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# Identifying limitations of Permanent Scatterers Interferometry for buildings monitoring

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**Abstract.** The Permanent Scatterer Interferometry (PSI) represents one of the most advanced monitoring techniques from space. In the current paper, the technique is applied for observing the movement behaviors of buildings found in the center of Romania's capital, Bucharest, in order to verify whether there is a possibility to differentiate among patterns. The main hypothesis of the research is that buildings respond to ground movement differently depending on their characteristics, such as age, construction material, and structure or height regime. Twenty-seven images acquired by the German TerraSAR-X (TSX) satellite, were processed in order to depict ground level deformations. The buildings were analyzed by classifying them in different categories, depending on their earthquake vulnerability, height and location. The results suggested that the movement patterns identified by the satellite depend mainly on the spatial distribution of the buildings.

**Keywords:** *Permanent Scatterer Interferometry, Urban monitoring, TerraSAR-X, InSAR*

## INTRODUCTION

In the last 100 years, the urban population of the globe has grown from 5% to 50%. The fact that in the next 30 years the urban population is expected to double implies a fast spreading of the urban areas, with the cost of green spaces, low quality infrastructure and uncontrolled spreading of built-up areas. To avoid these phenomena, the urban areas are being monitored with different techniques. Traditional methods of capturing demographic data, censuses and maps based on samples, are impractical and unsatisfactory for urban management purposes. Remote sensing – as a surface observation technique of the Earth – can help solve these problems by generating spatial information updated periodically.

Compared with other techniques used by remote sensing experts and geographers, the remote sensing of urban areas, especially using satellites, is a relatively new subject. In the past, aerial sensors used to be the main source of remote sensing data, but sensors on satellite platforms are now more popular, especially due to technical improvements that have allowed high-resolution images to be taken from high altitudes.

Even though optical sensors respond to many of the monitoring of the urban environment applications, the 3D component of cities, although substantial, cannot be captured in multi-spectral satellite imagery to a satisfactory level of detail. It is therefore necessary to use other types of sensors for observing the urban environment, such as the SAR (Synthetic Aperture Radar). Beside the thematic information that multispectral imagery can provide about urban environments, SAR images have the ability to improve the quality of classifications by exploiting the dielectric properties of microwave objects. This makes it possible to distinguish communication networks, individual buildings and green spaces by analysing the texture of objects on them or imagery representing data fusion between SAR images and multispectral images. Three-dimensional information about the built environment can be obtained by SAR imaging interferometric techniques that make digital terrain or surface models. In addition, Differential SAR Interferometry (DInSAR) allows monitoring of deformations that could affect soil and urban constructions.

## PROBLEM DEFINITION

Bucharest is one of the European capitals with a high number of old buildings (Armaș, 2006), especially in the center of the town. Being given its exposure to Vrancea earthquakes, the high population and the characteristics of the built-up area, Bucharest is very vulnerable to seismic hazard.

The heterogeneous built-up area of Bucharest consists in old buildings; built before 1940, made of concrete or masonry, without respecting any international construction codes. There is a large number of buildings that have been affected repeatedly by the earthquakes produced in 1940, 1977, 1986 and 1990. Local conditions can amplify seismic movements (Bozzano *et. al*., 2008).

The current study proposes the use of InSAR technology as an alternative method for faster identification of high-risk buildings by studying fine object movements. Accumulation of structural defects can lead to a change in the dynamic characteristics of structures (Doebling *et al*., 1996). In our study, we want to find out if satellite measurements are sufficient to distinguish between structural defects and those resulting from changes in non-structural components or environmental conditions.

Permanent Scatterer Interferometry (PSI) is the most advanced technique Differential Sar Interferometry (DInSAR), based on data acquired by SAR satellite sensors. Conventional techniques of DInSAR uses the information contained in the signal phase for at least two SAR complex images taken over for the same area at different times, from which pairs of interferograms are generated. Much of the results obtained with the DInSAR technique in the 1990s were achieved using the standard DInSAR configuration, which in some cases was the only one implemented due to the low availability of SAR data (Rosen *et al.*, 2000, Crosetto *et al*., 2005).

DInSAR results have been remarkably improved by advanced DInSAR methods, which use large sets of large SAR images that have captured the deformation phenomenon of an area over time. New techniques represent a great advance compared to conventional ones, given both the modelling capacity and the quality of the estimated deformations. Beginning around 1990, several methods have been proposed to work with large SAR databases, but a fundamental step was the proposed technique by Ferretti *et al*., (2000), called the Permanent scatterer technique. The technique has now been adopted and adapted by other researchers in the field, being accepted as Permanent Scatterer Interferometry.

The deformations of the surface could not be reconstituted for an entire image without loss of information in some areas, mainly because of temporal decorrelation. To prevent lack of information, the method uses objects (pixels) whose signal is stable over time. A method of identifying pixels that remain coherent in time to radar signal is to analyse the dispersion index, which represents the ratio between standard amplitude deviation and average pixel value in all images, analysed in a stack. Also, a large ratio between a pixel value and the average pixel surrounding it indicates that the pixel could contain a permanent reflector (Adam *et al.*, 2008). The reflectivity density depends greatly on the type of ground cover and can vary significantly in a studied area. The highest density of persistent targets is found in inhabited areas, which makes the technique of persistent targets particularly useful in monitoring deformation or elevations in urban areas.

## BUILDING ANALYSIS

In order to identify buildings that suffer degradations over time in Bucharest, an object-oriented analysis was applied in a restricted test area – the Old City Centre (Figure 1). The studied buildings are selected according to the existing terrain mapping. The results obtained from the PS analysis of 27 TSX images, obtained between 2011 and 2014, were used in order to analyze building movements, being given the wavelength of the signal (3 cm) and the magnitude of the expected movements.

Six blocks have been delineated containing a large number of buildings considered very vulnerable in case of earthquakes, mainly because of their age, structure and localisation. The buildings in the study area have a similar height, 1-2 floors, and older than 50 years. In the behavioural analysis of buildings, it was assumed that structural or surface degradation could be observed by interpreting the behaviour of buildings emerging from the displacements of the points detected at their level. With the help of the TSX images, which have a 3-meter-high resolution, hundreds of building-related points were determined. The comparison of building movements was based on the determination of the minimum and maximum values of the displacements suffered by all the points of the studied building, the determination of the average standard deviation of the displacements, as well as the interpretation of the graphical representation of the variation of movement for each point.

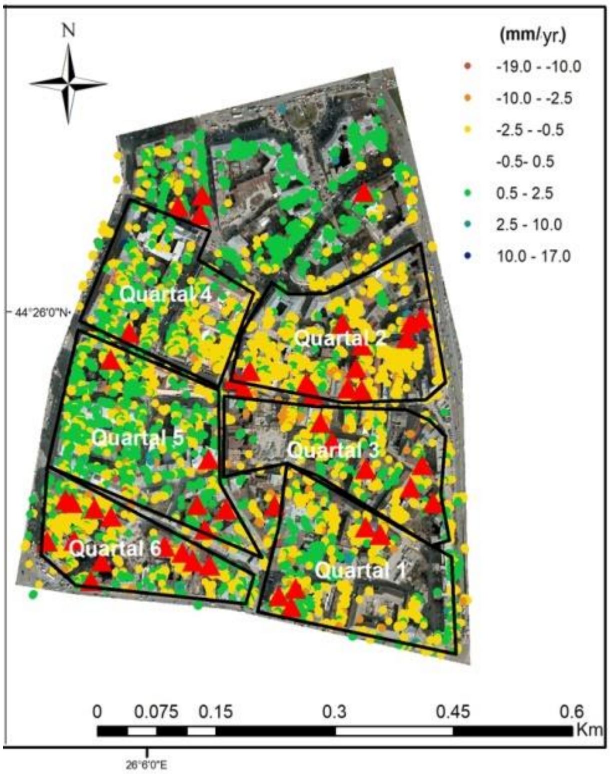

***Figure 1.*** *PS points resulted in the historical centre of Bucharest*

First, an analysis was carried out on buildings differentiated by their appertenance to the earthquake risk class 1, as classified by the authorities (Table 1).

The investigation continued with buildings with a different height regime in order to identify the influence of the buildings' attributes on the movements detected by InSAR. For this purpose, we chose the 5th and 6th quartals, where we could identify 8 buildings with different height regime, not classified in any seismic risk classes, for which the following data were calculated (Table 2):

***Table 1.*** *Statistical analysis of buildings classified according to seismic risk*

| Quartal | Seismic Risk | Points | Displacement statistics | | | |
|---|---|---|---|---|---|---|
| | | | Avg. (mm) | Min. (mm) | Max. (mm) | Std. dev. (mm) |
| 1 | Yes | 180 | -2.53 | -15.22 | 6.76 | ±1.80 |
| | No | 144 | -1.32 | -11.06 | 5.65 | ±2.02 |
| 2 | Yes | 143 | -2.40 | -11.26 | 7.54 | ±1.75 |
| | No | 150 | -2.23 | -10.23 | 4.56 | ±1.71 |
| 3 | Yes | 44 | -2.58 | -6.56 | 3.35 | ±1.45 |
| | No | 140 | -2.44 | -6.78 | 7.34 | ±1.65 |
| 4 | Yes | 151 | -1.68 | -8.42 | 7.23 | ±1.58 |
| | No | 160 | -1.34 | -6.35 | 7.34 | ±1.47 |

***Table 2.*** *Statistical analysis of buildings classified according to height from quartals 5 and 6*

| Quartal | Building type | Points | Displacement statistics | | | |
|---|---|---|---|---|---|---|
| | | | Avg. (mm) | Min. (mm) | Max. (mm) | Std. dev. (mm) |
| 5<br>6 | G+7 | 149 | -0.98 | -7.98 | 6.13 | ±1.38 |
| | G +4 | 48 | -1.25 | -7.72 | 4.34 | ±1.48 |
| | G +4 | 97 | -0.50 | -5.36 | 6.21 | ±1.37 |
| | G+1 | 43 | -0.82 | -5.55 | 4.74 | ÷±1.42 |
| | G+3 | 99 | -0.25 | -8.68 | 5.63 | ±1.40 |
| | Church | 36 | -1.87 | -8.07 | 10.32 | ±1.37 |
| | G+1 | 76 | -0.44 | -8.50 | 4.49 | ±1.64 |
| | G+1 | 100 | 0.40 | -9.03 | 8.00 | ±1.46 |

Table 3 summarizes the results obtained from the comparison of the statistical data calculated for buildings in P + 1 height, not included in seismic risk classes, in different regions, thus having a spatial distribution dispersed in all 6 considered quartals.

***Table 3** Statistical analysis of buildings classified according to height from quartals 5 and 6*

| Quartal | Points | | Displacement statistics | | |
|---|---|---|---|---|---|
| | | Avg. (mm) | Min. (mm) | Max (mm) | Avg. (mm) |
| 1 | 144 | -1.32 | -11.06 | 5.65 | ±2.02 |
| 2 | 150 | -2.23 | -10.23 | 4.56 | ±1.71 |
| 3 | 140 | -2.44 | -6.78 | 7.34 | ±1.65 |
| 4 | 160 | -1.34 | -6.35 | 7.34 | ±1.47 |
| 5 | 76 | -0.44 | -18.50 | 4.49 | ±1.64 |
| 6 | 100 | 0.40 | -9.03 | 8.00 | ±1.46 |

In figures 2, 3, 4 and 5, the variation of point displacement was represented for each quartal from 1 to 4, where buildings were classified according to the seismic risk.

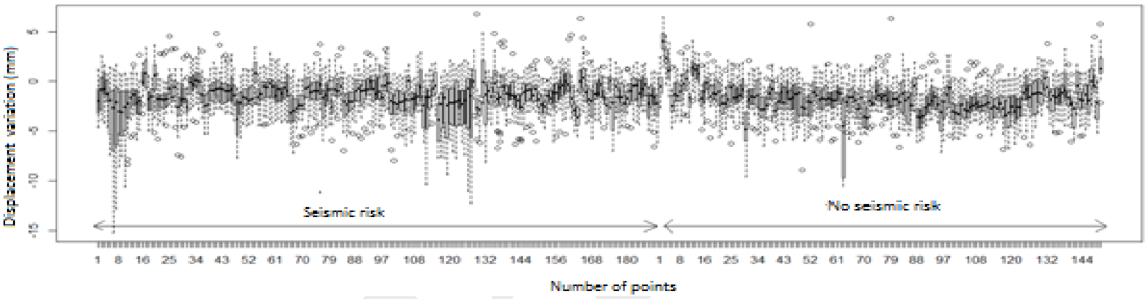

***Figure 2**. Graphical representation of displacement variatins of points in quartal 1, classifies according to seismic risk*

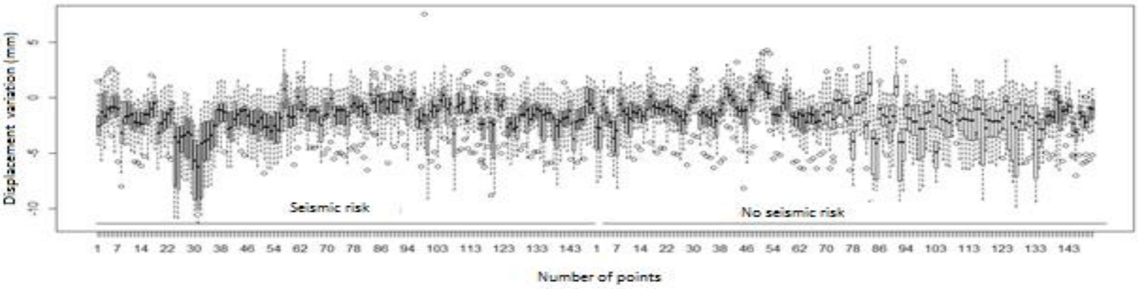

***Figure 3**. Graphical representation of displacement variatins of points in quartal 2, classifies according to seismic risk*

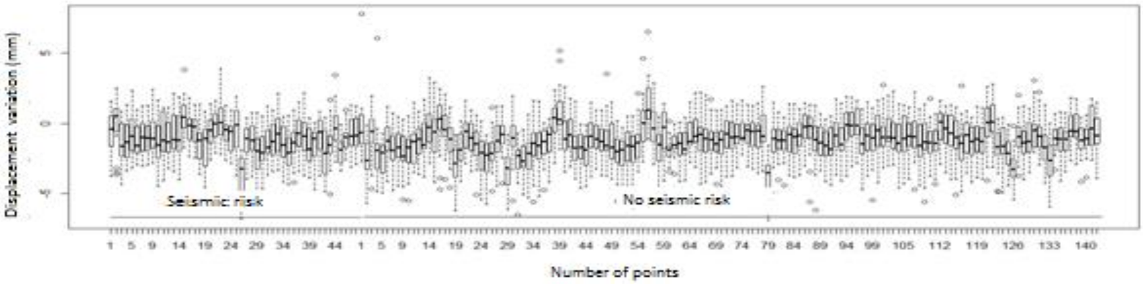

***Figure 4.** Graphical representation of displacement variatins of points in quartal 3, classifies according to seismic risk*

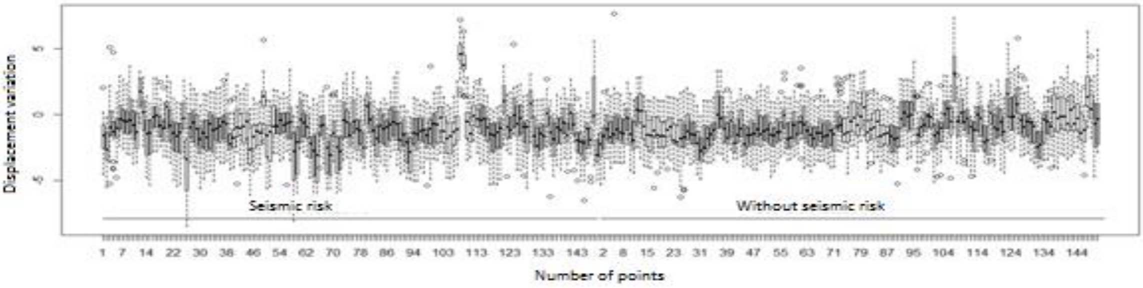

***Figure 5**. Graphical representation of displacement variatins of points in quartal 4, classifies according to seismic risk*

## RESULTS AND DISCUSSION

After analysing the values obtained for the displacements and variations of the points displacements, it is observed that the average, minimum and maximum values do not suggest any remarkable differences between the buildings. Statistical data suggests that movement detected by InSAR means cannot be considered a predictor for identifying buildings classified in high seismic risk classes. Both the average displacement values and their variation of this are rather indicators of proximity of the investigated buildings, taking into account that the analysis was made on buildings with a similar height regime.

Building-type analysis has led to inconclusive results for differentiation of movements according to the height regime. Regarding both the centralized values as well as the graphical representation of the displacement variation of points on buildings over time, no classes could be identified in which they could be ranked according to the description of the point movements.

The last analysis of the points on buildings took into account the hypothesis that satellite recordings can primarily detect the building deformations due to ground surface movement. Considering the revisit interval of 11-day satellite imagery, which cannot often be reproduced due to the influence of meteorological conditions on images, we can assume that the characteristic vibrations of the buildings are not captured by the linear processing of satellite imagery. Also, façade elements that may be damaged on a medium or severe degradation building may cause excessive displacement, causing a loss of coherence in SAR images.

Both the statistical data and the graphical interpretation show that the differences between the magnitude and variance of the displacements determined by interferometric processing are predictors of the spatial distribution of the analysed objects and not the individual characteristics of the buildings.

The same interpretation of the movements can be found in Armaş *et al.*, 2017, in which the cracks appeared on the façade of four individual buildings, the Parliament Palace, the Lazarus College, the National Archives and the City Hall's headquarters, were measured using a geological compass. The orientation of cracks appearing on the facade of buildings shows a correlation between nearby buildings and differences from buildings in a geomorphologically different area. As a result, the Palace of Parliament shows a predominantly East-West layout, which is also found in the building of the City Hall. At the headquarters of the National Archives and the Lazar College, the cracks are disposed of by the SVV-NEE. The headquarters of the City Hall, the National Archives and Lazar College headquarters also show cracks in the North-South direction, which are not observed on the Palace of Parliament building.

## CONCLUSION

The main objective of the current paper was to identify the limitations of InSAR techniques in observing building deformations in urban areas. In this purpose, we processed 27 TSX images acquired between 2011 and 2014 over Bucharest. The old centre of Bucharest was considered the area of interest due to the characteristics of the buildings found here.

The analysis considered three scenarios in which different building characteristics that could influence movement patterns were considered: first was the risk class of the building, the second was the height regime, while the last considered only the spatial distribution of points, in different regions of the city centre. The main conclusion was that the main predictor of building behaviour that was identified by InSAR techniques is spatial distribution.

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