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ENSURE E-LERNING TOOL

F02
An introduction to vulnerability definitions

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Reference reports:

Del. 1.1.1: Methodologies to assess vulnerability of structural systems (chap. 2.1, 2.2)

Del. 4.1: Methodological framework for an Integrated multi-scale vulnerability and resilience assessment (chap. 1.2, 3)

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1 Schools of thought in risk assessment

When trying to define the meaning of vulnerability and risk terms, one is faced to the large variety of possible definitions, depending for instance on the “object” focus for assessment (e.g. one single building or groups of buildings? lifelines? people? etc.).

There is no consensus on how to measure and to combine the various intrinsic components of risk, but whatever the model used to represent it, the result should be the same in the end. However, risk can be considered as a dynamical process with respect to time, and it can be derived basically from the convolution of two main components:

- The hazard is the probability of occurrence of a particular event (e.g. natural, technical) within a given time-period/geographic space.
- The vulnerability term represents the pre-disposition of elements at risk (buildings, infrastructures, people, services, processes, organisations, etc.) to be affected, damaged or destroyed by the event.

Recent publications also incorporate other components such as the coping capacity, the exposure -global value of elements at risk in a given territorial system-, the deficiencies in preparedness, the lack of resilience, etc. Hereafter are some of the existing definitions for risk.

- ISDR 2004:
  Risk = Hazard × Vulnerability
- UNDRO, 1979; Dilley et al., 2005:
  Risk = Hazard × Vulnerability × Exposure
- Used by the Technical Chamber of Greece in a project (1999-2005) aiming at proposing a national strategy for seismic retrofitting of existing buildings, with an additional coefficient k expressing the population density and the socio-economic significance of the function of the buildings (TCG, 2001):
  Risk = Hazard × Vulnerability × Exposure x k
- Used by the Technical Chamber of Greece in the 2nd phase of the same project (see section 3.6 for details):
  Risk = (Hazard - Design Seismic Action) × Vulnerability × Exposure x (factor to adjust damage to costs)
- For Alexander (2002), the risk is the probability that some given elements may sustain a particular level of loss due to a given level of hazard, whereas “Total Risk” means the sum of predictable casualties, damages and losses:
  Total Risk = Hazard × Vulnerability × (Σelements at risk)
- Villagrán De León, 2001:
  Risk = Hazard x Vulnerability x Deficiencies in Preparedness
- Hahn, 2003:
  Risk = Hazard + Vulnerability + Exposure – Coping Capacity
- Definition used by many agencies (see Villagrán De León, 2006):
  Risk = (Hazard x Vulnerability) / Coping Capacity

In this context, the coping capacity refers to the means by which people or organisations use available resources and capacities to face adverse consequences related to a disaster.

Whatever the definition of risk, it should include the potential effects of correlative impacts (socio-economic impacts on employment, production, etc.) or induced effects (hazardous industries impacts, dams collapses, fires and explosions, etc.) and the human or social dimension through the analysis of vulnerability factors (demographic, social organisational, political, educational and cultural aspects). Hence, risk assessment requires a multi-disciplinary approach that accounts not only for physical impacts, but also for less quantifiable factors, such as social, environmental, organisational and institutional factors.

In the technical/engineering literature for natural hazards (disaster risk reduction community), vulnerability is defined on a scale ranging from 0 (no loss/damage) to 1 (total loss/damage). It represents the degree of loss/potential damage/fragility of a particular element or set of elements at risk, within the area affected by a hazardous event characterized by a given intensity or level (e.g. see ISSMGE-TC32, 2004). This approach to vulnerability estimation is referred to as physical or technical, because it is related to the physical interactions between the potentially damaging agent and the vulnerable elements of the physical environment (e.g. roads, industries, public equipments and building stock vulnerability or urban tissues, infrastructures, building aggregates and individual buildings). Moreover, the methodologies to assess physical vulnerability are strongly dependent on the observation and resolution scale:

- At the *regional-territorial scale*, the analysis includes strategic elements such as roads, industries, public equipments; building stock vulnerability is carried out on “indirect” data such as building age, site occupancy indexes, social conditions of population, illegal building concentration, and so on.
- At the *urban-local scale*, the analysis includes urban tissues, building aggregates and individual buildings as well as in-depth analyses of strategic equipments.

In this vision, the human system is the passive agent in the vulnerability estimation and the conceptual affinity between vulnerability, fragility and loss is pertinent, as part of the consequence estimation. Accordingly, quantification of vulnerability is made through the use of a function -called indifferently vulnerability or fragility function-, which relates the probability of reaching or exceeding a given damage state with the type and intensity of the hazard, and for different classes (characteristics) of elements at risk. This vision dominates the engineering literature on the topic, where the emphasis is on the assessment of hazards and their impacts, while the role of human systems in mediating the outcomes is downplayed.

However, the vulnerability concept has also a broad coverage in social sciences, where the human system is put on the central stage. Such a concept is related to the management of various risks that the society faces, such as poverty, loss of life and/or health, food insecurity, effects of natural and anthropic disasters, climate and ecosystem changes, etc. Therefore, research on vulnerability in social sciences is always concerned with the question: “vulnerability to what?”. Although vulnerability assessment depends on the answer to this question and although there is no unique definition of vulnerability in social sciences, some general principles can be listed (Alwang et al., 2001):

“Vulnerability is probability of loss of welfare relative to a benchmark”

> *"A household is vulnerable to loss of welfare due to uncertain events"*
>
> *"Degree of vulnerability is dependent on the nature of risk and household's response capacity to risk"*
>
> *"Vulnerability is a time-dependent parameter as the risk and the household characteristics change over time"*
>
> *"The poor are more vulnerable due to their limited access to resources and limited response capacities to risk"*

Social/societal vulnerability concentrates on determining the coping capacity of the society or of the individuals in the society when a natural hazard hits. Hence, contrary to the hard sciences vision, it directs attention to the underlying structural factors that reduce the capacity of the human system to cope with a range of hazards, rather than the negative impacts following one specific hazard. Therefore, when assessing social vulnerability, the focus is on determining the indicators of society's coping capacity to any natural hazard and searching for the vulnerable groups/individuals in the whole society based on these indicators.

When considering physical vulnerability, there must be an attempt to further develop assessment tools for different types of structures (e.g. ordinary buildings, "special buildings", such as churches, theatres, public facilities, etc.) and different hazards. There are nowadays elements to build on, for instance the parameters to assess physical vulnerability are available in literature and in case studies for most hazards. However, there are still areas (e.g. landslides), where parameters useful for risk assessment are not available or not yet completely defined, or for which no consensus really exists. Unless for specific structures, physical vulnerability models can be derived and defined either on the basis of statistical processing of damage observations (with or without including the expert judgments), expert opinion, analytical/simplified-mechanical models or score assignment. All these methods are in general defined with reference to a typological classification, grouping set of exposed elements according to the peculiar features affecting their behaviour. Anyhow, there is still a need for further developments regarding the methodology, and the identified parameters have also to be corroborated through laboratory and computer simulations. A path has to be proposed in order to attain such a level of codification.

2 Generalities on vulnerability

Vulnerability relates to the consequences of the impact of a natural force, and not to the natural process or force itself. In practice, vulnerability and consequences are linked. There are basically two different approaches for examining vulnerability: one that is based on natural or hard sciences and another that is based on the social science methods and assumptions.

The natural science perspective of vulnerability dominates the engineering literature on the topic, where the emphasis in on the assessment of hazards and their impacts, putting aside the role of human systems in mediating the outcomes. Vulnerability in this case is defined as the physical vulnerability of the elements at risk, and it is an important component of consequence evaluation.

The social science perspective of vulnerability puts the human system on the central stage. It directs attention to the underlying structural factors that reduce the capacity of the human system to cope with a range of hazards, rather than the negative impacts following one specific hazard. There is no unique definition of vulnerability in social sciences, where different views and various definitions differentiate between natural, physical, ecological, technical, economical, social, political, institutional, ideological, cultural and educational vulnerability.

A possible link between both perspectives is the urban vulnerability concept, which is developed mainly in the geographical literature, and which tries to model vulnerability of the urban environment by considering the society's interaction with its physical environment based on a given magnitude of hazard. Here, the urban environment is considered as a system and the main focus is to determine the spatial distribution of urban vulnerability and determine the vulnerability hotspots for decision makers. Urban vulnerability combines social and physical vulnerability indicators into an overall vulnerability of the urban place (Cutter et al., 2000). Since the assessment is carried out on a spatial basis, use of GIS and spatial analytical models is widespread. However, urban vulnerability assessments are essentially used for earthquake and flood hazards (e.g. FEMA-NIBS 1999; Cutter et al., 2000; Rashed and Weeks, 2003; Haki et al., 2004). For instance, a Urban System Exposure methodology was developed in the framework of earthquake hazard (see GEMITIS, 2003; RISK-UE 2004), in order to implement a global and integrated Risk Reduction Strategy for improving the risk-assessment effectiveness in urban areas, including the generation of crisis scenarios and mid- to long-term seismic-impact assessment.

Regarding methodologies for assessment, existent techniques to supply data about vulnerability can be variously divided. This subdivision may apply or not depending on the nature of exposed elements (i.e. single building, tunnel or bridge to town, country, region) and the spatial scale or resolution for analysis (i.e. urban/local scale 1:500 – 1: 5000 for a bloc of buildings, network junction or regional/ territorial scale 1:5.000 – 1:50.000 for a whole network system or a territory).

Some techniques may be qualified as direct, i.e. supplying an effective prevision of damages caused by the threat or indirect, i.e. establishing a vulnerability index related to the external aggression through correlations.

It is worth noting that some approaches use either quantitative techniques - such as the damage probability or equivalent deterministic relations - or qualitative techniques - describing the vulnerability in terms of “low”, “middle” and “high”-.

The method used for evaluation of vulnerability may vary for different hazards and depends on the quality and quantity of available data. For large scale vulnerability evaluation, it is common to establish typologies of exposed elements and evaluate the vulnerability of a representative element exposed to the external aggression in the first step. The second step consists in attributing a vulnerability indicator (such as vulnerability index or fragility function) to the whole group of elements either uniformly or randomly in order to derive information about urban areas on the whole.

However, it is common to assess vulnerability by building fragility functions, relating the probability to reach or exceed a certain degree of damage to the force exerted by the relevant indicator(s) of aggression. The definition of this (these) indicator(s) or vector(s) and the evaluation of how relevant it is (they are) are very challenging. Whatever the methodology for the vulnerability may be, the definition of the fragility functions remains debatable, not only due to the possible complex response of exposed elements to the aggression but also due to the identification of aggression vectors themselves. For instance, the fragility curves for buildings subjected to tsunami-induced waves or flash floods ask for a pertinent choice of aggression factor(s) (water height, duration, impact-wave speed or kinetic energy?). Hence, a key step in assessing physical vulnerability is to acknowledge the type of physical stresses that will be sustained by affected structures (e.g. the stress provoked by ground shaking is different from that of pyroclastic falls, soil settlement or flooding, etc.). Furthermore, the various hazards present a variety of potential threats, according to varying levels of intensity, location and time of occurrence.

A second level at which hazard and vulnerability are interlinked relates to the possibility that given exposed objects or systems may be vulnerable, but may be considered as a threat for the community as well, in case a natural event strikes: vulnerability may well turn into more severe, increased or new natural as well as technological hazards in this case, leading to the so-called Na-Tech disasters.

Finally, another issue which is generally not envisaged in current vulnerability assessment methodologies is how to account for the combination of various natural hazards with different return periods. This is different from analyzing the impact of cascaded hazardous phenomena, as two or more hazards having a low level of intensity when considered separately, may lead however to an increased risk when occurring simultaneously. Hence, it is important to understand how vulnerability changes in the face of estimated/perceived extremes' return periods/likelihood vs. their estimated/perceived magnitude, and whether it will. Asking this question is relevant in the search for integration between the "disaster" and climate change communities. While the first has traditionally started any assessment from the characterization of the hazard (mainly in terms of probabilities), the latter has been focusing since the earliest stage of research on the adaptive capacity of communities likely to suffer the heaviest changes in the environment brought by climate change. How much those two different perspectives may learn from each other is relevant to ask, especially when uncertainties in modelling hazards (particularly enchained ones) and insurmountable difficulties in balancing between probabilities and extremes severity are taken into account.

3 Definition of different types of vulnerability

Different types of vulnerabilities can be found in literature and assessment experiences in various contexts. Within the Ensure project it has been decided to label those vulnerabilities as follows:

- physical vulnerability, referring to the propensity to physical damage. It comprises the physical features that make a given object, a given artefact, a given structure weak in facing an external stress, represented by the pressures and forces exercised by natural extreme in the form of acceleration, heat, energy etc. Therefore, physical vulnerability is the vulnerability aspect that is more strongly related to the characteristics of the threat, in that resisting to high winds requires different qualities than resisting to an avalanche or a landslide volume and mass.
- by the term systemic vulnerability we address the fragilities arising in one system as a consequence of the relationship among its components or of its dependence from other systems. As an example one may consider the systemic vulnerability of a hospital which relies on external lifelines for water, gas, electricity. The degree to which the hospital is able (or better unable) to sustain its ongoing activities and provide the necessary care when external lifelines are affected, represents its systemic vulnerability. The degree of dependency in this case represents the systemic vulnerability: even though the hospital itself is not damaged, neither structurally nor in its machinery or assets, it cannot function properly and provide care for the same victims of the feared event. Systemic vulnerability refers to vulnerability to losses rather than direct vulnerability to the stress, even though in some cases, like for example ash crises in volcanic eruptions, the same stress has a direct potential impact on the functioning of basic services, like transportation. While physical vulnerability addresses the structural and physical response to an external stress, systemic vulnerability addresses the functional performance expected when some level of physical damage occurred in one or more components of systems. It deals with the capacity (or lack of capacity) to continue functioning despite some level of disturbance in the system itself or in related ones.
- With the rather broad term of social vulnerability we address several components of societal coping capacity, ranging from individuals, to social groups, to communities, to organisations. Social vulnerability can be both physical and systemic, as people can be physically injured and harmed, but are also vulnerable to the lack of basic services, to the new conditions required by evacuation, temporary sheltering, et. In the same vein, organisations, like for example civil protection, can be harmed in their assets and personnel, or diminished in their capacity to react because of a variety of systemic failures, including the lack of coordination and collaboration among different agencies, problems in communication, problems in deciding about matters that hold significant juridical and moral challenges. An important distinction that has been introduced in WP2 is between social and human capital, intending that vulnerability of both should be appraised. For neither concepts universally accepted definitions can be found. Basically, we can assume that human capital refers to skills, dexterity (physical, intellectual, psychological) and judgement capacity, which may be lost during an extreme event; on the other side, social capital refers to the value of social networks affecting the productivity and capability of individuals and groups to cope and recover from an extreme event.
- With economic vulnerability we refer to the response economic sectors are able (or unable) to provide in the aftermath of an extreme event. Also in the case of economic vulnerability, both physical and systemic aspects must be considered. Economic assets can be physically damaged, but economic activities are clearly extremely vulnerable to interruption of

transportation services, to deficient lifelines. Days without the possibility to work, to receive products or to send them to destination constitute a net damage measurable in monetary terms.

Up to this point other words than vulnerability have not been used or with rather little emphasis. Within previous WPs, and particularly the first, devoted to the state of the art on the issue, the problem of definitions have been extensively tackled. Yet, there is the need to make a choice; it is strong convincement of the Ensure working group that a project, to accomplish successfully its task cannot simply remain at a definitional stage, comparing literature proposals; it must advance its own proposal, selecting, deciding on the interpretation that better fits partners' previous experience, the results of discussions during meetings and the analysis of case studies, both those used for gaining new insight and information and those used as test areas.

Some choices were already implicit in the way the project itself was constructed, but some relevant issues has emerged during the development of the project, which deserve to be considered before moving ahead to the description of the integrated framework.

The Ensure project adopted systemic approach to vulnerability and resilience assessment. Yet it is important to exactly define what "systemic" actually means. In WP1 and WP2 the various facets of vulnerability (physical, functional, organisational) and the "types" of vulnerability that can be found in literature (social, economic, territorial) have been explored. The framework was conceived as intrinsically systemic, in that various factors, systems and components concur to create vulnerability and resiliency patterns, both individually and through their multiple connections.

More specifically, the framework adopts a systemic approach at three distinct levels:

- first, the vulnerability and resilience of systems is appraised (natural, built environment and social) as it will be further explained in paragraph xx;
- second, the term "systemic" has been associated to vulnerabilities that arise as a consequence of systems interdependency and interconnectedness;
- third, the question of how the vulnerability and resilience of different systems interact with one another across temporal and spatial scale has been addressed.

4 Relationship among different vulnerabilities

WP2 can be considered a sort of turning point in the project, as it permitted to extensively analyse and search the relationship between different types of vulnerabilities as described in the previous paragraph: between physical and systemic, between physical, systemic and social, between systemic, social, economic, institutional and territorial.

The various types of vulnerabilities are not separated one from another, they actually influence each other. For example physical vulnerability is often the result of lack of good norms and regulations of the construction sector to build more resistant structures but it may be as well the result of poor inspection capabilities, of lack of compliance with existing rules and norms, no matter how well advanced they may be. Furthermore, as it was clearly raised during the development of WP2, the various types of relationship are part of a more general and integrated vulnerability, that of the built environment, where different aspects, social, institutional, economic and physical interact as do the different systems and subsystems that they characterize as far as their relative lack of resistance to natural extremes is concerned.

Such a complex interaction and interplay of vulnerability types has been labelled as “territorial” vulnerability, to make clear that the vulnerability of a region, a metropolitan area or an urban centre is much more than just the sum of the vulnerabilities of individual constructions. It has to do with the way regions, cities and their assets and facilities function, perform and are used by people, agencies and organisations.