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Can high-school students contribute to seismic risk mitigation? Lessons learned from the development of a crowd-sourced exposure database

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ABSTRACT

On a global scale, one out of three people is exposed to earthquakes, and most injuries and deaths in case of seismic events are caused by the damage or collapse of residential buildings. Knowing the type and distribution of exposed assets, in particular buildings, is thus paramount for effective mitigation of disasters. Citizens' involvement in disaster risk reduction activities is constantly increasing by means of crowdsourced data collection, education/training and citizen science activities. In particular, schools have a central role in engaging young students and increasing risk awareness and preparedness. In this work, we explored whether students' participation in this kind of activities can lead to the improvement of current exposure datasets, while increasing citizens' risk-related understanding. In 2021, due to the restrictions imposed by the COVID-19 pandemic, the National Institute of Oceanography and Applied Geophysics - OGS started a new project to be deployed in fully remote mode, named "CEDAS: building CEnsus for seismic Damage ASsessment". The project consists in the collection and elaboration of crowdsourced data on main residential buildings typologies of northeastern Italy, a seismically active area which suffered consequences from strong past earthquakes. During the project, 170 high school students collected reports on more than 3200 buildings, performing a statistical analysis of theing results. The CEDAS project makes a first step beyond crowdsourcing activities and applies citizen science to exposure development. Results allow identifying the most common building typologies in the region and the challenges and opportunities associated with data collection and analysis. The experience collected during the CEDAS project shows that crowdsourcing and citizen science activities can contribute to both enhancing the exposure data available for the scientific community and increasing risk awareness among young students in the region.

1. Introduction

At global scale, one out of three individuals is exposed to earthquakes, and the number of people living in areas prone to seismic risk has been constantly increasing in the last decades [1]. Seismic risk can vary substantially depending on hazard (i.e. the likelihood of occurrence of seismic events and related ground shaking), vulnerability (i.e. the damageability of elements) and the location and characteristics of the exposed assets (i.e. the exposure). In particular, the collapse of buildings, especially residential ones, is responsible for a substantial fraction of the fatalities and injuries caused by earthquakes at global scale [2]. Thus, in order to assess

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expected damages and to estimate seismic risk, it is important to know the number, type and distribution of exposed assets, such as buildings, in a given study area.

Exposure databases include information on population, buildings and infrastructures. For buildings the most common exposure indicators are the construction period, structural material and type, and the associated economic value (usually a fraction of the construction cost), particularly relevant for loss estimation. In the last decades, significant efforts have been devoted to developing exposure databases at global (e.g. Ref. [3] within the PAGER system), regional (e.g. Ref. [4] for Central Asia [5]; for Europe [6], for Middle East) and national scale (e.g. Ref. [7]. Such databases rely on multiple data sources, ranging from global datasets (e.g. night-time lights [8], to national and local-level data. Global and national data are usually collected at specific times (e.g. decennial census) and, despite their high granularity, they quickly become outdated. Local scale data are up-to-date and more reliable and allow validating lower-resolution datasets, but their availability is usually scarce and their collection is time-consuming [9]. Collecting up-to-date local-scale exposure data is then paramount for increasing the reliability and the resolution of exposure layers.

Crowdsourcing activities are increasingly used for disaster risk mitigation purposes and allow collecting timely information on risk-related data [10]. Trained citizens can provide information on perceived shaking (e.g. Refs. [11,12]; [45]), post-event damages (e.g. Ref. [13] and buildings' vulnerability [14]. Most of the existing crowdsourcing activities however are carried out after seismic events, while less attention has been devoted to the collection of exposure information. There are in fact very few examples of building questionnaires explicitly designed for the collection of exposure data [15]; [43]). The type and specificity of fields included in such forms depend on specific personnel involved (experts, e.g. Qi et al., 2016, or citizens, e.g. Grigoratos et al., 2020). Differently from hazard and vulnerability, which are mostly assessed by specialists, exposure information can be collected by a relatively large number of properly trained citizens, so as to increase the spatial resolution and granularity of exposure data. Another advantage is that exposure data collection can be performed without time constraints. However, the potential of citizens' involvement for exposure development has not yet been exploited to the full: besides collecting information, activities should be focused on data analysis and interpretation with scientific methods. This implies making a step forward with respect to the simple crowdsourcing activities: crowdsourcing, in fact, refers to a basic, mere data collection activity, while citizen science also involves data analysis and interpretation [16].

Citizen science activities have the twofold objective of collecting data and increasing citizens engagement and participation [17]. Citizens' participation in risk-related scientific activities has proven to be very effective for increasing risk awareness (e.g. by an increased understanding of the hazardous phenomenon) and preparedness (e.g. by drills and exercises) and is strongly encouraged by the Sendai Framework for Disaster Risk Reduction [18]. Risk awareness and preparedness are in fact paramount in order to react better prior, during and after seismic events, and can strongly reduce both casualties [19]. There are several examples of activities deployed with schools to assess risk perception and increase awareness (e.g. Ref. [20]; Georgescu et al., 2014; [21,22]. However, there is evidence that seismic risk awareness is lower in young citizens that have no memory of historical events [23], but can also vary depending on social and individual perspectives (e.g. Ref. [24]. Increasing awareness and preparedness is thus particularly relevant for schools that have a central role in engaging young citizens and training them to react in case of seismic events. In addition, involving students in citizen science activities adds up to the crowdsourcing approach by increasing risk-related knowledge and awareness while contributing to disaster risk reduction [25].

The National Institute of Oceanography and Applied Geophysics - OGS has been engaged since many years in citizen science activities for disaster risk mitigation purposes, including educational and training activities [20,26,27]. OGS operates at the global scale but is located in Friuli Venezia Giulia (FVG, northeastern Italy), where it deploys multiple activities related to the seismic monitoring and operational support to civil protection in case of seismic events [28]. The area is prone to strong seismic events (e.g. Ref. [29], and underwent several destructive earthquakes in historical times [30], including the M6.5 Friuli 1976 earthquake, which caused the collapse of hundreds of buildings and claimed about 1000 lives in the alpine area and the foothills. In 2021, due to the restrictions imposed by the COVID-19 pandemic, it was not possible to host the usual "in person" training activities. As a viable and effective alternative, OGS promoted a series of online activities, such as the project "CEDAS: building CEnsus for seismic Damage ASsessment". The CEDAS project is the first attempt to apply citizen science to exposure development, and involves both crowdsourcing and citizen science activities. The project consists in the collection and analysis of building exposure data in the FVG region. For that, students were trained to use an online data collection form and analyze observational data with common scientific tools.

2. The CEDAS project

2.1. Methodology

The CEDAS project was deployed by OGS in collaboration with 5 schools of the FVG region, involving more than 170 high-school students. The project activities lasted 3 months and consisted of 2 main phases: data collection and data analysis (Table 1). Both phases

Table 1
Schedule of the project, including the date of each plenary virtual meeting, the description of the meeting and the topics covered during the training sessions.

Date	Description	Training topics
5th March	Meeting 1: Presentation of the project	Fundamentals of exposure assessment and data collection
5th March - 8th April	Phase 1: Data collection	
8th April	Meeting 2: Data analysis and interpretation	Data manipulation, statistical analysis, plotting and interpretation
8th April - 28th May	Phase 2: Data analysis and interpretation	
28th May	Meeting 3: Final public event. Discussion of results	Basic risk-related concepts (exposure, vulnerability, risk)

were preceded by specific training activities focused on the concepts necessary to carry out the activities (Table 1, 'Training topics'). Both phase 1 and 2 included intermediate meetings with tutors for verification and discussion and were concluded with brainstorming sessions, where tutors discussed the efficacy of their actions. All the meetings, including those for direct training of students, were delivered in virtual mode. The training material (including the meeting recordings) was then shared remotely with students and teachers through cloud solutions, and remained available during the whole project (e.g. to help the students in the data collection phase). Since the onset of the project and during the whole activity, the tutors from OGS were available to interact with teachers and students via telephone, email or ad-hoc online meetings.

During the first meeting, OGS researchers presented the main goals and organization of the project to the teachers and students, along with a brief general introduction to the concepts of earthquake hazard and exposure. Then, the data collection activity was described to the students, introducing the exposure indicators and the survey form to be used for the activity (see 2.2 for details). For each exposure indicator in the form, the OGS team showed specific examples based on pictures collected in the FVG region. The survey includes specific questions for the different building indicators, such as age, material, story number. To facilitate the classification process, under the assumption that identifying building typologies is generally easier and more intuitive for non-experts than assessing their specific characteristics (e.g. age, material), we trained the students about the existing correlation between these two indicators, and therefore how to use one (the typology) as a proxy for the other (age and material). The training material included examples for different building typology, underlining the correspondence with age and material classes (e.g. rubble masonry is usually associated with older buildings, brick masonry with more recent ones, steel buildings with recent structures). An example of the training material is included in the SI (Fig. S1) and shows the relationship between buildings' age, material and typology for a selected typology. Fig. S1 also shows examples of the training provided to identify a building's story number and the presence of specific features. The subjectivity of the evaluation was particularly stressed during the training, pointing out that there are no 'wrong' answers to most questions, but rather different views of the same object. The importance of observation (e.g. the building position, the context) was highlighted as a way to reduce the subjectivity of the answers. Particular attention was devoted to explaining the relation between landuse and spatial distribution on buildings (e.g. historical centers, commercial/industrial areas, suburbs) and the implications for identifying the building typologies.

During the second meeting, the OGS researchers instructed the students on how to analyze the collected data, interpret their findings and present them publicly. Given the limited amount of time, the training focused on the practical activities, showing examples on how to handle the collected tabular data were shown, as well as on how to perform a basic statistical exploratory data analysis. However, the data analysis requires some minimal statistical background which was only partially covered during the training. As most of the collected observations consist of qualitative estimates (cardinal or nominal ones), the standard statistical summaries (e.g. average and standard deviation) are not applicable. Hence, some basic tools for graphical summary (e.g. histograms, pie-charts, etc) and correlation analysis (e.g. bi-variate categorized histograms) were introduced. When dealing with qualitative ordinal estimates (e.g. 'high', 'medium', 'low'), it is possible to convert them into a numerical representation to facilitate further statistical elaboration. For instance, the conservation status of buildings was expressed with a qualitative rating (optimum, good, poor, bad), which was converted into a 1-to-4 numerical rating. Students also learned how to pre-process the collected data with the aid of numerical spreadsheets, in order to select and filter various fields based on specific attributes. Once the data were prepared for the analysis, students were instructed on how to elaborate statistics and present their results through simple plots (e.g. histograms, pie charts) for the main exposure variables (e.g. age, material). Finally, hints for the interpretation of results were provided, by means of a list of essential questions, such as: "Which are the most common typologies of buildings in your study area?", or "Do you notice any similarity/relation between the typology, material and age distribution in your study area?".

The third meeting was led in the form of a public event. The event involved representatives of OGS and school principals of each school, and was organized in order to show and discuss the results developed by each school. First, the OGS researchers provided a general introduction on basic risk-related concepts, explaining the role of exposure and vulnerability for risk assessment purposes. Then, each school had the chance to present the work done and discuss their findings. Finally, the OGS researchers discussed the final comparison of the results and their interpretations, stressing the importance of the data for disaster risk mitigation purposes.

2.2. The survey form

Traditionally, when developing an exposure database, residential buildings are classified using taxonomies that can be general (e.g. Hazus database, intended for global-scale assessments [31], or more specific (e.g the GEM taxonomy, [32]. There are a number of forms proposed for residential buildings classification at global scale (e.g. World Housing Encyclopedia, https://www.world-housing.net/) or country-specific. In Italy, for example, there are multiple building forms that were proposed for different purposes, such as collecting post-earthquake damages (e.g. AeDES form [33], assessing the vulnerability of specific building typologies [34] or identifying homogeneous town compartments (e.g. Ref. [9].

The form developed for this project was created ad-hoc for the students and for the specific purpose of collecting exposure data, based on the abovementioned standard forms used in engineering praxis. Exposed buildings are classified based on the use (question 6), distinguishing between residential and non-residential (e.g. industrial, commercial). Critical facilities are those which have a strategic function in case of emergencies based on the Civil Protection regulation (e.g. civil protection infrastructure or premises, fire stations, police stations, city hall). Following the Italian regulation definition, such buildings are referred to as 'strategic' in Table 2. There is also a class 'other' to be used in absence of information. Some indicators originally contained in existing building technical forms were simplified into general classes (e.g. construction decades were simplified into four classes, defined based on the knowledge of the buildings construction phases in the study area, e.g. Ref. [35] for northeastern Italy). For example, in the proposed classification, "intermediate-age" corresponds to buildings constructed between 1950 and 1980. Conversely, some of the indicators in the standard forms were not included, being too technical for high-school students (e.g. the identification of some specific structural features such as roof types). Other features, visible from the outside of the building (e.g. the presence of big terraces or roof tiles, the shape of the building) were additionally included being easily recognizable by non-experts. Some of the non-structural indicators in the Cartis form [36] were also included, such as the presence of big terraces and roof tiles, as well as evidence of retrofitting (e.g. tie beams visible from the outside) or renovation processes. Regarding the conservation status, the survey included two questions, one for identifying possible sources of misconservation (e.g. cracks, mold) and another where students were asked to provide a final (subjective) rating. Finally, we asked if, for residential buildings, there was the presence of commercial activities in one of the floors. These indicators were selected because the related information can contribute to the definition of the characteristics of common building typologies prone to nonstructural damages and subsequent injuries (e.g. big terraces or roof tiles can fall apart, commercial activities in the basement floor can cause weak floor failures). In addition, the identification of such features could be a way to test and train the observation skills of the students.

Table 2 summarizes the list of exposure indicators included in the survey and the provided options, if any. All the answer's options in the form were discussed during the training also using dedicated visual examples (e.g. SI1). Note that most of these indicators correspond to taxonomy codes in existing building taxonomic classification (e.g. GEM taxonomy [32], and can therefore be used for a further building classification. The form was created with the *Google forms* tool, which allows online accessibility, cloud storage of data and basic processing capabilities. All indicators were associated with example images representative of the different typologies and features, to facilitate the student interpretation. Students could also upload one or more pictures of the building, taken either from the phone (if the survey is deployed in situ) or as Google Street View snapshot (GoogleMaps, http://www.googlemaps.com).

Table 2
Structure of the building form with indicators (marked with * if mandatory) and options provided to respondents (if any). All questions included the 'I don't know' option which is not included in the table.

Group	Indicators	Options (if provided)
General data	1. Upload one or more picture of the building	
	2. Building address*	
	3. Municipality*	
	4. District/hamlet, if any	
	5. Number of dwellings*	1,2,3,4,5–10,10-20,>20
Use	6. Building use*	Residential, commercial, industrial, strategic, touristic, other services, other
Building typology	7. Typology *	1- Historical building (isolated or attached), 2- intermediate-age attached buildings, 3- intermediate-age family house, 4- modern or new family house, 5- intermediate-age terraced houses, 6- modern or new terraced houses, 7- intermediate-age apartment buildings, 8- modern or new apartment buildings, 9- intermediate-age industrial building, 10- intermediate-age commercial building, 11- modern or new commercial building, 12- modern or new industrial building
Age	8. Age of construction*	1- historical (constructed before 1950) 2- intermediate age (1950–1980), 3- modern (1980–2005), 4- recent (constructed after 2005).
Material	9. Structural material*	1- Historical masonry, 2- modern masonry, 3- reinforced concrete, 4- wood, 5-steel
Context	10. Building position*	Stand-alone, attached to one building, attached to multiple buildings, terraced houses
Geometry	11. Storey number*	Number
	12. Presence of basement*	Y/N
	13. Presence of specific features	Presence of garages, soft-floor, commercial activities at the ground floor, big terraces or prominent roof, irregular height, tie-beams, signs of renovation
	14. Building shape*	Square, rectangular, L-shape, C-shape, other or irregular
Roof	15. Roof type*	Flat, one/two/three/four slopes, irregular
	16. Presence of roof tiles*	Y/N
State of conservation	17. Building used or abandoned*	Abandoned, under construction, rarely used, frequently used
	18. Signs of damage or malfunctioning*	Presence of cracks, mold, wall damages, windows in bad conditions, roof in bad condition, no signs of malfunctioning
	19. Conservation status*	optimum, good, poor, bad
Final questions	20. Communication with residents*	no interaction, positive, neutral, negative
	21. Available information*	Personal knowledge of the building, observation in situ, virtual observation, information gathered from residents, other people's opinion
	22. Confidence degree*	Low, medium, high

2.3. Analysis of the crowdsourced data

During the project, students collected information on more than 3200 buildings by means of the survey form accessible online from the mobile phone or from the computer. The data collection activity was carried out partially in person and partially remotely due to Covid-19-related restrictions (using Google Maps and Street View tools). Based on the address field, each building survey was georeferenced through the Google Maps tools. The spatial distribution of the surveys (yellow dots) is shown in Fig. 1. The collected data were grouped into 7 sub-areas, each one containing approximately 400 building surveys (Fig. 1). Note that Gemona del Friuli, which had a greater group of students, was associated with two sub-areas.

Each school received two sets of data: the full dataset and the subset corresponding to its own sub-area (Fig. 1, black squares). The data were distributed in the form of a spreadsheet table to each group to perform the statistical exploratory analysis following the recommendations provided by the OGS tutors (see Table 1). For this purpose, some user-friendly online tools for statistical data analysis (e.g. EasyStat, https://easystat.com; Jamovi, https://www.jamovi.org) were suggested to the students, to facilitate data processing and graphical representation (as most of the students do not have specific software or programming skills). The statistical analysis was performed also by the OGS researchers, as independent verification of the data quality.

The performed analysis were:

- Single-variable statistics for age, material, height and other variables in the crowdsourced exposure dataset.
- Multiple-variable statistics for the most relevant combinations of the exposure parameters (e.g. age and material, age and conservation, material and height).
- Analysis of the distribution of building typologies in the different study areas
- Comparison of specific building characteristics between the different study areas (e.g. roof type of historical masonry buildings)

Such analyses were performed for the total dataset and for the specific sub-areas in order to compare the results and identify typical features for the sub-areas (Fig. 1). Finally, each student's group produced a final presentation, which was publicly discussed during the conclusive event.

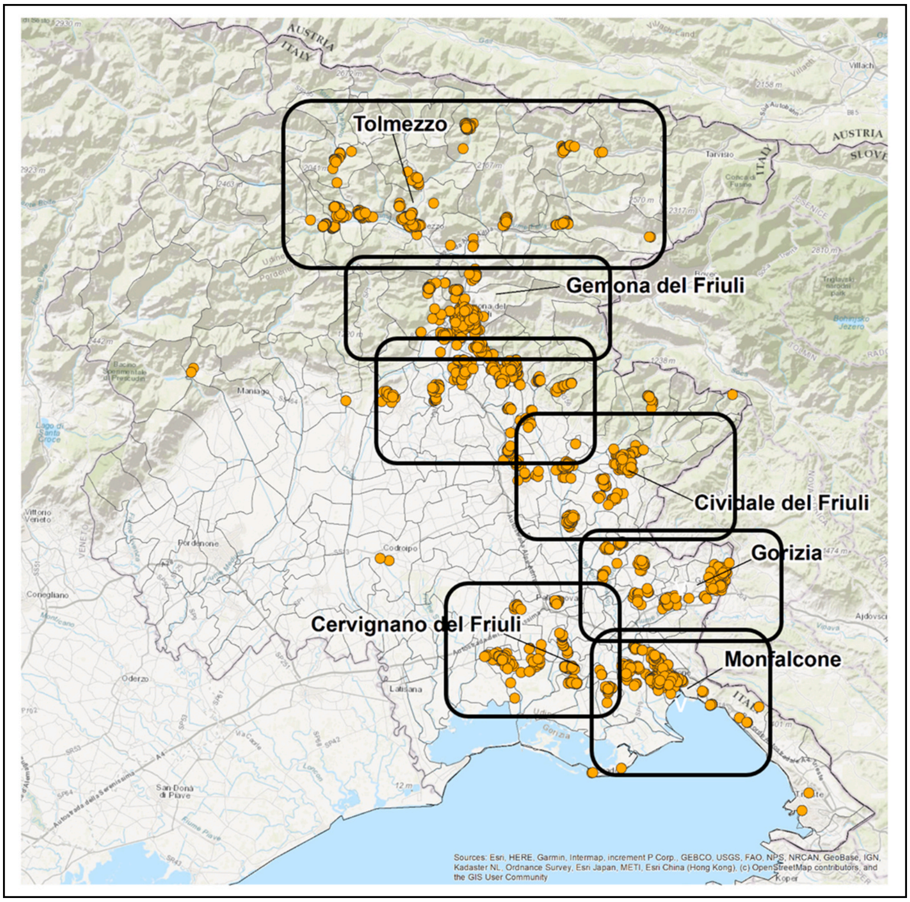

Fig. 1. Study area and location of the collected data (points). Collected data were divided into 7 sub-areas identified (black squares).

2.4. Validation of the crowdsourced data

The collected data were validated based on direct expert evaluation of a subsample of buildings surveyed by the students, for which pictures were available. First, we selected 100 representative buildings, uniformly sampled from the 7 sub-areas of the dataset. The sampling was performed using the ArcGIS 'Subset features' tools, whose algorithm ensures homogeneous coverage of the study area (Fig. S2 in the electronic supplement). The analysis was done for three main exposure indicators: buildings age, material and typology. For each indicator, the options were associated with numeric values (Table 2, questions 7, 8 and 9) in order to support statistical analysis. The reply 'I don't know' was associated with a null value. Then, OGS experts assessed the selected indicators by inspecting the available building pictures. Results were finally compared with the corresponding ones collected by students. Such procedure, although simplified, allows a first order ground-truth validation of the collected data, clearly under the assumption that the OGS expert assessment is correct and not biased. In addition, the collected data were validated against existing exposure data sources available for the territory, in particular against two datasets:

- The land use plans available for the region. In the last years, regional land use plans were homogenized into 5 macro-classes for the entire FVG region (A,B: historical center and first expansion areas; C: recent or new residential areas; D: industrial areas; E: agricultural areas; F: services areas). An automated spatial analysis allowed to estimate the number of buildings associated with specific use (e.g. industrial) with the corresponding areas in the land use plans.
- The last comprehensive building census, performed in 2011 (Istat, 2011). The census contains indicators on residential buildings age and material, aggregated over municipalities or census units. A comparison was performed between the material, age and storey number contained in the ISTAT dataset and the ones in the CEDAS dataset. This comparison was performed at the municipality level and at the census unit level. The former was performed comparing the CEDAS dataset with the ISTAT data collected in all municipalities in the sub-areas (Labels of Fig. 1) with the exception of those with less than 1% of the samples. The city of Udine was also excluded because it is the second town in the region but comprised less than 5% of the surveys in the corresponding sub-area.

The results of the validation process have been presented and discussed with the students during the final meeting of the project.

2.5. Understanding issues in crowdsourced data collection and interpretation

At the end of the project, an evaluation questionnaire was distributed in order to collect feedback from students and teachers. The questions were focused on the deployment of the activity, and aimed at identifying issues in the data collection and interpretation. In particular, it was asked about the difficulties experienced by students in collecting and analyzing the data, and about the conditions in which they deployed the work (e.g. if they were alone or in group, if they planned the work in advance, etc.). Finally, it included specific questions about the perceived usefulness of the project for themselves and for the scientific community, and about the students satisfaction about the project. Questions on students' appreciation and willingness to repeat the activity are intended to measure the engagement and quantify the project impact. The list of questions asked during the questionnaire is included in the SI (Table SI1). A shorter questionnaire was provided to teachers in order to assess the issues experienced during the project and the perceived usefulness of the project.

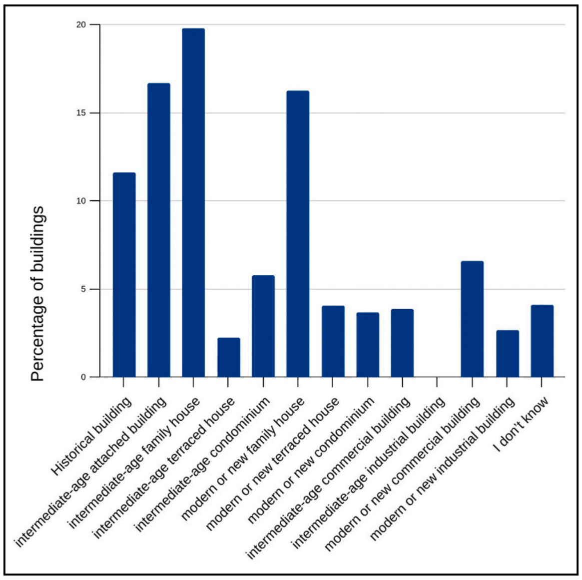

Fig. 2. Percentage of buildings surveyed for each building typology considered.

3. Results

3.1. Buildings typologies in FVG

During the CEDAS project, we collected more than 3200 forms of which approximately 65% were compiled of residential buildings. The remaining surveys include commercial buildings (10%), critical facilities (6%) and other public and private services (7%). Less than 5% of surveys are collected for touristic structures and industrial buildings. The collected data allow analyzing the buildings characteristics both in the entire dataset and in the different sub-areas. Results of the statistical analysis provide the distribution of different building typologies in the whole dataset and in the different sub-areas, pointing out the differences between them. The distribution of typologies in the entire CEDAS dataset is shown in Fig. 2. All areas see the prevalence of four building typologies: historical buildings, intermediate-age family houses, modern or new family houses, intermediate-age attached buildings. The most common building typology observed during the data collection is the middle-age single family building, for which 639 surveys were collected, accounting for 20% of the entire CEDAS dataset. Based on the collected data, it is possible to define its specific features and identify differences among the same typology in different areas.

Fig. 3 shows the distribution of the most common building typologies in each of the sub-areas considered in this study. Intermediate-age family houses and attached buildings are present all over the studied area. Historical buildings are present in a higher fraction in Tolmezzo, Gemona and Gorizia. Modern buildings are present mostly in Gemona, Monfalcone and Cervignano. In particular, the statistical analyses performed showed that attached houses and new houses are particularly frequent in Monfalcone.

An example of the results from exploratory data analysis performed by each group of students is shown in Fig. 4. The plots highlight the peculiarities in building materials in the specific area, namely the Cervignano Area, where “Modern Mansory” turns out to be more frequent than in the other areas of the FVG region, which are characterised mainly by “Reinforced Concrete” buildings.

3.2. Result of the validation process

Results of the validation based on the expert assessment are illustrated in Fig. 5 and in Fig. 6. The correspondence between students (CEDAS) and expert (OGS) assessments is investigated by exploring the one-to-one relation between assigned classifications (Fig. 5) for three main features: typology, age and material, as well as by comparing the distributions associated with each of the selected variables

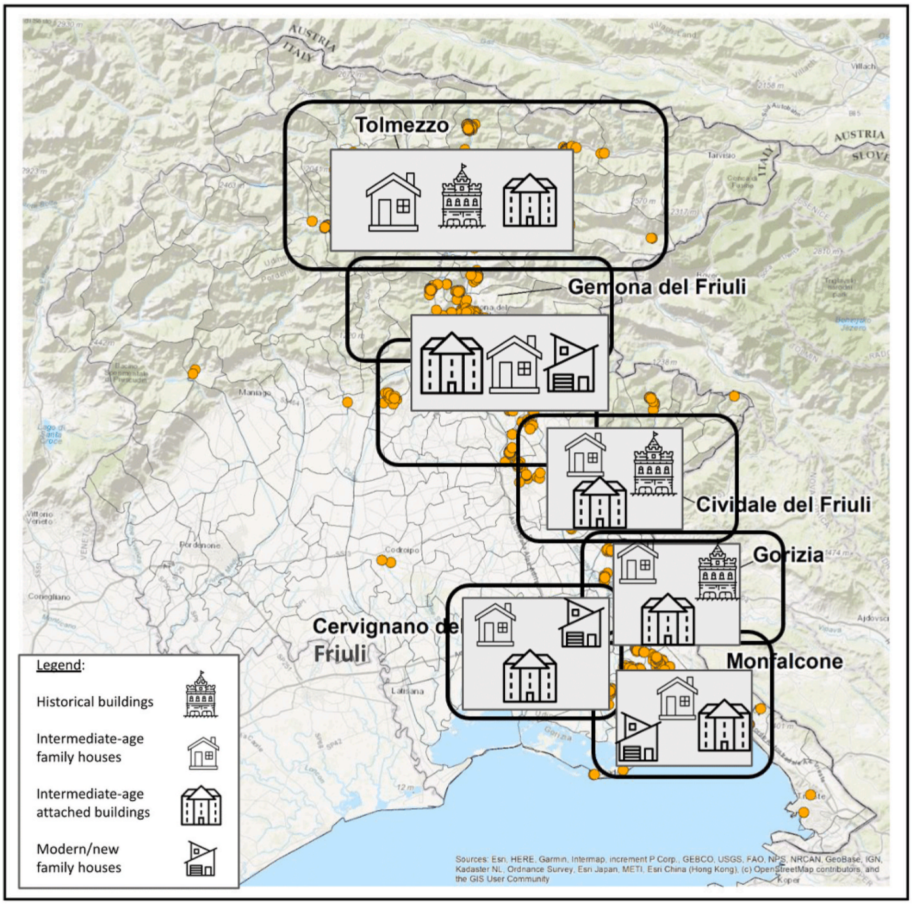

Fig. 3. Distribution of the four most common residential building typologies in the region (described in the legend) in the different study areas. For each area, the three most common building typologies are shown in the corresponding boxes (building icons provided by the Noun project https://thenounproject.com/).

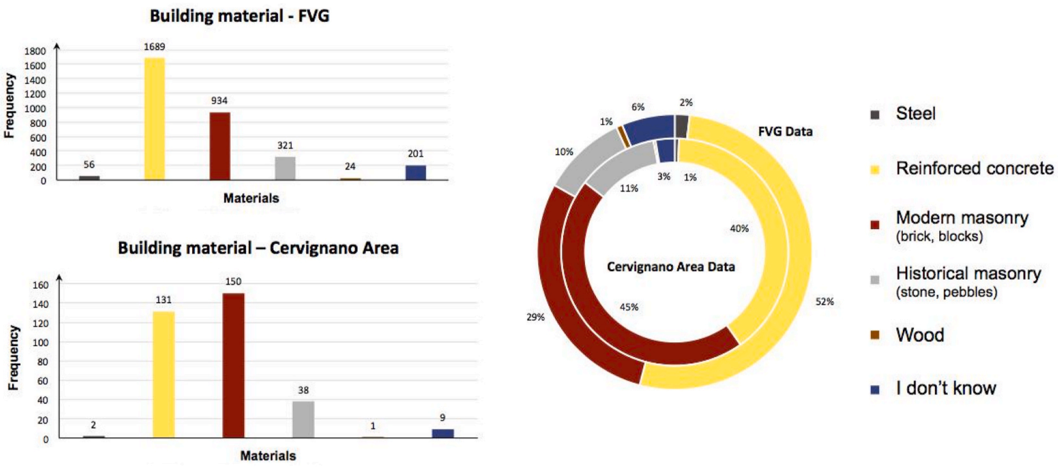

Fig. 4. Graphical comparative analysis of building materials for the entire FVG region and within one of the selected areas (Cervignano area), as obtained by the students during the data analysis and interpretation phase (labels translated into english for clarity).

(Fig. 6). To this end, the typology, age and material categories are converted to numerical classifications ratings following Table 2 (questions 7, 8 and 9 respectively).

The frequency-scatterplots of students versus expert assessments show that they are evidently correlated for all of the considered features (Fig. 5), with Spearman Rank correlation coefficients: R (typology) = 0.87; R (age) = 0.81 and R (material) = 0.71 respectively, the largest differences being observed for the assessment of typology and building materials. The plots in Fig. 6 show the number of samples in each class identified for typology, age and material (a,b,c, respectively), The sample dataset (blue, CEDAS) is in overall good agreement with the expert assessment (red, OGS). The building typologies for which the higher discrepancies are shown (Fig. 6a) are historical buildings and intermediate-age attached buildings. Students successfully identify the age classes, in particular the recent or new buildings (Fig. 6b, class 4). As for the material, the main differences are found for reinforced concrete buildings. Quantitative statistical assessment, performed by Chi-square test for observed (CEDAS) versus expected (OGS) distributions, indicates that the difference between the distributions, obtained based on students and experts assessments, is not significant for all three investigated features (p-values 0.35, 0.59 and 0.62 for typology, age and materials, respectively).

The validation against land use plans show that more than 95% of historical and old buildings are located in the corresponding areas in the urban plans (i.e. the historical center and first expansion areas). Similarly, 95% of industrial buildings are located in the corresponding land use areas (i.e. industrial areas). Finally, a high fraction (84%) of the intermediate-age family houses are located in urban development areas, which were mostly developed during the Italian economic boom (recent or new residential areas). However, the single family houses are also found in other urban areas, showing that this typology was widely used in the region from 1950 to recent times.

Fig. 7 shows two examples of buildings identified within specific land use areas, respectively for correct and wrong typology identification. In Fig. 7a, a residential building was correctly identified within an industrial area. Land use plans were introduced only after the ‘50s, and the classified areas can include small fractions of other land use types. In this case a new industrial area incorporated a few rural buildings previously constructed. The historical city center in Fig. 7b (green, star-shaped area) is expected to contain mostly historical buildings with a minor fraction of recent ones. The two buildings in the pictures were both identified as modern

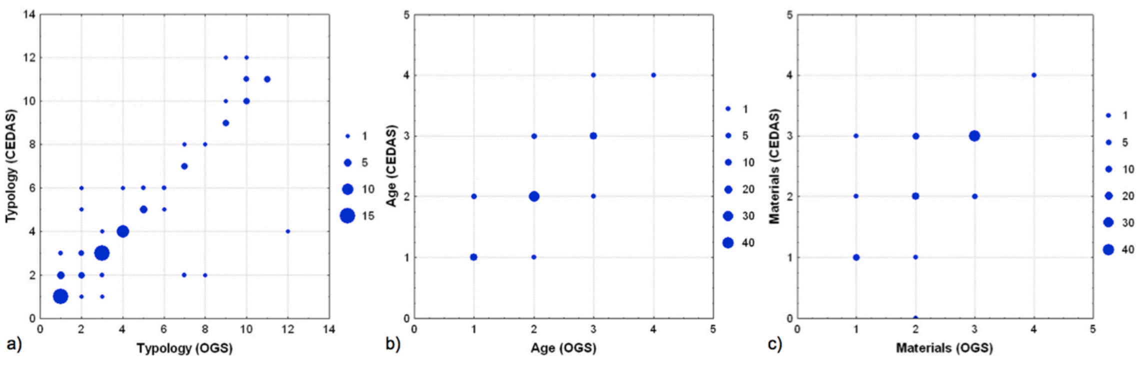

Fig. 5. Frequency scatter plots showing the correlation between assessments performed by students (CEDAS) and experts (OGS) for the three considered variables: building typology, age and material.

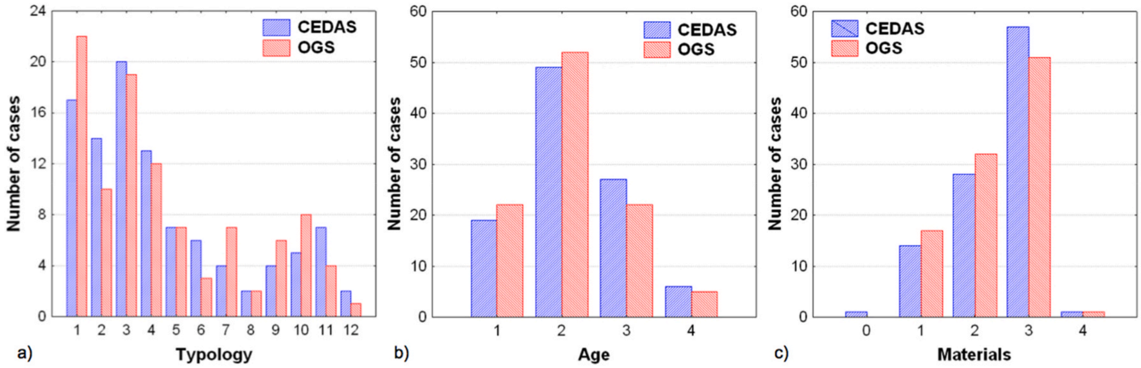

Fig. 6. Comparison between the assessment performed by students (CEDAS, blue) and OGS experts (OGS, red) for the three considered variables: building typology, age and material (a,b,c respectively).

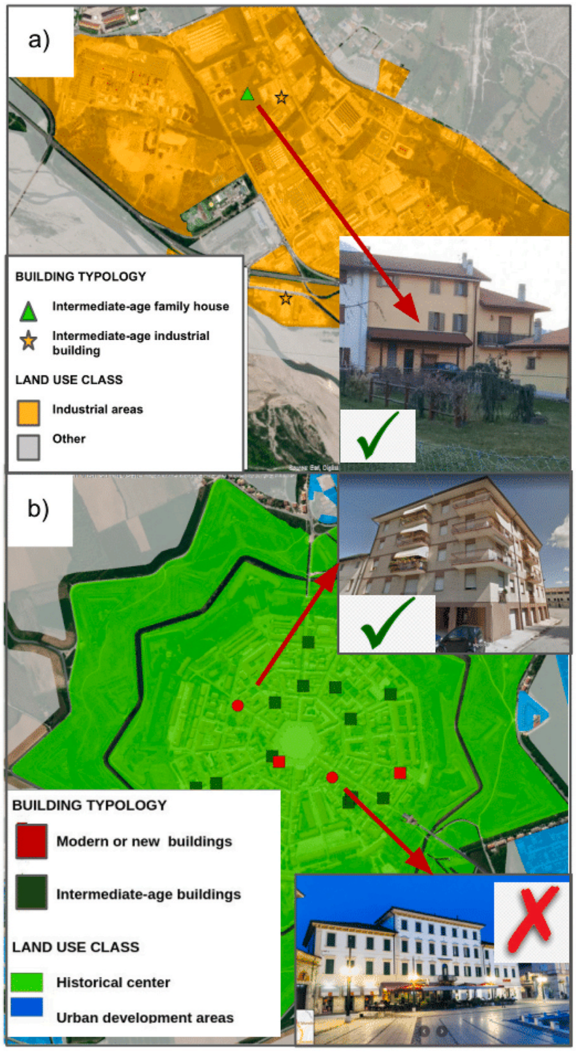

Fig. 7. a) example of correct identification of a residential building within an industrial area; b) examples of correct and wrong typology identification in a historical city center.

condominiums, but one of them is actually an historical building which underwent a reformation process.

The comparison of collected data with the ISTAT census at municipality level shows that the CEDAS dataset has an overall similar age and material distribution than the ISTAT dataset. Results of the comparison for building material are included in the SI (Table SI2). The fraction of URM buildings are very similar between the Istat and CEDAS datasets in all municipalities except Tolmezzo and Cividale, where differences between 10 and 15% are found. However, there are greater discrepancies in the fraction of RC buildings, mostly due to the different fields used in the Istat and the CEDAS survey. The Istat material classification includes the category 'other/mixt', not used in our survey. This category is compared here with the other options of question 9 (Table 2), including the 'I don't know' option. The percentage of RC buildings is higher in the Cedas dataset, while the Istat dataset contains a higher fraction of 'other/mixt' buildings. This suggests that other/mixt buildings are more difficult to recognize, and they are often confused with RC buildings. Interestingly, municipalities with a large number of 'I don't know' replies show a better matching of the CEDAS and Istat dataset. Students might have classified the mixt buildings either in the "I don't know" or in the RC option, causing a lower or higher discrepancy, respectively. This hypothesis will be investigated in detail in future work. Finally, the comparison of age classification shows that the discrepancies are higher for historical and intermediate-age buildings (but always lower than 20%). It is worth mentioning that the 'I don't know' answers are always below 2% for this question.

3.3. *Students' feedback on the activity*

The final evaluation questionnaire was compiled by approximately half of the students. The number of answers normalized by the total number of participants was greater for Tolmezzo, Monfalcone and Cervignano, and lower for Gemona and Cividale. The students from Gorizia did not participate in the final survey. Half of the students did not participate, probably because the survey was conducted after the end of the school year and, in some cases, overlapping final school exams.

Regarding the data collection process, 55% of students think that half an hour is a fair amount of time to collect information about a single building, while 30% think that it's too much. Almost half participants planned the building surveys in advance, which implies a certain reasoning and preliminary observation of the environment. 45% of participants prefer to compile the form in situ, and another 35% would prefer a hybrid (in situ and online) mode. Very low fractions of respondents (less than 10%) would compile the form online, or have no preference.

According to the respondents, the most difficult aspects to be gathered are building age of construction, followed by the structural material (selected by approximately 70 and 60% of participants, respectively). Assessing the number of storeys was also quite difficult according to 34% of students. 20% of respondents experienced some difficulties in identifying buildings' specific features (Q13). Finally the building typology was selected among the most difficult parameters by only 13% of respondents (Fig. 8a).

While 25% of respondents experienced some difficulties in organizing the data collection, a higher fraction (45%) experienced some difficulties in performing the statistical data analysis. In addition, most students found it difficult to interpret the results (Fig. 8b): a rating of 3 and 4 out of 5 was selected by respectively 34 and 30% of students. Interestingly, 70% of students pointed out that the (online) group activities are very useful for interpreting the results (4 and 5 rating level).

Besides achieving new skills (e.g. ability to recognize specific building types or land use areas), students also consolidated existing ones, in particular those associated with scientific subjects, statistical notions in particular. Based on the questionnaire replies, more than half participants had already had experience with Excel, but more than 70% of them feel that their competences have increased during the project. In general, very low fractions (less than 5%) did not acknowledge the usefulness of the tools used for statistical analysis (Excel, Easystat).

The final part of the questionnaire was devoted to assessing the familiarity of respondents with seismic events and their perception of the activity developed during the CEDAS project (Table S1, 'Final feedback' section). Table 3 shows the percentage of respondents who perceived at least one earthquake (column 1), who heard about earthquakes (column 2). 97% of respondents confirmed to have heard sometimes about earthquakes in their area of residence, while 85% had felt at least once an event. Table 3 also shows the percentage of participants who perceived high usefulness of the project (rating of at least 4 over 5) for themselves and for the scientific community (columns 3 and 4, respectively). 75% of respondents consider that the results of this project are useful or very useful for scientific purposes, and their percentage is substantial in all municipalities, with higher values for Gemona and Cervignano. However, replies are scattered with regards to the perceived usefulness of the project for themselves, with the majority of respondents in the

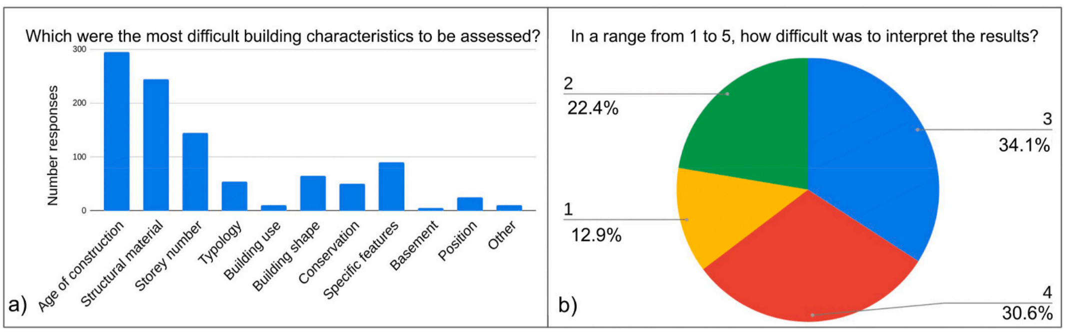

Fig. 8. a) Most difficult characteristics to be gathered during the data collection and b) Perceived difficulty in interpreting the results of data analysis.

Table 3
Percentage of respondents who perceived at least one earthquake (column 1), who heard about earthquakes (column 2) and who perceived high usefulness of the project for themselves and for the scientific community (columns 3 and 4, respectively). Results are provided for each municipality and for all replies. Gorizia is not included since the students did not compile the questionnaire.

Municipality	% respondents who felt an earthquakes in their municipality	% respondents who often heard about earthquakes	% respondents which perceived high usefulness for itself (4 and 5 rating)	% respondents which perceived high usefulness for science (4 and 5 rating)
Tolmezzo	100	92	62	69
Gemona	86	62	15	84
Cividale	70	50	10	60
Cervignano	94	35	70	88
Monfalcone	75	15	5	60
All replies		49	30	74

medium level (3 out of 5). The values vary on a wide range, from 70% of respondents who think the project is useful for themselves in Tolmezzo, to 5% of students in Monfalcone.

Most respondents appreciated the activity (30% and 47%, respectively for level 3 and 4 over 5). The majority expressed a medium willingness to repeat it next year (level 3 over 5) and a 25% manifested a strong willingness to do so (level 4 and 5). It is worth mentioning that teachers expressed a high interest in the activity, but also recognised some difficulties in managing the communication with the students and carrying out the statistical data analysis in remote mode (in presence hands-on tutorials could have been much more effective). These difficulties are mostly due to the restrictions caused by COVID-19, which forced the activity to be mostly developed online. However, during the final event, both teachers and school principals expressed an overall positive feedback and great interest in deploying similar activities in future.

4. Discussion

4.1. Crowd-sourcing activities for exposure development

The data collection form presented here can be used as a blueprint for similar activities in other areas worldwide. However, it needs to be specifically adapted to the context (e.g. by updating the age classification according to the building stock characteristics of the study areas). In addition, data collection should be preceded by a specific training which is also context-dependent and based on images taken from the students' environment (and thus more recognizable for them).

One of the greater challenges of crowdsourcing is that collected data rely on a subjective evaluation [16]. During the training, the subjectivity of the assessment was underlined on multiple occasions. The survey contained a specific question on the perceived confidence in compiling the building form: approximately 40% of participants feel very confident with their answers, and another 60% feels quite confident, and very little fraction show a low confidence. In addition, the survey questions with a higher number of 'I don't know' answers are the ones about structural material and presence of the basement. Based on the responses to the final questionnaire, students experienced difficulties in assessing building material and age (Fig. 8), which are two of the most important indicators for vulnerability and damage assessment, as they allow associating each building to specific building codes. In the case of FVG, it might be particularly difficult in case of low-rise, intermediate-age buildings in Italy, that can be constituted by unreinforced masonry, RC frames or a combination of the two. This difficulty has also been observed by Ref. [37] for 1-to-6-storey buildings in China. The validation process also shows that some students were able to identify residential building types even if they were located in unexpected places (Fig. 7a), but building reformation can give misleading information and cause errors in the attribution of typology and age of the buildings (Fig. 7b). According to the final questionnaire replies, building typology was much easier to recognize for most students (Fig. 8a). This seems to confirm our original assumptions that identifying building typologies is somehow easier and more intuitive than assessing their specific features (e.g. age, material). Finally, it is worth mentioning that exposure data were collected based on the *Google forms* tool which proved very useful for a pilot project aimed at testing the possibility of collecting exposure data and developing citizen science activities. However, the georeferencing process performed by Google is not always accurate. Specific apps developed for the purpose of crowdsourced spatial data collection might improve the quality of the geolocalization and support broader projects of this kind in the future. The validation process was carried out based on expert assessment of a subsample of investigated buildings which provided solid ground-truth evidence of the reliability of the collected data. In addition, the comparison with existing spatial proxies (i.e. land use) allowed a rapid and automated, although simplified validation of the whole dataset, applicable in absence of building pictures. Thus, despite the subjectivity of the evaluation, the bias on the building selection (acknowledged by students during the final event) and the possible georeferencing flaws, the data collected into the CEDAS dataset are coherent with the existing exposure data available (Section 3.1).

4.2. Citizen science for risk awareness

In the last decade, the importance of citizen science as a promising scientific research method became evident [38]. Previous experiences showed that involving young citizens in scientific activity related to risk assessment can increase their risk awareness and preparedness (e.g. Ref. [39]. As emerged in the FVG region, forty years after the 1976 earthquake, the memory of a community fades, and young generations have little knowledge of past catastrophic events, even if they had catastrophic consequences [23]. In addition, the memory of the facts is overwritten by the very popular, but sometimes incorrect beliefs. Thus, raising awareness is particularly strategic in young generations that live in seismic-prone areas. For more than 10 years, OGS had developed several activities with school students in northeastern Italy, so as to avoid this loss of memory. Such activities include general training and dissemination of seismic-risk-related concepts [27], as well as more specific training on geophysical characterization of soils (Barnaba et al.,. 2018) and software development [40].

Despite the great advantages of citizen science approaches, there are also many open challenges, in particular related to the long-term educational impact of the activities. In order to be effective, citizen science projects should be sustained for a long time and integrated into existing policies [16]. The CEDAS project is part of the continuous and long-lasting educational and training efforts deployed by OGS at different levels [41]; submitted [42]; and for different target groups (e.g. civil protection volunteers, journalists). This activity, which will be maintained over the time, has the potential to keep high risk awareness and preparedness in FVG, and in the long-term can contribute to mitigating potential impacts of seismic events.

According to the post-activity questionnaires, students are quite familiar with earthquakes and think that the project has a high importance and relevance for the scientific community (Table 3). However, the two indicators of perceived usefulness for individuals and for the scientific community do not seem correlated. For instance, in Gemona, few students perceive a high usefulness for themselves, while most respondents identify the usefulness for the scientific community. On the contrary, in most municipalities the perceived usefulness for oneself seems to be positively correlated with the familiarity with earthquakes. Differences in perceived usefulness of the project (section 3.3) might thus depend on several factors, including the impact of past events (e.g. those of the Friuli 1976 earthquake in Tolmezzo and Gemona), the degree of seismic activity in the different areas and the impact of past risk-related training and educational activities.

Replies to the final questionnaire show that there is an overall medium-to-high personal motivation and perceived usefulness related to these projects. The fact that the majority of students appreciated the project and wish to repeat it shows a good level of engagement. However, strong emphasis on students' engagements should be put in the future to improve these results and involve more participants. Systematic citizen science activities on risk-related topics might contribute to increasing the interest on the topic and, subsequently, the students' motivation. The final survey replies show that students preferred practical activities, such as collecting data in the field, and group activities, which eventually circumvented the difficulties in data processing and interpretation. Such difficulties are probably related to the students' background and in particular their previous knowledge and familiarity with statistical concepts and computational tools, which partially depends on the specific school programs. Citizen science activities such as this one should ideally build on school programs, so that school sets the basis for specific training activities. Students, in fact, expressed their satisfaction for having an opportunity to apply the tools and lessons learned during standard courses, and appreciate their scope and practical use. Alternatively, this activity might be associated with preliminary scientific training programs, or might be adapted to the specific context, defining more focused exercises. One of the most important lessons learned is that activities such as the CEDAS project should be properly tailored to the specific skills and context, for instance by assessing in advance the level of experience of students with the tools to be used (e.g. Excel spreadsheets), or the availability of mobile phones and network coverage for online data collection in the areas of interest. Brainstorming sessions demonstrated it might be possible to optimize the data collection and analysis procedures, so as to fully exploit the participants expertise and, at the same time, to allow collecting sound feedback also from participants with limited skills. The use of online questionnaires is nonetheless a powerful tool to successfully deploy such activities, which turned out essential at all stages of the project development.

Increasing citizens' risk awareness and preparedness and their knowledge of the exposed assets can contribute to mitigating risks in seismic prone areas. We argue that the active involvement of students in practical activities can increase both their observation ability and their personal engagement, strengthening the educational impact of citizen science activities. Virtual activities are a powerful tool to reach a wide audience (e.g. a larger number of students from different schools). However, a good trade-off should be reached between virtual interaction and activities in presence. Field-based activities and personal interaction can contribute to raising their interest on scientific topics, and set the basis for an evidence-based scientific culture for the young generations. Future efforts will be devoted to repeat the study, applying the lessons learned during this pilot, and deploy it at a larger scale. In addition, collected data will be used to enrich the current exposure dataset and subsequently the damage assessment procedures currently developed for north-eastern Italy [44]; [35].

5. Conclusions

In this pilot study, we explored the potential of crowdsourcing activities in gathering up-to-date exposure data. The collected data provide useful insights on the distribution and characteristics of typical buildings, and allow to enhance current exposure layers for the study area. But the CEDAS project goes beyond mere data collection and includes data analysis and interpretation: we tested the citizen science approach for seismic risk mitigation purposes with school students. Virtual tools allowed us to reach a large number of students and involve them in practical activities, gathering reliable data while improving students' skills and competences. The CEDAS experience produced valuable results at two levels, which both concur, in different ways, to disaster risk mitigation. On the one hand, the activity allows collecting up-to-date crowdsourced exposure data, which are paramount for developing reliable risk estimates. On the other hand, it contributes to educate citizens, increasing risk-related knowledge and risk awareness in young generations. The CEDAS project was motivated by the need to provide a practical solution to the Covid-19-related restrictions and the subsequent disruption of practical activities with students. However, its applicability goes beyond the Covid-19 situation, and provides a framework that can be adopted in future engaging a broader audience of citizens in seismically active areas worldwide.

Data and resources

Italian census data were provided by the Italian National Institute of Statistics (Istat, Italy), and their use is allowed for research purposes. Land use maps for FVG were provided by the SITeP (Sistema Informativo Territoriale Pianificazione) department of the FVG region for research purposes. All crowdsourced data were collected and managed using the Google suite tools of OGS, and will be stored by OGS for research purposes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2021.102755.

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