Integrated Approach to a Resilient City: Associating Social, Environmental and Infrastructure Resilience in its Whole

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Abstract

Rising complexity, numbers and severity of natural and manmade disasters enhance the importance of reducing vulnerability, or on contrary – increasing resilience, of different kind of systems, including those of social, engineering (infrastructure), and environmental (ecological) nature. The goal of this research is to explore urban resilience as an integral system of social, environmental, and engineering resilience. This report analyses the concepts of each kind of resilience and identifies key factors influencing social, ecological, and infrastructure resilience discussing how these factors relate within urban systems. The achievement of resilience of urban and regional systems happens through the interaction of the different elements (social, psychological, physical, structural, and environmental, etc.); therefore, resilient city could be determined by synergy of resilient society, resilient infrastructure and resilient environment of the given area.

Based on literature analysis, the current research provides some insights on conceptual framework for assessment of complex urban systems in terms of resilience. To be able to evaluate resilience and define effective measures for prevention and risk mitigation, and thereby strengthen resilience, we propose to develop an e-platform, joining risk parameters' Monitoring Systems, which feed with data Resiliency Index calculation domain. Both these elements result in Multirisk Platform, which could serve for awareness and shared decision making for resilient people in resilient city.

Keywords: resilience; resilient city; urban system; multirisk platform;

JEL Classification: Q54

1. Introduction

In the recent decades, natural and manmade disasters became more frequent and with more destructive effects. Secondary consequences of natural disasters such as electrical, heating or water supply breakdowns, failures of communication systems indicate vulnerability of modern cities. In the 21^{st} century societies find themselves to be "hostages" of the techno–scientific progress, as the progress made by the post–modern world not only induces growth of the existent risks but also generates local and globally–expanding hazards that have never been known before. Consequently, the society aimed at social welfare becomes a risk society. These changes force policy–makers and scientists from all over the world to dedicate more attention not only to issues of ensuring safety, but also to taking up the challenges generated by the continuously changing forms of safety and security.

More than two decades ago, one of the leading sociologists in disaster research field E. L. Quarantelli (1991) identified several disaster development trends:

- Emerging and developing new technologies, which were not recognized in the past, could cause potentially dangerous events, i.e. breakdowns in communication systems, and application of biotechnologies for destructive purposes. Such events likely to transform to technological crises and disasters, are as follows:
- Technological progress in some cases could diminish some threats. However, sophisticated technologies could introduce complexity when fighting old threats, which are left behind;
- Old threats are gaining new conformations, rising number of complex and synergetic disasters. Such events cause increasingly severe consequences crosscutting geographical boundaries;
- Hazardous events increase in both in terms of extending and destructive effects, more various populations suffer from disaster consequences;
- Rising variety and complexity of urban systems causes emergence of new threats and aggravates conditions of fighting against old threats.

Statistics on disaster consequences over the last decades proved the truth of E.L. Quarantelli’s (1991) predictions. Therefore, researchers from different fields continue to resolve broad scientific problems of how unpredictability and complexity of potentially hazardous situations be mitigated and public safety increased under conditions of a risk society. An important part of solution of this problem is associated with the need to analyse and assess what factors determine vulnerability (or resilience) of different human, environmental, engineering and mixed systems. Urban systems are the complex ones. Consequently, they encompass and synergize vulnerabilities and strengths of every single system mentioned above.

The ever increasing urbanization and industrialization processes substantiate the topicality of research on resilience of cities. In urbanized territories industry “with its accompanying new kinds of technology is spreading everywhere” quantitatively increasing and qualitatively worsening the disasters of the 21st Century (Quarantelli, 1992).

Corresponding topicalities discussed above, with our study we are driven to contribute to resilience research approaching urban resilience as an integral system of social, environmental, and engineering resilience. To achieve this goal we focus on:

- Analysis of concepts of each kind of resilience;
- Identification of key factors influencing social, environmental, and engineering resilience;
- Discussion on how these factors relate with urban systems;
- Insights on conceptual framework for assessment of complex urban systems in terms of resilience: development of a tool joining risk parameters Monitoring Systems, Resiliency Index resulting in Multirisk Platform.

The concept of resilience has only recently been extended to the disciplines related to environmental and urban risks. It has been mainly used in the post-event, in support of early intervention strategies. It is now very important to extend the concept of Resilience to the prevention phase, through the definition of a “Resiliency Index”, which is an integral part of the Risk Plan to help define the Risk Mitigation Plan.

The research methodology encompasses theoretical methods such as literature analysis, logical analysis and synthesis and conceptual modelling. For further researches, we project the design of the index of resilient city and testing of its components.

2. Revealing the complexity of resilience concepts

The concept of resilience is multi-level, multi-disciplinary, multi-structural, and multi-focus. The multi-level diversity could be expressed by attribution of resilience to diverse social levels: individual, family of group, organization, community, and global society. The multi-disciplinary characteristics of the term of resilience mean that this phenomenon is being researched from different perspectives: psychology, sociology, risk, crisis and disaster management, urban planning, engineering etc. The multi-structural diversity explains that resilience could be attributed to different types of structures: social, organizational, physical, ecological, complex etc. The multi-focus diversity illustrate a wide variety of goals, which achievement incorporates resilience building: focus on preservation of ecosystems, energy, air, water etc., focus on preservation of cultural heritage, focus on people's psychological resilience, focus on saving human lives, property and environment during disasters etc. In such complexity of conceptualization of resilience, we measure our analysis of theoretical interpretations of resilience to research of social resilience (at different levels), urban systems related infrastructure resilience, and environment (ecological systems) resilience.

2.1. Concepts of social resilience

The concepts of social resilience focuses on the resilience at different levels starting from the individual level, continuing with group/family, organization/institution, community, and finishing with the level of society as a whole. Feeling of safety is among the most essential primary human needs on which the quality of life depends. Therefore, social resilience primarily is discussed from the perspective of psychology.

Research on psychological resilience is augmenting over the past two decades. Psychology researchers have proposed numerous definitions, and notions of psychological resilience that vary depending on the context within which the research was conducted and researcher's conceptual perspective (Fletcher and Sarkar, 2013). M. Rutter (1987, p. 316) defines psychological resilience as “protective factors which modify, ameliorate or alter a person's response to some environmental hazard that predisposes to a maladaptive outcome”. Other definitions include factors of hazard development (before, during, and/ or after some potentially or actually harmful event). Such examples are resilience notions of H. H. Lee and J. A. Cranford (2008, p. 213), that “the capacity of individuals to cope successfully with significant change, adversity or risk”, and definition proposed by B. Leipold and W. Greve (2009, p. 41) stating that “an individual's stability or quick recovery (or even growth) under significant adverse conditions”. As our research is being performed within the area of disaster management, introduction of aspects of harmful event development phases (pre-, during, post- event) into definition of resilience is a substantial matter.

As mentioned above, psychological resilience is orientated not only to individuals, but expands to family/group, organization and community levels. However, diverse elements determining resilience are specific at each level. *Individual psychological resilience* encompass such aspects as perseverance, balance and harmony, self-reliance, capacity of stress control, confidence, sense of community, communication, positive emotions and thinking, problem solving, support systems etc. (em-BRACE, 2012, see Figure 1). These factors act as mechanisms enhancing or limiting personal resilience.

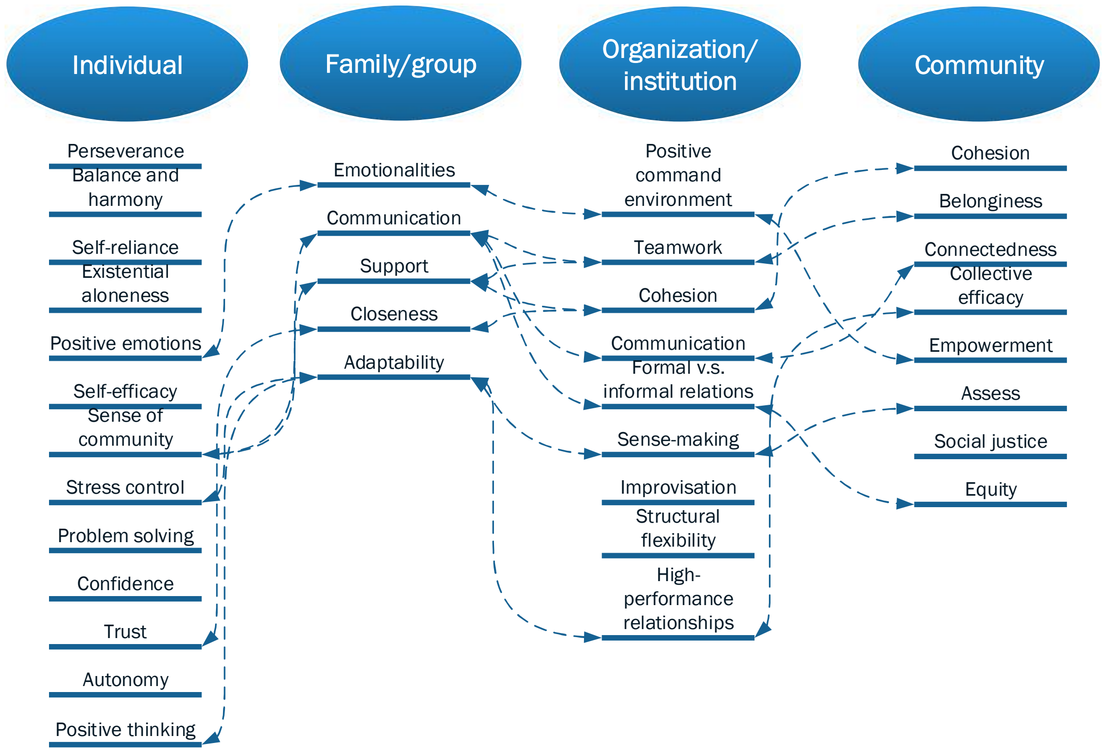
Conceptualizing social resilience, as an important consideration of the interaction between people and their environments takes place (Waller, 2001) from the perspective of meta-model of stress, emotions, and performance (Fletcher, Hanton and Mellalieu, 2006; Fletcher and Scott, 2010), the overcoming of negative effects of risk trajectories, amplification of protective factors and recovery of emotional well-being (Ong *et al*, 2006) highly depend on the closest social environment as an individual operates in. Processes of "perception, appraisal and coping, as a consequence, result in positive or negative responses, feeling of mental states, and outcomes" are mediators in stressful situations (Fletcher and Sarkar, 2013). Therefore, such characteristics of individual resilience as positive affect (Schaubroeck, Ganster, and Fox, 1992), self-esteem (Ganster and Schaubroeck, 1995), self-efficacy (Schaubroeck and Merritt, 1997) are moderated at family, group or organization level.

Protective factors at *family or group level* include, but are not limited to emotionality, communication, support, closeness and adaptability (em-BRACE, 2012, see Figure 1). Therefore, developed mechanisms to achieve resilience at this level influence psychological resilience in terms of choice of a vital and authentic life (Wagnild, 2010), increasing resistance against stress and recovery afterwards (Bonanno *et al*, 2006; Fergus and Zimmerman, 2005).

Organizational and institutional resilience behaves as factor to overcome, resist against and recovery after disturbances rising from any unexpected potential harmful event disrupting routines as well as everyday risks, stress and strain (Vogus and Sutcliffe, 2007). Building of organizational resilience aims at "positive adjustment under challenging conditions such that the organization emerges from those conditions strengthened and more resourceful" (Vogus and Sutcliffe, 2007). M. Linnenluecke with colleagues (2012) argue, that organizational resilience is determined by the capacity to unfold rapidly unexpected events and to persist external disturbances; to respond in rapid and/or non-routine manner to such events and to absorb extreme change; and to recover from impacts of events. Mechanisms to achieve resilience include but not limited to sense-making, mistake orientation, organization architectures (centralized vs. decentralization), structural flexibility, redundancy, high-performance relationships, mix-institutional approaches (formal & informal) etc. (em-BRACE, 2012, see Figure 1). The right balance of characteristics of aforementioned determinants could enhance the capacity of an organization to respond to diverse anticipated and unanticipated events that lay outside the range of previous experience, and may require an extension of established routines and procedures (Linnenluecke *et al*, 2012; em-BRACE, 2012).

For our research interest, the most important aspect of social resilience is community resilience. J. Twigg (2009) proposed definition of community resilience as the capacity of a community to "anticipate, minimize and absorb potential stresses or destructive forces through adaptation or resistance; manage or maintain certain basic functions and structures during disastrous events; recover or 'bounce back' after an event". This definition encompasses aspects of disaster management cycle (i.e. before, during and after potentially harmful events), but we continue conceptualization of resilience notion from psychological resilience perspective. From this perspective, as key factors, influencing community resilience, emerge cohesion, connectedness, empowerment, collective efficacy, social justice, assess and other elements (em-BRACE, 2012, see Figure 1). However, even those researchers, who investigate community resilience from the perspective of disaster management process, do not exclude psychology-related resilience dimensions from their focus. Disaster readiness is determined by integration of "network of adaptive capacities (resources with dynamic attributes) to adaptation after a disturbance or adversity", and community resilience is manifested in population "mental and behavioural health, functioning, and quality of life" (Norris *et al*, 2008).

Figure 1. Levels and components of social resilience



Summarizing concepts of social resilience is crucial to insight overlapping of all layers of resilience: individual, group, organization and community. Figure 1 demonstrates how some of the elements of individual psychological resilience transcend to community level of resilience all the way through family/group and organizational levels, and on contrary – community resilience factors mirror at individual level.

2.2. Engineering system (infrastructure)-centered resilience: critical infrastructures and the Resiliency Index definition

Research on people perceptions of different dimensions determining resilience (emBRACE, 2013) revealed that inhabitants of disaster-prone areas identify disaster-resistant buildings and infrastructures as the most important indicators of resilience (15 of possible 16 rating points). Therefore, *infrastructure resilience* is investigated not only by researchers of the geophysics-seismic engineering, safety, contingencies and infrastructures disciplines (e.g. Boin and McConnell, 2007; Bruneau *et al*, 2003; Fritzon *et al*, 2007; Hellström, 2007, and others), but also in some extend intervenes in psychological resilience research area. As T. O'Rourke (2007) states, a resilient engineering system is one that manifests itself as diminishing failure probabilities; reducing consequences from failures (in terms of lives lost, damage, and negative economic and social consequences); shortening time for recovery.

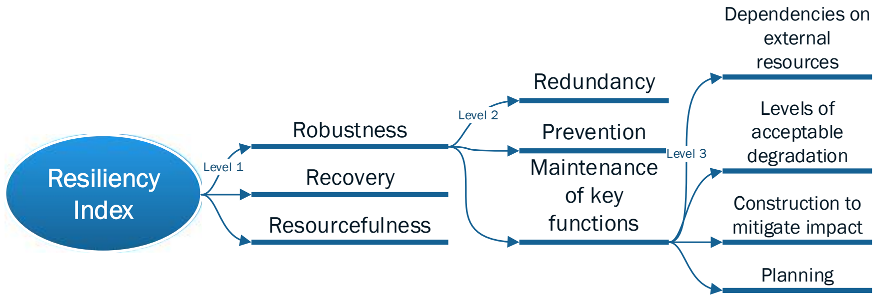
Within safety and security disciplines, the most important assets, systems and networks (physical or virtual) to be preserved against natural and manmade disasters are those, that deemed so vital to the country that their "their incapacitation or destruction would have a debilitating effect on security, national economic security, public health and/or safety" (US Department of Homeland Security, 2010). They are defined as critical infrastructures. This term encompass different sectors, for example: energy, water, transportation systems, food and agriculture, dams, emergency services, healthcare and public health, government facilities, chemical and critical manufacturing, national monuments and icons, commercial facilities, communications and information technology etc. (Fisher and Norman, 2010). When research comes to the question of what are components of resilient infrastructure, scholars and practitioners agree on those: robustness, recovery, resourcefulness. Robustness characterizes the “capability of the system to resist a specific event”, recovery discloses the “capability of the system to recover after a crisis”, and resourcefulness describes “both the current resources (e.g. training and/or planning) developed to support the facility’s robustness and new resources to support the recovery of the system” (Fisher and Norman, 2010).

The notion of resilience of infrastructure is tightly related to notions of infrastructure vulnerability (expresses protective measures of infrastructures) and criticality (assesses the importance of infrastructures), and all three of those frame the notion of risk. The relationship between vulnerability, resilience and criticality, i.e. an overall risk, can be expressed by applying a “bowtie” representation, which integrates fault trees and event trees, which illustrate causes, threat (hazards) and consequences and allows explanation of pre- and post-event elements (Philley, 2006). The “bowtie” model originally was designed for assessment of chemical processes, but it does not allow foresee independences among events of different risk (Shahriar *et al*, 2012). Therefore, for complex infrastructures that are established in multi-risk environment other risk assessment methodologies are developed. One of such tools is Global methodology of risk assessment developed by the US Department of Homeland Security and Argonne National Laboratory to estimate the protective measures, resilience and criticality of facilities. These elements are assessed joining three indexes – Vulnerability index, Criticality index and Resiliency index – in an overall risk index for each critical infrastructure (Fisher and Norman, 2010).

It is important to note, that aforementioned indices (Resilience, Vulnerability and Criticality) in some methodologies encompass Hazard sub-index related to land on which the infrastructure is built, and the Exposure sub-index related to the people living or working in the building (or in the area). While in other methodologies Hazard index and Exposure index could be set as self-contain branches of overall Risk index for complex urban or territorial system.

Resilience notion plays key role in this methodology, as it is determined by preparation, response, and recovery, which characteristics represent overall efficiency and effectiveness of risk management. The key integrated indicators of Resilience Index are those mentioned above (robustness, recovery and resourcefulness) and they represent first level of resilience assessment (see Figure 2).

Figure 2. Fragment of the index of an infrastructure’s resilience within Global methodology of risk assessment (developed according Fisher and Norman, 2010)



For each indicator of Infrastructure Resilience Index of 1st level, indicators of second level are developed, and each indicator from 2nd level splits to more detailed third level indicators. Figure 2 demonstrates the logic of Resilience Index development and a fragment of all three level indicators. Risk index, which includes resiliency, vulnerability and criticality indexes, helps to understand better the relationship between components of critical infrastructures, between critical infrastructures and environment, therefore, allows better preparation to react in case of disaster or any kind of crisis. Because infrastructures evolve over time, application of index has to be a dynamic process in order to be able to capture current state of this evolution. Therefore, assessment of infrastructure resilience applying index calculation technique serves as an important component of resilience monitoring system.

Even the concept of critical infrastructure is a specific well defined area in disaster/crisis management discipline, we put our focus on it because urban settlements include a number (or even all kinds) of critical infrastructures (i.e. water, transportation systems, emergency services, healthcare and public health, commercial facilities, communications and information technology etc.). Therefore, notion of critical infrastructures is implicated in our research on resilient city.

2.3. Environment oriented (ecological) resilience perspective

Ecological resilience is a term closely linked to the concept of environmental sustainability. Growing concerns about global sustainability stimulates research proving that “booming cities present great risks for the future” (Isenhour, 2011). As the 2007 State of the World Report notes, the most powerful word’s resources destructors and polluters are cities, disturbing environment sustainability in direct or indirect manner (UN, 2007). Despite this, urbanization continues exposing duality of its effects on environment. On one hand, cities are assessed as offenders of nature and triggers of climate change. On the other hand, technological progress, breakthrough of environment focused scientific tools and policies, measurement of pollution characteristics in compact living areas and other means concentrate the potential of cities to become bases of sustainability (Yanarella and Levine, 2011). Therefore, even there is determined definition of ecological resilience, we could hardly isolate ecological resilience from social systems as both environment and society are coupled and interact in non-linear manner.

Ecological resilience focuses on capacities of an ecological system to “absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks” (Walker *et al*, 2004). The alike definition could be applied for social-ecological resilience, as the scope of such resilience building is developing a capacity of cross-scale interacting complex system to respond and absorb disturbance, to self-organize, to learn and adapt. A resilient system “can absorb exogenous shocks without changing its basic processes”, while loosing of resilience could result in fundamental changes even from the small-scale disturbances (Witten *et al*, 2011).

Resilience of ecological system, and thereby, its sustainability is influenced by social determinants, i.e. peoples’ sustainable behaviour. Currently evolving trends promoting a “go green” behaviour is conditioned by “thinking green” at an individual level, which expands to “green business” at an organizational level (Go green members program, 2014), further – to “green cities” at an urban community level, and finally – towards “green economy” at an upper social levels (UNEP, 2010). The globally expanding concept of low-carbon, resource efficient and socially inclusive green economy strives at "improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP, 2010). All the "green" concepts are related to the principle of "think globally, act locally". For enhancing resilience and sustainability, it is crucial that environmental issues are percept as being of global trans-boundary nature, but actions to address them need concerted local actions (Collins and Kearins, 2010).

Undoubtedly, ecological resilience interacts not only with social resilience, but with infrastructure/engineering resilience too. In environment and industrial areas recently evolved substantial policies fostering eco-innovations that could boost "resource productivity, efficiency, competitiveness and helps to safeguard the environment" (Eco-innovation action plan, 2011). Relating eco-innovations to our research topic on the development of resilient cities, eco-innovative solutions are topical for "waste treatment, drinking water, sustainable construction materials, and building insulation" **(**Eco-innovation action plan, 2011). Eco-innovative solutions targeting at clean technologies are expected to reduce impacts on ecological system, enhance resilience to environmental stresses, thereby, to contribute to sustainable development.

Generalizing the concepts of social, infrastructure and ecological resilience within the context of sustainable growth, the interlinks between these concepts through eco-actions are apparent. In social system, thinking green expands to green business and fosters striving for green economy. Green economy, which is supported by eco-innovative solutions applied for social, engineering and environmental structures, is expected to result in preservation and more efficient use of resources, and enhanced "capacity to deliver smart, sustainable and inclusive growth" (Eco-innovation action plan, 2011**).**

3. Developing a framework of awareness and shared decision making for resilient people in resilient city

The definition of the urban and regional system Resilience happens through the synthesis of the different elements (social, psychological, physical, structural, and environmental, etc.), which are able to define in a simple and direct way the ability to react to a disaster. For further research we focus on developing a framework for information management through the Multirisk Platform. The main components that we are focusing on is the Resiliency Index (within other risk assessment instruments) and combination of innovative tools (in our framework such tools are monitoring systems and multirisk platform).

3.1. Resiliency Index

The use of a Resiliency Index can greatly simplify a large-scale view of the area, making it easy to compare resilient capabilities of each component, even for non-experts people as administrators, citizens, associations and institutions, but also managers of private companies. Index could help to make explicit priorities in terms of risk mitigation, enabling both, public operators (politicians and administrators) to improve the use of the funds, today already greatly reduced, giving priority to areas most exposed. In addition, it could serve for citizens to become aware of the risk level existing in the area where they live and work and private entrepreneurs to evaluate where to direct their investments, considering also factor related to safety.

There could also be a prediction of different levels of information from the synthetic index according to the different users, from experts to non-expert, so they can contribute to the improvement of the general level of resilience by awareness choices also in every day life.

The coefficient of resilience, however, presents a criticality that, if not considered, could be useless all the preliminary analysis carried out: the data is not changeable and is evolving very quickly, being connected with both exogenous and endogenous factors to the system.

The normal structural decay of a strategic building resulting in the deterioration of the materials, as well as an exceptional natural event may change significantly the original level of entire resilience system. Without a method of continuous updating of the data, the Resiliency Index is likely to provide wrong information about the real situation; therefore we cannot think of a Resilience Index definition without connecting it to a system of continuous monitoring of physical/structural, social, and environmental parameters.

That system may be “expert” (managed by operators in the area of prevention such as the Civil Protection) carried out through automatic control systems and "non-expert" (directed to community resilience) given by citizens, organizations and individual volunteers that indicate critical conditions, using specific tools such as APP or WEB.2.0 Channel. These reports should be evaluated by experienced staff that play a role as a final filter by selecting the real condition of the hazard.

3.2. Innovative tools

In order to analyse the corporate websites, a website analysis tool was created to determine the degree to which a company is marketing its sustainability on its corporate website. The questions developed to analyse the websites were based on the attributes of sustainability and website quality and is divided into three categories: a) user friendly, b) transparency, and c) content.

To achieve the goal of ensuring an effective and fast response in case of natural disaster it needs to enable tools for centralized and expert data management, support by a system which ensures constant and real time data updating. These innovative tools that can greatly reduce the amount of damage to a person and their assets are Multirisk Platform strictly connected with Monitoring System

Monitoring system. The monitoring system is composed of two different methods of control, one particularly expansive but not widespread throughout the territory, called "expert" and the other open to all citizens and to associations (even to those who are not engaged in risk management) defined “non-expert”. The expert system consists of punctual control elements, linked to Strategic Buildings and to risk areas, networked by expert data analysis system able to interact with the Multirisk Platform. The “non-expert” system consists of applications for Smart Phone or WEB portals dedicated to the items of risk, through which the citizens can send reports of abnormal situations. These reports should be evaluated by expert staff, which could select those ones that are critically important for the whole system. These tools can become basic elements for the growth of the risk awareness and prevention techniques among the population.

Multirisk Platform. The Multirisk Platform is an e-tool able to acquire different sectorial data and return in real time, on a cartographic basis, through post-processing algorithms based on shared values. The MP includes the design and development of a combination of cutting edge technologies and custom algorithms linked into a well-integrated application that can be customized to each emergency management authorities' needs. The basic suite combines graphic representation tools and web applications, based on specific algorithms. The Multirisk Platform is able to relate the risks associated with various events and, through the connection with the monitoring system, it can return data up to date and reliable information to the sector operators.

Figure 3. Information management system through the Multirisk Platform

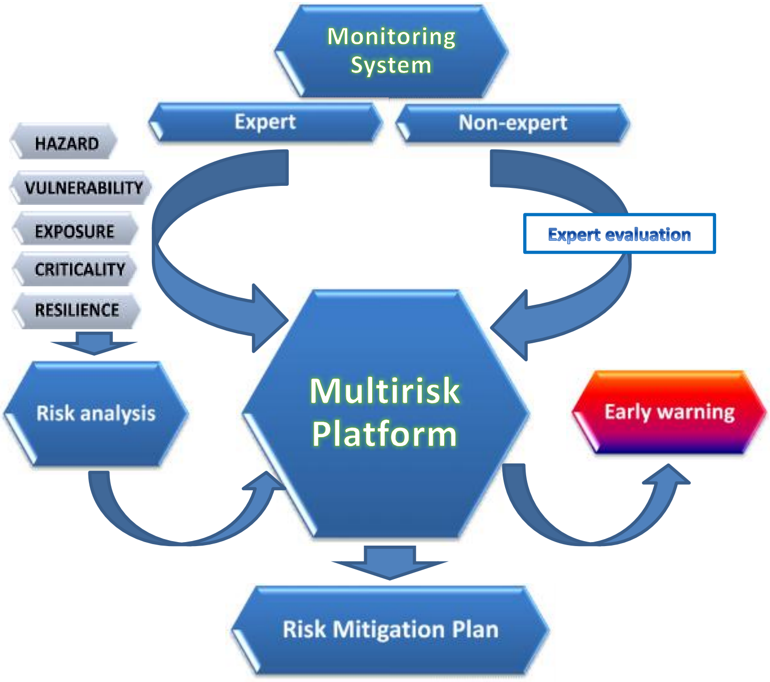


Figure 3 clarifies the role played by the Multirisk Platform that may be considered as the intelligent centre of the complete emergency management system, because it takes into account all the natural risks, constantly checking the component elements that compose them, arranging the update of the Mitigation Risk Plan and activate the Early Warning System.

It could be achieved as an ideal situation for a resilient community, an aware protagonist of the knowledge process, in a city more resilient, through this virtuous process, made up of synergy among the various sectors of society, without exception.

4. Conclusions

Possibility to live in an environment without fear of being victimized by any kind of danger is one of the basic conditions of human wellbeing. Stability before, absorption and resistance that follow during disasters, and recovery as the final stage after disasters define a resilience of any system: social, infrastructure, environmental, or the complex one. At the conditions of rising complexity, numbers and severity of natural and manmade disasters, resilience studies expand in subject matter, and expand from solely technical concepts, relevant to resistance of infrastructures, to a human-centred, environment-oriented and mixed systems' resilience.

In the context of growing unsafely related to climate change, ecological resilience emerges as one of the topical concepts within other perspectives towards resilience. Urbanization processes inflict on ecological resilience in a crucial manner. However, cities play a dual role in terms of ecological issues being the most severe pollutants, and at the same time, they are mediator from where the best eco-innovative solutions can emerge and be implemented. Therefore, interaction of social and ecological systems and influence on resilience of each other is not self-evident and requires comprehensive studies.

Urban systems are the complex ones including social, engineering and natural systems. Therefore, in terms of resilient city development, the resilience of all three systems should be under consideration. Elements of environmental, social and physical structures interact and influence each other. Consequently, urban system resilience assessment should encompass investigation and evaluation of all these three spheres. For the purpose to perform resilience assessment that is methodologically defined would be important to introduce Resilience Index of complex urban system or territory, which is combined of social, infrastructure and environmental resilience sub-indexes.

In many cases nothing could be done to stop natural disasters, but it is possible to mitigate their impacts. The accurate and reliable data and information related to severity of imminent or possible disaster and to the characteristics of social, infrastructure and environment resilience should support readiness and response processes. For such purposes, integrated risk monitoring and risk assessment systems (which include resilience index) could serve. A Multirisk Platform using data of both systems would serve as an innovative tool for early warning activation and information processing system for risk mitigation planning.

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