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ENSURE E-LERNING TOOL

F09
The resilience concept

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1 Resilience in the international risk reduction initiatives

The resilience concept, although investigated since 1970s, has gained prominence in the disaster field after the Hurricane Katrina occurred in August 2005, when a lack of resilience was largely complained. Nevertheless, the term is mentioned in many of international reports devoted to risk reduction and sustainability initiatives published in the last 15 years.

In the guidelines prepared for the World Conference on Natural Disaster reduction (UN, 1994), held in Yokohama, the following declaration is reported: "There is a strong need to strengthen the resilience and self-confidence of local communities to cope with natural disasters through recognition and propagation of their traditional knowledge, practises and values as a part of development activities".

Five years later, within the IDNDR Programme Forum (IDNDR, 1999), the participants promoted the adoption of "policy measures at the international, regional, sub-regional, national and local levels aimed at reducing the vulnerability of societies to both natural and technological hazards through proactive rather than reactive approaches". Such measures had to be addressed to "the establishment of hazard-resilient communities and the protection of people from the threat of disasters". It is worth noting how, within this line of thought, the spread of a new awareness addressing something that was different from the traditional concept of "resistance" can be observed and how a proactive approach, especially for what concerns governments actions, is invoked to achieve resilience.

Referring to climate change, the IPCC Third Assessment (2001) report provides a first "institutional" definition of resilience, expressed in comparative terms with vulnerability. According to IPCC, a resilient system or population is not sensitive to climate variability and change and has the capacity to adapt. In such a way, resilience represents the flip side of vulnerability.

In line with IPCC, but by a mirror perspective, ISDR[1] (UN/ISDR, 2002) defines vulnerability as a function of the susceptibility or resilience showed by socio-economic systems and physical assets to the impact of natural hazards.

The same ISDR (2004), a couple of years later, officially introduces the concept within the field of disasters, including resilience into its glossary devoted to the basic terms of disaster risk reduction. Resilience is defined as "the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure"[2] . It is worth noting that the components of the traditional and pragmatic formulation of risk are pointed out in this definition: hazard and exposure in an explicit manner, vulnerability through some concepts closely related to, namely adaptation and resistance in face of likely damages.

[1] ISDR was launched in 2000 by UN General Assembly Resolution A/54/219 as successor of IDNDR.

[2] Further, according to ISDR (2002), such capacity is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures. The same meaning will be adopted later by IRIN/OCHA(2005), quoted by UNU/EHS(2006).

OECD (2004) focuses the attention on the relationship between adaptive capacity and natural disasters. In this respect, it is stated that "adaptive capacity can be defined as the vulnerability of a society before a disaster strikes and resilience after the fact"[3]. Hence, resilience is related to adaptive capacity rather than directly to vulnerability. In the report, it is suggested that an enhancement in resilience "can be achieved by implementing a series of precautionary measures that would lower the cost of relief (e.g. social safety nets, improved communications), and preparing adequate contingency plans for rapid medical and humanitarian responses".

The humanitarian organization IFRC (2004) proposes a "shift in thinking" in the field of disaster, concerning the need for putting resilience ˜ in terms of strengths, skills, and resources ˜ at the heart of the aid debate rather than just vulnerability. As a consequence, the emphasis on identifying and building strengths represents a paradigm shift in approaching risk. Resilience is adopted in the understanding of "the capacity to survive, adapt and recover from a natural disaster. Resilience relies on understanding the nature of possible natural disasters and taking steps to reduce risk before an event as well as providing for quick recovery when a natural disaster occurs".

After the World Conference on Disaster Reduction, held in Kobe in January 2005, the Member States of United Nations adopted the Hyogo Framework for Action 2005-2015 (UN/ISDR, 2005), with the overarching goal to build resilience of nations and communities to disaster, by achieving substantive reduction of disaster losses by 2015. HFA defines five areas of priorities for action, guiding principles and practical means for achieving disaster resilience for vulnerable communities in the context of sustainable development. With respect to resilience the following priorities for action are identified:

- knowledge, innovation and education represent a need for building a culture of safety and resilience at all level;
- the development and strengthening of institutions, mechanisms and capacities is a strategic goal for building resilience to hazard.

According to OECD (2008), interested in investigating the conditions determining fragility for a state, resilience consists in the ability to cope with change driven by sudden shocks or long-term changes. It derives from a combination of capacity and resources, effective institutions and legitimacy, all of which are underpinned by political processes that mediate state-society relations and expectations.

The last ISDR's updating of disaster risk terminology (UN/ISDR, 2009) provides the following definition of resilience: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions". The major innovative element in such definition is represented by the inclusion of "time" as a parameter for evaluating resilience. Finally, it is worth mentioning that the resilience concept has widely permeated the last session of the Global Platform for risk reduction, organized by UNISDR and held in Geneva in June 2009.

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[3] By collocating the adaptive capacity into different temporal span with respect to the disaster occurrence, this definition explains the fact that adaptive capacity is considered as part of vulnerability by some authors and as part of resilience by others.

The presented overview shows how resilience is often referred to as a "panacea" within the disaster field. Apart from some definitions, potentially embodying a wide spectrum of evaluation parameters and some general hints (e.g. precautionary measure, developing and strengthening of institutions, etc..), how pursuit an effective enhancement of resilience as overarching goal of disaster risk reduction is still a nebulous matter. As a consequence, this chapter is addressed to draw an outline of resilience by an operational perspective, starting from a deepening of both the roots of the concept in the ecological field and the influences that it received from the Complexity and Sustainability theories.

2 Resilience theory: roots and evolution

The term resilience, from Latin *resilio*, means "to jump back" (Klein et al., 2003). From a scientific point of view, it has been used, at first, in physics where it was assumed to refer to the resistance of a material to shocks, namely the quality of being able to store strain energy and deflect elastically under a load without breaking or being deformed (Gordon, 1978). Nevertheless, the application of the term in a technical meaning - in that some attempts aimed at providing related quantitative measures have been carried out - grounds on the field of Ecology (Carpenter et al., 2001).

In this paragraph, wide room is devoted to this perspective due to the strong influence that it has had on the resilience thinking and due to the transfer of its meaning from ecological to disaster field. Hence, Ecology represents an adequate entry point for any discussion related to resilience.

The concept of resilience was being studied by ecologists since Seventies to know why some species survived in environments with high uncertainties and/or affected by catastrophic events. They initially adopted the term in the same sense as in physics. In 1973, Holling assumed resilience for referring to one of the property through which the behaviour of ecological systems could be described. He defined resilience as "a measure of the ability of a system to absorb changes of state variables, driving variables, and parameters, and still persist and by doing so, it is responsible for the persistence of relationships within a system" (Holling, 1973). The most innovative aspect of such meaning is given by its separation from the concept of stability whereas, according to Holling (1973), stability represents "the ability of a system to return to an equilibrium state after a temporary disturbance". He added that "the more rapidly the systems returns, and with the least fluctuation, the more stable it is". With the aim of underlining this difference in meaning, he stated that a system can be very resilient and still fluctuate greatly (low stability). Hence, "stability" is representative of a system perspective in terms of equilibrium states. In this respect, already in 1973, Holling came to the conclusion that "an equilibrium centered view is essentially static and provides little insight into the transient behaviour of systems that are not near the equilibrium". For this reason, an equilibrium view doesn't fit to deal with the ecological systems that are likely to be continually in a transient state, even in absence of disturbance agents.

The admission of the existence of one or more equilibrium states has entailed a twofold characterization of the resilience concept. Some years later, Holling (1996) himself breaks down resilience into two typologies:

- engineering resilience;
- ecological resilience.

In fact, Holling stigmatizes the "ability to return to a stable steady-state following a perturbation", as defined by Pimm (1984), as engineering resilience, putting it in opposition to an ecological resilience. The last one better fits with "designing with ecosystems" since it describes "conditions far from any equilibrium steady state, where instabilities can flip a system into another regime of behaviour". As a consequence, whereas the engineering resilience emphasizes the efficiency, constancy and predictability aspects, the ecological resilience emphasizes the persistence (maintaining existence of function) and robustness (preservation of the structure of the system in the face of perturbations) aspects (table 1).

Table 1: Engineering and ecological resilience (extracted by Folke, 2006)

Resilience concepts	**Characteristics**	**Focus on**	**Context**
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibrium states, stability landscapes

The "engineering" attribute is chosen by Holling according to the common approach of engineers aimed at designing systems with a single operating objective. Engineering resilience is permeated by "an implicit assumption of global stability, that is, that only one equilibrium steady state exists, or, if other operating states exist, they should be avoided by applying safeguards" (Holling, 1973).

According to their definitions, the two types of resilience are measured in a different manner (fig. 4): ecological resilience (left side) is measured by the magnitude of disturbance that can be absorbed before the system changes its structure by modifying variables and processes that control its behavior. In Adger's representation (fig. 4) this magnitude is given by the distance between a pre-disaster level and a threshold (dotted line) beyond which the system flips into another regime of behaviour[4] . On the other hand, engineering resilience is measured "by a return time, the amount of time taken for the displacement to decay to some specified fraction of its initial value" [5] (Pimm, 1991). The concept of rapidity needed by a given system to return to equilibrium following a perturbation, has been embodied in common dictionary definitions of resilience, for example as ability of people to feel better quickly after something unpleasant, such as shocks and injury[6] , as well as in the updated ISDR's definition of resilience included in its report on disaster risk terminology (see § 1).

[4] The different arrows are representative of the plurality of equilibrium states that a system can assume after a disturbance.

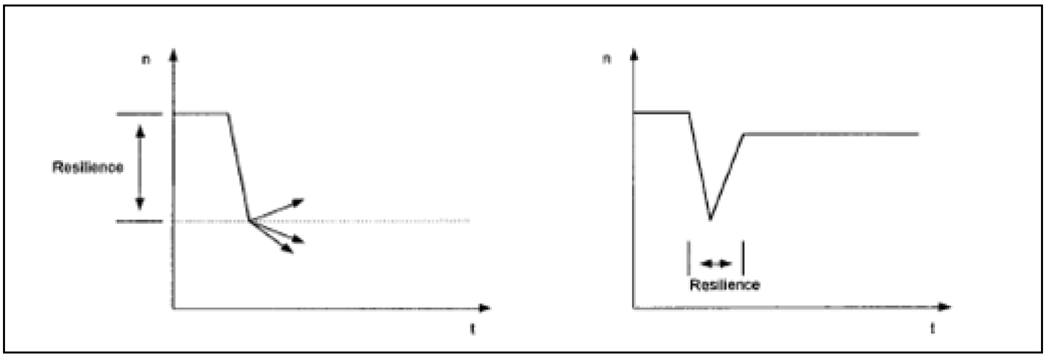
[5] With reference to some considerations afterwards developed, it is worth underlining the effectiveness range of Pimm' s definition. According to Ludwig et al., (1997) it "applies only to behaviour of a linear system, or behaviour of a non-linear system in the immediate vicinity of a stable equilibrium where a linear approximation is valid".

[6] Adapted from Oxford Advanced Learner's Dictionary (2005).

Walker et al. (2004) expand the definition of resilience as follows: "resilience is the capacity of a system to absorb disturbance and reorganize[7] while undergoing change as so still retain essentially the same function, structure, identity and feedbacks"[8] .

The aspect of resilience concerning the resistance and the absorption of disturbance is more properly called "stability" by Berkes and Folke (1998) even though resilience includes something else, for example, the capacity to "conserve opportunity for renewal of the system and emergence of new trajectories" and opportunity for recombination of evolved structures and processes after a disturbance (Folke, 2006; Berkes and Folke, 1998). These capacities become preeminent when discussion on resilience moves, on behalf of Resilience Alliance[9], from the ecological field to another one, namely the socio-ecological field (SES).

Figure 4: Ecological (left side) and engineering resilience (right side) measures (Adger, 2000)



An earlier definition of SES is that provided by Gallopin et al. (1989): "any system composed of a societal (or human) component (subsystem) in interaction with an ecological (or biophysical) component". The hierarchical structure in which SES are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring and renewal, is described by Gunderson and Holling (2001) by the term Panarchy (see annex 1) that is a key concept to understand the evolving nature of complex adaptive systems.

Carpenter et al. (2001) single out three essential properties of Resilience that will be later adopted as a sort of manifest of resilience by the Resilience Alliance:

- the amount of disturbance a system can absorb and still remain within the same state or domain of attraction;
- the degree to which the system is capable of self-organisation;
- the degree to which the system can build and increase the capacity for learning and adaptation.

[7] A similar definition was already provided by Louis Lebel (2001) quoted in USAID/ASIA (2007): the potential of a particular configuration of a system to maintain its structure/function in the face of disturbance, and the ability of the system to reorganize following disturbance-driven change and measured by size of stability domain".

[8] This meaning for resilience is well represented by the model of "basins of attraction".

[9] Resilience Alliance is a network of scientists which aims to stimulate academic research on resilience and inform the global policy process in sustainable development. Nowadays, it represents the main authority in the field of resilience.

These properties, even if related to different aspects, find a common source in the Theory of Systems and in its evolution into the Complexity theory. In detail, the concept of self-organization, initially meant as a property of systems resulting from the interaction with external factors, is expanded when it is applied to the complex adaptive systems that have the potential to learn by experience, specifically to process information and adapt accordingly (Bankoff et al., 2004).

The other prominent cultural source which has strongly contributed to the evolution of the resilience thinking is represented by the theory of Sustainability.

Both Complexity and Sustainability theories assume as starting point a vision grounded on a systemic approach and both recognize the existence of factors, within systems, that are responsible for change and that represent a source of uncertainty due to the fact they act in a not predictable manner.

According to Waldrop (1992), the Complexity theory deals "with stability and change in systems that are complex in the sense that they consist of a great many independent agents that interact with each other in many ways". The many ways through which the different components of the systems can interact with each other define the main character of a complex system that is the non-linearity of its relationships and, as a consequence, the possibility of having more than one solution.

Within the Complexity theory, Prigogine (1967) developed his theoretical construct of "dissipative structures" [10] through which he referred to those open systems that stay in condition far from equilibrium and, as a consequence, have to be described by non-linear equations[11]. In many non-linear systems, significant modifications could be observed following to small changes of parameters: such systems are defined "structurally unstable". In detail, the critical points of instability are called points of bifurcations[12] in that, in their correspondence, the system can evolve according to different directions compared with the previous one. By a physical perspective, new forms of order emerge as a result of the growing comprehensive disorder transfer towards outside[13]. This happens in correspondence to bifurcations and is mirrored by sudden changes of direction. As shown by Prigogine, such instabilities occur only in open systems that act in condition far from equilibrium, or in other words, only within the "dissipative structures". What happens after these critical points in terms of evolution in direction strongly depends on the previous history of the system, or in other words, on the path followed to reach the point of instability (Capra, 2001). Further, the dissipative structures show a great susceptibility even to small fluctuations occurring in correspondence to bifurcations. Since such fluctuations are not known a priori and occur by chance, it is not possible to foresee the path followed by the system (Capra, 2001). The emergence of new structures and new forms of behaviour, resulting by synergic effects of non-equilibrium,

[10] The term was coined by himself to stress the coexistence of both change and stability

[11] Moving from Math to Physic, this same process is expressed by the "feedback loop" concept (Capra, 2001).

[12] The points of bifurcations, and more specifically, their topology, will be later taken into account by the mathematician Thom (1972), author of the "Theory of Catastrophes" where catastrophe is used in place of point of bifurcations.

[13] Hence, whereas the energy dissipation was linked to an idea of "loss" by the perspective of the classic thermodynamic, the introduction of the "dissipative structures" has allowed to interpret this same dissipation as a source of order.

irreversibility, feedback loop and instability, represents the higher expression of what is called self-organization within the Complexity theory (Capra, 2001).

With respect to complex adaptive systems, the term self-organization refers to "agents interacting locally according to their own principles or intentions in the absence of an overall blueprint of the system" (Stacey et al., 2000). Adaptive systems do not just passively respond to events; they actively try to turn whatever happens to their advantage (Waldrop, 1992). Such an interaction becomes source of further unpredictability and uncertainty. The importance of the uncertainty component has been highlighted in many other typologies of systems as well.

In the socio-institutional field, the political scientist Wildavsky (1985) takes into account two different ways of coping with uncertainty: anticipation and resilience. Whereas "anticipation relies on detecting problems and trying to avoid them[14]" (Handmer and Dovers, 1996) and seeks to preserve stability, "resilience accommodates variability" (Wildavsky, 1988). Extending this line of thought, Dovers and Handmer (1992) adopt resilience as a useful concept for defining responses to ignorance/uncertainty and risk. In detail, the authors single out two typologies of strategies:

- reactive resilience as that one approaching the future by strengthening the status quo and making the present system resistant to change[15];
- proactive resilience as that one accepting the inevitability of change and trying to create a system that is capable of adapting to new conditions and imperatives (Handmer and Dovers, 1996).

As referred by the authors, this meaning for proactive resilience, is quite similar to the resilience advocated by Holling (1973), Wildavsky (1988) and to Conway's (1987) sustainability concept[16] as the ability of the system to maintain productivity following large disturbance. Even Dovers and Handmer (1992) provide their own definition for sustainability in terms of responses to change: "sustainability is the ability of a human, natural or mixed system to withstand or adapt to endogenous or exogenous change indefinitely". Hence following a comparison of their definitions, a tight connection emerges between the concept of sustainability and the proactive resilience one.

As observed by Common and Perrings (1992), the relevance of the concept resilience for sustainable development was on the table in the economic field since the late 1970s. Moreover, these authors state that a necessary condition for sustainability is that current economic activities should not result in the loss of system resilience; in such a way, they strongly link resilience and sustainability. Levin et al. (1998), quoted by Perrings (2006), refer to resilience as the preferred way to think about sustainability in social as well as in natural systems. Folke et al., (2005) state that the major challenges for research on sustainability is how to stimulate the emergence of multilevel and adaptive management systems that can secure the capacity to

[14] The anticipation approach implies a deterministic vision; in fact as referred by Handmer and Dovers (1996), "implicit in this approach is the belief that a very low level of ignorance is achievable: Ignorance can be identified, then reduced or eliminated".
[15] such terms, reactive resilience can be seen as a quest for constancy and stability.
[16] Conway's definition has been developed in the context of agricultural system.

sustain the ecosystem services[17]. Hence, as resilience represents also the degree to which the system can build and increase the capacity for adaptation (Carpenter, 2001) it is not surprising that Folke et al. (1998) pinpoint ecologically adapted management practices and social mechanisms for both resilience and sustainability.

Many of the mentioned authors (Perrings, Folke, Hanna and Levin), devoted to interdisciplinary studies grounding on sustainability, in collaboration with the Beijer Institute and University of Florida[18], give life to the Resilience Network. It was a research program that later developed into the Resilience Alliance, a consortium of research groups and research institutes from many disciplines who collaborate to explore the dynamics of social-ecological systems. The most important insights of resilience and sustainability in SES have been synthesized by Resilience Alliance in a report entitled "Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformation[19]" (Folke et al., 2002), in which resilience and adaptive capacity are described as key properties for sustainability. Moreover, some policy recommendations based on the role of resilience in the context of sustainable development are suggested in the report. These recommendations are essentially targeted to:

- the implementation of frameworks addressing building adaptive capacity;
- the creation of action platforms for adaptive management processes and flexible multi-level governance;
- the generation of knowledge and cope with change in such a way to create a diversity for management options of significance for responding to uncertainty and surprise;
- the development of indicators of gradual change and early warning signals of loss of resilience and possible threshold effects;
- the management of diversity for insurance to cope with uncertainties and the implementation of structured scenarios and active adaptive management processes[20].

In such a way, the policies recommended by Resilience Alliance greatly emphasize, through Resilience thinking, concepts as ecological thresholds, uncertainties and surprise. Even the sustainability debate is permeated by uncertainty, so that the precautionary principle appears as an official recognition of pervasive uncertainty in some statutory law and is the reason for many major sustainability policies although it is vague, inoperative by itself and open to wide interpretation (Handmer and Dovers, 1996). In line with the above comments, Adger (2003) asserts that "the unfocussed aspirations for sustainability are captured in the notion of resilience" and recognizes that "the message of resilience is more radical for policy-makers

[17] Ecosystems are seen essentially as ecological services providers.
[18] Holling was directly involved in this initiative as Professor of University of Florida.
[19] The report is sustainability-oriented in that it has been ordered by the Environmental Advisory Council of the Swedish Government for the forthcoming World Summit on Sustainable Development (WSSD) and published in ICSU series on Sustainable Development.
[20] It is worth noting that in the above mentioned report, Folke et al.(2002) present resilience exclusively in its positive acceptation by neglecting to consider that a system showing resilience is not always representative of desirable conditions (The concept is more precisely expressed through the model of basin of attractions). By this perspective, one year before the report, Carpenter (2001) stated: “Unlike sustainability, resilience can be desirable or undesirable. For example, system states that decrease social welfare, such as polluted water supplies or dictatorships, can be highly resilient. In contrast, sustainability is an overarching goal that includes assumptions or preferences about which system states are desirable.

than that of sustainability". In such a way he attributes a more operational and pragmatic meaning to resilience with respect to sustainability.

In the field of sustainability some attempts have been devoted to define operational indicators as well. By this perspective it is worth noting how they often match with resilience indicators. As an example, Dalsgaard et al. (1995) recognize "diversity, cycling, stability and capacity[21] as crucial system properties with respect to sustainability assessment of local agro-ecosystems.

Finally, it is useful to give a glance to the objectives of sustainable development[22] according to Gallopin (2003): "sustainable development must aim not only to preserve and maintain the ecological base for development and habitability, but also to increase the social and ecological capacity to cope with change, and the ability to retain and enlarge the available options to face a natural and social word in permanent transformation". If one replaces "ecological base" with "structure/state" and bears in mind that capacity to cope with change is an intrinsic aspect of resilience, the achieved conclusion is that getting resilience is a main goal of the sustainable development policies. Such consideration appears as fully complementary to Resilience Alliance point of view, according to which building resilience is a medium towards sustainability. Fiksel (2006), in a paper devoted to the two issues, supports the last thesis and states that "the sustainability of living systems, including humans, within the changing Earth system will depend on their resilience" and that "achieving sustainability will arguably require the development of resilient, adaptive industrial and societal systems that mirror the dynamic attributes of ecological systems".

To sum up, there is no doubt that the two concepts are closely related so that one becomes premise for the other with roles appearing often as interchangeable.

3 Resilience into the disaster field

This paragraph explains the main reasons leading to the adoption of the Resilience concept into the disaster field and broadly justified by the opportunities that resilience provides for dealing with concepts like non-linearity, change, surprise and cross-scale effects which are very relevant within the disaster field.

As previously highlighted, the main cultural source from which a technical meaning of the concept stems has been Ecology. The ecological and the disaster field have been put in parallel by some authors interested in the wide discussion on sustainability. Within this discussion, the need for integration of issues concerning all aspects of both natural and human systems was a main topic. First among them, Handmer e Dovers (1996) state that "it would make sense to look at ecology and disasters research" due to the fact that they represent "two areas of

[21] In this context, capacity refers to the quality of soil and water resource base and its ability to produce and sustain biomass (Dalsgaard et al., 1995)

[22] Gallopin (2003) stresses also the difference between sustainability and sustainable development "The concept of sustainable development is quite different from that of sustainability in that the word "development" clearly points to the idea of change, of directional and progressive change.

human experience where change and the interaction of human and natural systems have been addressed before". The authors argue that "it is proposed as axiomatic that managing ecological change (pursuing sustainability) and coping with hazards and disasters should share some common problems and features. Fundamental to both is the need to cope with pervasive risk and uncertainty" and, in this respect, the attribute of resilience, understood as "ability to operate in the face of this uncertainty", is required. According to the authors, the disaster field and the ecological one are similar also due to the fact that they share the "attention paid to systems approach[23] to the problems". In such a way they can further take into account the complexity of systems.

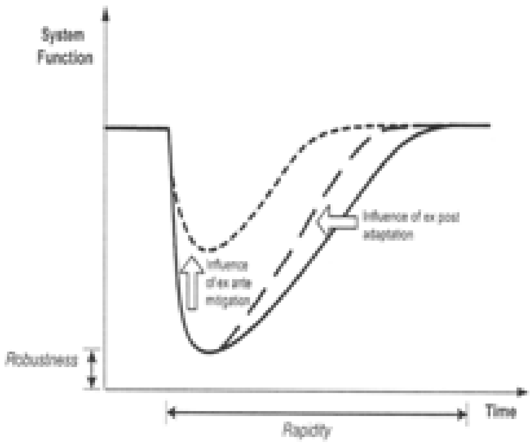
As previously shown, one of the findings of the complexity theory has been the recognition of self-organization as a characteristic of complex dynamic networks[24] (Kauffmann, 1993). The first application of the Complexity theory in the field of disaster has just focussed on this topic. In fact, Comfort (1994) assumes self-organization as a fundamental aspect of investigation within the analysis of a disaster response system: "disaster serves as a mechanism of transition in complex, social systems that can be either be used to redesign the system's structure and performance to fit more appropriately the vulnerabilities of its environment, or unattended, creates the conditions for more serious or costly disruption at a later time". Comfort (1994) defines the self-organization as "a spontaneous reallocation of energy and action in response to changes in the operating environment". Such definition is quite similar to the "capacity to adapt existing resources and skills to new situations and operating conditions" to which Wildavsky (1988) has referred to as resilience. Hence, resilience can be interpreted as a sort of indicator for the self-organization level of the social system. In line with this conclusion, even if starting from different premises, the Resilience Alliance put "the degree to which the system is capable of self-organisation" as a dimension of resilience. The self-organization property emerges at the occurrence of a disturbance. According to Gallopin (2003), "all living systems are exposed to unavoidable stresses and disturbances as a consequence of their being an open system". Such disturbances can push the system across given thresholds and shift the system from one stable state to another, that is in line with Holling's school of thought. As resilience declines, the amount of disturbance needed to cross the threshold declines (Walker and Meyers, 2004).

With reference to the disaster field, natural and technological hazards can be considered particular typologies of disturbances (or perturbations) and as consequence, they can affect the system, causing shifts from one equilibrium state to another one. They can induce non-linear response in that responses are not linked to the typology of the disturbance by a cause-effect relationship. The non-linearity of these relationships is also the most characteristic aspect of their complexity. Non-linearity entails the coexistence of more than one outcome and a related significant susceptibility depending on the initial conditions of the system. Shifting on the disaster field, Comfort (1999) refers that "vulnerable communities demonstrates a sensitive dependency upon initial conditions. That is, the capacity of a community to mobilize collective action in response to perceived risk depends directly upon the degree of awareness, level of skills, access to resources, and commitment to informed action among its members prior to the occurrence of a damaging event". "Reconstruction" is not even sufficient in terms of response

[23] The system approach implies recognising that "any defined system will also be a subsystem" and that "dynamic interdependency" exists among the elements of the systems. (Handmer and Dovers, 1996).
[24] Complex networks are referred to as "adaptive" or "dynamic", because they are constantly changing their interrelationships based upon the needs of individual agents and environmental impacts.

to an event as reported by one of the axioms of resilience presented by Vale and Campanella (2005). In fact, the authors affirm that "the process of building is a necessary but, by itself, insufficient condition for enabling recovery and resilience" as "cities are more than the sum of their buildings. They are also thick concatenations of social and cultural matter, and it is often this that endows a place with its defining essence and identity" (Campanella, 2006).

Figure 5: Influence of ex-ante mitigation on the performance of a system after a disaster (McDaniels et al., 2008)



With respect to a disaster, even mitigation actions have to be taken into account as part of the initial conditions framework. As shown in fig. 5, by a performance perspective[25], the extent of robustness, adopted as a performance dimension, which is lost by a system following a given event, strongly depends on the ex-ante mitigation programme[26].

A hazard, seen as a perturbation inducing change, represents a point of bifurcation in correspondence of which, different trajectories of the system can result. The scarce forecasting capacity for such trajectories represents an important source of uncertainty because it doesn't allow to apply actions of control on the post-event conditions of the system due to the fact that they are not known. In this respect, as suggested by Pelanda (1981), what makes "abnormal" an event or, in other words, what places an event out of its range of normal variability, is not only its rarity in terms of frequency but, overall, the lack of control, by both a cultural and technological perspective, on its effects. By this point of view, the resilience perspective appears as a strategy for a shift from those policies that aspire to control change in systems assumed to be stable, to those managing the capacity of (socio-ecological) systems to cope with, adapt to, and shape change (Folke, 2006). Hence, it can be deduced that even if "the last goal of a system remains control" as stated by Comfort (1999), a strategy based on such aim is not adequate to cope with uncertainty; on the contrary the resilience approach fits in this purpose as it assumes uncertainty as one of its main premises (Folke, 2006; Berkes, 2007).

[25] This approach is widely developed in next paragraph.

[26] By this perspective, del. 2.1.2 has highlighted how planning activities serving risk mitigation objectives are the main drivers of change into the structures of vulnerability relationships, hierarchies and distribution in pre-disaster terms.

Another useful concept that can be permutated from the ecological to the disaster field, refers to the cross-scale effects embodied in the concept of panarchy (see annex 1). In this respect, Walker et al. (2004) argue that some loss of resilience, at some scales, is an inevitable feature of the cross-scale dynamics in complex adaptive systems. Transferred to disasters, this concept reminds to the fact that an event occurring in a given place can have consequences that spread over areas even quite far from the place of the occurrence. This fact entails the need for thinking in terms of interactions within systems at both spatial and temporal different scales. The concept of panarchy includes also another idea allowing a further analogy with the field of disasters, that is "the creative destruction". The term was coined in 1942 by the economist Shumpter to refer to a phenomenon in which bankruptcies eliminates inefficient enterprises, freeing up resources for a more efficient use. Holling (2001) uses the term with regard to "a phase of rapid reorganization during which novel recombinations can unexpectedly seed experiments that lead to innovations in the next cycle"[27]. Such rapid reorganization is requested also in the immediate aftermath of a large disaster and can be coupled with what is better known as the "window of opportunity" period. In fact, in this phase, the political attention and social pressure tend to reach their maxima and the greatest investments are made (Bosher, 2008). This period is also recognized as the time in which something like three quarters of all legislation relevant to disasters is passed. In this respect, for example, just few months after the Sarno mudflows in which more than 150 people were killed, a law decree (180/98 turn into law with L. 267/98) passed to ensure the assessment of landslide risk of all the country's 20 regions; furthermore, investments in landslide risk investigation followed the legislation[28]. Christoplos (2006) carried out a detailed analysis on factors both contributing and contrasting the effectiveness of this "window of opportunity".

Shifting on a practical ground, an example about a bad management of a disaster aftermath is represented by the Mexico city earthquake case (del. 2.1.2). In fact, administration and decision makers managed the recovery phase in such a way to lead to an unfair distribution and redistribution of means and hence, to interpret resilience according to a "speculative" perspective that is clearly in contrast with the positive meaning generally associated with the term. It is worth reporting also what happened after the 1998 earthquake Mitch. The "temporary housing built after hurricane Mitch in 1998 had become permanent by 2001, simply because no other housing alternatives had been offered. Because these houses had been built as temporary shelter, they were not adapted to the seismic conditions in Central America, and collapsed during the 2001 earthquake" (Wisner, 2001). Within this experience, a clear waste of the "window of opportunity" emerges due to:

- a lack of integration of measures towards different typologies of disturbance/hazards;
- a disregarding of temporal scale effects.

Indeed, adopting a resilience thinking to face the emergency phase should have provided a contribution in this regard, since, at least as it is conceived in Ecology, it emphasizes the cross-

[27] Such aspect is in line with what stated as a conclusion of Del. 2.1.2: "Resilience, especially in the relief/recovery period, is a catalyst for vulnerability change, transfer and transformation".

[28] Bosher (2008) by arguing that "this is one example of a more or less universal process in which change is achieved largely after the event, rather than before it", denounce the lack of policies grounded on prevention actions.

scale relationships and suggests to examine the effects of a given measure, implemented with respect to a specific perturbation, in the light of other typologies of perturbations.

To sum up, the presented remarks corroborate the assumption according to which thinking in terms of resilience can be advantageous in the field of disasters due to the following aspects:

- resilience is conceived as a conceptual approach to deal with uncertainty and future change with respect to traditional approaches mainly focused on system's control;
- resilience represents a premise for a proactive response to disasters as it embodies the concept of adaptive and learning capacity, that is typical of living systems;
- resilience gives room to the emergence of new configurations of the system (even more desirable than the previous ones) after a disturbance, as a result of the self-organization capacity that is typical of complex systems;
- resilience paves the way to recognize the role of the initial condition of a system in its evolution pattern following the occurrence of a given event. In such a way, there is an implicit assumption of the importance of effective mitigation measures towards more or less likely hazards;
- resilience exalts the cross scale effects related to a given event. Such aspect assumes particular relevance with respect to chained events such as the na-tech disasters that probably represent the most significant example of events whose evolution is characterized by non-linear dynamics.

4 The dimensions of Resilience

The previous insights on resilience have highlighted as the concept is largely oriented to implement policies of coping with a wide spectrum of shocks as sources of change and uncertainty, and to provide useful suggestions for increasing capabilities of self-organization, and preserving and improving capacity for learning and adaptation.

Nevertheless, up to now due to the heterogeneity of approaches and aims and to the different disciplinary perspectives, both the definitions of resilience and of its main components or dimensions are very heterogeneous so that Rose (2007) stated that "resilience is in danger of becoming a vacuous buzzword from overuse and ambiguity". Therefore, in this paragraph, the main studies focused on resilience have been analyzed, in order to provide an overview of the main research findings on this topic.

In detail, the main performance dimensions having a reverberating effect on resilience, as reported by current scientific literature, have been collected in table 2 according to different typologies of systems. Once again, the ecological field and its extension into the socio-ecological domain offer fundamental remarks for singling out such characteristics. The researches related to this field are namely the one of Folke et al.(2002) that represents a synthesis of Resilience Alliance thinking and the one of Walker et al.(2004). Fiksel (2003) faces the problem by a clear system perspective grounding on the opportunity of designing industrial product and service systems; in detail he couples the aspects of resilience with those referring to sustainable development. Godshalk (2003) deepens the problem by a planning perspective, stating that "since hazard planners must cope with uncertainties, it is necessary to design cities that can cope effectively with contingencies". The author, starting from previous researches on the topic, gathers some resilience principles fitting cities systems with respect to the threat of natural hazards and terrorism. Another contribution developed with reference to urban system is provided by Chuvarajan et al. (2006) that investigate how improving municipal resilience can be a strategy to reach sustainability and proposes implementable measures to improve both resilience and sustainability. Some diagrams for barriers and supporting factors of resilience are reported in the appendix of the work. Maguire and Hagan (2007) recognized resistance, recovery and resilience as the three properties characterizing a resilient community. In fact, in an ongoing process, a resilient community predicts and anticipates disasters; absorbs, responds and recovers from the shock; and improvises and innovates in response to disasters. The economic perspective is represented by the contributions of Van der Veen (2005) and Briguglio et al. (2008). Van der Veen introduces redundancy, with respect to an analysis of vulnerability to flooding, in terms of "ability to respond to a disruption" and, as a consequence, with a clear reference to resilience. Briguglio et al. (2008) propose a generic economic resilience index built on four variables: macroeconomic stability, microeconomic market efficiency, good governance and social development. The concepts of efficiency, rapidity and flexibility act as background to all the dissertation.

Some researchers of MCEER[29] provide a relevant contribution, presented in Bruneau et al. (2003), on the dimensions of resilience. In detail, they carried out the R4 model (robustness, rapidity, redundancy, resourcefulness) which refers to the resilience of social system in face to earthquakes. The authors define community seismic resilience as the ability of social units (e.g. organizations, communities) to mitigate hazards, to contain the effects of disasters when they occur, and to carry out recovery activities in ways that minimize social disruptions and mitigate the effects of future earthquakes. Seismic resilience can be achieved by enhancing the ability of a community's infrastructures to perform during and after an earthquake (lifelines, structures) as well as through emergency response that effectively cope with and contains losses and recovery strategies that enable communities to return to levels of predisaster functioning (or other acceptable level) as rapidly as possible. In addition to the aforementioned properties of resilience, the framework of Bruneau et al. (2003) includes the following "dimensions" (but according to our perspective, it should be better defining them as "domains") of community resilience: technical, organizational, social and economic.

These domains constitute the TOSE framework whereas:

- the Technical one refers primarily to the physical properties of systems, including the ability to resist damage and loss of function and to fail gracefully. The technical domain also includes the physical components that add redundancy (Tierney and Bruneau, 2007);
- the Organizational one refers to the capacity of organizations that manage critical facilities and have the responsibility for carrying out critical disaster-related functions to

[29] Multidisciplinary Center for Earthquake Engineering Research.

make decisions and take actions that contribute to achieve the properties of resilience, namely robustness, redundancy, resourcefulness and rapidity (Bruneau et al., 2003);

- the Social one encompasses population and community characteristics that render social groups either more vulnerable or more adaptable to hazards and disasters. Social vulnerability indicators include poverty, low levels of education, linguistic isolation, and a lack of access to resources for protective action, such as evacuation (Tierney and Bruneau, 2007);
- the Economic one refers to the capacity to reduce both direct and indirect economic losses resulting from earthquakes (Bruneau et al., 2003).

According to Tierney and Bruneau (2007), the TOSE framework emphasizes a holistic approach to community and societal resilience, looking beyond physical and organizational systems to the impact of the disruptions on social and economic systems. The MCEER's research has been used as a benchmark for practitioners more than once. Chang and Shinozuka (2004) refine Bruneau's approach by reframing the measure in a probabilistic context. Davis (2005) explores the concept of resilience before, during and after disaster impact and presents various case studies to indicate how resilience operates or fails to occur and why. Tierney and Bruneau (2007) reaffirm the validity of the R4 approach for highlighting the multiple path to resilience. Within the MCEER's framework, UNESCAP[30] (2008) takes into account only the robustness, redundancy and resourcefulness dimensions. In fact, rapidity is excluded due to the fact it depends also on the degree of shocks experienced. The UNESCAP report examines resilience coupled with resource efficiency as key factors for strengthening efforts to improve the sustainability of economic growth, with a specific focus on Asia and the Pacific in a risky development context.

Table 2: Potential framework for a Resilience index (UNESCAP, 2008)

	Robustness	Redundancy	Resourcefulness
Economic resilience			
Ecological resilience			
Social resilience			

A potential framework (table 2) for a resilience index is suggested in the report with respect to different domains. (economic, ecological and social).

Finally, McDaniels et al. (2008), with a specific reference to infrastructures systems, develop a conceptual framework for understanding the factors that influence resilience with respect exclusively to robustness and rapidity. Furthermore, the author presents some flow diagrams

[30] United Nations Economic and Social Commission for Asia and the Pacific

for understanding kinds of decisions that can be pursued within infrastructure systems to foster these two dimensions of resilience.

5 Turning resilience into operational terms

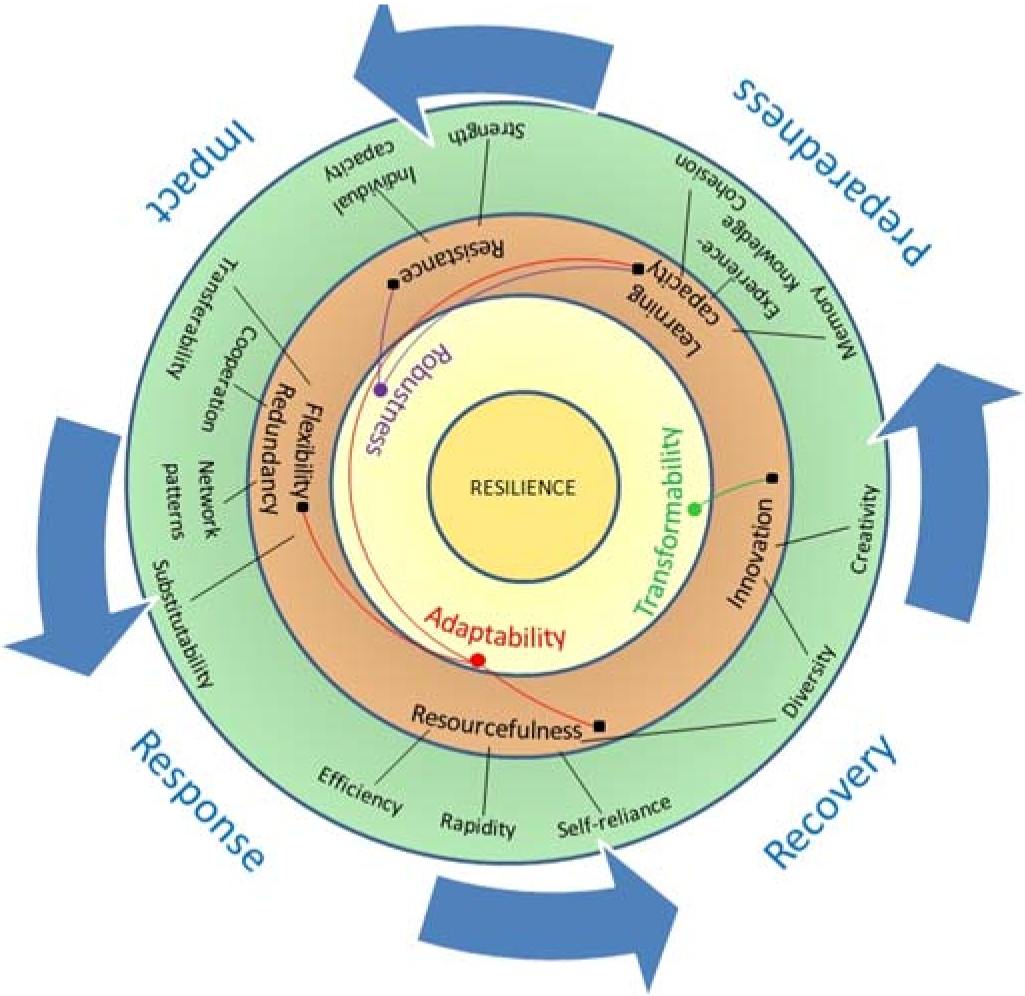
Resilience is often invoked in concomitance of sudden shocks without considering that an erosion of resilience across time and space is a gradual and probably unconscious process. This threat has been underscored by Folke et al. (1996) with respect to ecosystems that "fails to signal" the long-term consequences of loss of resilience, continuing to function in the short term even though resilience declines. Hence, the need for the availability of a set of parameters emerges in order to monitor resilience across time and different spatial scales and also to control the effectiveness of risk reduction efforts (Chang and Shinozuka, 2004). On the opposite, what is currently missing are operational tools to assess resilience.

Hence, in this paragraph two different approaches for turning resilience into operational terms will be provided. A first one, refers to the Bruneau's model which represents a first attempt for measuring quantitatively some of the resilience dimensions sketched above. A second one, based on the main dimensions of resilience reported in table 2, is addressed to identify a framework of the key performance dimensions of resilience. Such a framework should be useful for both driving suitable policies towards an increase of resilience and providing insights on the extent to which current mitigation measures - generally aimed at reducing hazards, exposure and vulnerabilities - effectively contribute to enhancing resilience.

5.1 The key dimensions to enhance resilience

In this paragraph, a first attempt to provide a logical plot of the main dimensions of resilience as they have been gathered from scientific literature is presented. Some dimensions, being very similar to or included in other dimensions, have been neglected, (e.g. cooperation and collaboration are very similar; self-reliance includes also autonomy) whereas others have been synthesized in a single concept (e.g. networks and spatial patterns have been synthesized in the dimension "network patterns", due to the fact that networks, among the different types of spatial and organizational patterns such as hierarchical or mono-centric ones, are those that guarantee a higher flexibility). It is worth noting that the selected dimensions are very heterogeneous, in that some of them represent very wide and general concepts related for example to different meanings of the resilience itself, others are more specifically related to the abilities or features of a system which can be improved or strengthen to enhance resilience. Moreover, the different dimensions gain prominence in different phases of the disaster cycle: some of them are very relevant in face to the impact, others come on stage in the long term.

Figure 8: The key dimensions of resilience in the disaster cycle



According to such considerations, the key dimensions of resilience have been arranged into a circular scheme, following the main phases of the disaster cycle: impact-response-recovery-preparedness. Moreover, within the circular scheme, the dimensions have been sorted into concentric circles that, starting from the most internal one in which resilience has been placed, drive toward a progressive specification of the resilience concept.

In detail, the most inner circle includes resilience; the second one represents the three main components or aspects of resilience itself that have been presented up to now: robustness, adaptability and transformability which can be interpreted as the main goals to achieve in relation to the different phases of the disaster cycle in order to enhance the resilience of a system; the third circle includes the key dimensions which have to be preserved and strengthen in order to enhance the three main components of resilience (robustness, adaptability, transformability); finally, the most external circle includes those dimensions, strictly related to the previous ones, that can be modified through specific policies in order to positively contribute to enhance resilience in all its components.

The previous discussion on resilience has highlighted an evolution of the concept from a meaning fairly close to the ability of elements or systems to withstand a given level of stress or demand without suffering losses or failures (robustness), to a capacity to adapt in face of the consequences (in terms of losses or failures) due to a hazardous event (adaptability) and, finally, to the possibility to turn the disaster into an opportunity by creating different conditions, sometimes more desirable, in respect to the pre-impact configuration (transformability). The three mentioned dimensions can be considered the main components of resilience; hence, they are not linked in the scheme since they can be considered as three sides of a single concept which have to be enhanced to make a system resilient in relation to a wide variety of external stresses. The three selected components clearly explain that resilience is different from being only the converse or the flip-side of vulnerability due to the fact it includes the opportunity for change and transformation that goes far beyond the assumptions of vulnerability. In other terms, looking at resilience as the flip-side of vulnerability, a primary role only to a single aspect and namely to the Robustness one is assigned. The latter is indeed strictly related to the maintenance of an equilibrium state (Carlson and Doyle, 2002) and is also identified with a structural stability concept (Tu, 1994). In this respect, only robustness can be interpreted as the "flip side of vulnerability" as already suggested by Gallopin (2006).

The three main components of resilience gain relevance in different stages of the disaster cycle. In detail, the robustness of a system arises during the impact "time"; a system can resist to the impact without showing any mark of weakening or at least showing a gap from its ordinary structural or functioning conditions that is temporary, depending on the duration of the disturbance. Adaptability is more relevant in the immediate aftermath of the impact, including the emergency phase; it can be defined as a "transition" phase, which can be referred to the short-medium term after the impact (response phase): according to its different levels of adaptability, a system can bounce back to a previous state or shift toward new ones. Finally, in long term and namely during the recovery phase there is room for changing and innovating the systems.

Shifting from the second to the third circle, some of the selected dimensions are strictly related to only one of the components above mentioned, others are very relevant to more than one.

In detail, robustness largely depends on the resistance of an element/system to an impact, that means that the hit element or system will be not damaged, or on the flexibility of the element or system, related to the capacity of quickly bouncing back after the hazardous event (Briguglio et al., 2008).

Resistance has been recognized as an important dimension of resilience by different authors; nevertheless, it represents a positive feature, in that it enhances resilience, when the hazardous event occurs but it can even represents a negative factor during the response or recovery phases. For example, the resistance of an institutional system to adapt or to change in face of an un-expected large size event, due to its rigidity or lack of flexibility, may largely frustrate quick decisions and actions (Menoni, 2001) as in case of Kobe earthquake during the emergency.

Flexibility and resourcefulness have been identified as the two main dimensions on which adaptability depends. Flexibility increases, on one hand, the robustness of the system by limiting the loss of functioning resulting from the impact while, on the other hand, guarantees the adaptive capacity of a system (Godshalk, 2003). In the scheme, flexibility has been associated to redundancy due to the fact that the latter represents the key-feature for increasing flexibility. Resourcefulness has been recognized as a key dimension both in response phase, to improve adaptability, and in the recovery phase, to enhance transformability. The latter is also strictly related to the dimension termed innovation, which represents the ability of a systems to reorganize itself in face of a disturbance. Innovation - arising in long term after the impact of a hazardous event - characterizes the recovery phase.

A key dimension for improving both robustness and adaptability of a system is the learning capacity one. Nevertheless, the latter plays a key role in the phase of preparedness in order to improve resilience for future events.

As mentioned above, each dimension has been linked and specified through other dimensions that are placed in the most external circle.

In detail, resistance has been linked to strength and individual capacity which can be mainly referred to the built environment and to the social domain respectively.

Flexibility and redundancy can be improved through different mechanisms aimed at overcoming dependence. Among such mechanisms it is worth mentioning transferability and substitutability (Van der Veen et al., 2005), largely widespread in relation to economic activities or to infrastructures, and intentional (designed) or spontaneous spatial and organizational network patterns, showing a higher flexibility than the hierarchical or mono-centric ones.

Another relevant dimension to improve flexibility is cooperation among the different actors of the system, especially by an institutional perspective. Cooperation or collaboration is in fact a form of redundancy in that it provides a multiplicity of opportunities that are very useful especially in the immediate aftermath of a disrupting event.

The key dimensions to guarantee or to improve resourcefulness has been recognized in rapidity, viewed by an organizational perspective (e.g. emergency), efficiency, aimed at optimizing the available resources, making a rational use of them and self-reliance, that implies autonomy, satisfaction of needs through local resource, lack of dependency linkages.

Moreover, resourcefulness is largely dependent on diversity too. The latter strongly supports the richness and the variety of available resources, enhancing in such a way resourcefulness. Moreover, it has been largely recognized as crucial to cope with uncertainty and surprise. According to Folke et al. (2002), diversity also provides a mix of components whose history and accumulated experience helps to cope with change, and facilitates redevelopment and innovation following disturbance and crisis. As a consequence diversity is also linked to transformability in that it provides spurs for innovation. The latter is linked to another non tangible resource that is creativity. This dimension gains prominence after the end of the emergency phase and in detail in that period generally defined as “window of opportunity”. Creativity plays an important role also in scenario thinking - due to the fact that less expected events and combinations of effects with a low probability of occurrence could be taken into account - and mitigation measures that involve implementation of the lessons learnt in the creation of new policies and activities that will increase the community’s resilience (Mileti, 1999). Both scenario thinking and design of mitigation measures are typical of the preparedness phase, completing in such a way the disaster cycle.

In this phase, wide room has been devoted to learning capacity which is key to increase both robustness and adaptability. It largely grounds on past experience that constitutes a support for the re-organization of the system requested after a disaster in face of future events. Experience should be spread and become knowledge (e.g. knowledge of events, damages, mitigation measure, good practices, etc.). Furthermore, past experience has to be included into collective memory that is an important dimension addressed not exclusively to adaptation but also to the following step that is transformation. A call to memory is in fact requested also to elaborate novelty solutions even if memory and innovation are apparently in conflict. The success of a learning process is also greatly influenced by the level of cohesion existing within the community. In fact, in case of a good cohesion level, experience is more easily communicated and memory more easily preserved.

Summing up, the plot represents an attempt to integrate different approaches and schools of thought by providing a systematization of the main dimensions enhancing resilience reported in current literature and an interpretation of their role and their mutual influences.

Such an attempt can be considered as a first step towards an operational tool for driving policies addressed to enhance resilience, even though it clearly requires further deepening mainly addressed at outlining qualitative or quantitative indicators for measuring and monitoring the efficacy of the implemented policies.