events

Literature on direct, indirect and secondary damage is rather significant and there is still no perfect consensus on what those terms mean; however, larger convergence by the scientific and practitioner communities has been achieved in more recent years thanks to efforts at the European and international levels.

At the former level, one may consider the results of the Conhaz project (Meyer et al., 2015), the Nedies project (Van der Veen et al., 2003) and, lately, the work carried out by the European Commission on disaster loss data (De Groeve et al., 2013; EU technical working group, 2015). At

the international level, the work carried out within ECLAC (Cepal, 2014) and the post-disaster needs assessment (PDNA) (GFDRR, 2013) has provided relevant approaches to pave the way for the SFDRR.

### 2.4.4.1 Indirect damage due to ripple effects in complex systems

The need to consider other types of damage as well as damage to multiple systems stems from the recognition that real events are much more complex than the representation of physical damage to few assets. Cascading effects, enchained failures, malfunctions of critical lifelines and inaccessibility to facilities and affected areas may be more severe in terms of impact and victims than the physical damage itself (Park et al., 2013). This can be considered as the systemic facet of indirect damage due to the interconnection and interdependency of urban and regional systems as well as among components of complex systems (Pitilakis et al., 2014).

As for systemic aspects, there have so far been few and partial attempts to model them to make them part of a more complete risk assessment (Bruneau et al., 2003). The MATRIX (2013) and the Syner-G (2014) projects can be recalled here, in particular with reference to the work done on modelling lifeline disruption due to natural disasters. By analysing in detail the models provided by both projects, it is evident that even though they are rather formalised, expert decisions must be provided at crucial nodes in order to run them. This is consistent with the fact that there is not enough

statistical evidence for each type of malfunction of complex lifeline systems to allow for a more general formalisation of the evaluation procedure. In fact, until recently, only anecdotic narrative was available, accompanied by a few numerical figures. Few written reports regarding damage suffered by lifelines in case of floods are available (Pitt, 2008; Ministère de l'écologie, 2005). As for earthquakes, only recently the EERI reports providing first reconnaissance analysis of events have introduced a more in-depth section on lifelines. For the volcanic risk a rather interesting work has been conducted upon observations for a few eruptions, e.g. the Puyehue-Cordón Caulle 2011 eruption in Chile (Wilson et al., 2013; Craig et al., 2016; Elissondo et al., 2016) and the Shinmoedake 2011 eruption in Japan (Magill et al., 2013). Such efforts have not produced the number and extensive data available for physical damage, yet they represent an important first step that would require more focus on future efforts of collecting and analysing post-disaster damage data.

#### 2.4.4.2 Indirect economic damage

Even less evidence is available for indirect damage on economic systems induced by direct damage, lifelines failures, and losses due to business interruption. Such damage and losses include induced production losses suffered by suppliers and customers of affected companies, the costs of traffic disruption or the costs of emergency services. Evidence to date suggests that indirect damage is more important in big disasters than in more trivial ones. For example,

Hallegatte (2008) demonstrates that significant indirect loss for the state of Louisiana only arises when direct losses exceed EUR 50 billion. In a separate study, he also demonstrates that indirect impacts are greater if a natural disaster affects the economy during the expansion phase of its business cycle than if it touches it during a recession phase (Hallegatte et al., 2007).

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*Systemic interconnections and complexity of modern societies require new approaches of damage analysis and representation with respect to the ones that have been in use so far. Post-event damage assessment can provide key knowledge regarding multiple types of failures and indirect damage and loss.*

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Compared to direct physical effects, indirect economic losses are much more difficult to measure. Additionally, there are limited available sources of data for measuring indirect losses. It seems that defined and agreed-upon protocols for identifying and collecting useful data in this domain are still missing or are still in their early stages. Insurance data on business interruption are of limited value for that purpose, as most indirect effects, for example power outage, do not qualify for compensation under business interruption insurance. Moreo-

ver, insurance data must be indexed by insurance market characteristics (e.g. market penetration and average deductibles) to allow correct data interpretation and cross-country investigations. Also, until recently, most insurance companies tended to treat this data as private asset.

The limitation of accessible primary data have led to attempts to measure indirect losses using economic models of the type that have long been utilised for economic forecasting, such as:

- simultaneous equation econometric models (Ellison et al., 1984; Guimares et al., 1993; West and Lenze, 1994),
- input-output models (e.g. Rose and Benavides, 1997; Boisevert, 1992; Cochrane, 1997),
- computable general equilibrium models (Brookshire and McKee, 1992; Boisevert, 1995).

Studies evaluating model-based estimates (Kimbell and Bolton, 1994; Bolton and Kimbell, 1995; West, 1996) show that models developed for traditional economic forecasting tend to overstate the indirect effects. Differences to observed impacts from post-event economic surveys are by 70 % to 85 % (West and Lenze, 1994). The reason for this overestimation of both indirect regional economic losses from natural disasters and indirect regional economic gains from reconstruction is that statistically based economic models have been designed primarily to forecast the effects of a lasting impact.

The historical interlinkages embodied in these models are likely to be substantially disturbed and temporarily

changed during a disaster. Dynamic adjustment features such as recovery, resilience, interregional substitution, inventory adjustments, changes in labour supply, number of displaced, etc. are not reflected in these models. In short, these models must be substantially revised in order to produce reliable estimates of indirect effects. Computational algorithms modelling supply shocks, post-event supply constraints and time-phased reconstruction in disaggregated spatial settings (as, for example, applied in van der Veen and Logtmeijer, 2005 and Yamano et al., 2007) seem promising to overcome this methodological gap.

#### 2.4.4.3 Changes needed to improve post-disaster damage and loss data availability and quality

In order to obtain a more comprehensive and satisfactory overview of damage to assets, systems and sectors following a disaster, more consistent and systematically gathered data to address the complexity of real events are needed. Furthermore, as already suggested by the World Meteorological Organisation guidelines (2007), efforts of data collection should be reiterated in the same areas in order to detect trends that cannot be seen a few hours or days after the event and to monitor the rehabilitation and recovery process.

To achieve such a goal of obtaining and maintaining a more robust repository of different types of damage to multiple sectors, a standardised reporting system, similar to the PDNA or to the so-called Retour of Experience in France (Direction territoriale

Méditerranée du Cerema, 2014) would provide significant advantages. First, because they will permit comparison between cases across geographic regions and time; it will then be easier to recognise similarities among cases and aspects that are specific to each case. Second, data collected and processed in the same way for key variables will allow us to obtain statistical evidence for some variables that at present are described only in a qualitative way. Third, more comprehensive and comparable reports will permit the building of a body of knowledge on different types of damage to several sectors that can support decision-making for a more resilient recovery and to feed pre-event modelling, as suggested in Figure 2.14.

##### 2.4.4.3.1 Costs versus physical damage

Another field that would require substantial advancement relates to the reconciliation between different ways of representing damage and losses. Engineers generally provide a physical representation of damage in terms of affected buildings, bridges, lifelines and plants (and related components). Costs of asset repair or substitution can then be estimated. It is less easy than generally perceived to find an exact match between the estimated repair and substitution costs and the real expenses that are declared for the reconstruction of the same items (Comerio, 1996). This can be due to the fact that costs of amelioration are included too or that, if not governed, the process may lead to some distortions where someone takes undue advantage of the disaster. Extra costs may be due also to the exces-

sive amount of needed repair material or workers from other areas to be recruited as local capacities are overwhelmed.

Furthermore, there are spatial and temporal scale issues that cannot be neglected; for example, the shift from individual items that are assessed to entire sector categories, like the shift between individual residential buildings to residential land uses. For an attempt of alignment, one may consider the recent work carried out by Amadio et al. (2015).

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*More comprehensive post-event damage analysis will provide fundamental knowledge to a variety of stakeholders. Innovation is needed to reconcile the 'engineering' representation of the physical damage and the economic assessment of direct and indirect damage and loss*

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The economic damage, however, is not restricted to the translation of physical damage or services malfunction into monetary terms. Instead, it reflects the economist's perspective, according to which loss goes beyond repair and reconstruction needs and comprises the total effect the damage will have on a given economy (either local or national) in terms of lost resources and assets (Pesaro, 2007).

Such resources can be linked to material damage, to business and service interruption or to the fact that customers will be lost as a consequence of prolonged businesses' interruption, etc. Systemic effects due to the failure or malfunction of lifelines and services can be described in terms of numbers (days/hours of interruption, number of customers without service) or in terms of the economic loss that has been caused by such a failure. The two representations of damage and losses do not fully coincide; instead it would be very important to find correspondences between them.

## 2.4.5 Conclusions and key messages

### Partnership

A stronger partnership among a variety of stakeholders is required to achieve a more comprehensive and realistic picture of complex disasters' impact on society. Despite claims related to the usefulness of risk models for decision-making, researchers devoted attention to models that were already satisfactorily developed and to sectors for which it was relatively easy to get data (Grandjean, 2014). In fact, the focus of many scientific studies is improving the quality and the reliability of models, independently of completeness in terms of covered sectors and types of item. Completeness is important, however, for decision-makers. Local and regional governments are certainly interested in assessing not only the potential physical damage to buildings and a limited number of assets, but also the larger systemic effects, potential disruption

of services and businesses and overall impacts on the regional economy. Depending on whether their role is managing prevention or emergencies, they are keen to know which sectors deserve more resources to reduce future risk and how expected damage will be distributed in space and in time.

Insurers are also interested in enhanced damage modelling and in a wider view of impacts that may shape the environment in which the damage they will have to compensate for occurs. In fact, duration of interruption is a crucial factor, particularly for businesses. In recent years, insurance companies have become more active in supporting their customers after an event to reduce such a duration. Knowing in advance what 'external factors' may impact on the capacity to return to normal operations will allow us to better tailor advice for mitigation that is increasingly recognised as part of insurers' work to diminish their own financial exposure.

Ultimately, we conclude that improved risk models supported by larger and more refined evidence derived from the observation of what actually happens after real events is for the benefit of risk mitigation measures, be they structural or non-structural.

### Knowledge

The potential benefits for risk modelling that may be provided by enhanced damage data collection and analysis is still an open issue for both academic researchers and practitioners. Following a review of existing methods of damage modelling in Europe and the United States, Hubert and Ledoux (1999) had already suggested that post-event surveys may provide more 're-

ality' to assessments by subtracting the field of imagined and hypothesised damage and providing more evidence from observed and surveyed damage. They suggest this is necessary, particularly for those sectors such as lifelines and industries, for which risk models are still in their infancy in terms of robustness and completeness. In fact, as shown in this chapter, knowledge is more advanced in the field of direct physical damage to certain assets, in particular buildings, while less so with respect to other sectors and different types of damage.

### Innovation

Multiple innovations are needed to enhance our capacity for damage modelling. First, there is the need to substantially improve post-disaster event and damage data collection and analysis (Barredo, 2009) to account for the different types of damage to multiple sectors that are currently missing. Second, there is a need to reconcile different interpretations of damage, not only in terms of definitions, a field where significant advances have been achieved, but also in terms of adopted units of measure and methods to aggregate cost at different scales.

Closer interaction between engineers, volcanologists, geophysicists, geographers and economists has to be sought in order to understand the implications and the links between different ways of accounting for and reporting damage and loss. This would permit an advancement of risk modelling by overcoming the apparent randomness of current assessments, which for some risks and for some assets are provided as damage index, and for others as costs.

Also, a more comprehensive framework considering spatial and temporal scales should be adopted in risk assessment. As for the former, it would be established looking at the chain of potential impacts, physical and systemic, and the quality and quantity of exposed elements and systems (including economic systems). Therefore, damage should not be considered only in the core area, where most physical damage has occurred, but case by case in the area of relevance, which can range from local to global in some extreme instances (Nanto et al., 2011). As for the temporal scale, it is key to reiterate the data collection at time intervals relevant for the type of event that has occurred. This will help to provide risk assessments with a clearer timestamp. A shift from a static representation of damage, defined in a pre-assigned time (often not made explicit), to more dynamic representations is necessary to show how damage changes and what type of damage becomes more prominent at each stage of the disaster event (impact, emergency or recovery).

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