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Proactive risk management and integrated knowledge for the governance of urban systems: Urban vulnerability in the case of Gran Santo Domingo

Elena Cervelli[a], Serena Micheletti[b], Marina Rigillo[c,]*

[a]*CIRAM, University Federico II of Naples, Via Mezzocannone 16, 80134 Naples, Italy*
[b] *CNR-IRISS , National Research Council, Istitute for Research on Innovation and Services for Development, Via Sanfelce 8, 80134 Naples, Italy*
[c] *DiARC, University Federico II of Naples, Via Toledo, 402 - 80134 Naples, Italy*

Abstract

The paper updates and concludes the research presented at the first Symposium ISTH2020, held in Reggio Calabria in May 2014. It discusses a multi-criteria approach to identify urban vulnerability with respect to seismic risk. Starting from the case of Santo Domingo, but with the goal of providing tools for the assessment of urban vulnerability elsewhere, we have elaborated a knowledge-oriented approach aimed at managing different types of vulnerability (morphological, social, and functional). The study proposes a set of criteria for the spatialization of a wide range of indicators of social and morphological vulnerability of the city of Santo Domingo, in the Dominican Republic. This is characterized by a high exposure to risk due to both the probability of seismic hazard (the Haiti earthquake of 2010) and the specific urban vulnerability caused by recent urban growth. The research has been carried out in the framework of the "Estudio de la Amenaza Sísmica y Vulnerabilidad Física del Gran Santo Domingo" and proposes an original approach to GIS and multi-criteria analysis as effective tools for managing vulnerability assessment.

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Keywords: resilience; vulnerability; governance; adaptability; cognitive process multicriteria evaluation

* Corresponding author. Tel.: +39-081-253-84-05.
E-mail address: mrigillo@unina.it

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1. Introduction

The paper updates the multidisciplinary research project “Estudio de la amenaza sísmica y vulnerabilidad física del Gran Santo Domingo” funded by the European Union (EU) and managed by the United Nations Development Programme (UNDP) in Dominican Republic. The project aims at reducing seismic risk by working on both hazard prediction and vulnerability assessment, especially focusing on urban planning and construction procedures. The study is based on the theoretical assumption that vulnerability (be it social, urban, or economic), always denotes the system's susceptibility to an event (natural or otherwise), or its inability to cope with the event (Adger, 2006; UN-ISDR, 2015).Therefore, the assessment of urban vulnerability is a key task in risk management. Linked to the risk and the risk management from disasters, and also resulting from studies on hazards (Burton et al., 1978, Mitchell et al. 1989; Cutter, 1996; Menoni and Pergalani, 1996; Menoni, 2001), vulnerability has become a specific subject in the last two decades. As such, it has witnessed the development of specific models to define urban vulnerability, in which humans are not only seen as victims, but also as an active (pro-actor) contributors and modifiers, able to change the urban contexts vulnerability (Kates, 1996). An important advancement in the field was the recognition of the spatial connotation of urban vulnerability as the result of the man-context interaction (Rashed and Weeks, 2003).

Effective risk management can save lives, but also becomes a powerful tool for urban planning that helps avoiding economic shocks, helping people to build a more secure future, changing the logic of action from "combat the crisis" to "managing the risk, proactively and systematically" (Hallegatte et al., - World Bank, 2010, WDR 2014). The theme of disaster risk management, rather than disaster management (UN-ISDR, 2005; UN-ISDR, 2015; EU, White Paper, 2009), is (or should be) an increasingly common component of land use policies and of spatial planning. This would allow the definition of strategies and actions to prevent the transition from risk to disaster.

Starting from the definition given by the United Nations (UN, 1979), risk is a function of three parameters, each of which represents a stressing agent, of the system vulnerability and of the quantity/quality of the affected elements. In cases where it is not possible to act directly on the source of danger, as in the case of seismic events, proactive risk-management focuses on the exposed systems and on reducing their vulnerability. Such kind of action has a special focus on urban systems due to both the consistency and the quality of the elements at risk and because of the high probability of trigging risk chains off (UN-ISDR, 2015).

The use of GIS helped us to define vulnerability of urban systems, through the study of urban dynamics and their representation (Edwards, 2007; Emmi and Horton, 1993; Rejeski, 1993; Mejia- Navarro et al., 1994; Stein et al., 1995; Cova and Church, 1997; Kehelt, 1997; Kappos et al., 1998; FEMA-NIBS, 1999; Menoni et al., 1999; Cutter et al., 2000; Radke et al. 2000; Rashed and Weeks, 2003). Compared to the early, deterministic approaches to vulnerability, the integration between GIS and the multi-criteria decision analysis has contributed to the construction of dynamic models that are able to recognize different types of urban vulnerability, and to represent this variability graphically. Indeed, the types of urban vulnerability vary according to the different sources of danger and their intensity, and according to the specific urban dynamics within the system. Vulnerability also depends on urban morphology, social preparedness, and economic context.

The paper presents an empirical method for the analysis of urban vulnerability that is specifically related to seismic risk. The study offers databases, considerations, processes, and calculations that maybe used in other applications (integrated risk). The paper therefore aims to integrate cognitive and executive processes, and to provide tools to support decision-making and governance for the stakeholders. The international project "“Estudio de la Amenaza Sísmica y Vulnerabilidad Física del Gran Santo Domingo” aimed at providing effective tools and methodologies for supporting the public and private entities involved in urban planning and in the construction sectors to face a "Big One" event. This ongoing project has been funded by the European Union and is being done in collaboration with the European partners: the National Research Council of Italy (IRISS), the Instituto Geologico y Minero de España (IGME), the Bureau de Recherches Géologiques et Minières (BRGM) of France. The present work is part of the activities carried out by the CNR part of ″Estudios de Vulnerabilidad Urbana y Social del Distrito Nacional" (Actividad 2.1) and "Elaboración de una metodologia para el aumento de la resiliencia y las capacidades de respuesta de frente a sismos de la población en una area urbana escogida del Distrito Nacional"(Atividad 3.1). The paper discusses the multi-criteria evaluation approach for assessing the critical areas

of urban context. This is understood as an upgrade able and versatile tool for decision support and for the definition of "medidas", i.e. actions and policies to be taken to implement the urban resilience. At the same time, it emphasizes the versatility of the cognitive process, adapted to fit the Dominican context (data availability, territorial dynamics), but easily upgradeable and versatile for other purposes. The paper is divided into three sections: the first is dedicated to the methodology applied. The second shows the results obtained. The third is devoted to some reflections on the knowledge process carried out and the possible implications of the results in the policy and operational framework of the Dominican context.

2. Materials and methods

2.1. The Dominican context and the seismic risk

Latin America and the Caribbean area are critical areas in terms of urban vulnerability, because of the second-highest number of disasters per year (after Asia), and the highest rate of urbanization in the developing world, with 80% of the population living in cities (Keefer et al. - World Bank, 2010; Shah et al. - World Bank, 2012). The Dominican Republic, due to its environmental and geological conditions, is particularly exposed to a number of hazards, such as earthquakes, floods, erosion, and tsunami (Comisión Nacional de Emergencias República Dominicana, 2011). Therefore, since the 1970s, with the contribution of organizations and international institutions, it has undertaken measures to strengthen its capacity to reduce the impact of natural disasters and to increase resilience (Pelling, 2003). In particular, since the early 2000s (L.147-2002), it has launched a new organization for the seismic risk management system -the Disaster Risk Reduction (DRR)- with the introduction of specific instruments and responsible bodies. Its focus has shifted to the factors that turn a natural hazard into an unnatural disaster (Hallegatte et al. - World Bank, 2010). Other regions with high seismic hazard – e.g. Japan, California, and Chile - have taken action to limit the risks with different methods and tools. All these countries have enforced anti-seismic construction standards and codes, as well as measures for education to the damage. However, whereas Japan and California have the economic capacity to implement the most innovative technological resources, Chile, as a developing country, has focused its risk management strategy on preparedness, i.e. on the capacity and knowledge of governments and citizens in case of risk and emergency (UNISDR, 2015). Several factors make the reduction of seismic risk a lengthy process: the time required to raise awareness about likely earthquakes, to implement the relevant education and to implement integrated governance between institutions, organizations, associations and citizens.

The paper aims at assessing the benefit of using a multi-criteria approach, in a GIS environment. The main phases of work have been:

- The construction of a methodology for integrated knowledge of the area in terms of vulnerability
- The articulation of a specific criteria tree, through the multi-criteria approach and the choice of targeted indicators
- The creation of indicators and thematic maps for their evaluation

2.2.1. The construction of a methodology for integrated knowledge of the area in terms of Vulnerability

In order to provide effective information for managing a risk, urban vulnerability is considered through various categories, such as: physical, social, economic, and environmental (Menoni and Pergalani, 1996; Menoni et al., 2000; Rashed and Weeks, 2003; Carreño et al., 2009). Based on these assumptions, the issue of urban vulnerability of Santo Domingo was studied through the definition, articulation, and breakdown of social and physical components that constitute the urban system. Then, the different outcomes were integrated into a single evaluation grid, called Urban Clusters. The literature shows different approaches to measure vulnerability (Mitchell et al. 1989; Cutter, 1996; Menoni, 2001; Rashed and Weeks, 2003; Edwards, 2007; Barbat et al., 2009). The most widely used models include deductive, inductive, and combined methods (Brecht et al. - World Bank, 2013).

Deductive approaches use quantitative methods based on patterns of past disasters and their damage and losses. However, the data on losses are often insufficient, especially for large-scale investigations, and often have not been rigorously recorded. Inductive approaches determine risks through a combination of weighted variables for the vulnerability: for example, factors such as GDP, poverty rates, or the population density are taken as indicators. A common criticism is the lack of universally accepted procedures for assigning values and weights to the various factors that contribute to the risk of vulnerability. Here, we use an inductive approach in which vulnerability is conceived as a feature of the urban system and is evaluated through a combination of physical-environmental and social-cultural factors specific to the context.

The cognitive process was developed in cumulative steps:

- Articulating Urban Vulnerability in analytical terms: Exposed Elements Vulnerability, Morphological Vulnerability, and Social Vulnerability
- Within each aspect of vulnerability, the criteria have been organized into systems and components, using a tree-structure that formed the basis for the next multi-criteria evaluation
- The articulation and explanation of the criteria, using specific indicators. Indicators refer to classifications and definitions adopted and developed by national and international statistics institutes (EUROSTAT, ISTAT,etc.), and they are processed for the specific context. The process of analysis and knowledge of the context has been structured to be easily implemented, upgraded, or modified.

2.2.2. Criteria-tree, multi-criteria approach and indicators

The debate on urban vulnerability does not necessarily converge to a single definition of the problem (Sinnott, 1989; Voss and Means, 1989), because of its complex and variable structure. The multi-criteria approach to the urban vulnerabilities has allowed us to combine and transform spatial databases (input) in degrees of vulnerability (output) and to structure a transparent, implementable, modifiable, and adaptable assessment process. The study starts from the project of a specific criteria-tree, which defines the hierarchy and the relations among the criteria considered. The selection of criteria/indicators set has been a fundamental part of the process. According to the model developed by Malczewski (1999 and 2006), the criteria have to be: (1) complete (i.e. they cover all aspects of a decision problem); (2) operational (i.e. meaningful to a decision situation); (3) decomposable (i.e. are amenable to partitioning into subsets of criteria, which may be necessary to facilitate a hierarchical approach to decision analysis); (4) non-redundant (i.e. avoid the double-counting of decision consequences); and (5) minimal (i.e. have the property of the smallest complete set of criteria characterizing the consequences of a decision).

2.2.3. Indicators and thematic maps elaboration

For each criterion/indicator, a thematic map (in raster or vector format) was built. Mapping and classification have been developed through basic GIS operations (overlay, buffering, Euclidean distance, kernel density, etc.). GIS technology has been employed for its capacity to analyze, manage, and process a significant amount of alphanumeric and spatial data. Due to the different types of data available, to the different types of products and formats, and to the difficulties connected to the exchange, reuse and integration of data from different sources, it has been necessary to systematize the data. This has been done by computerizing and geo-referencing the acquired material; by defining the information structure of the geographic databases; by rendering the geometric component and its associated attributes; by organizing layering in different categories, theme and datasets; and by preparing thematic maps and layout structures (dressing layers, legends, etc.).

The reference system for cartographic processing is UTM WGS84 - time 19N. To supplement the available data, international and national agencies were contacted: National Statistics Office (ONE), Ayuntamiento National District; Cultural Heritage Office - Directorate Historical Center. Finally, we integrated information, data, and products from European partners (BRGM and IGME), thus integrating different kinds of knowledge and entering the information into a single knowledge process of the urban system.

The individual indicators of the maps were compared and related by systems and, subsequently, by components (Rigillo et al., 2014). In order to enable a joint and integrated assessment between the various indicators, each map was standardized, and its values were subsequently weighted, by means of multi-sector discussion tables. The result has led to the development of maps depicting our assessment of urban vulnerability.

The calculations were carried out using the specific software support with platform to multi-criteria decisions, ILWIS 3.8.3 (52North, ITC, Enschede, The Netherlands).

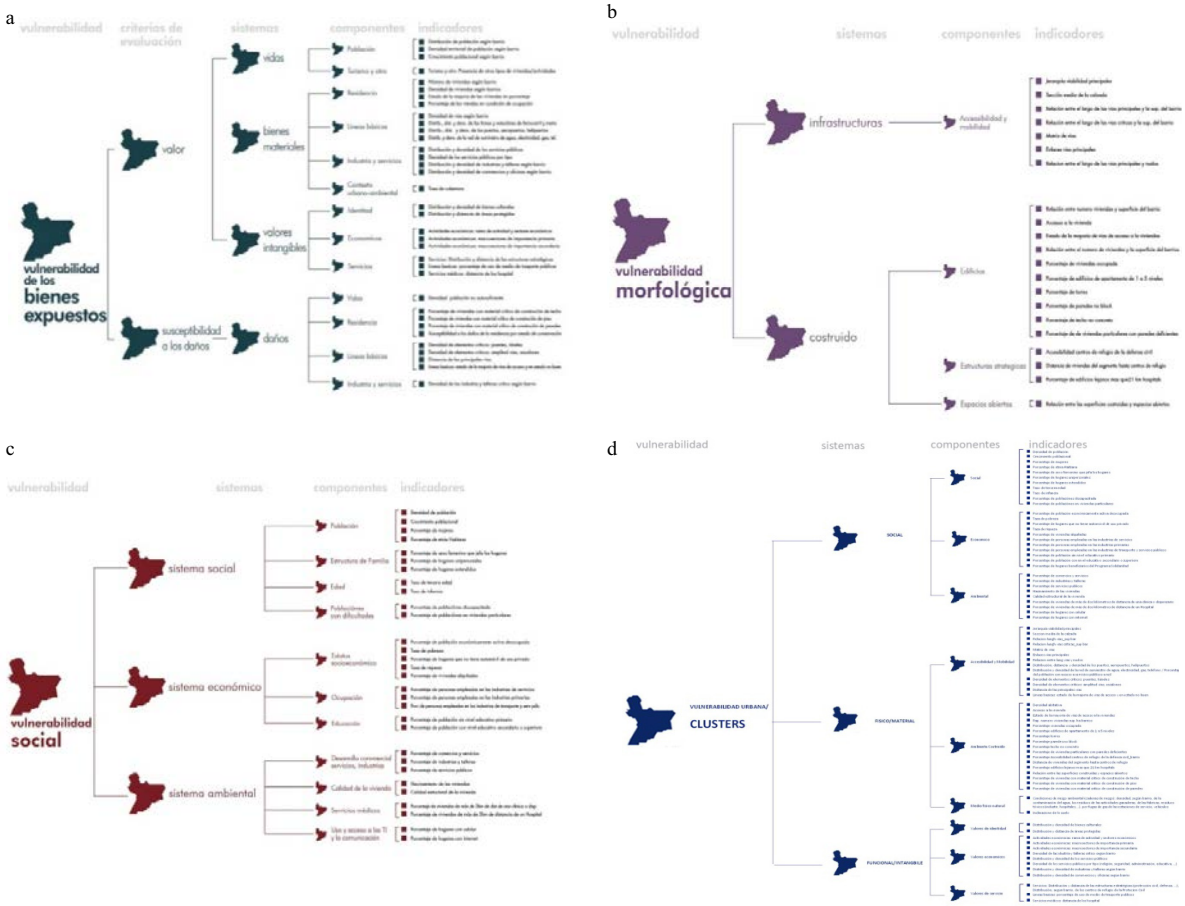

Fig. 1. Criteria-tree detailing the components of vulnerability: (a) exposure; (b) morphologic; (c) social; (d) clusters.

3. Results

The work ended with the drafting of three maps of urban vulnerability: Vulnerability of Exposed Elements, i.e. human, physical, and intangible capital (this map represents how the city works and how it is organized); Vulnerability of the Urban Morphology, specially focusing on the urban patterns and the urban permeability (this represents how the shape of the city could act as catalyst in case of the earthquake and in terms of emergency-response capability); Social Vulnerability, i.e. who uses different areas of the city and how.

Subsequently, the comparative assessment of the three maps has allowed the identification of the urban vulnerability clusters, or the articulation of homogeneous areas in terms of vulnerability. These maps enabled us to highlight which areas most urgently need to implement measures for resilience. Therefore, the originality of the work consists in having prepared drawings of the seismic risk, with a specific focus on the spatial organization of

the urban structure, morphology, and the social structure. At the same time, the work proposes a knowledge process that may be used also for the study of other types of risks (such as hurricanes, heat islands, and hydrogeological risks), for the design of related planning measures (municipal regulations, the designing of blocks depending on the vulnerability of the neighborhood) and for improving the dialogue with the stakeholders of the economic system (insurance companies, construction companies). Ideally, these tools could help institutions to transition from an auto-resist to an auto-prevent formula, addressed to a wide range of stakeholders.

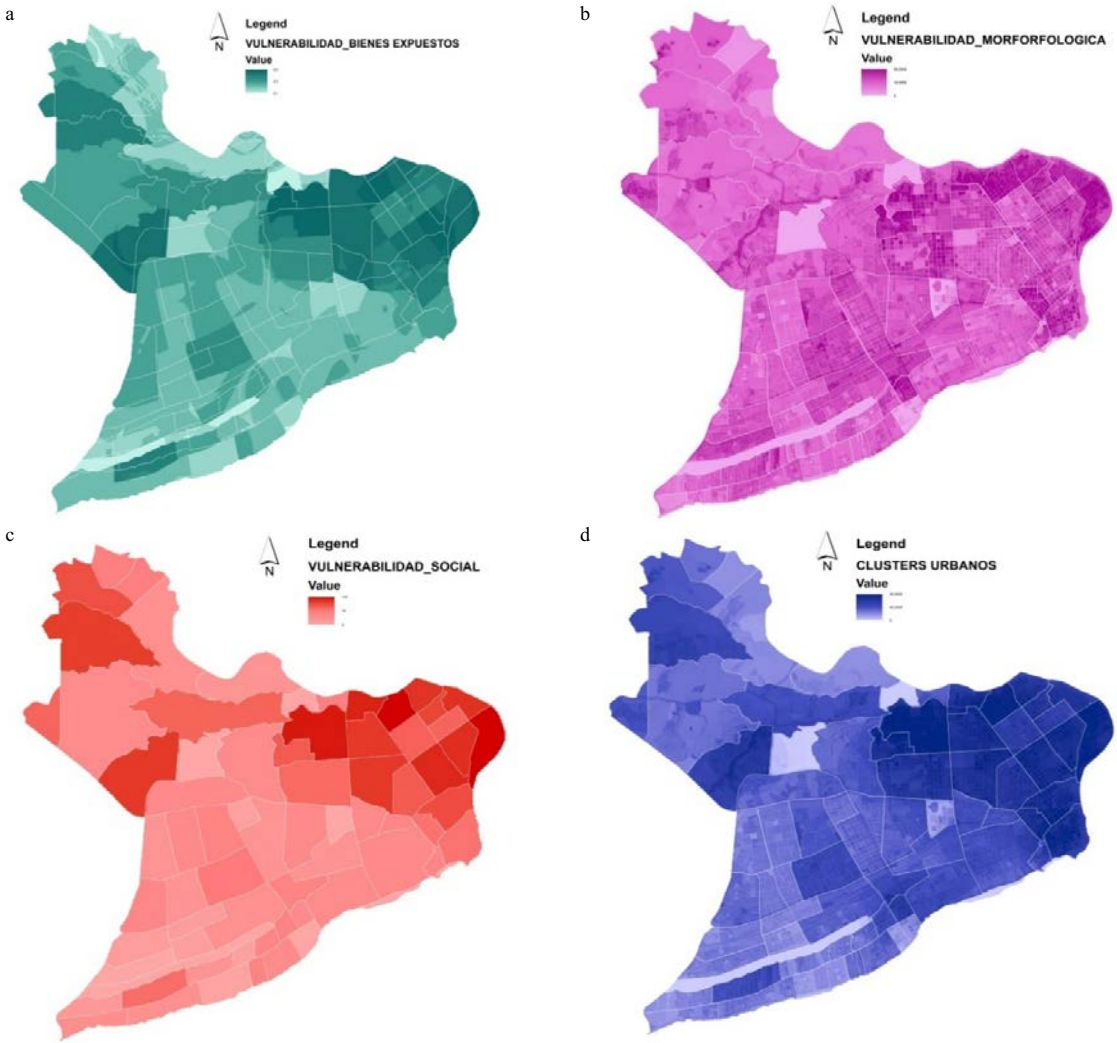

Fig. 2. Urban vulnerability maps detailing: (a) exposure; (b) morfologic; (c) social; (d) clusters.

4. Conclusions

The aim of the work was to study of the Dominican urban system vulnerability and, at the same time, to provide local institutions with tools for:

- Building a transparent and easily upgradeable database (the Urban Vulnerability maps are specific to the context in question, tailored to Santo Domingo, and the indicators refer to a rather updated database - Population Census ONE 2010); the cognitive process has also integrated the results produced for the project by BRGM and IGME partners (geological, environment hazard components), as by pooling different knowledge and skills
- The development of knowledge models and process that are adaptable and versatile to further study and work on the urban context (the multi-criteria approach has ensured the rationality of knowledge process and the tree structure allows the dynamic re-use of information, finalizing the work even for different objectives); the construction of the criteria-tree allows a continuous process and the downscaling and contextualization of indicators: the project not only intends to provide the involved institutions with a static data inventory, but also with processed information (indicators), according to an integrated and functional knowledge, usable also for different purposes
- A confrontation and dialogue with local stakeholders, public and private, on the activities and conditions to undertake for urban development and the implementation of urban resilience (in this case, the multi-criteria approach has guaranteed the ability to create alternative and acceptable, even conflicting, and upgradeable scenarios).

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