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Evolution, Recent Progress and Perspectives of the Seismic Monitoring of Building Structures in Romania

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The seismic instrumentation of structures in order to assess their condition and to track it over long periods or after representative events has proven to be a topic of large interest, under continuous development at international level. The seismic hazard of Romania poses one of the most dangerous threats for the country, in terms of potential physical and socio-economic losses. In recent years, taking advantage of the new scientific and technological advances, among which the exponential growth in computational resources, significant improvements have been made in extending the seismic networks for structural monitoring and using the data as input for products and services addressed not only to the research community but also to stakeholders. The paper covers focused aspects of the topic for Romania, referring to past developments of the most important institutions and seismic networks in the country and the current status, including the research and regulatory gaps. Currently, three main research and academic institutions perform structural health monitoring of twenty-two buildings in Romania. As the number of monitored buildings grows and new actors in the private sector start to get involved in the process, the need for data standardization and a regulatory framework increases. Ongoing national and international projects (PREVENT, SETTING, TURNkey) address these issues and outline the roadmap for future actions of the main institutions responsible for seismic risk reduction, including authorities, research and academia.

Keywords: seismic monitoring, structural health monitoring, building structures, seismic instrumentation, Vrancea earthquakes

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INTRODUCTION

An essential activity for seismic countries is the monitoring and tracking of the condition of the building stock, aiming to ensure the safety of the population and quick recovery after extreme events. This endeavor has proved important not only for preparedness, mitigation and decision-making in emergency situations, but also for opening and supporting a wide range of multi-disciplinary research approaches. The condition assessment of aging structures and infrastructures is becoming a more and more critical issue, especially when developing life extension and replacement strategies. A cost-effective maintenance strategy should aim for minimizing the total life-cycle cost of a structure, considering the costs for preventive maintenance, inspection, monitoring, repair, and failure losses (Bergmeister et al., 2003). The importance and the benefits were analyzed, by assessing the Value of Information (VoI) for structural health monitoring (SHM) systems, by Pozzi and Der Kiureghian (2011) and Kamariotis et al. (2022).

The main objectives of SHM are to assess the structural condition and to rapidly detect the changes that could reveal damage occurrence, based on vibration recordings. The research in the field of SHM was initiated with a special focus on the aerospace, nuclear power and gas exploration industries (Doebling et al., 1996; Sohn et al., 2004). The following decades witnessed a large and diversified development of SHM approaches and methods, supported by the progress of sensing technology, computer hardware and software and leveraged by the need of integration of SHM in earthquake early-warning (EEW) systems (Cosenza et al., 2010; Wu and Beck, 2012; Su et al., 2020; Iaccarino et al., 2021; Sivasuriyan et al., 2021).

In Romania, a country affected by recurring earthquakes originating from various shallow and intermediate-depth sources (Radulian et al., 2000), a large percentage of the building stock dates from before 1963 (Lungu et al., 2008; Pavel et al., 2016), the year of the enforcement of the first mandatory seismic design code, with many of them being highly vulnerable. According to data from the latest National Census (2011), more than 40% of the residential building stock in the whole country and more than 44% in the capital city Bucharest were erected before 1963. The significant losses generated by the 1977 Vrancea earthquake (when almost 33,000 buildings were partially or completely damaged), highlighted the need for an improved seismic design of buildings and for extending seismic instrumentation.

The extensive implementation of SHM systems and rapid damage assessment tools is nowadays essential for assisting decision-makers to set up strategies for the retrofit of the vulnerable building stock. Several countries have already elaborated specific guidelines and standards for the seismic instrumentation of buildings (Çelebi, 2000) and SHM (ISIS Canada, 2001; Mufti, 2002—Canada; Teshigawara et al., 2004—Japan; Moreu et al., 2018; Yang et al., 2017—China; Porter et al., 2004; Rücker et al., 2006). At present, no detailed regulations for SHM exist in Romania, even though several buildings and infrastructures are monitored and several research projects in the field have been completed or are in progress.

The article presents an overview of the evolution and current status of the seismic instrumentation of building structures in Romania, with reference to the international research and regulatory framework and to the national implementation. It covers a broad perspective, from long-term SHM under operational conditions to seismic monitoring of structures under weak-to-moderate Vrancea earthquakes. The current research gaps regarding the seismic instrumentation of structures in Romania are discussed, as well as potential future actions to overcome these issues, including the improvement of the national legislation in the field.

EVOLUTION OF THE SEISMIC INSTRUMENTATION OF BUILDING STRUCTURES IN ROMANIA

In Romania, seismic monitoring of buildings started in the 1960's, when buildings in several cities were instrumented, mainly for scientific purposes, by the National Institute for Building Research, INCERC[1] (Georgescu et al., 2010). By the time the M_W 7.4, 4 March 1977, Vrancea earthquake occurred, four accelerographs were installed at the top and in the basement of two reinforced concrete (RC) buildings, located in the cities of Bucharest (RC shear walls, 11 stories) and Galati (RC frames, 12-story) (Berg et al., 1980; Balan et al., 1982). The first reference also mentions partially instrumented multistory buildings, with accelerographs installed, at that time, either in the basement or near the top, located in Bucharest (RC frames, 13 stories), Bacau (RC shear walls) and Focsani (masonry, 3 stories). In addition, in the years before the 1977 earthquake, an extensive campaign was conducted to determine the dynamic characteristics of various buildings, by ambient vibrations measurements. The database compiled from these measurements was used, after the earthquake, as a reference to assess modifications of natural periods for 47 residential buildings in Bucharest, with various structural systems and numbers of stories ranging from 8 to 18 (Balan et al., 1982). The availability of the reference values was crucial for later seismic vulnerability assessments, given that a large part of the mentioned buildings was based on standardized designs. It was shown that an increase of the natural period of vibration of the buildings with less than 20–25% was associated with low damage, percentages of 25–50% corresponded to light damage, while multiple, systematic or local and significant damage was observed for percentages higher than 50%.

The seismic network of INCERC evolved significantly after the 1977 earthquake, when new strong motion accelerographs were used for the instrumentation of multistory residential buildings, hotels, public and administrative buildings (Craifaleanu et al., 2011). The height of the monitored buildings ranged between 4 and 11 stories, with the recording equipment typically placed in the basement and at the top floor. In 2010, the seismic network of URBAN-INCERC consisted of over 100 stations, with 11 instrumented buildings (Georgescu et al., 2010). A database of seismic records obtained on buildings instrumented by INCERC during strong earthquakes (M_W 7.1, 30 August 1986; M_W 6.9, 30 May 1990, and M_W 6.4, 31 May 1990), was compiled (Borcia et al., 2013, 2014, 2015; Craifaleanu and Borcia, 2015). The seismic data recorded in buildings were analyzed by Popescu

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[1] Today a branch of the National Institute for Research and Development in Constructions, Urban Planning and Sustainable Spatial Development, URBAN-INCERC

and Demetriu (1994, 1994b, 1996) and by Demetriu and Borcia (Demetriu and Borcia, 2001; Demetriu, 2002). For the data recorded on a RC building during the 1986 earthquake, Popescu and Demetriu (1994) identified five vibration modes on each direction by running a system identification algorithm based on fitting of multivariate autoregressive model (MAR), assuming a multi-input single-output system. Popescu and Demetriu (1994) reported the initial (35–40 s) nonlinear behavior of a 12-story RC building during the 1986 earthquake, based on recorded acceleration components.

Two buildings in the Bucharest area and an experimental building at INCERC were instrumented in 1996–1998 in the framework of the Collaborative Research Center "Strong Earthquakes: A Challenge for Geosciences and Civil Engineering" project SFB 461 (Wenzel, 1997), with the National Institute for Earth Physics (INFP), the Technical University of Civil Engineering Bucharest (UTCB) and INCERC as partners (Aldea et al., 2004b). In 2003, for 3 months, one pair of strong motion instruments was deployed in a 11-story RC building, headquarters of the Institute of Atomic Physics (TURN), to study the influence of the building structure on the seismic waveforms. The monitoring was conducted within the framework of the Urban Seismology (URS) project (Ritter et al., 2005), having as partners the University of Karlsruhe and INFP.

Another structure of interest, instrumented by National Centre for Seismic Risk Reduction (NCSRR[2]), was the Faculty of Civil, Industrial and Agricultural Buildings (FCCIA) of UTCB, a RC frame, low-code building. The experimental data recorded during ambient vibration monitoring campaigns were used to validate its numerical model. In addition, the soil-structure interaction (SSI) analysis revealed slight interaction effects, however with no significant numerical impact (Demetriu et al., 2012).

The progress in the seismic instrumentation of buildings occurred in the broader context of the general development of the seismic networks in Romania. In addition, it should be mentioned that distinct monitoring is performed, by other organizations, for dams, bridges or for the subway lines in Bucharest. These construction categories are, however, beyond the scope of this paper.

CURRENT STATUS OF STRUCTURAL HEALTH MONITORING FOR BUILDINGS IN ROMANIA. RECENT PROJECTS

With the enforcement of the 2006 and 2013 editions of the Romanian seismic design codes, P100-1/2006 (UTCB, 2006) and P100-1/2013 (UTCB, 2013), both drafted by UTCB, the seismic monitoring of structures has gained additional momentum. The in force code state mandatory instrumentation for importance-exposure class I buildings, as well as for buildings higher than 45 m above ground level, located in areas with peak ground design acceleration values equal or greater than 0.25 g. In addition, since 2005, a Ministerial Order (OMTCT/OMAI No. 1995/1160 from 2005/2006) requires all the public and private buildings to be instrumented, if they have more than 16 stories (or are more than 50 m-high) or have a developed area larger than 7,500 m^2. At present, INFP, URBAN-INCERC and UTCB monitor twenty-two buildings in Romania (**Figure 1** and **Table 1**). Information on instrument types and representative photos are provided in the **Supplementary Material**.

At URBAN-INCERC, the National Network for the Seismic Monitoring and Protection of Building Stock is the department in charge of the operation of the seismic network, including the instrumented buildings (Dragomir et al., 2015a; Dragomir et al., 2015b; Dragomir et al., 2016; Dragomir et al., 2021). Currently, URBAN-INCERC monitors, mainly for research purposes, eight buildings with various functions and occupancies, located in Bucharest (7) and Iasi (1); six of these are connected online to the Data Center of the Institute. The instrumentation of these buildings consists of at least two sensors (ground floor/basement and top); two of them also have sensors close to the building, in free-field conditions. Other buildings have at present only ground-level sensors installed, complete instrumentation being envisaged in the future. In addition, short-term building vibration monitoring is being conducted, generally focused on actions induced by industrial or transportation activities. In a study conducted by Dragomir et al. (2017b), the fundamental period (0.18 s) of the Biotechnology Faculty building (BTH) was experimentally determined based on the Fourier Spectra (FS) of several recordings and validated with the values from the design code (0.15 s) and by using the Operational Modal Analysis tool of the ARTeMIS Modal Pro software[3] (0.19 s). Dragomir et al. (2017a) estimated the fundamental frequency for two other buildings, a 10-story RC shear walls apartment block (BLA) and a 15-story RC shear walls office building (APL), using noise and earthquake data. Applying the FS, they found fundamental frequencies of $f_x = 1.73$ Hz and $f_y = 2.05$ Hz for the first building, and $f_x = 1.5$ Hz and $f_y = 1.3$ Hz for the second building, respectively. Moreover, there is an ongoing experimental project for real-time damage detection in buildings (Dragomir et al., 2019; Dragomir et al., 2020) using ARTeMIS and an extensive campaign, in the framework of the ECOSMARTCONS project, for the seismic instrumentation of the premises of national research institutes all over the country. Starting with 2022, the Data Center of URBAN-INCERC has implemented SeisComP[4].

Significant progress in seismic instrumentation was made within the Japan International Cooperation Agency (JICA) Technical Cooperation Project "Reduction of Seismic Risk for Buildings and Structures", in which the NCSRR instrumented four representative buildings in Bucharest (Aldea et al., 2004a; Aldea et al., 2007a; Aldea et al., 2007b): the Romanian National

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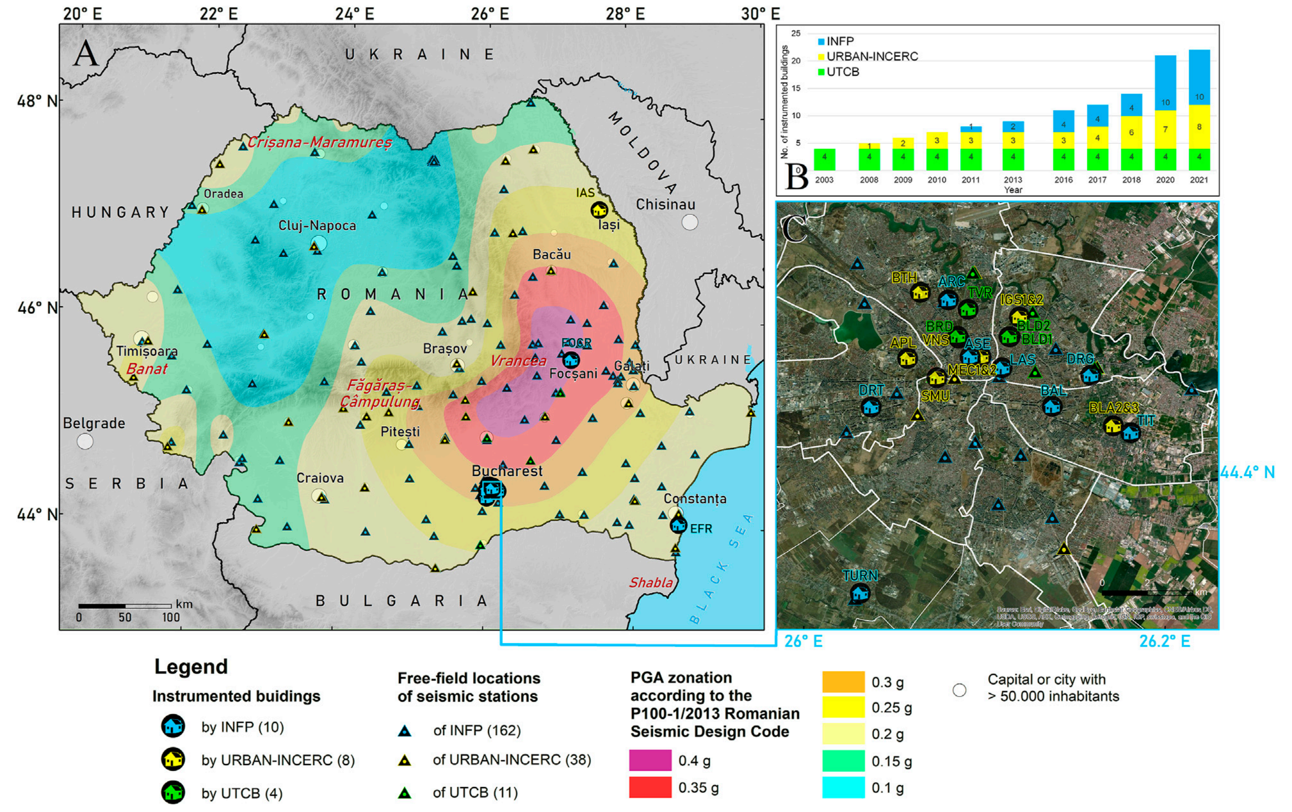
[2] NCRRS functioned between 2003 and 2010. The seismic instrumentation installed by NCRRS continued to be operated by URBAN-INCERC and at present by UTCB

[3] https://svibs.com

[4] https://www.seiscomp.de



Year	UTCB	URBAN-INCERC	INFP
2003	4		
2008	4	1	
2009	4	2	
2010	4	3	
2011	4	3	1
2013	4	3	2
2016	4	3	4
2017	4	4	4
2018	4	6	4
2020	4	7	10
2021	4	8	10

FIGURE 1 | Map of the seismic stations installed in buildings, by INFP (10 buildings, 36 sensors), URBAN-INCERC (8 buildings, 20 sensors) and UTCB (4 buildings, 13 sensors) and free-field, and the seismic zonation from the Romanian seismic design code P100-1/2013, indicating the main seismic sources (red text) **(A)**, the timeline of the installation year for the 22 currently instrumented structures, for each institution **(B)**, and a detailed map of Bucharest with the instrumented structures and free-field stations **(C)**.

Television (TVR), the BRD-SG Tower (BRD), and two residential multistory buildings (BLD1 and BLD2). Several detailed analyses of the modal frequencies, based on ambient vibration and earthquake data, were performed on the BRD-SG Tower, a newly constructed RC office building (Demetriu and Aldea, 2006). The SSI effect was investigated based on free-field and borehole data by Aldea et al. (2007c). For the same building, Perrault et al. (2013) proposed a methodology to reduce the uncertainty of the single-building fragility curve using experimental data. First, a linear MDOF model was adjusted for experimental modal analysis using a Timoshenko beam model (Boutin et al., 2005) and based on Anderson's criteria (Anderson, 2004). Then, the structure's response to a large set of accelerograms simulated by the SIMQKE software (Gasparini and Vanmarcke, 1976) was computed and, for the final step, the fragility curves were constructed by comparing numerical inter-story drift with the threshold criteria provided by the Hazus methodology (FEMA, 2003) for the slight damage state. Recent research on SHM, performed by UTCB, widened the scope of previous studies, approaching heritage buildings, such as the minaret of the Royal Mosque in Constanta (Aldea et al., 2018), and traditional Romanian timber framed masonry houses (Aldea et al., 2020).

In 2011, a heritage building of the University of Economic Studies (ASE), located in Bucharest, was retrofitted using seismic isolators and viscous dampers, the first action of this kind in Romania. INFP was in charge of SHM and of the efficiency assessment of this innovative solution, by placing accelerometers under and above the seismic isolators. Data recorded during two seismic events (M_W 5.5, 28 October 2018 and M_W 4.8, 31 January 2020) revealed a reduction of the acceleration amplitude by a factor ranging from 2.0 to 3.8, for the two horizontal components. The same promising results were reported for the same earthquakes on another heritage structure equipped with earthquake-protection system in Bucharest, the Arch of Triumph (ARC), with reductions of acceleration amplitude by a factor up to 4.5 (Balan et al., 2020).

INFP is currently monitoring 10 buildings, with 36 sensors (**Table 1**). The instrumentation setup consists of strong motion sensors located mainly at the ground (or basement) level, at an intermediate floor and at the roof level. New low-cost sensors (Raspberry Shake[5] RS3D and RS4D) are tested to extend the building monitoring network in the framework of the TURNkey[6]

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[5] https://raspberryshake.org

[6] https://earthquake-turnkey.eu

TABLE 1 | Characteristics of the instrumented structures.

Institution	Station code	Construction year/period	Structure type	Number of stories[a]	No. of sensors	Location of sensors	Instrument code[b]
URBAN-INCERC	APL	2008	RC Shear walls	2B + GF + 14S	3	B, 4th S, 14th S	GRN + EPI
	SMU	1978/retrofitted in 1996	RC Shear walls	B + GF + 13S	3	GF, 6th S, 14th S	K2 + EPI
	IGS1&2	1968	RC Frames	B + GF + 7S + partial story	2	GF, partial story	ETNA2
	MEC1&2	1969	RC Frames	B + GF + 6S + mechanical floor	2	B, mechanical floor	ETNA2
	BLA2&3	1971	RC Shear walls	B + GF + 10S	2	B, 10th S	GRN; ETNA
	BTH	2016	RC Frames and shear walls	B + GF + 2S	3	B, partial story + free-field	GRN + EPI
	VNS	2000s	RC Shear walls	3B + GF + 14S + mechanical floor	2	3rd B, roof	ETNA
	IAS7	1985	RC Frames	GF + 3S	3	GF, 3rd S + free-field	GRN + EPI
UTCB	BLD1	1980s	RC frames	B + GF + 10S	4	1st S, 5th S, 11th S, 12th S	K2 + EPI
	BLD2	1960s	RC frames	B + GF + 6S	4	B, 4th S, 7th S + free-field	K2 + EPI
	TVR	1960s	RC frames	B + GF + 13S	3	B, 14th S, 15th S	K2 + EPI
	BRD	2003	RC dual	3B + GF + 18S	2	3rd B, 19th S	K2 + EPI
INFP	ARC	1922/retrofitted in 2016	RC	27 m	3	GF, top + free-field	TSA-SMA; K2 + EPI
	ASE	1905/retrofitted in 2011	Masonry	B + GF + 2S + attic	2	GF	K2 + EPI
	TURN	1973/retrofitted in the 1990s	RC shear walls	B + GF + 9S	10	B, 1st S, 3rd S, 6th S, 7th S, 10th S	IDAS + TSA-100S; RS4D; RS3D
	FOCR	1971	RC frame	GF + 8S	3	B, 4th S, 8th S	TSA-SMA
	EFR	2008	RC frame	B + GF + 2S	3	B, GF, 3rd S	RS4D
	DRG	1982	Large panel structure (precast shear walls structure)	B + GF + 8S	3	B, 5th S, 8th S	RS4D
	BAL	before 1963 (<1940)	Unreinforced Masonry	B + GF + Attic	2	B, attic	RS4D
	DRT	before 1963	Large panel structure (precast shear walls structure)	GF + 8S	3	GF, 5th S, 9th S	RS4D
	TIT	1963–1977	Large panel structure (precast shear walls structure)	B + GF + 10S	3	GF, 5th S, 10th S	RS4D
	LAS	2008	RC frame	3B + GF + 11S	4	3rd B, GF, 5th S, 11th S	RS4D

[a] *B—basement story; GF—ground floor; S—story/stories.*

[b] *The instrument type and representative photos are presented in **Supplementary Table S1**—Supplementary Material.*

and PREVENT[7] projects. Low-cost sensors (Micro-electromechanical systems - MEMS accelerometers) have proven useful and provided promising results when used for early-warning systems (Nof et al., 2019), small local earthquake detection (Cascone et al., 2021) or even initial ground-motion assessment (Holmgren and Werner, 2021). However, their usability and reliability for SHM has not yet been extensively studied. The very high level of digital noise is masking any type of low-amplitude ambient vibrations. This type of sensors should be of paramount importance in case of earthquakes with $M_W > 6.0$, given the amount of data they can provide from a larger number of instrumented structures, when compared to professional equipment, within the same monitoring expenses.

The data from all stations are transmitted in real-time to the Romanian National Data Center (RONDC) of INFP. For data acquisition, quality control and recording, real-time data processing and exchange, network status monitoring, automatic and interactive event detection and location, waveform archiving and distribution, INFP has run, since 2008, SeisComP, in parallel with Kinemetrics Antelope[8] (Marmureanu et al., 2021).

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[7] https://prevent.infp.ro

[8] The Boulder Real-Time Technologies, Inc. (BRTT) https://brtt.com

Recently, Tiganescu et al. (2020) analyzed the dynamic characteristics (fundamental period and damping ratio) of the three representative high-rise buildings from Bucharest, based on ambient vibration data recorded during a two-day measurement campaign. The fundamental periods obtained using FS analysis, Random Decrement Technique (Cole, 1973) and Transfer Function were validated against results computed using empirical formulas from the design code corresponding to each building. The values were consistent for both the fundamental period and the damping ratio of the buildings, regardless of the method and of the measurement day. However, small diurnal and weekly variations were reported for the two parameters, due to small differences in atmospheric conditions and building occupancy at different moments of data acquisition.

Preliminary analysis of earthquake data recorded on structures during the latest moderate magnitude Vrancea seismic event (M_W 5.5, 28 October 2018) highlighted different behaviors and trends, depending on the structural characteristics and of the existence of earthquake-protection system. Amplification and reduction of motion on different frequency ranges were revealed, with clear peaks corresponding to the dynamic characteristics of the buildings (Tiganescu et al., 2019).

The Bighorn module, an extension of the Antelope package, is also used at INFP to perform seismic monitoring of structures. The system computes near real-time response spectra and issues alarms, depending of the level of exceedance of a preset limit spectra. This procedure was tested for Bucharest using the 28 October 2018 earthquake data (Balan et al., 2019). The reporting service is currently performed in an offline environment, on request. The permanent seismic stations installed in buildings were used in a recent study conducted by Grecu et al. (2021) to assess the effect of the COVID-19 related restrictions on the level of high-frequency content of the ambient vibrations generated by human activity. Significant noise reductions (40–80%) on the 15–40 Hz frequency range for stations in and near buildings were associated to the mobility restrictions of people working inside the office buildings and with the shift to online classes for educational units.

In the context of other studies highlighting the influence of atmospheric conditions on the dynamic parameters of structures (Clinton et al., 2006; Herak and Herak, 2009; Mikael et al., 2013; Guéguen and Tiganescu, 2018), a case-study building (TURN) was instrumented with both seismic sensors and a meteorological station (Tiganescu et al., 2021a), in the framework of the PREVENT project. A fundamental frequency variation analysis was conducted on a 72-h dataset of ambient vibration and earthquake data, using the Frequency Domain Decomposition method (Brincker et al., 2001). Small variations of the fundamental frequency were observed in the ambient vibration regime, while for the forced vibrations (earthquake) the variation was larger (drop of 10%) and followed by a recovery. Moreover, correlation of the atmospheric and environmental conditions (mainly air temperature, relative humidity and wind speed) with the building's natural frequency was tested, but with no sharp conclusions due to limited timespan.

DISCUSSION

A large number of buildings, representing different typologies (construction period, structural system, material, height, exposure to earthquakes, vulnerability) were previously and are currently instrumented in Romania, as a need for acquiring pre-, during and post-event vibration data. From the point of view of the coverage of areas of interest considering seismic hazard levels and building exposure, there is still a need to instrument and monitor structures that could be affected by crustal earthquakes (**Figure 1A**), in seismic zones such as Banat, Fagaras-Campulung, Crisana-Maramures or nearby Shabla, Bulgaria.

The effort is ongoing by means of national and international projects involving seismic instrumentation of structures and the development of web platforms for data and metadata inventory (SETTING[9] or TURNkey) and waveform acquisition, processing and visualization (PREVENT). Data standardization for easy integration in international infrastructures such as European Plate Observing System - EPOS (Luzi et al., 2016; Astorga et al., 2020) and for use in international research projects is another objective that the Romanian research and engineering community working on SHM is envisaging.

In addition, the low and narrow-band frequency content of the ground motion, observed in Bucharest for large-magnitude Vrancea earthquakes (Lungu and Cornea, 1988; Lungu et al., 1992; Craifaleanu, 2011), and its effect on different building typologies (Ambraseys 1977), needs further investigations. Outcomes of the seismic monitoring of structures can also significantly help as input for refined rapid seismic loss estimates, using already available systems such as SeisDaRo (Toma-Danila and Armas, 2017).

There is also a crucial need to continuously develop and upgrade the national guidelines regarding SHM, including clear requirements for modern digital sensors, standard installation procedures, data acquisition and processing. Currently, there are no specific procedures for the elaboration, checking and approval of the seismic instrumentation plan. A better definition of the technical specifications of the digital accelerometers is needed, regarding their minimum sensitivity, the maximum amplitude that can be recorded, the frequency sampling, the storage, and the time precision. Moreover, online access should be mandatory ensured for easy maintenance and periodical checks on the system operational status. The data processing and results interpretation should be performed by specialists, using well-established routines and algorithms, to obtain reliable results and to avoid any artefact errors or uncertainties that can arise and propagate during the signal processing stage.

In the recent years, the collaboration between Romanian institutions involved in the health monitoring of structures (URBAN-INCERC, UTCB and INFP) has been enforced by joint research projects and publications (Tiganescu et al., 2021a; Tiganescu et al., 2021b; Tiganescu et al., 2021c; Marmureanu et al., 2021). A system integrating URBAN-INCERC's SHM system and INFP's

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[9] https://setting.epos-ro.eu

EEW was proposed by Dragomir et al. (2016). The SETTING project, as well as the Romanian consortium[10] contributing in the EPOS research infrastructure[11] aim to provide a national research platform consisting of a standardized inventory of organizations which could provide data, products, and services relevant for the field of Earth Sciences—including SHM relevant categories. The platform will be designed to meet the needs of various user communities (research, academia, industry and general public). The effort to strengthen the collaboration with local and central authorities has gained momentum, as well, as several researchers from the three institutions are participating in the elaboration of a national strategy for the seismic risk reduction of the building stock, and in the development of a national emergency procedure in case of a strong earthquake. A special SHM section will be held at the third European Conference on Earthquake Engineering and Seismology (Bucharest, 2022), as a step towards bringing together the significant actors in the field and bridging the gap between research, academia and industry.

AUTHOR CONTRIBUTIONS

AT and I-GC designed the paper, and all the authors contributed to the manuscript. AA and RV contributed to the part referring to UTCB network, I-GC and C-SD contributed to the part referring to the URBAN-INCERC network, AT, BG, DT-D, and S-FB contributed to the part referring to the INFP network. DT-D designed Figure 1. All the authors contributed to the Discussion section.

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SUPPLEMENTARY MATERIAL

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