INTERNATIONAL JOURNAL
OF
CONSERVATION SCIENCE

ISSN: 2067-533X Volume 16, Issue 2, 2025: 1213-1222 www.ijcs.ro

DOI: 10. 36868/IJCS.2025.02.29

PRESERVING URBAN INFRASTRUCTURE: ASSESSMENT OF NATURAL DISASTERS USING MODERN TECHNOLOGIES

Petru CERCEL [1], Catrinel-Raluca GIURMA-HANDLEY[1,*],
Alexandru POSTAVARU [1], Ion GIURMA [1,2]

[1] "Gheorghe Asachi" Technical University of Iasi, Faculty of Hydrotechnics, Geodesy and Environmental Engineering,
[2] Academy of Romanian Scientists (AOSR), 54 Splaiul Independentei Street, Sect. 5, 050094 Bucharest, Romania;

Abstract

In recent years, the integration of advanced technologies like Ground Penetrating Radar (GPR), drones, and video inspection cameras has revolutionized emergency response and disaster management.[1][2][6] These technologies offer enhanced situational awareness, efficient decision-making, and improved safety for emergency response teams.[6][14] Modern technologies play a crucial role in detecting natural disasters, helping to protect urban infrastructure and minimize damage. Advanced sensors, satellite imagery, artificial intelligence (AI), and Internet of Things (IoT) devices enable real-time monitoring of environmental conditions, allowing for early warning systems that enhance disaster preparedness. AI-powered data analysis predicts potential hazards, while drones and remote sensing provide accurate assessments of at-risk areas. Additionally, cloud computing and big data analytics facilitate rapid decision-making, ensuring efficient resource allocation and emergency response. Smart infrastructure, equipped with automated detection systems, can mitigate risks by triggering preventive measures such as structural reinforcements and evacuation alerts. By integrating these technologies, cities can enhance resilience, reduce economic losses, and safeguard communities against the devastating impact of natural disasters. This study explores the application and effectiveness of modern disaster detection technologies in urban environments.

***Keywords**: Ground Penetrating Radar (GPR), Emergency Response Technologies, Subsurface Anomaly Detection, Drone Mapping, Real-Time Data Collection*

Introduction

Natural disasters, such as earthquakes, hurricanes, floods, wildfires, and landslide, pose significant threats to urban infrastructure [1-3], causing severe economic losses and endangering lives. As cities continue to grow and become more densely populated, the need for effective disaster detection and mitigation strategies has become more critical than ever. Traditional methods of disaster monitoring often rely on manual observation and historical data, which can be slow and insufficient [4-6] in predicting or responding to sudden catastrophic events. Ground Penetrating Radar (GPR), drones, and video inspection cameras are three such technologies that have proven invaluable in emergency response scenarios [7-14].

This paper explores the role of modern technologies in detecting natural disasters, their impact on urban resilience, and the challenges associated with their adoption. By leveraging

* Corresponding author: catrinel-raluca.giurma-handley@academic.tuiasi.ro

technological advancements, cities can significantly reduce disaster-related risks, protect critical infrastructure, and enhance sustainability in the face of increasing environmental uncertainties.

Following an information from the Trifești City Hall regarding the occurrence of a landslide at the home of a citizen from the village of Trifești, which caused the destruction of the resistance structure of the building and the evacuation of the owner, it was ordered by order no. 14 of 28.10.2016 the formation of a Technical Support Group for the management of emergency situations generated by earthquakes, landslides and landslides to assess the situation on the spot and draw up a statement of findings.

Equipment from the NRW office was used, such as the Stream EM GPR, the drone with spectral analysis camera, as well as the video inspection camera.

Experimental

Ground Penetrating Radar (GPR)

Ground Penetrating Radar (GPR) is a non-invasive geophysical method that uses radar pulses to image the subsurface [1-2]. It is particularly useful for detecting objects, changes in material properties, voids, and cracks in the ground. GPR is widely used in various fields, including archaeology, geology, and civil engineering, and its application in emergency response is increasingly being recognized.

In emergency response, GPR is particularly valuable in search and rescue operations. It can be used to locate victims trapped under debris or collapsed structures by detecting voids or disturbances in the ground [4,14]. Additionally, GPR is essential for assessing the stability of buildings and infrastructure after a disaster, allowing teams to identify potential hazards before entering a site.

The NRW department tried to scan the streets where there is supposed to be any soil crumbling,[1][3] around the area where the earth collapsed, with the equipment provided, namely the STREAM EM georadar. The scans performed in number of 4 with a total length of approximately 6 km have relevant the existence of several areas with anomalies (Fig 1).

The images represent a screenshot taken in the GPR scanning software, namely STREAM - EM, where the scans performed in the field are superimposed on the image from Google Maps.

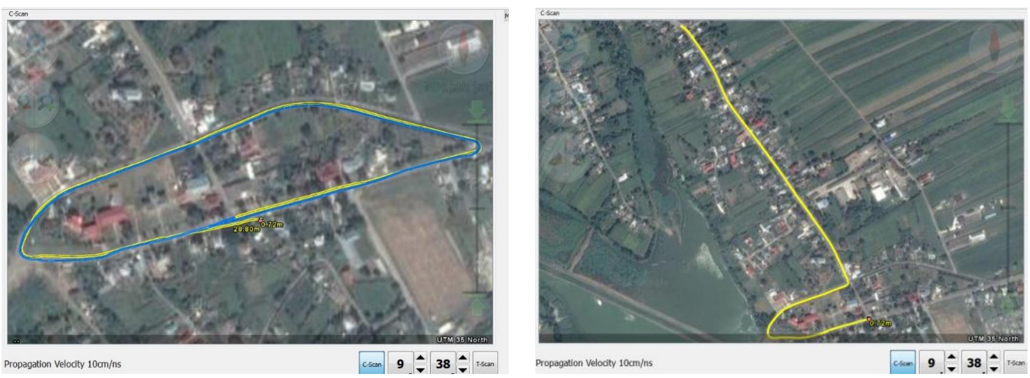

Fig. 1. Overview scan (area of Trifești about 0.3962 km^2, 39.616 ha)

Drones

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have seen rapid adoption across various sectors due to their versatility, ease of deployment, and ability to access hard-to-reach areas. In emergency response, drones are equipped with high-resolution cameras, thermal imaging sensors, and even LiDAR systems, [6-8, 10] enabling them to capture detailed aerial views and assess disaster-stricken areas. Drones are particularly effective in providing real-time aerial reconnaissance in disaster zones. They can quickly survey large areas, identify the extent of damage, and locate survivors. Drones equipped with thermal cameras are invaluable for night-time operations or in situations where visibility is poor.

The NRW department continued the following actions carried out exactly in the order of their enumeration; aerial photography with the UAV system provided in order to have the orthomosioac of the respective area as well as to observe other possible anomalies from a high altitude [6-9] (Fig. 2).

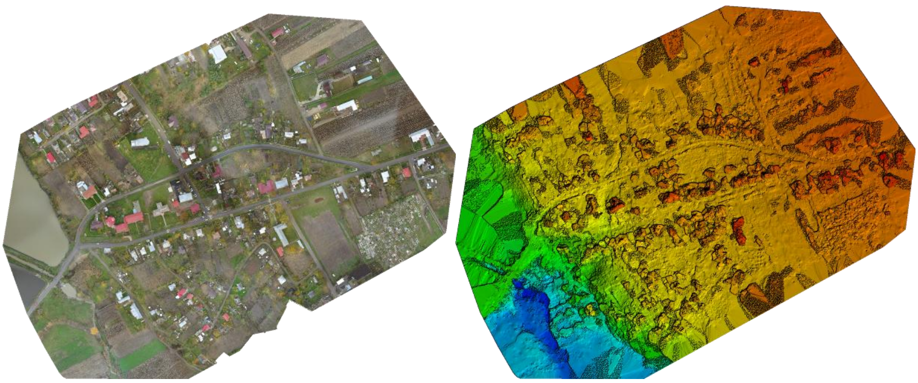

Fig. 2. Aerial overview (Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification)

Video Inspection Cameras

Video inspection cameras, including borescopes and pipe cameras, are tools that allow visual inspection of confined spaces and inaccessible areas [11, 12]. These cameras are equipped with flexible cables and LED lighting, providing high-resolution video feeds in real-time. In emergency response, video inspection cameras are essential for inspecting confined spaces, such as collapsed buildings, underground voids, and sewer systems. They can be used to locate trapped individuals, assess structural integrity, and identify hazards without putting responders at risk [11].

Results

Using G.P.R

Water retained on the surface does not have the possibility of draining, but is exhausted either through evaporation, or by penetrating the ground, or through both phenomena simultaneously.

Because of the high dielectric permittivity of water, areas with increased level of moisture must have high contrast on microwave images.

The first anomaly identified in the scan shows the breaking of the land as well as the possible existence of a structure (Fig. 3).

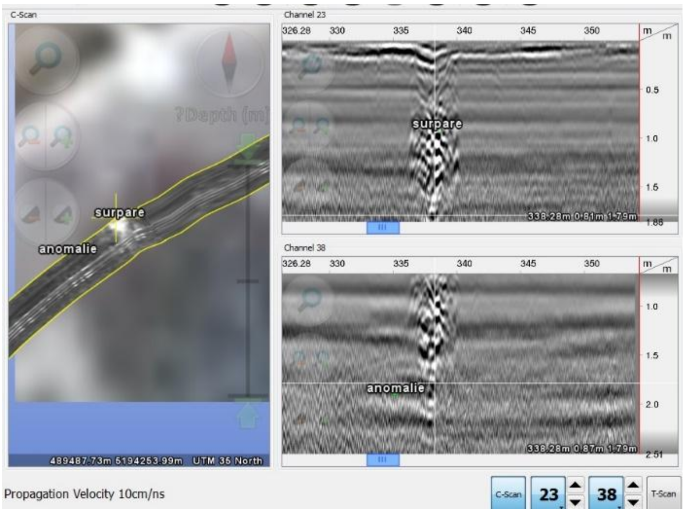

Fig. 3. First anomaly identified

The second major anomaly identified by the GPR is shown in the image below, where you can see the fact that the earth broke and that area was covered with another layer of earth and compacted. It should be mentioned that the soil layer will continue to collapse (Fig. 4).

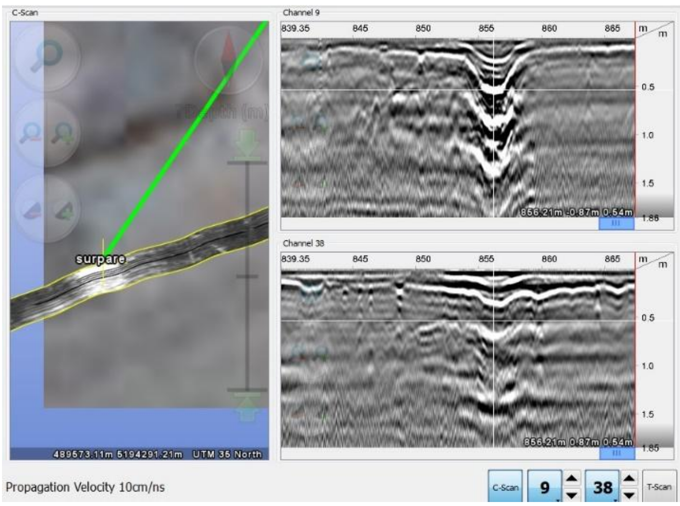

Fig. 4. Second anomaly detected

Other anomalies were also identified as a result of the progressive passage on the streets in question. In the two images, you can see different pipeline crossings, as well as the soil layer at a depth of approximately 65 cm, which either moved or was not properly compacted, as well as the existence of the water infiltration layer that starts at a depth of approximately 1, 9 m, also pipelines where identified as shown in Figure 5.

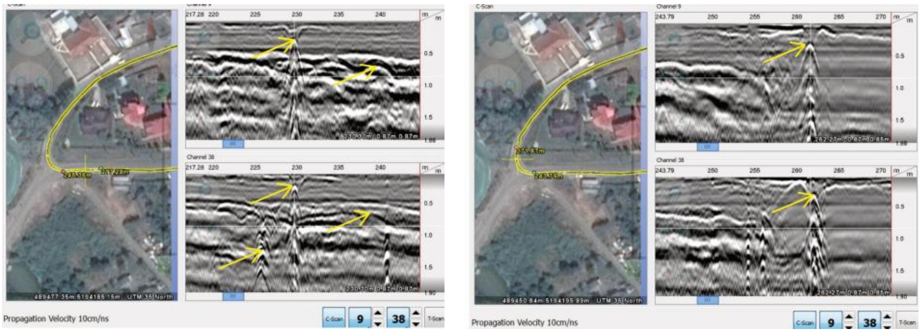

Fig. 5. More anomalies identified also pipe lines (yellow arrows in the picture shows the anomaly like pipe lines)

As a result of scanning the pedological layers without calibration, the existence of at least two different soil layers with different compactions can be observed on the scanned streets (Fig. 6).

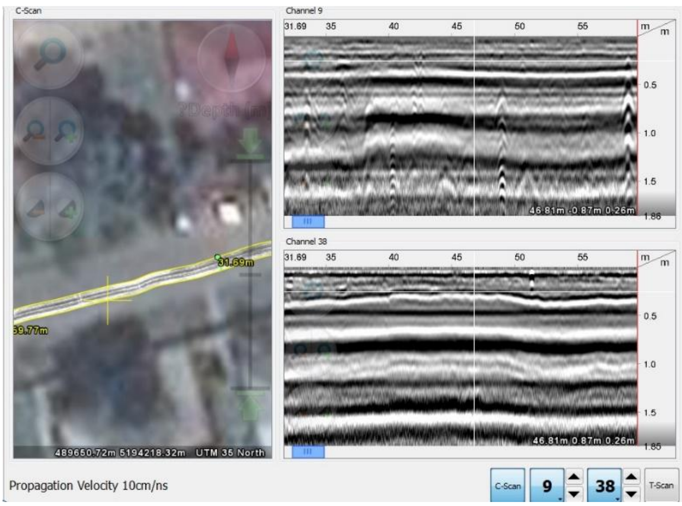

Fig. 6. Soil compaction (scan was done with STREAM EM GPR and analysis in GRED HD software)

Next, scanning with GPR was carried out on the street in front of the Church, where an anomaly could be observed which turns out to be underground soil movement. This phenomenon can occur due to natural processes such as erosion, seismic activity, or changes in groundwater levels, as well as human activities like excavation, tunneling, or construction [1][3].

Natural porous media are usually sedimentary rocks (sands, sandstones, limestones, dolomites, clays and marls).

Soil movement can lead to significant structural issues, including foundation damage, sinkholes, and landslides, posing risks to buildings, infrastructure, and the environment [1, 3].

Understanding and monitoring underground soil movement is crucial for preventing these hazards and ensuring the stability of the ground, as we see in the next picture almost the all house is down, and the remaining walls are cracking (Fig. 7).

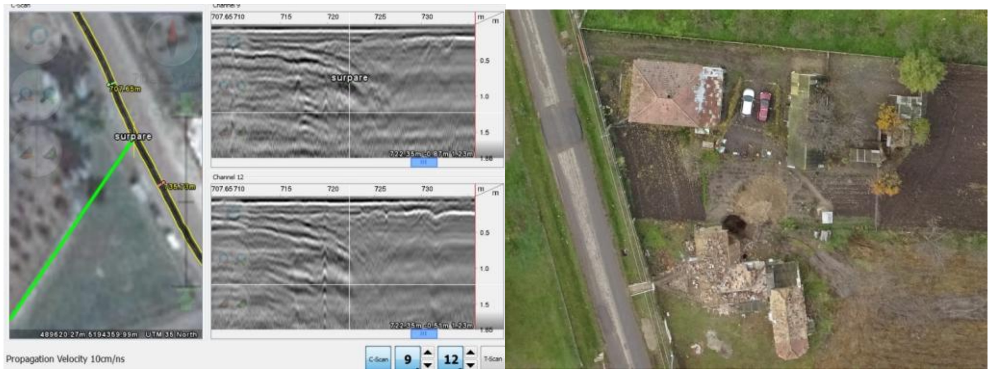

Fig. 7. Soil movement (scan also performed with GPR STREAM EM and data acquisition done with GRED HD software)

GPR provides real-time data and can be quickly deployed in the field, making it an ideal tool for emergency situations [6, 14]. However, its effectiveness can be limited by the type of material it scans through, as well as the depth of objects detected. Highly conductive materials such as wet clay or metal can reduce the penetration depth and resolution of GPR signals, and the terrain in the area was wet clay which made scanning difficult [1, 3].

Using drones

As a result of the aerial mapping, the software marked several areas with soil differences and of all the anomalies, only a few remained that should be checked by the people in the area in order to be eliminated or investigated further (Fig.8).

Fig. 8. Identified areas with height differences (image from the drone at a height of 120 m)

The primary advantage of drones is their ability to rapidly deploy and cover extensive areas that might be inaccessible or too dangerous for human responders. They also reduce the risk [6][7] to personnel by allowing remote inspection of hazardous sites. However, drones are limited by battery life, weather conditions, and legal restrictions on their use in certain areas [6][9].

Using camera inspection

The next step was the video inspection carried out on the property, where cracks in the soil layer and the existence of some formations (possibly objects) could be observed. Fig.9.

Fig. 9. Findings using video inspection (video inspection done on the property affected by the land sliding)

Video inspection cameras offer a high level of detail and are relatively easy to deploy [11]. They are particularly useful in confined space operations where other forms of inspection are impractical. However, their effectiveness can be limited by the length of the cable, camera resolution, and the physical constraints of the environment being inspected.

In the minutes concluded following the completion of the field evaluation, it was found that the collapse of the land, with a macroporous structure sensitive to moisture, was caused by the existence at a depth of approximately 5 meters of an old tunnel from the time of the ruler Stefan the Great (estimated to be over 500 years old), whose dimensions and trajectory can only be determined following a geological study.

Under these conditions, during the CJSU meeting, a decision was approved according to which eight measures were established, with deadlines and responsible parties:

- signaling the area, at the border with the public domain, to prevent the access of both owners and visitors;
- cessation of use of the affected construction;
- tracking the evolution of landslides/landslides by authorized persons, appointed by decision of the mayor of Trifești commune and informing the permanent technical secretariat of the CJSU weekly (or immediately if the situation requires it);
- carrying out, as an emergency, by an authorized laboratory, a geotechnical study on the phenomenon of loss of land stability in the village of Trifești, in order to identify the causes that led to the land subsidence;
- based on the geotechnical study, a feasibility study will be carried out that will indicate the most appropriate solutions from a financial point of view for the safety of homes and social objectives that may be affected by landslides;
- informing the National Committee for Emergency Situations about the land grab in the village of Trifești and, if the situation requires it, requesting its support;
- the Neamț County Council will analyze the possibility of granting financial support to the municipality of Trifești in order to apply emergency measures for the proper management of this situation.

The last scan was made with GPR TR80 (Fig. 10) at a depth GPR that only works on the frequency of 80 Mhz.

In the image on the left we have the GPR radar scan, at the intersection of the two reflections of electromagnetic waves there is an anomaly, an anomaly that turned out to be a collapsed old tunnel. In the image on the right we have a picture representing the entrance to this tunnel, discovered a few meters from the scanned area. The location identified with the help of the STREAM EM georadar is in the yard of the affected property, starting from a depth of 2.5 m to 5 m.

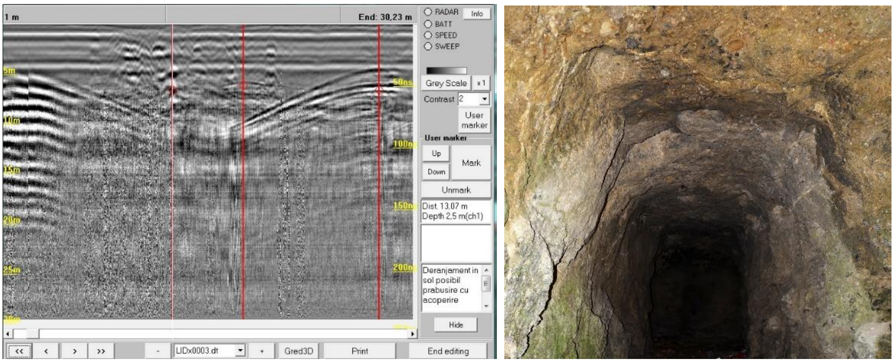

Fig. 10. Scan of a collapsed tunnel (tunnel excavated by the CJSU team and immediately closed for the preservation and protection of citizens and any artifacts inside it)

Discussions

The findings of this study confirm the critical value of integrating modern technologies—Ground Penetrating Radar (GPR), unmanned aerial vehicles (UAVs or drones), and video inspection cameras—in disaster risk assessment and management [13, 14], particularly in urban areas prone to soil instability and structural degradation. The case study from Trifești provided a practical context in which these tools worked together to deliver high-resolution data that guided authorities toward evidence-based decision-making and timely interventions.

GPR played a central role in detecting subsurface anomalies such as variations in soil compaction, voids, and the presence of an ancient collapsed tunnel [1, 3]. Its non-invasive methodology made it ideal for surveying potentially unstable ground without disturbing it further. Although the effectiveness of GPR can be affected by high-conductivity materials like wet clay, it still produced actionable insights that significantly contributed to the understanding of the soil dynamics in the area. These observations highlight the necessity of using adaptable scanning techniques in diverse geotechnical conditions.

Drones added a vital aerial dimension to the investigation, enabling quick, safe, and wide-scale mapping of the affected site. The generation of orthomosaics and digital surface models (DSMs) allowed for detailed terrain analysis, including the detection of height differences and surface anomalies [6,8]. The real-time data collection capabilities of drones, coupled with their ability to access dangerous or unreachable zones, improved operational efficiency and safety. However, the study also notes limitations such as restricted battery life and sensitivity to weather conditions, which must be considered in operational planning [6, 9].

Video inspection technologies further enhanced the diagnostic process by visually confirming cracks and potential obstructions in confined or structurally compromised spaces.

Their ease of deployment and ability to operate in otherwise inaccessible locations provided essential visual validation of geophysical and aerial findings. Despite their limited range due to cable constraints and spatial obstructions, these cameras proved valuable in high-risk settings.

A significant conclusion drawn from this study is that using these technologies in isolation is less effective than combining them into a synergistic framework. Their integration amplifies the strengths of each method—depth detection, aerial overview, and visual inspection—while compensating for their individual limitations. This multi-layered approach not only ensures a more comprehensive understanding of the disaster site but also minimizes the exposure of human responders to hazardous environments.

Future work should focus on optimizing these technologies to overcome existing limitations, including improving GPR signal penetration in challenging soils, extending drone flight endurance, and enhancing the flexibility and resolution of inspection cameras [3,9,11].

Continued innovation and interdisciplinary collaboration will be key to refining these tools and ensuring their applicability in increasingly complex disaster scenarios.

Conclusions

The integration of modern technologies such as Ground Penetrating Radar (GPR), drones, and video inspection cameras has proven to be an effective strategy for the rapid assessment and management of natural disasters. In the Trifești case study, these tools enabled the identification of critical anomalies—including underground voids, unstable soil layers, and a collapsed historical tunnel—providing essential data for emergency response planning.

Despite limitations related to terrain conditions and equipment range, the technologies collectively enhanced situational awareness, supported non-invasive inspections, and minimized risk for field teams.

The findings led to the implementation of targeted safety measures, including site restrictions, structural assessments, and geotechnical studies. This approach demonstrates how technology-driven disaster management can safeguard urban infrastructure and reduce human and economic losses. As climate risks increase, investing in such tools and in specialized personnel remains crucial for improving community resilience and ensuring timely intervention in vulnerable areas.

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Received: January 20, 2025
Accepted: May 18, 2025