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Research Report no. 2:

Methodology for urban and periurban areas analysis and monitoring using optical and radar data

Part of the Doctorate Thesis:

Remote Sensing Techniques for monitoring urban and periurban areas using optical and radar data

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Summary

1. Infrastructure monitoring using InSAR techniques

In the case of urban real estate, heritage buildings or old buildings receive particular attention. Engineers who are evaluating the condition of buildings often study causes that have led to their collapse. Most often, the cause of the building crash is sought in the way the structure yielded (Atkinson, 1998). Such studies can be used to improve the construction of future structures. InSAR's ability to look in the past could be a unique asset in studying the causes of construction collapse by identifying early degradation (Metternicht et al., 2005). Using this technology, it it manifests at the surface of a structure, the deformation over time may be observed earlier. An engineer usually issues a series of hypotheses about the possible causes of collapse that can now be verified and possibly validated using InSAR techniques.

There are three basic principles that should be used as a guide to infrastructure studies using InSAR:

- Random character: The location and number of points on a building cannot be arbitrarily foreseen or imposed;
- Large deformations: The study of large deformations may be affected by ambiguity of the phase;
- Spontaneous Deformations: If the deformation evolution occurs within a single measurement cycle (from one satellite to another) then it cannot be identified.

1.1. Building degradation and structure failure

Studying the failure causes for buildings involves collecting and analysing data to determine the cause and the development of the phenomena (Eisenhardt, 1989). The collapse of a structure depends on the load and the ability to withstand this load without the structural integrity being affected (Ellingwood, 2006). According to Euorocode 0 - Fundamentals of Structural Design (2011), the loads to which a building can be subjected are of three types: permanent loads, such as structural elements, underground water pressure or pre-tensioning of the elements, which remain approximately constant over time; live loads, such as people, cars, furniture, rainfall, wind and temperature variations, which vary the most over time; accidental loads such as earthquakes, explosions or fires, which are characterized by large magnitudes and catastrophic consequences, but with a low production likelihood.

Phases in which buildings are ceded are categorized in literature in three categories:

- The cause triggering the failure mechanism;
- Mechanism of failure;
- Failure;

The cause of failure is the event that leads to a loss of stability, rigidity or power (failure mechanism), which ultimately causes the collapse of the building. When analyzing the cause of failure, engineers are trying to determine the mechanism of responsible failure and the cause of failure. So the engineers investigating the cessation cause start from the final event to the initial one, that is, study the cessation, and then observe how it was produced, in order to finally determine its cause (Fig. 1).

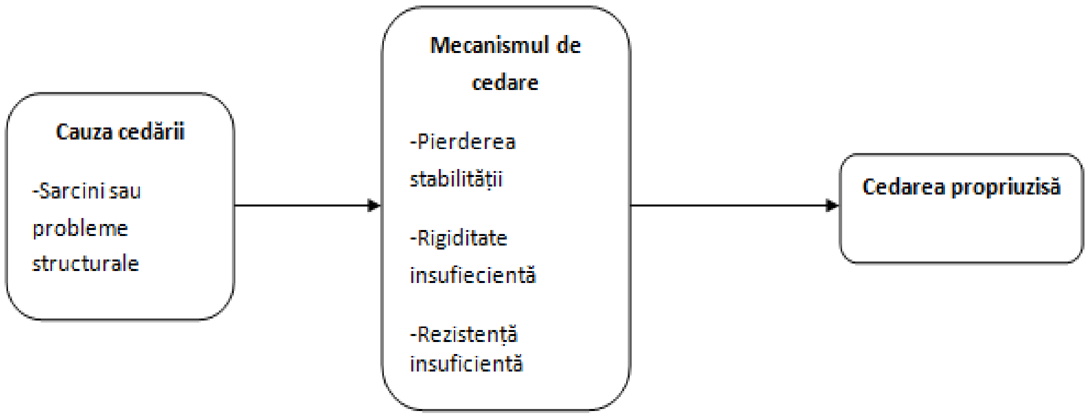

Figure 1. The steps of investigating the process of building failure

1.1.1. Cause of failure

Loss is caused by the load affecting a structure, and the ability of the structure to withstand the load. In other words, where Sd represents the load or force acting on the structure, and Rd is the strength (stability) of the structure then:

$$Sd \leq Rd \qquad (1);$$

Failure is always caused by a load overload or a lack of resistance required to support the load. Van Herwijnen (2009) states that the failure of a structure may have 4 main causes

:

- **Aging,** which causes biological and chemical processes of material degradation, such as iron corrosion. Structural elements can yield over time also due to the impact of loads or wear;
-
- **Nature**, which is manifested by earthquakes, floods, hurricanes or other extreme phenomena that may affect the integrity of a building;

- **People's influence** can be intentional or unintentional. Intentional causes include explosions for demolition. Unintentional causes are fire resulting from short circuits or unintentional collisions with buildings;

- **Structural errors,** which can be divided into the following subcategories:
    a. *Design errors*: These can include a multitude of causes, from choosing unsuitable materials to calculation errors. Using new materials can also lead to design errors;
    b. *Building errors*;
    c. *Unforeseen loads*, which may include extreme rainfall or changing the destination of a building that results in an overburden of the building, which was not originally envisaged;
    d. *Unforeseen failures* (may include design errors)

1.1.2 Failure mechanisms

The mechanism of failure is the way in which it yields a material, part of a structure, or a whole structure. It always occurs due to a lack of resistance, stability or stiffness relative to the structural loads. In this case, only mechanisms that can displacements are interesting because InSAR technology detects the movement. An element may be affected by different types of motion, such as translation, rotation, transmutation or fracture.

As far as the ability of InSAR technology to capture a failure mechanism is concerned, it depends not only on the type of movement but also on the location of the creeping element. Because technology is based on satellite measurements, it should be borne in mind that not all elements of a building are captured in the processed images.

2. Built-up environment in Bucharest

Being ranked as the 10th city in the world and the first in Europe in terms of vulnerability to earthquakes, Bucharest is considered the city with the highest seismic risk in Romania (Armaş, 2006). The location on three faults, the large population and the large number of old buildings increase the vulnerability of the city to the strong earthquakes that occur regularly in Vrancea. There are a number of factors influencing the seismic risk of the capital (Carreño et al., 2007; Poljanšek et al., 2012), of which the most important are: the geographical position - 100-170 km from the Vrancea epicenter; the large number of buildings with over GF + 3 floors, concrete or brickwork, built before 1940, with structures designed to withstand only the action of gravitational force, and degraded in advance by strong earthquakes produced in the 1940s, 1977 , 1986 and 1990; the non-existence at national level of seismic codes during the construction of these buildings, providing the necessary knowledge and technical standards for the construction of strong earthquake resistant structures; local conditions that lead to the amplification of seismic movements, with destructive effects on the existing structures; period of vibration of high buildings built in the interwar period similar to the vibration period caused by the powerful earthquakes in Vrancea, which produces resonant, destructive effect for high buildings (Vlad & Vlad, 2008).

To prevent the loss of life and material in the future, the authorities are trying to classify buildings according to the risk of collapse at the next earthquake. The notion of seismic risk is closely related to seismic vulnerability and seismic hazard.

"The **seismic vulnerability** of a building is a measure of the nature and extent of the degradations and damage caused to the construction of seismic actions of different intensities." "The **seismic hazard** of a site is a measure of recurrence of seismic events having certain peculiarities on that site within a given timeframe." "**Seismic risk** is a measure of anticipated degradation and damage to a site located within a given timeframe."

It is noted that the seismic risk depends on the seismic vulnerability of the construction and the hazard of its location. Seismic vulnerability, seismic hazard and seismic risk are expressed by probabilistic probabilities. In practice, the three sizes are quantified by numerical indicators. In the established normative (Government Ordinance 20/1994) for buildings in Bucharest, the seismic risk of a building located in a seismic area (Fig.1) is considered conventional by fitting into the four seismic risk classes. The list of seismic risk buildings in Bucharest was updated by the local authorities on October 30, 2015. According to the most recent data, 374 buildings with extremely high seismic risk, 189 being classified as "public hazards" (Figure 2). Another 2100 buildings fall into classes with lower risk, requiring consolidation. By the time the data was published, only 28 buildings had been consolidated. However, the inventory process proves to be cumbersome because the techniques for detecting structural defects in buildings are complex and time consuming (Glaser et al., 2007). In the overall characterization of the probable behaviour of the building to future seismic actions, the technical expert must take into account a large number of factors, of different nature. Generally speaking, valid rules cannot be used to quantify these factors, but by judicious interpretation of the results of all investigations made in the expertise, by comparison with other similar situations, through engineering judgments, the construction in question can be framed in one of the four classes of seismic risk.

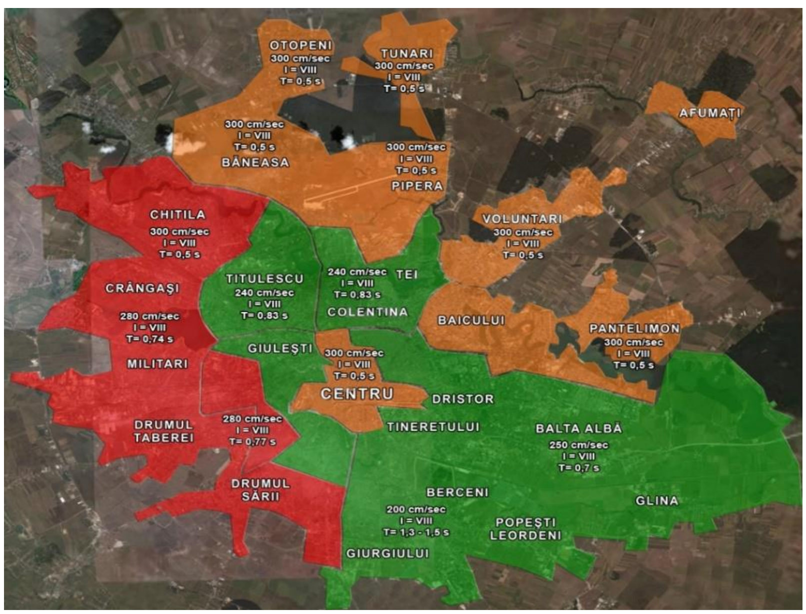

Figure 2. Ground acceleration zones in earthquake in Bucharest. Green - low acceleration; Orange - medium acceleration; Red - high acceleration. (Source : www.riscseimsic.ro)

2.2. Distribution of buildings in Bucharest by collapse risk classes

A number of 4 seismic risk classes is established from the point of view of the seismic risk, in the sense of the likely effects of earthquakes, characteristic of the site, on the existing constructions on that site:

__The RsI__ class, corresponding to high earthquake collapse constructions having the intensities corresponding to the seismic calculation areas (design earthquake) (Figure 2);

__Class RsII__, corresponding to constructions where the collapse probability is low but where major structural degradation is expected;

__Class RsIII__, corresponding to constructions where structural degradations that do not significantly affect structural safety are expected but where degradation of non-structural elements may be important;

__The RsIV__ class, corresponding to constructions where the expected seismic response is similar to the one for new constructions designed on the basis of the provisions in force.

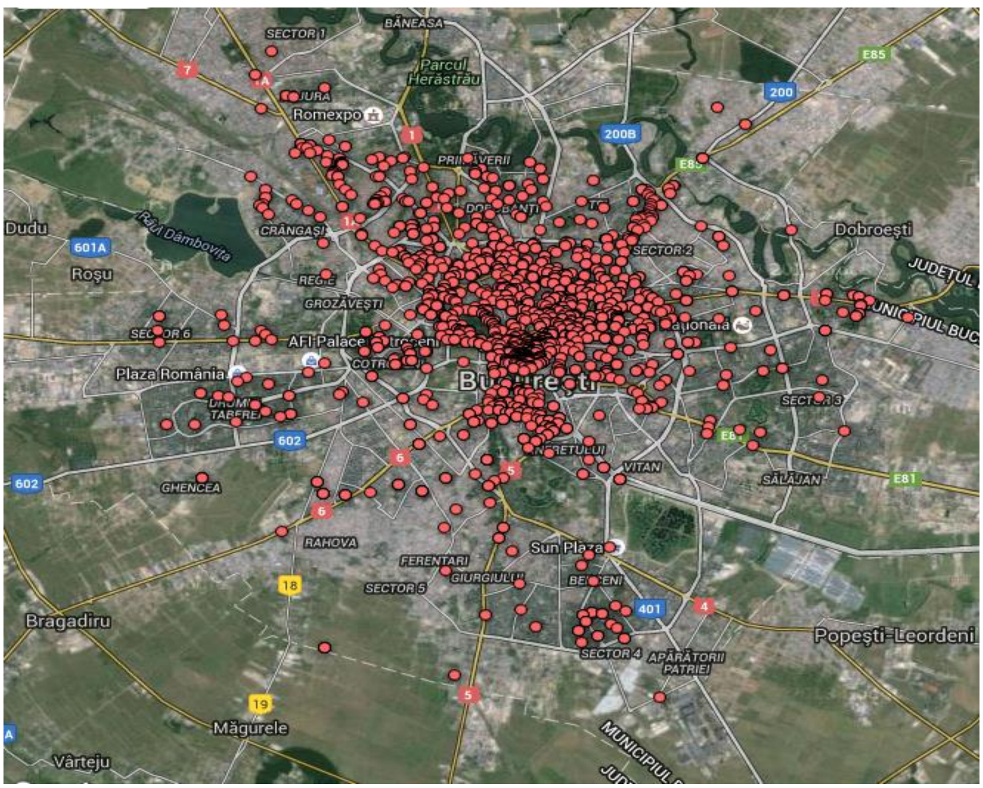

Figure 2. Buildings in Bucharest classified as RSI risk (source: www.riscseismic.ro)

In the decision making for seismic risk classes, the expert consider the seismic area in which the construction is located and criteria for the construction of the building (Eastman et al., 2011), behavior in exploitation and seismic actions, such as:

- the category of the structural system;

- general construction conformation in terms of the expected seismic response;

- the nominal degree of insurance against seismic actions (index R);

- the presence of weak areas in terms of resistance capacity in relation to the requirements in the structural elements with a major role in taking over seismic loads;

- Probable nature of failure of vital structural elements for building stability: ductile, limited, frail ductibility;

- how to solve the constructive details of the sections (eg cross-sectional reinforcement in the plastic areas, potential, anchoring of the reinforcements, demolition, etc.);

- the age of the construction (the year of construction);

- the number of significant earthquakes through which the construction has passed;

- structural degradation caused by earthquakes;

- state of non-structural elements;

- the height and mass regime of the building, etc.

The weight of the various structural assessment criteria is determined by an expert.

As an alternative to identifying high-risk buildings, our study proposes using InSAR technology as a faster way of identifying fine object movements. Accumulation of structural defects can lead to a change in the dynamic characteristics of structures. 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. Also, the precision of InSAR technology in detecting the dynamic features of the infrastructure needs to be considered.

2.3. Methodology for using InSAR technique for building monitoring

The objective of this study is to verify the feasibility of InSAR technique in monitoring and examining the causes of degradation of historic buildings in Bucharest. For our study we will first consider the database of buildings classified as seismic risk class I. The first important information to be known in the case of the buildings under consideration is general information about it. The location, number of floors, type of building and building destination are important. If they exist, knowledge about possible types of deformations affecting buildings would also be important: the description of the deformations, the moment of discovery, the building materials, the structural parts involved, the tasks and the technical causes.

Studies by Terwel et al., (2012) and Terwel (2014) describe that in the case of buildings whose structure is affected by deformations, this becomes visible on the surface. Signs that may indicate deformations include cracks, element shifts, or corrosion, as well as other indicators of physical degradation. For the current study, this category is very important because the identification of some indicators of building degradation is one of the most important aspects of the analysis of structures in distress.

There is a number of conditions that need to be met by buildings that are monitored with InSAR:

- Deformations can only be observed if they are not very large (≥1.5 cm / month), are not visible on the outside, or have an evolution shorter than 11 days (the TerraSAR-X and Sentinel-1 satellite review cycle). Spontaneous deformities or crashes cannot be observed with InSAR. One of the causes of spontaneous collapse is also extreme weather, such as high rainfall and snow or strong wind.
- Because it is impossible for the satellite to make observations during the construction, renovation or demolition of a building, the only phase in which a building can be traced from space is the use phase. According to Terwel's (2012) studies, 66% of structural errors can be identified in the building use phase, even if they were previously triggered.
- Deformations must be visible on the facades of the buildings. The visibility of the deformations can be divided into two groups: direct visibility and indirect visibility. Direct visibility refers to deformations directly affecting the façade, indirect visibility refers to deformations affecting the structure of the building's strength, influencing the exterior walls of the building.

Since most buildings classified as seismic risk class I are old buildings, the condition that deformations develop over the period of their use is met. Also, most buildings suffer distortions due to aging and degradation of the building material, so they are suitable for monitoring with InSAR technique because the deformation evolution time is long.

In investigating the cause of deformations and eventually the collapse of buildings, there is a triggering cause that initiates a failure mechanism that ultimately leads to collapse. In the present case, the buildings that will fall on the next Vrancea earthquake are unknown, but we have a database containing some of the buildings with a high probability of collapse.

Investigation engineering analyses the cause of building failure. A cause triggers a failure mechanism that ultimately leads to collapse. Evolution of movements caused by torsion, non-elastic deformations, and fractures or bending effects are difficult to detect with InSAR. To be identified, these types of deformations must either be visible on the outside of the building or cause special displacements of the construction as a whole. Deformations of the resistance structure can affect the structural integrity of the building, making it visible externally. The fact that InSAR can also identify parts of the building that are not affected by the damage and allow a comparison with the affected parts makes this technique a useful means of supporting assumptions such as the evolution of the buildings failure in time.

2.3.1. Methodology for building monitoring

Building monitoring seeks to identify indicators of degradation, or indications that there is a risk of degradation in the future. The purpose of this chapter is to analyse how InSAR could be used as a monitoring tool to serve to identify those high-risk buildings in Bucharest. Firstly, the difference between investigating the causes of collapse and monitoring buildings needs to be considered. Investigation consists in identifying the mechanism that led to building failure and the triggering cause after the occurrence of a degradation (Chong et al., 2006). Monitoring, on the other hand, attempts to capture the initial phase of a degradation, precisely to prevent collapse. While the previous chapter focused on describing how to identify the movements that caused the collapse, this chapter refers to those movements that indicate future degradation.

As an initial point, deviation from anticipated behaviour is considered to indicate future yields. Pratesi et al., (2015). In this chapter the central subject is the causes that induce structural movements. Structure deformation is caused by the forces acting on the structure and its strength. A change in forces or structural strength could cause a change in the stability of the structure.

This chapter contains a brief introduction on how to use building monitoring. Then there are two types of monitoring, object-oriented and data-based. Object-Oriented Monitoring focuses on a particular building, analysing how it can be monitored using InSAR data. Data-based monitoring requires data to be interpreted without looking at a particular building.

In the case of object-oriented monitoring, a particular building whose properties are known is being analysed. The movements of a structure can be caused by the forces acting on a building and the strength of its structure. In the case of such monitoring, it is assumed that in the beginning the constructions are not affected by any deformation, so that the occurrence of a change in deformations during the monitoring indicates the beginning of a degradation. The following will be presented how object-oriented monitoring can be used to detect anomalies in structure movements.

In the case of data-based monitoring, no pre-defined building is considered, but it is selected areas of interest that are being examined. In this case, possible degradations may be indicated by anomalies in the data held, if these data describe the movements of a building. The overall boundaries within which the movements of a building have to fit so that it can be considered stable is analysed. This chapter concludes with conclusions on how InSAR can be used for object-oriented or database-based monitoring.

2.2.1. Principles for the application of building monitoring methodologies

Liu and Tomizuka (2003) state that engineers are looking for new technologies and analytical methods to help identify the onset of structural degradation. These systems are called structural health monitoring systems. The structure health monitoring process involves observing structures for a period of time using periodic measurements. By analyzing these measurements, the current state of a structure can be determined. The result of this process is periodic that information on the ability of the structure to continue to behave normally within acceptable admission limits should be constantly updated to detect possible degradation due to aging or the environment.

Lynch and Loh (2006) describe structural monitoring systems that have been widely adopted abroad to monitor the behavior of structures during earthquakes, strong winds, and possible additional loads. Structural monitoring systems can be found including aircraft, ships and civil structures (Table 1). For example, some buildings complying with design codes for structures located in regions of high seismic activity have individually installed structural monitoring systems. In East Asian countries, there are regulations for the construction of bridges that provide for periodic certification of bridges through vibration monitoring systems (Doebling et al., 1998). There are no codes in Romania to set up rules for building monitoring, and buildings with a high seismic risk are too numerous to benefit from one own monitoring system. InSAR has the potential to contribute to the development of SHM as a building monitoring system.

Table 1. Comparison between building monitoring techniques

Monitoring technique	Accuracy	Sampling	Coverage	Temporal resolution	Limitations
Tahimetry	0.6 mm	dcm	small	continuous	Obstruction
Leveling	0.3 mm	manual	small	manual	Obstruction
GNSS		manual	average	continuous	Accuracy and availability are weather dependent
Terrestrial scanner	2 mm	mm	average	continuous	Obstruction
Photogrammetry	15 mm	mm	small	continuous	Obstruction
InSAR	2 mm 0.4 mm for time series	m	large	11 zile (TSX)	Small point density in vegetated areas Displacement in the LOS of the satellite

2.1.1.1. Object oriented monitoring

The object-oriented building monitoring is presented in this chapter. In this case, it is the structure of the building is known and, therefore, specific deformation limits can be formulated. For this technique, the properties of the building are of interest. This subchapter first describes the influences that can cause building deformations, the properties of InSAR targets on buildings, and finally shows how object-oriented monitoring should be deployed using PS-InSAR

2.3.2.1.a. Building properties

For this type of monitoring, the number of PS points on a building is known, and the travel limit conditions are imposed according to the properties of the buildings.

There are a number of important information that needs to be known to formulate the limit conditions for InSAR data that are contained in a list of the different elements of a building and why they are important for monitoring deformations:

- Layout of the beams: these depend on the vertical deformation limits;
- The height of the structure;
- Structural system: the external deformation of the building cannot be determined without knowing the structure of the building; the important parameters are whether the structure is monolithic or not, if there are expansion joints, and how the structure is connected to the outer shell;
- Influence of the environment: activities in the vicinity of the building and extreme weather conditions can lead to deformations;
- Forces acting on the building: are most important for old buildings, as they are the ones that cause long-term distortions;

2.3.2.1.b. Properties of the PS points on buildings

In the object-based building monitoring, the number and location of PS targets on the building are known (Ferretti et al., 2000, Ferretti et al., 2001, Hooper et al., 2007). The details of the information obtained depend on the location of PS points, number of PS points, the quality and number of images used to determine PS points. The more PS points and images available for a building, the more information is available. A big disadvantage is that the location of PS points can not be determined a priori, but their distribution is random on the outside of the building. A possible solution for cases where it is desired to track the movements of certain parts of a building is the use of corner reflectors, which are objects with high coherence in the field of radar waves (Fig. 4).

If there is only one point on the building, the only drives that can be deducted are those in the vertical direction. The relationship between satellite data and horizontal motion is not yet well-known to draw conclusions if the movement is unknown. One method that determines horizontal displacements is the use of data acquired by satellite at ascending and descending movements in orbit (Figure 5).

Figure 4. Corner reflector for radar signal

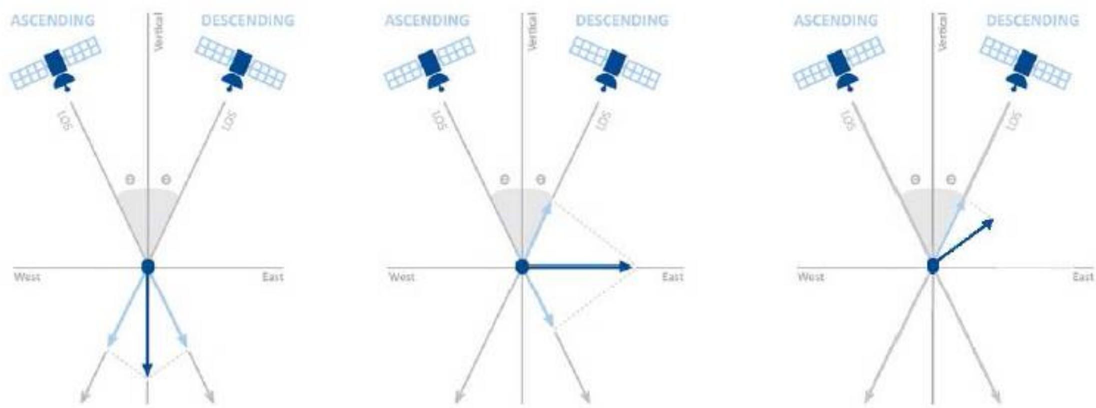

Figura 5. Determination of the displacement vector of a PS point. The black arrows indicate the direction of movement of the PS point, and the blue arrows indicate the satellite travel vector recorded in the descending and ascending orbit.

When there are several PS points on a building, two variants may appear as regards the location of the points. Points can measure different parts of the structure or the same parts of the structure. Different parts are formed by expansion joints, balconies or parts that do not have any structural properties. Two points on different parts of the structure can be seen as a satellite as a single point on the building. The only advantage is that the movement can be tracked compared to the other point on the building. When there are two points on the same part of a structure, it is possible to calculate the relative displacement between these points, and hence the behaviour of the structural element surprised by the PS points. The more points on the structure, the more related parts can be analysed. If, on one side of the building, all the points move in the same direction with the same magnitude, it could indicate problems at the foundation. If a displacement has a high value at a certain point in the structure, then gradually drop off at the other points of the structure, it could indicate a collapse of a column in the internal structure. Behaviour of neighbouring points can give more detailed information on the exact location of the structural problem. For better interpretation of the results, it is also advisable to know the movement of the soil surrounding the building, which can be deduced from the points showing movements in the same direction.

If the locations of the PS points for ascending and descending orbit are approximately the same, and the displacements are similar, the displacement is assumed to be vertical. If the deduced movements indicate movements in opposite directions, then the movement of the structure is assumed to be horizontal. If the same location can be captured by three or more satellites, one can also deduce the rotation of an element. The number of satellites and the number of dots deduced for a building clearly influence the monitoring capabilities.

2.3.2.1.c. Description of the monitoring process

In order to better understand the changes taking place between two SAR passes and implicitly to capture the moment when alarming situations arise, the estimated movement of the structure needs to be analyzed. Any structure deforms continuously over time under the influence of the working forces that act on the building and its strength. When the structure and its surroundings are known, these movements are known, these movements can be anticipated. When unexplained movements occur in the deformation of the building, they can be caused by the formation of a deformation mechanism. Through InSAR monitoring, the cause of the fault could be identified at an early stage, before the total failure of the building would take place. That is why monitoring of buildings focuses less on the moment the building is released, and more so on the observation of the cause and the failure mechanism. There is a different type of approach than the cessation investigation. The following subchapter analyzes the causes that cause movement of structures over time for a better understanding of how InSAR data is interpreted and how to use this technique to monitor and identify moments when the failure mechanism is triggered.

2.3.2.2. Monitoring structures using InSAR databases

This subchapter will present another approach to structure monitoring, based on InSAR data. For this type of monitoring, the structure is unknown, and this leads to a different approach than the one used to monitor the object-based building. For this type of monitoring, general guidelines must first be made to identify potential damage. With data-based monitoring, the entire area is monitored, with no regard for specific structures. The first data-based monitoring step of a building is to determine the location of the PS point to determine if there is a building in that location. The second step is to recognize the values that could indicate damage. For this purpose, general travel limits for these points should be set, maximum deformations allowed horizontally and vertically for each type of construction. These limits must be laid down in a country's building regulations. The deformation limits are analyzed based on the Eurocodes. The deformation limits are divided into three categories: vertical beam deformation, horizontal column deflection, and rotation and deformation of the foundation. For vertical deformation, a single position of a satellite may be sufficient. In cases of horizontal deformation or rotation, different orbits of the satellite are needed.

These deformation limits can support the search for degradation of buildings. One major drawback, however, remains the fact that each building is unique, has different deformation boundaries, and therefore any degradation may be different, being difficult to identify and interpret. Most deformations having predetermined limits are those of the foundations, the vertical deformations of the beams or the horizontal ones of the columns being more difficult to fit within certain limits.

2.3.2.2.a. Beam deformation

Vertical deformation of a beam is called bending. This can be caused by vertical loads or those due to temperature changes. Curved beams can be seen by satellite if they are part of the main load bearing structure, they support the roof structure, or they are part of the roof structure. The curvature of a bead can be identified if the limit values are known / the magnitude of the curvature is different for fixed and bearing beams. In addition to the design equations, it appears that the magnitude of the displacements depends on the loads, the type of material, the moment of inertia and the length of the elements. The length difference will have the greatest impact on the curvature value. If it is assumed that the only one that changes over time is the force acting on the structure, then the curvature is a linear deformation. The Eurocodes set design limits for vertical movements. These limits are described in the figure below (Figure 6)

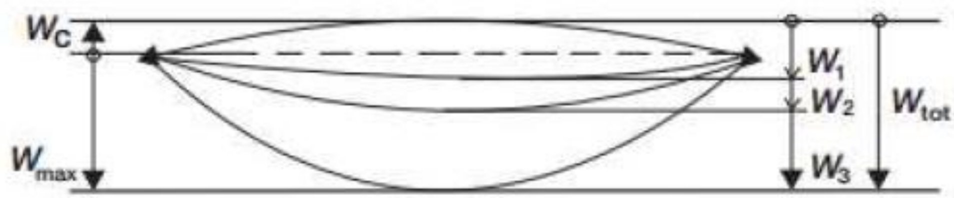

Figura 6. Curvature of a horizontal object (Source: NEN-EN 1990 (2002))

In this figure, (Wc) is the deviation. (Wmax) is the total deformation, considering the deviation (Wc). (W1) is the initial deformation caused by the floor's own weight, influenced in short intervals by the properties of the material. (W2) is a long-lasting deformation that can be calculated using quasi-permanent forces and properties of the long-term building material. W3 is the additional deformation caused by live loads. (lrep), not shown in the figure, is the opening, given by the distance between the pillars. Crack-sensitive partition walls have a design travel limit equal to 1/500 of (lrep). The elongation is W2 + W3. For floors and roofs, which are extensively used by people, the maximum displacement is 3/1000 of (lrep), calculated with frequent loading combinations. For other roofs, the deviation limit is 1/250 (lrep), calculated using characteristic load combinations.

If we consider the old buildings in Bucharest, most of them are inhabited buildings. Peter sets the limits of the movements from which the situation can be considered alarming, the dimensions of the buildings and the design boundaries provided by the Eurocodes must be taken into account. Old buildings are either block of flats, houses with terrace, houses with common walls, or individual buildings. In the table below, the Eurocodes were used to set the travel limits (Table 2).

Table 2. Vertical bending limits of the horizontal elements according to the opening of the structure

Building type	Frequent opening (mm)	Maximum vertical bend per floor, according to the code
House	5100	10.2
House with common walls	5800	11.6
Block of flats	8300	16.6

Limit displacements are known and defined only for floors and beam openings and do not say anything about leaving columns or other parts of the structure. There are no limits in the Eurocodes for these trips. Another definition of the vertical displacement limits can be made using the length of the openings between the beams. Most of the beams in buildings made of reinforced concrete or steel. A beam can extend up to 60 meters, but this type is rarely used. Generally, openings greater than 20 meters are avoided in the construction of residential buildings, much less in the case of buildings older than a century. Frequently used floor systems such as hollow baseboards inside can have openings up to 18 meters. This can result in a maximum deformation of 36 mm, but this is rarely used. Supported dimensions for openings are 6, 7.2, 8.4, or 9.6 m, resulting in deviation threshold values from 12 mm for 6 m to 19, 2 mm for 9.6 m apertures.

2.3.2.2.b. Column displacement limits

The horizontal deflection of the columns is caused by horizontal loads, temperature, buckling, and second order effects. A column may be susceptible to buckling if the support element is small in size compared to the height of the column. The magnitude of the deformation caused by the veil cannot be calculated and is therefore unknown. If at first a column bends under the action of horizontal forces, it may also suffer later because of vertical forces as the load becomes eccentric. This additional deformation of a horizontal deformation is called a secondary effect. This movement is part of the horizontal movement, so it cannot be evaluated separately by InSAR technology. Single-storey buildings may experience a bend of maximum h / 300, where (h) represents the height of the lowest floor. For industrial buildings, this value is h / 150. For multi-storey buildings, this deformation becomes h / 300 for each floor, and h / 500 for the entire building (NEN-EU 1990-2002).

For horizontal movement, the element that influences travel computation norms is the height of the floor. The ceiling height must be at least 2.2 meters for new houses and 2.1 meters for existing houses as defined by the Eurocodes. Offices and other buildings must have a minimum height of 2.6 meters for new buildings and 2.1 meters for existing buildings. These heights are the space between the ceiling and the floor. For the total height of the building, the height of the floor and the ceiling should be added. In the case of offices, many ceilings are low for installation. The total floor height for dwellings is estimated to be 3 meters and for offices around 3.5 meters. This results in a maximum deformation of 10 mm for one-storey houses and 11.67 mm for offices. In the following graph, the maximum deformation values of buildings with different floor numbers for wellings and offices (Figure 7) are displayed.

A horizontal deformation of 12 mm may be problematic for a one-storey building, but not for a multi-storey building. That is why the height of a building must be known before the data is interpreted. In addition, the satellite that moves in one direction does not have a high sensitivity to horizontal movements. Thus, a 12 mm deformation in the eastern direction is expressed in measurements as 4.5 mm. The same 12 mm deformation in the north direction is expressed by a -1 mm movement in the satellite measurements. Hence, horizontal deformation is impossible to measure using a single satellite. A two-satellite monitoring in ascending and descending orbits and the assumption that a building moves in a horizontal direction without being affected by vertical movements is a very ambiguous assumption. A movement of 12 mm in the north or east direction will be measured by the satellite as -1 mm or 4.5 mm, regardless of the direction of the satellite movement. This affects most the applicability of horizontal movement monitoring in measurement studies.

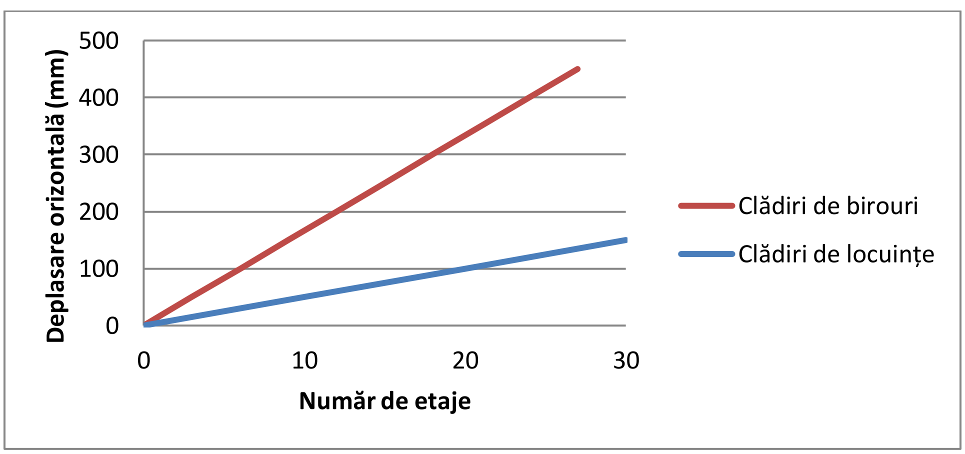

Figure 7. The value of horizontal displacements according to the type of building and the number of floors

2.3.2.2.c. Deformation boundaries of foundations

Deformation of foundations has received more attention over time compared to other elements in the structure of buildings. One reason could be the fact that a large number of buildings have problems with the foundation because of their location, the decrease in groundwater level, negative creep, mold and bacterial degradation, or construction errors. Problems in the basement are manifested at the surface by cracks, bends and locking of doors or mirrors (Van Leeuwen, 2010).

According to F3O, large displacements (minimum 3mm / year) require repair. This value can be considered as a limit value for the speed of travel. Korff et al. (2013) also determined that the displacement differences between elements of the same structure can be measured if there are sufficient points and for the determination of the travel limit, the 3mm limit must be divided by 2. A difference of at least 1.5 mm / year between two structural elements of a building become so alarming.

2.3.3 Considerations on the utility of the two types of monitoring

The forces acting directly on PS points are the forces that influence the behavior of the exterior elements of the buildings. They depend on temperature, wind, precipitation or accidental loads. The forces that influence the movements of a building have been centralized in the table ... along with how they affect the movements of a structure, and the ability of InSAR technology to detect movement.

InSAR measurements are especially suited for monitoring vertical movements due to the sensitivity of satellite measurements in this direction. The vertical vertical movements of a point are influenced by temperature, precipitation, groundwater changes, or other loads. These movements can often be obtained from other data as well. To monitor the building as an object, it is important to note that the movement of a PS point is a combination of different variables, described in a motion equation of a structure:

$$\Delta PS = \Delta Rw + \Delta Rp + \Delta RT + \Delta Rds + \Delta Rdf + \Delta Rv + \Delta Ra + \Delta Rm + \Delta Rs + \Delta Rgw \quad (2)$$

ΔRw – wind load;

ΔRp – precipitation load;

ΔRT – temperature variation load;

ΔRds – structure weight load;

ΔRdf – interior weight load;

ΔRv – occupant's weight load;

ΔRa – accidental loads (earthquake)

ΔRm – material degradation load;

ΔRs – surface deformation load;

ΔRgw – water table load;

In fact, it is difficult for all real movements to relate to the theoretical movements. Often not all forces acting on a building are known. The equations describing the movements are an approximation of reality, and the sensitivity of the satellite in certain directions also plays an important role.

Table 3. Types of tasks whose load influence can be detected using InSAR technology

Load type	Direction	Change is	PS points detection	Detectable:	Potrivită pentru observarea cu ajutorul InSAR:
Static	Vertical	Incident, caused by rennovations	Indirect	Sudden displacement	No
Time degradation	Vertical and horizontal	In first years and incident	Indirect	Slow gradual evolution in time	Yes
Wind	Horizontal	In random points	Direct, on facades and roofs	Magnitude variations	No
Precipitation	Vertical	Seasonal, caused by snow	Direct on roofs	Direct, în relație cu precipitațiile	No
Temperature	Vertical and Horizontal	Periodical, daily changes	Direct, on facades and roofs	In direct link to temperature	No
Indoor load	Vertical	Changes depending on building types	Indirect	It does not influence exterior elements	Yes, but rarely influences outside elements
Accidental	Vertical and Horizontal	Incident	Indirect	Sudden displacements	No

Settlement	Vertical and horizontal	After first construction years or due to surrounding influences	Indirect	Displacements of buildings and of the surrounding buildings and soil	Yes
Groundwater table	Vertical and horizontal	Precipitations, soil, surroundings	Indirect	Displacements of buildings and of the surrounding buildings	Yes

Data-based monitoring of buildings can be done by monitoring an area and identifying explanations for movements that may involve buildings. Horizontal movements cannot be monitored using databases because knowledge of the structure is required for correct data interpretation. It is only possible to identify a possible horizontal movement in the east direction. As far as vertical movements are concerned, those that should be researched in detail are greater than 17 mm. Data-based monitoring is best suited for foundations. Movements usually evolve over time, and their magnitude may be quite high. Particular attention must be paid to the translation of the upper part of a building. Moves of 3 mm / year on the vertical, or 1.5 mm / year relative to another point on the building, indicates problems.

3. Methodology for the application of InSAR technology for the monitoring of historical buildings in Bucharest

The methodology outlined in this chapter is based on the use of some information classification indexes contained in each PS Point to assess the state of degradation of urban infrastructure at local scales, taking into account the types of degradation described in the previous chapters. In order to identify buildings suffering time degradation at Bucharest level, both object-oriented and database-based monitoring will be applied. Firstly, test areas are based on a priori defined buildings, based on the existence of terrestrial monitoring data. After application of the object-oriented monitoring methodology to the test areas, the methodology for identifying buildings with possible deformations using data sets for a city-wide generalization will be applied.

Points are grouped into "test areas" that correspond to buildings and their surrounding areas. Such a classification has been described by Lan et al (2012).

The indices used refer to the density of the PS points in a test area (I_D), and to the critical deformation degree of the separate structures and the adjacent areas (I_{CS}, I_{CZ}), respectively. Distribution of displacement values on building façades can be classified as Isolated or diffuse (d), according to the Displacement Distribution Index (IDV). IC and ID indices will be broken down into classes A through E to simplify the interpretation of the results.

The steps for classifying PS points and identifying the hazard hazard for each structure will include:

- Calculate the I_D of the I_D;
- Calculation of critical deformation indices for individual structures and adjacent areas (I_{CS}, I_{CZ});
- Integrate additional information with calculated indices;

3.1. Defining test areas and selecting PS points

Valid PS points are selected by delimiting two areas: the perimeter of the studied object is drawn with orthophotomaps, and the adjacent area is considered a buffer of this object. The adjacent buffer zone is the area whose stability is considered important for an object. The size of the buffer area is based on the spatial resolution of the SAR satellite images (in the case of TSX it is 1.7X3.4 m). The size of the buffer area is important because it must include points that are georeferenced a few meters outside the boundaries of the object but result from a double reflection on the corners formed by the building walls and the terrestrial surface. Also, the considered buffer area can eliminate errors that occur when designing PS points on the support used to identify buildings (Fig. 8, 9).

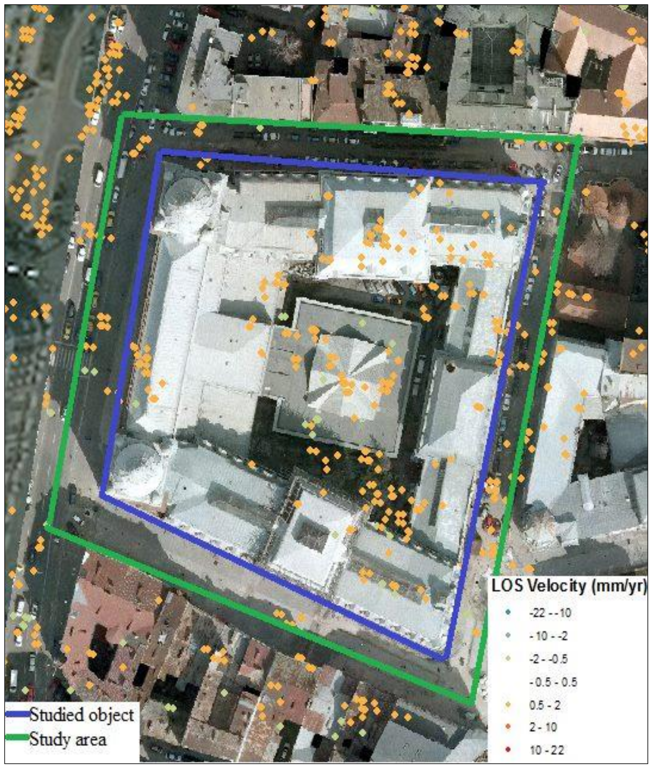

Figure 8. Example of delimitation of the test area and the studied object

3.2. Calculation of density index, I_D of points in an area

This index shows the degree of coverage of the object and the areas with PS points, or the degree of information for a studied area. The numerical value of this index reflects the PS (PS / m2) density in the test area.

The density of the PS points for the studied subject (D_O) is first calculated. If this is equal to 0, lower or higher than a fixed value for the mean density of the PS points (Dm), then the assigned partial value is 0, 0.25 or 0.5. The density of the PS points for the area around the studied object (Yes) is calculated using the same partial scale as in the case of D_O. I_D is then obtained as the sum of DO and Da so that the ID takes values between 0-class E and 1-class A, with a difference of 0.25 from one class to another. Thus, class E corresponds to areas without any PS point, which means that the critical deformation index cannot be calculated. In this situation, it is not advisable to extrapolate the points near the studied area, because the behavior of the buildings is individual, and can only be influenced by the surface they are found, but it does not entirely depend on it.

As Colesanti and Wasowski (2006) mentioned, the same average density Dm could not be used in peri-urban areas because the density and type of construction in these areas are different from those characterizing urban areas (Bayarri et al., 2015).

The average density D_m is obtained by calculating the average of the D_O and D_a values characterizing a test area. D_m also depends on the type of data used, and can be adjusted for medium resolution satellites (Envisat, ERS) and large (TerraSAR-X, CosmoSkymed).

3.3. Calculation of critical I_C deformation index

This index numerically expresses the condition for the study object and the surrounding area, based on the maximum value (Vmax) of the displacement speed expressed along the line-of-sight (LOS) line of the satellite for the entire monitoring period, for all points in the test area. Similarly to the density calculation, and for the IC index, first two ICO and ICA indices corresponding to the object and the surrounding area are first calculated. Starting from the Vmax value found in the respective control areas, the I_{CO} and ICA are classified using 5 classes for the critical deformation index, IC, whose interval is determined by the limits of the speed range determined for the entire area under study.

Speed ranges distinguishing stable objects from unstable are determined on the basis of radar technology parameters used to determine displacements and distribution of velocity values throughout the PS database. Class A indicates stable objects. Its limits depend on the precision achieved with a single radar measurement as well as the frequency of the signal used. In the case of the X-band radar sensor, the recommended standard deviation of the points is 0.5 mm (class A having Vmax ≤ 0.5 mm / year). As mentioned in the literature (Hanssen, 2005; Crosetto et al., 2010; Cigna et al., 2013), speeds greater than 3 cm / year lead to loss of coherence of SAR images. Class E is set based on the distribution of the speeds of all PS points. The ranges are set to cover most of the PS points resulting from processing for the entire area of Bucharest.

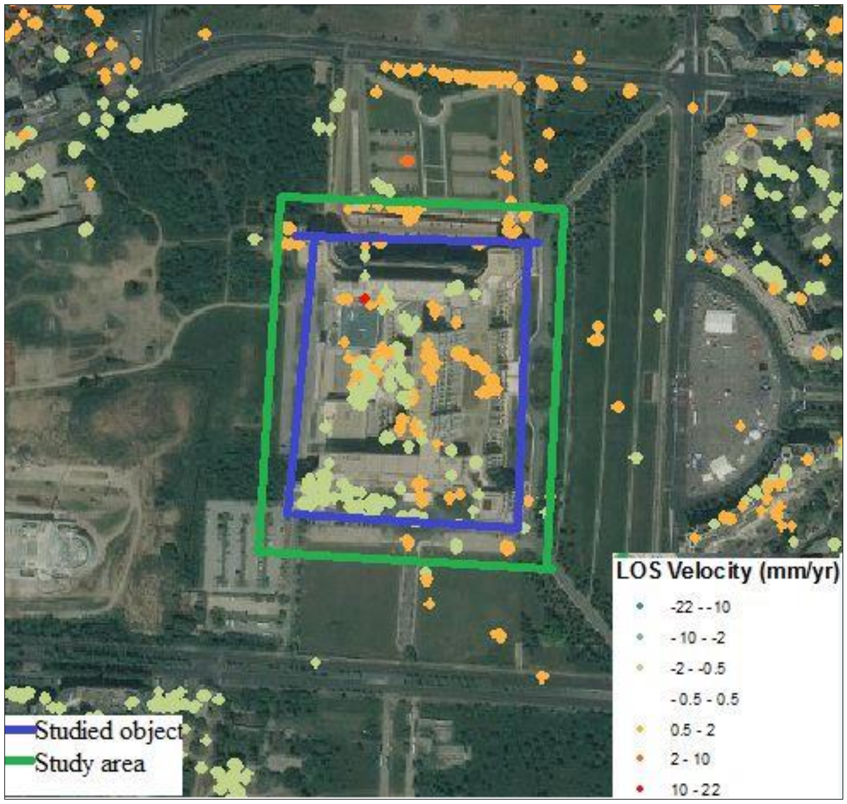

Figure 9. Example of delimitation of the test area and the studied object - Parliament Palace

3.4. Calculation of the displacement rate index, I_{DV}

The number of unstable points and their spatial relationship with the stable PS points in the test area does not influence the value of the IC index. To express numerically the estimated displacement distribution, the velocity distribution index (I_{DV}) to be calculated for each test area using the formula:

IDV = (g / G) x 100 (3)

Where "g" represents the maximum value between (Vmax-Vmin) and (Vmean-Vmin), and G of (Vmax-Vmin) with Vmax, Vmin and Vmean represents the maximum, minimum and average arithmetic mean PS speeds in the control zone.

I_{DV} shows the degree of symmetry of all points in a test area relative to Vmean, and can indicate whether there are at least 3 points within its perimeter.

4. Expected results

The result of the study will consist of a classification of historical buildings in Bucharest according to their health index, which may have values in 5 intervals. Classes are determined by calculating a critical deformation index, Ic, which depends on the density of points of a studied object and the surrounding area. Infrastructure health classes will be marked from A to E, Class A being consistent with stable objects, and E indicating serious cases of instability. The classification can be represented as a map where the buildings are represented by the value of the health index (Figure 5).

The identification of buildings with high seismic risk is a challenge because the way the affected structure behaves depends on the height, construction materials, age of the building or the type of soil on which it is built, as well as the acceleration of the soil in the event of an earthquake.

Therefore, an InSAR study should include a large sample of buildings located in different areas of Bucharest. To eliminate the movement due to seasonal influences, a set of at least 20 images to be taken over a period of 1 year will be used, which will be validated with terrestrial monitoring over the same period. It is also important to check if InSAR technology can provide sufficient accuracy to monitor infrastructure behavior. To this end, the study will validate satellite measurements using terrestrial infrastructure monitoring measurements using high precision classical and GNSS techniques. Terrestrial validation will be done both for the results obtained from satellite imagery for soil movements, but also for the movements occurring at the level of the structures.

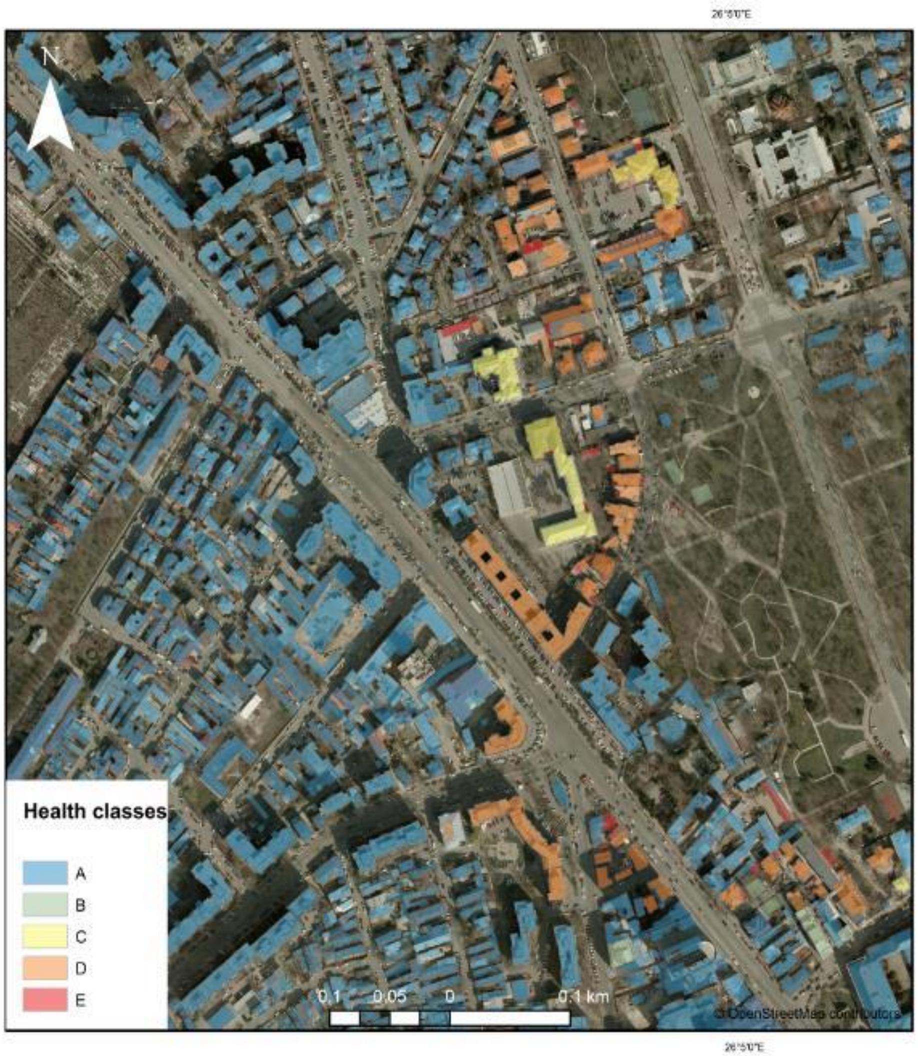

*Figure 10. Example of Classification of Buildings Depending on the Degradation Condition Resulting from the Deformation Critical Index***Bibliografie**

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