Multihazard and vulnerability in the seismic context of Bucharest Capital City (HERA)

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SUMMARY
The project aims to identify and quantify urban phenomena for the development of a fast analysis instrument that would allow spatial visual representation of the environmental vulnerabilities in Bucharest, from the perspective of the seismic risk as a multi-hazard generator. The final product of this project is a complete data base including urban environment parameters. It offers also a variety of analysis procedures validated statistically and ecologically in order to identify the hazard and vulnerability situations in different scenarios of seismic risks, which will be available for the local authorities in an easy to use web interface. In the same time, in order to sustain Bucharest's strategy for seismic risk reduction, the project structured and diversified the information communicated to the population through different types of contextually adapted messages, based on the identification of the psychosocial circumstances and pattern indexes in the process of coping to the seismic risk.

Keywords: GIS systems, vulnerability, Bucharest

1. INTRODUCTION

As the number of disasters is increasing, the need to understand and define vulnerability is becoming highly important, especially concerning practical applications and methods (EM-DAT, 2010). The common understanding of vulnerability and, especially, the ability to measure it are considered the key for solving disasters through managing the consequences and setting targets (Kasperson *et al.*, 2005, Birkman, 2006).

The concept of vulnerability is used in a broad field and for different spatial levels, due to its multi-faceted and scalar-depended character. Vulnerability is broadly defined as the "potential for loss" (Petak and Atkisson, 1982; Mitchell, 1989; Thywissen, 2006), or as a predictive variable that designates the potential of being harmed relative to the elements at risk and event intensity (Kates, 1985; Ionescu et al., 2009).

Up to the launch of HERA project, Bucharest's context was never approached through a complex multidisciplinary urban vulnerability perspective. The HERA Project was launched in 2007 by the University of Bucharest, and came to an end in 2010. Bucharest was chosen as HERA test area because it is highly vulnerable to earthquakes and is affected by profound socio-economical change. The project filled a gap, given the absence of recent studies on social elements at risk, especially for this location, as well as the need to improve the vulnerability analysis. The project was awarded funding from the Romanian national funding agency and was connected to the COST (European Cooperation in Science and Technology) action "Semantic enrichment of 3D city models for sustainable urban development".

2. PREVIOUS CASE STUDIES

From the perspective of seismic vulnerability on global level there are 4 models of urban planning: preparation (Fiedrich, 2004, adapted the HAZUS system for Bucharest in frame of the German project SFB461, proposing the model EQ-RESCUE of decision of the intervention zones), mitigation (there is no model for Bucharest), resilience (Bruneau et al, 2003 and the RISK-UE project, Mouroux and Le Brun, 2006a and 2006b) and of post-disaster recovery (there is no model for Bucharest).

The managing of post earthquake disaster interventions can benefit of computer support. Fiedrich (2004) proposed the integrative model EQ-RESQUE to support the prioritisation of intervention zones and the efficient allocation of help-and-rescue resources through action proposals. The EQ-RESQUE model can be applied in two environments:
1. Simulation of the dynamic disaster environment and resources allocation in a pre-earthquake phase for training;
2. Decision process modelling using software agents. These agents are mathematically optimised based on collected expert knowledge concerning the multiple tasks, the communication structures and decision competences within the disaster staff.

Best known is an early example of such an IT tool: HAZUS (FEMA, 1999) a US standardized methodology that contains models for estimating potential losses from different hazards including earthquakes. Potential earthquake parameters, the built substance, and the infrastructure are used to compute scenario physical damage and socio-economic losses. Secondary events, like post-earthquake fire, are included.

The “Disaster management tool“ (Markus et al., 2004) is another instrument more recently devised to approximate damage and number of victims and provide communication and information support to staff involved in managing disasters. The tool, specially designed for pre-event training and post-event disaster management was tested in civil protection exercises and includes a computer aided damage estimation tool (EQSIM). EQSIM was applied for the centre of Bucharest in frame of SFB 461.

In frame of the RISK-UE project a methodology for earthquake scenario assessment through global impact analysis was developed. Distinctive features of European cities, considering current and historical buildings, as well as their functional and social organisation, and their differences from the built stock taken into account in HAZUS, were considered. The project was divided on one side in work packages that are specific to different methodologies (seismic assessment, urban exposure), and on another side to the characteristics of participating cities (Barcelona, Bitola, Bucharest, Catania, Nice, Sofia, Thessalonica). For example, a work package entitled „Urban System Analysis” (Masure and Lutoff, 2006) deals with urban zoning using the ”Urban-System-Exposure” methodology: system components and their functionality, then the “elements-at-risk“, their exposure quantified by means of different indicators, and the vulnerability factors were analysed. On this basis problems and opportunities were identified (SWOT analysis). The spatial distribution of strategic or vulnerable elements was mapped in GIS. The elements were ranked according to their role in the system during normal, crisis and recovery periods. After appropriate consideration of the problems posed by seismic risk, “management-plans“ and “plans-of-action“ are proposed for strategic implementation by decision-makers through land-use decisions. This is one of the rare approaches integrating urban planning into earthquake research. Later on in Italy the Crotone project applied a “minimal (strategic) urban structure” (SUM) approach building on this.

The HERA project continues the direction begun by RISK-UE as a more complex approach, based on a holistic view of the urban „organism”, which covers the variety of human-environment interactions, being, through its complexity, a pioneering approach at national level, following the trend of similar studies at international level.

3. OBJECTIVES OF THE PROJECT

The project aimed to identify and quantify urban phenomena for the development of a fast analysis instrument that would allow spatial visual representation of the environmental vulnerabilities in Bucharest, from the perspective of the seismic risk as a multi-hazard generator. Bucharest is a populous city located in the alluvial Romanian plain, on the terraces and interfluves between two small rivers. The morphologically unstable footprint of the city is under the influence of Vrancea seismic zone. This seismic zone contains a very high concentration of hypocenters in an approximately vertical volume located at intermediate depths ($60 \leq h \leq 200$ km) in the curvature of the Carpathian Mountains. The seismicity rate (3–4 shocks of magnitude 7.0 Mw per century) is unusually high for such a narrow, seismically active volume (Radulian et al., 2006).

The main objectives of the HERA project were:

- To develop a most comprehensive spatial database for Bucharest, integrating the natural phenomena (hazards) in a socio-economic urban context approached through its historical perspective.
- To create earthquake scenarios based on urban vulnerability analysis and enabling risk analysis of direct and indirect costs.
- To identify and test psychological factors linked to risk perception, which will be the base of an emergency seismic risk communication plan that will be a component of the local plan for managing the emergency situations in accordance to the National Communication Strategy for Emergency Situations, approved by the National Committee for Emergency Situations.
- To develop integrated methodological tools in GIS and ecologically and statistically validate this methodology.

4. ORGANISATION OF THE PROJECT

The 6 phases of the project, which took place between September 2007 – December 2010 were:

⇨Phase I (14/09/2007 – 14/12/2007): Documentation study and finalising of research strategies; database design and conceptual software model.

⇨Phase II (15/12/2007- 15/07/2008): Complex investigation of the urban organism: physical support resulted in: integrated diachronic analysis of the evolution of the city, on the specific support of the natural environment, and the study of the local seismic effects due to superficial structure (through noise measurements).

⇨Phase III (16/07/2008-30/01/2009): Complex investigation of the urban organism: socio-historical conditions. The phase concluded with three milestone results: the multicriteria evaluation of the urban vulnerability; correlation of the possible effects between the directivity of seismic radiation and the built environment; the concept and the test of a standardized questionnaire on the perception and representation of seismic risk.Phase IV (1/02/2009-30/05/2009): Complex investigation of the urban organism on microzone level concerned the performance of the complex database in the pilot zone: the historic nucleus of Lipscani.

⇨Phase V (31/05/2009-30.12.2009): Multi-hazard modelling at different spatial-temporal scales in the context of the social dimensionality of risk, with performance of the psychosocial enquiry at city level on a representative sample of over 1300 people and the design of a multi-criteria interrogation and filtration module of the data in the database for the pilot entity.

⇨Phase VI (1.01.2010-10.12.2010): Complex investigation of the urban organism was concerned with the finalisation and testing of the software product at the level of the pilot entity and the construction of the message in crisis situations.

Partners in the consortium were four Romanian universities and an internationally recognised research centre:

- University Of Bucharest - prof. Iuliana Armas; National Institute for Earth Physics – INCDFP, dr. M. Radulian; The Bucharest Academy of Economic Studies – ASE, prof. M. Dardala; the National School of Political and Administrative Studies Bucharest – SNSPA, dr. I. Stănciugelu; Technical University of Civil Engineering of Bucharest – UTCB, dr. Al. Aldea

5. DEFINITION OF THE METHODOLOGY DEVELOPED IN THE PROJECT

The method proposed during this study was based on digital and statistical spatial information resulted from 1:2000 topographical plans, satellite pictures, data offered by the Statistics Regional Department of Bucharest's Municipality, archives and historical maps, field observations concerning age, functionality and current condition of the buildings, the height and number of floors, demographical and accommodation aspects, the degree of daily and weekly occupation, natural environmental features etc.

As concerns the seismic hazard in Bucharest area, we adopted two scenarios: (1) observed seismic hazard for a typical case (the Vrancea event of 30 August 1986, $M_w = 7.1$) and (2) computed seismic hazard for the maximum expected earthquake ($M_w = 7.7$). In both cases, the seismic hazard is expressed in terms of intensity values.

The earthquake of 30 August 1986 is the best instrumentally recorded major seismic event of Vrancea. Ten instruments, which were operating in 1986 in the Bucharest urban area, provided valuable seismic ground motion recordings.
The hazard dispersal for the maximum expected earthquake was computed using the procedure proposed by Marmureanu et al. (2010). This procedure summarizes all available observation data on the target area (from 1977, 1986 and 1990 Vrancea earthquakes) and takes into consideration the local structure effects, including the non-linear characteristic of the soil. Both probabilistic and deterministic approaches were combined to assess the seismic hazard values.

The overall vulnerability computation derived from the general qualitative equation for risk assessment (BUWAL 1999; UNDP 1994; UN-ISDR, 2004; IADB 2005):

$$R = H * V_{ov}$$
$$V_{ov} = V_t / C, \qquad (1)$$

where R = risk,
H = hazard,
V_{ov} = overall vulnerability
V_t = total vulnerability, considered as a function of seismic susceptibility of the urban area in connection with the socio-economic vulnerability of the built space
C = capacity of the urban system to withstand disaster (coping capacity).

The input set of maps focused on four vulnerability criteria:
- Social vulnerability,
- Economic vulnerability,
- Physical vulnerability (assessment of the buildings),
- Environmental vulnerability (susceptibility to the earthquake hazards).

In addition, we estimated the coping capacity based on an analysis of distance to the hospitals, fire stations and police stations, distance from green and barren areas and, also, considered the literacy rate index.

The buildings' vulnerability to the seismic risk was calculated only for the old city centre, through the investigation of 358 single buildings using a parameter called the 'vulnerability index', measured for each category of vulnerability (Cherubini et al., 1999) based on the knowledge about the effects of earthquakes on different building framework structures

The most common framework building structures for the buildings investigated were (Lungu et al, 2003):
(i) Brick framework buildings with floors and ceilings made out of small bricks M3.2 (34.09% of all buildings);

(ii) Brick framework buildings with wooden ceilings and floors M3.1 (22.44%)
(iii) Reinforced concrete framework with irregular configuration RC3.2 (20.45%)

The most common building type was the brick structure with a medium height (56%). The majority of the buildings in the old city centre were planned/ built without taking into account the seismic risk and were included in the 'no-code' category. The buildings included in the 'high-code' category, or class H are new constructions or constructions that were strengthened to comply with the current regulations regarding seismic risks.

Each building was included into a vulnerability category from A to F according to the European scale for seismic intensity EMS-98 and based on the type of framework and the expert's opinion (the experts took into account more aspects such as the planning code, the height and state of the building). For each vulnerability category, the vulnerability was described by a probabilistic distribution based on the statistic analysis of the damages observed at previous earthquakes. The majority of the buildings from the old city centre (85%) are mainly included in the A category (19%) or B category (66%).

In the same time, in order to reduce the vulnerability and also increase the safety of the urban environment, the educational system must work hand in hand with the physical system for implementing mitigation measures. In this context, in order to support the strategy of reducing the seismic risk in Bucharest, the project diversified the information/warning message for the population through different types of contextually adapted messages, based on the identification of the psychosocial state and pattern indexes in the process of coping to the seismic risk. This objective aimed the improvement of intervention in crisis situations, but also in the preparatory (pre-disaster) and resilience (post-disaster) stages.

6. APPLICATION OF THE METHODOLOGY - RESULTS

The end product of the project was a complete data base at the level of the urban environment parameters, and offered a variety of analysis procedures validated statistically and ecologically in order to identify the hazard and vulnerability situations in different scenarios of seismic risk, in an attractive GIS interface that is easy to use and implement in emergency situations management and the sustainable territorial planning.

The multi-criteria module for spatial analysis (MAS) was created as an ArcMap extension (ArcGIS) and developed as a tools menu. The parameters considered are decided by the user and represent attributes that are characteristic for the statistical population. In the case of our research, the statistical population was represented by the buildings analyzed in the old city center and the parameters were: year the building was built, location, vulnerability, risk, vicinities, etc. The extension offers the advantage of applying different statistical methods of data analysis (cluster analysis, main components analysis and discrimination analysis) and visual spatial representation of the results, as well as in a table format and as a chart (Fig. 1).

This software can be universally applied to evaluate the spatial associations on a huge number of variable to identify their concentration in key factors that are important in understanding vulnerability aspects specific for the natural environment linked with specific human use.

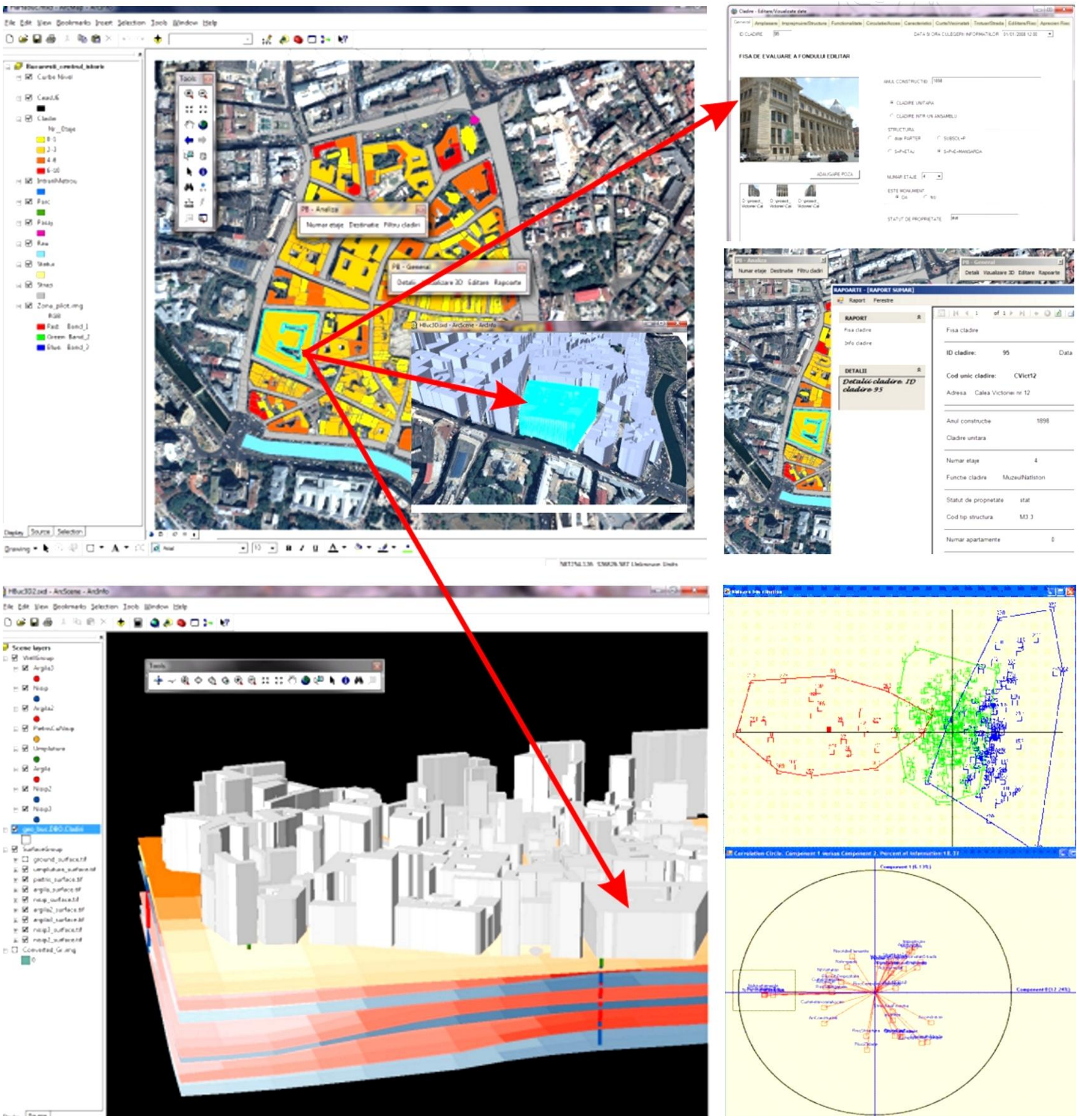

Figure 1: Historic centre detail: 3D views; View building information and reports, geology and graphical reports of statistical results

Innovative aspects are:

- The implementation of statistical procedures that were improved and adapted to describe the special links between different phenomena;
- The implementation of spatial patterns based on types of statistical structures;
- The graphical representation of results in a new and suggestive way.

7. IMPACT OF THE PROJECT

The creation of an IT tool for the analysis of the urban space was very useful for both, the field of scientific analysis as well as at practical-application level (risk management and regional planning). The benefits of the project can be found at theoretical, teaching and scientific level, as well as at practical-application level. The results obtained were disseminated through dedicated journals, participation at international conferences (constant representation at the EGU-Vienna, with the organisation of the session NH9.12. *The impact of natural hazards on urban areas and infrastructure*, in May 2010), through editing of books, including in international renowned publishers (Springer), the creation of a webpage of the project, through the thematic enrichment of some courses, in the framework of the master courses on the topic and in the elaboration of two doctorate thesis, which will deepen – in different directions – the results of the project. The project enabled to participation to the COST action TU0801 European network of projects dealing with "Semantic enrichment of 3D city models for sustainable urban development".

9. CONCLUSIONS

In terms of seismic hazard, Bucharest is in a particular situation, in the sense that ~~only~~ if the ~~radiation~~ magnitude of seismic waves emitted by the hypocentre ~~source~~ is coupled with ~~intensive modes~~ local geology that favours the propagation of the waves the greatest damage is generated. Specific local geological features can induce high levels of shaking on the ground surface.

The ground accelerograms (measuring ground-shaking) recorded from Vrancea earthquakes highlight several features, with direct repercussions on the expected effects. Firstly, the prevalence of high vibration period (1-2s) for strong shocks, which is responsible for the destructive effects on ~~tall~~ high buildings of 8-12 floors, low buildings being much less affected. The impact of seismic waves seems to fall sharply for earthquakes with magnitudes lower than 7 (Mercalli or Richter?).

Another important feature of the repercussions on the effects of recorded seismic vibration is dependent on the directivity of focal depth. This feature enhances the NE effects when the focus is located at the bottom of the seismic zone (h > 120 km) and the SV effects when the focus is placed on top of the seismic zone (h < 120 km).

Another conclusion is that time of seismic waves recorded in Bucharest from Vrancea earthquakes in many cases show a greater amplitude on the radial component (approximately the N-S direction), compared with transverse component (about the E-V direction). This effect can be explained by the predominance of reverse fault type focal mechanism with a plan about breaking down oriented NE-SW.

On the background of hazard analysis, within the project, analyses were conducted to assess the vulnerability of buildings according to the types of load bearing structure and seismic intensity. They were developed from previous typologies developed in frame of the RISK-UE project, which took into account the architectural vulnerability. Also, complex seismic risk and vulnerability analyses have been conducted on the scale of the whole city with multi-criteria methods.

From the perspective of sociological research on disasters and emergency communication system, a major concern in crisis management centres on the coordination of the behaviour of individuals and organizations. This is especially crucial in disasters, as it is specific the emergence of entity groups that never existed before the crisis, their functioning can be crucial during disaster and post-disaster response.

In this respect, an important objective of the project was to identify patterns in behavioural responses to the stress of environmental uncertainty (whether it is a simple motor/verbal reaction or a complex emotional-cognitive one). Psychosocial analysis led to the development of effective models of seismic risk communication.

The social science approach is new in this project in comparison to the previous researches mentioned. Previous approaches do not take into account social vulnerability and psychological factors. Also a new element is the development of the multi-criteria approach methodology taking into account these factors at a city scale, having as a basis the statistical data on the wards and not data for each building.

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