GeoPatterns, Vol. I, Issue 1, April 2016, pp. 11-14

A summary of CRMD research on Bucharest

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Abstract. Due to its environmental issues, Bucharest has always been a constant attraction for our research Centre works. Three major collaborative projects funded from the state budget focused on the urban vulnerabilities at Bucharest city level: HERA, REVEAL and GEOSPACE. The paper summarizes the innovating topics and the main outcomes of this research.

Keywords: *urban vulnerability, multi-criteria analysis, InSAR, GNSS, diachronic cartography, nonlinear dynamics*

Due to its environmental issues, Bucharest has always been a constant attraction for our research Centre works, research being funded from the state budget.

Early research topics mainly focused on the environmental vulnerabilities in sector 3, especially in the historic center area where a series of psychometric analysis on risk perception were generated. The findings, published in Risk Analysis and Natural Hazards journals, showed that the population's perception of environmental risks declines if its living standard falls.

The first major project on Bucharest area was HERA (Multi-hazard and seismic vulnerability in the context of the city of Bucharest, http://www.hera.ase.ro/). HERA Project summed up for the first time the collaboration of various researchers representing Earth sciences (seismologists, geologists and geographers), social sciences (psychologists), engineering (civil engineers), and computer scientists.

The participation was shared among three universities (University of Bucharest – UB, Technical University of Civil Engineering of Bucharest – TUCEB and The Bucharest Academy of Economic Studies – ASE) and a major research center (National Institute for Earth Physics – NIEF).

The project was perceived as original by means of its design and implementation of an interdisciplinary spatial multi-criteria methodology. The method represented an integrated evaluation of the vulnerability of the urban space through inferential analysis implemented in the GIS environment.

Unfortunately, the project funds were cut by half in 2008 (although the project website was requested to mention the initial amounts). Consequently, only the historical Centre in Lipscani area could still be mapped properly.

The UB team and its TUCEB partner generated precise and accurate mapping reports on the terrain, including the state of the buildings, their functionality, structure and the building materials. The reports included data analyses according to the buildings functionality and their inhabitants at various timings of the day. The teams also conducted perception quantitative interviews which offered a clear picture of the historical center state in 2009.

The application made by the IT team of The Bucharest Academy of Economic Studies consisted of a usable tool in ArcGIS for query data and analysis of the state of buildings. This tool was based on more than 350 buildings reports representing the field inventory of all buildings in the historical Lipscani area (Figure 1).

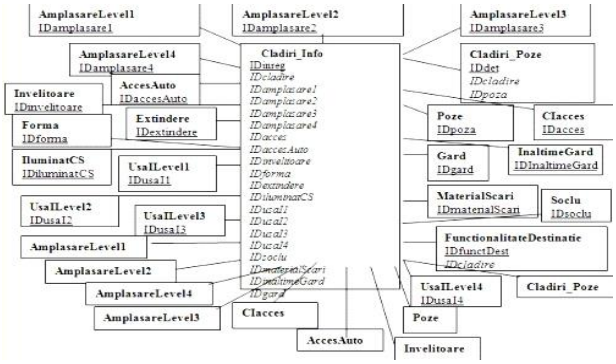

Figure 1. *Database scheme for buildings consisting of spatial and non-spatial elements*

Besides editing and visualization of buildings-related spacial and non-spacial information, the tool created was endowed with multiple filtering features (Figure 2):

a. a complex building filter allowing ranking by predefined characteristics such as age, state, function, height or historical heritage listings;
b. a building filter based on the number of floors;
c. editing/visualization of the information on buildings;
d. a building filter according to their functionality purposes.

The application generates reports on the buildings situation that are easily saved or printed for later perusal. In order to collect all relevant information, the data obtained herein were further listed according to the main features of the building. Upon inquiry of the data base, the tool then generated a synthetic report called 'Info Building'.

For an as easy as possible analysis, the data visualization could be performed both in 2D (ArcMap) or 3D (ArcScene). The two representations are simultaneously displayed and permanently correlated. The modification or selection of an element in one of the two visualizations is immediately reflected in the other one. The 2D and 3D visualizations of the buildings in the studied area facilitated a more accurate analysis.

Principal Component Analysis and Discriminant Analysis were implemented in an integrated tool of statistical analysis and results visualization (Figure 3).

In 2011 and 2013 the CMRD research team succeeded in two more scientific research projects whose focus was again laid on Bucharest vulnerability quantification and intended to understand the complex interactions between natural and social elements.

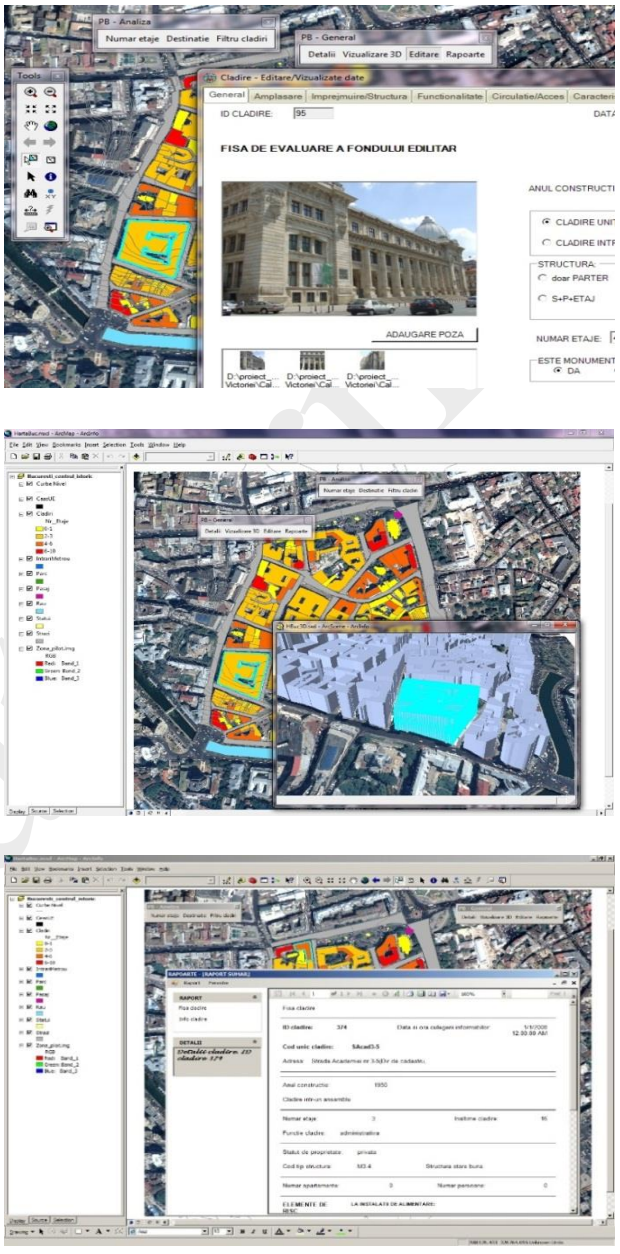

Figure 2*. Filtering, visualization and reports*

Figure 3*. Example of statistical methods for analysis*

1. REVEAL Project (Spatial and temporal patterns of urban vulnerability in Bucharest http://www.geodinamic.ro/reveal*)* was budgeted by the Executive Unit for Financing the Higher Education and University Researches. Spanned between 2011-2016, it targeted the evaluation of *environmental vulnerabilities in a time-space framework*. The objective of identifying urban vulnerabilities due to natural and anthropogenic factors in the seismic risk context of Bucharest was achieved via diachronic cartography and satellite interferometry (InSAR) techniques, correlated with geomorphological mapping and multi-criteria statistical approaches based on 1992, 2002 and 2012 census data. Results captured the space-time history of the city evolution and the vulnerability of its natural support, in relation to the physical and the socio-economic vulnerabilities.

The research new results are summed up according to the following innovating topics:

- Mapping of vulnerability of the built substance in accordance with seismic directivity. Based on a unique approach and on relevant hazard scenarios, the seismic loss estimation at Bucharest building level was shaped for the first time with analytical methods. The methodology applied relied on 48 vulnerability curves for buildings, on the Improved Displacement Coefficient Analytical Method included in the SELENA software for computing damage probabilities and on multiple seismic hazard scenarios. The 2011 and 2002 census data were standardized according to the framework of the near-real time System for Estimating the Seismic Damage in Romania (SeisDaRo). Results show the suburbs and the old city centre buildings bear the highest percentage of damages; the buildings profile aforementioned is characterized by a higher number of low-storied buildings.
- The geomorphologic vulnerability was for the first time assessed by using Differential Synthetic Aperture Radar interferometry, or DInSAR, LiDAR, and results derived from classical methodologies (i.e. diachronic cartography on detailed historical maps from 1852 until present), orthophotomaps (2006, 2008, 2010), and field research.
- The socio-demographic and economic vulnerability analysis based on a multi-criteria approach provided an image of powerful and deep social transformations rooted in the 1990s. We addressed social vulnerability as a context-dependent issue as developed by Cutter *et al*. (2003). We continued the analysis of social vulnerability in Bucharest as developed by Armaș and Gavriș in 2013, creating the social vulnerability index for Bucharest, based on the 1992, 2002 and 2011 census data.
- Quantitative population and building loss assessments due to an earthquake hazard. The population loss estimation for three selected earthquake scenarios resulted by multiplying: a) the complex social vulnerability index b) with the estimated ratio of severely damageable buildings, c) and with the population numbers in each census unit. The maps represented the quantified maximum affected population values, per unit, in percentages. We provided useful estimated figures for a possible number of severely injured, in connection with the current levels of local medical preparedness. To estimate building vulnerability we used the Improved Displacement Coefficient analytical method in the SELENA software. The building loss estimation for three selected earthquake scenarios resulted by multiplying: a) building vulnerability, b) with the number of buildings in each census unit.

2. Conducted between 2013 and 2015, the **GEOSPACE** research project (Identifying linearity /non-linearity in landscape evolution by integrating satellite-based radar interferometry and ground-based monitoring data. Study area: Bucharest, http://www.geodinamic.ro/geospace) was funded by the Programme for Research-Development-Innovation for Space Technology and Advanced Research.

We applied satellite-based radar interferometry to capture aspects of vulnerability in the urban landscape within the context of the nonlinear dynamical systems (NDS) theory. To identify the underlying dynamics of

the empirical data, linear/non-linear time series analysis (dynamics) were used in spatial analysis, and deterministic/stochastic – linear/nonlinear trends in landscape evolution. The results lead to better interferometric-based ground displacement products in Bucharest and a more effective process of interpretation of complex dynamics based on a holistic approach achieved by a multidisciplinary team of scientists and engineers. The project teamed up two universities (UB and TUCEB) and Optoelectronica 2001 S.A – a research institute. University of Bucharest was represented by the Faculty of Geography and TUCEB by the Faculty of Geodesy, the most important Romanian institution in the geodesy higher education field.

Multitemporal InSAR methodologies (initially applied to ERS, ENVISAT satellite data and later refined using TerraSAR-X satellite data), change analysis products using optical satellite data (i.e., Landsat imagery), and conventional geological and geomorphological methods captured the space-time evolution of the city. The most popular multi-temporal differential interferomtery (DInSAR) techniques, like PS (Persistent Scatterers) and SBAS (Small BAseline Subset) techniques were used for monitoring surface deformations in different types of areas. The radar displacement products were for the first time in Romania validated using Global Navigation Satellite Systems (GNSS), leveling geodetic measurements, as well as by conventional geological and geomorphological methods.

The research novel results were compiled according to the following innovative topics:

- Higher-level products development for ESA Third Party Missions (e.g. TerraSAR-X) within the Earthnet Programme, including validation campaigns, development, installation and maintenance of validation equipment (i.e. ground-based instrumentation for match-ups with satellite data), and supporting activities for validation (databases of in-situ measurements for match-ups).
- Robust and accurate monitoring and prediction of environmental state and changes based on long-term EO observations (complemented by in-situ data) addressing the new scientific challenges for ESA's Living Planet Programme in the framework of the Earth Observation Envelope Programme (EOEP). The project improved the understanding and quantification of the natural processes and human activities and their interactions, in order to better assess the relationship between urbanization and the natural evolution trends and hazards.
- ***This project was the first international assessment of chaos theory to geomorphological systems by applying two different approaches to identify the underlying dynamics of the complex empirical data achieved by diachronic geospatial analysis using historical maps, and historical satellite images data analysis: (linear/non-linear) time series analysis (dynamics) and spatial analysis, to identify deterministic / stochastic – linear / nonlinear trends in landscape evolution***.

The innovative outcome was that ground displacement trends are characterized by long term memory, which on the long term are forming interesting attractors.

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