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Remote earthquake damage reconnaissance missions: "Business as usual" through technology and networking

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Abstract

On Sunday 22 March 2020, while most of Europe was experiencing lockdowns to contain the COVID-19 pandemic, a Mw5.3 earthquake hit the capital of Croatia. The event caused damage to buildings and critical infrastructure in the Zagreb city centre and surrounding villages. While the intensity of the earthquake and the resulting casualties and damage are minor in comparison to past events worldwide, its timing makes it worthy of investigation. After an earthquake, there is only a small window of opportunity to gather perishable data. The pandemic and the unprecedented restrictions imposed on air-travel made it impossible to launch a traditional earthquake reconnaissance mission in a suitable time frame. To gather damage data on this earthquake, a team of UK researchers worked remotely and alongside a Croatian team of seismic engineers and practitioners. Together, they explored how the use of a standardised app-based data collection tool and a spatial data infrastructure for data managing and mapping can support remote earthquake damage reconnaissance missions. First of its kind, this initiative is particularly important considering the uncertainty surrounding this novel virus and the possibility that we may see more of these events in the future.

The paper offers an overview of how the circumstances of this event and the paucity of data on the Web prompted the idea of remote data collection. The paper illustrates in detail the tools and the method used for the Remote Zagreb Mission. The paper collates the important lessons learnt on how the advancement of data collection tools and the widespread internet connectivity that permeates our daily life can be harnessed to conduct remote earthquake damage reconnaissance missions and training, and thus bring communities exposed to seismic hazards closer together through shared knowledge, capacity building, and networking.

Key words: earthquake, COVID-19, data collection, technology, networking

1 Introduction

On Sunday 22nd March 2020, at 6:24 am local time, the capital of Croatia and the surrounding villages were struck by a Mw5.3 earthquake. With a maximum reported intensity of VII-VIII (Strong) on the MCS Macroseismic Intensity Scale, the event – which was followed by numerous aftershocks – resulted in damage to both building and critical infrastructure, one direct fatality, and 26 injuries. Even though the intensity of the event and the resulting consequences are those of a minor event, the Zagreb earthquake has spurred significant interest in the scientific community because it was the first significant natural disaster to occur while Croatia, as well as most of Europe, was in lockdown for the containment of the COVID-19 pandemic. This circumstance makes a compelling case for the international scientific community to study the Zagreb Earthquake and learn how the temporal concurrence of a pandemic event and of a natural disaster change how the latter event is managed.

Inarguably, the restrictions imposed on air-travel since the start of the pandemic have affected the ability of international research groups to visit Croatia and collect data in the field in a suitable time frame. Looking at the specific issue of earthquake damage reconnaissance, this paper investigates how the challenges of the lockdown have been met with innovative technological solutions to allow a UK-based research group to continue to collect and analyse data remotely.

The paper describes how the data collection and management tools, which are being developed for the Learning from Earthquake - UK project, have been applied to the Zagreb case study. Conclusions are drawn on how technology and networking can allow the international community to operate "as usual" even when direct data collection is not possible. It also highlights how the same tools can be used in "peace-times" to build opportunities for capacity building and networking amongst international research groups.

2 The Learning from Earthquakes – UK data collection and management tools

2.1 The project and its objectives about standardised data collection and management

The importance of geographic information in the field of Disaster Risk Reduction and Response has substantially grown in recognition since the early 2000s [1]. Maps have become essential to emergency managers as well as governments, across all stages of the emergency management cycle [2].

Nowadays, the ubiquitous diffusion of web-connected portable devices and smartphones [3] and the fact that data are at times collected involuntarily by large groups of users (e.g. big data) has led many to believe that collecting valuable data has become so inexpensive that the intrinsic value of the data itself has de facto decreased. While it is true that using electronic devices is more practical than using film cameras, paper forms and GPSs, the collection of geolocated and standardised data is still very expensive, in terms of the time spent to achieve standardisation. The value of the collected information also depends on the time of capture and on the possibility to capture the same data again.

In the context of rapidly changing post-disaster scenarios, geolocated data about damage are high-valuable and, at the same time, highly perishable - due to the need of the response teams to progress rapidly towards a "return to normalcy". And so, it is even more compelling that, once collected, disaster data are managed and stored efficiently to avoid data loss. Once collected, disaster data are analysed by different actors at different times. The way the data is managed and distributed to its users affects its suitability for use in the decision-making process that follows a disaster, and also the possibility to compare multiple events and they have unfolded over time.

A Spatial Data Infrastructure (SDI) is the best-suited technology to achieve these objectives. An SDI is an infrastructure aimed at supporting the data management (including storage), discovery, access, and easy retrieval and reuse of the geographic data collected, and can be designed to support very varied users' needs. Unlike storage devices, the use of metadata (i.e., data about the data) assists in the classification of the data and, in turn, promotes the integration of data coming from disparate sources and thus limiting - if not eliminating - the need for parallel and costly data collection campaigns. Altogether, these characteristics make an SDI an ideal tool for use in the Disaster Risk Reduction and Response field.

As part of the Learning from Earthquake (LfE) UK project, an SDI and an app-based data collection form are being developed to support the data needs of the Earthquake Engineering Field Investigation Team (EEFIT). The Earthquake Engineering Field Investigation Team (EEFIT) is a joint venture between industry and universities, conducting field investigations following major earthquakes. Data are usually collected by team members deployed to the affected areas, which are trained to collect data following protocols that have built and improved on during the decades in which EEFIT has remained active. In the past decade, EEFIT has responded to the technological advancement in data collection by introducing new ways to collect geolocated digital data. From the lessons learnt from past missions, new data needs have emerged, and these are now being addressed with the development of the standardised forms for digital data collection in the LfE app and the SDI.

2.2 The LfE Mobile app

Structural damage assessments are an integral and essential part of the recovery process from a natural disaster. In the aftermath of a disaster, engineers aim to assess the buildings within the affected areas to assess, to identify the damage, to assess the safety of affected buildings and determine their usability. They also aim at identifying buildings requiring emergency strengthening and to avoid further collapse during after-

shocks. Ideally, their role is also to provide data to the authorities to plan further relief and rehabilitation measures, but also to inform the wider scientific community and re-evaluate existing codes of practise and to develop more detailed vulnerability models for pre-hazard damage assessment [4].
A systematic collection of damage data becomes a key element of this process, because – if done properly – it reduces the time required to complete the work, it ensures that no valuable information is lost, it leads to a realistic assessment of the building capacity and it helps understanding more of how to improve such behaviour when designing new buildings in hazard-prone countries.
The LfE mobile app builds up from past field experiences and currently available paper forms such as the AeDES and the ATC-20 forms, whilst also endeavouring to improve these forms through a user-centred, tier-based assessment flowchart aiming at gathering non-repeated sets of damage data which allow conducting a homogenised large-scale damage assessment, the structure of which is reported in Figure 1. The LfE Mobile data collection form is served to the user via the off-the-shelf Device Magic App, which allows users to create customised forms for data collection. The LfE data collection form has been developed ad-hoc and considers the specific needs of the EEFIT community.

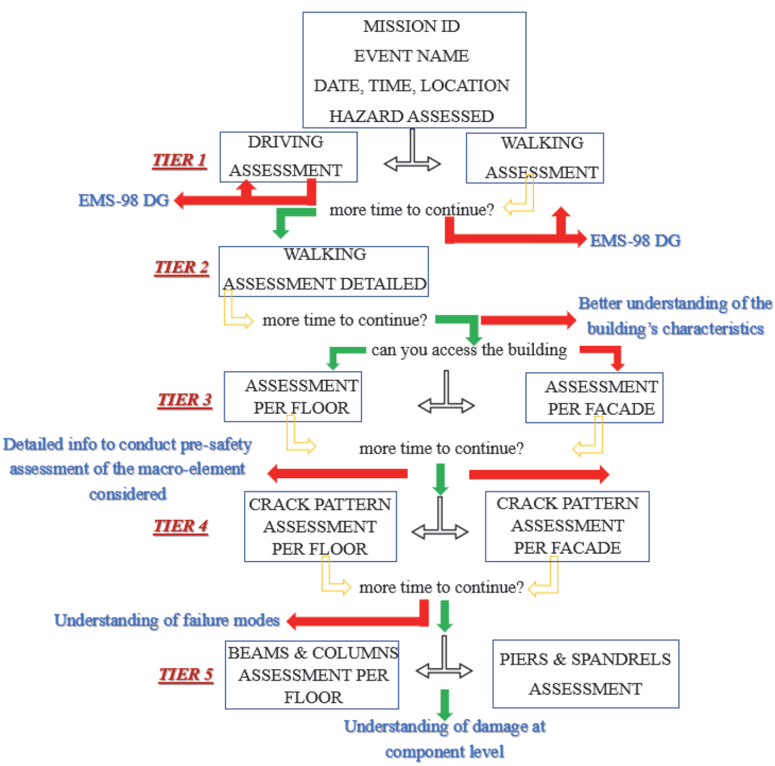

Figure 1. Tier Assessment flowchart of LfE Mobile App

2.3 The EEFIT - Spatial Data Infrastructure

The EEFIT Spatial Data Infrastructure is designed with a user's needs-centred approach to accommodate data collected in reconnaissance and recovery missions as well as training. Since missions can occur in places and times where internet connectivity may not be present, the SDI is designed to work on two complementary systems. The offline local SDI is hosted on a laptop computer which is carried during mission times. It is used to upload all the data that are collected during the mission, so that "no data is left behind" and that perishable information about the data is collated into a centralised place at the time of collection. Once uploaded the data are analysed by ad-hoc scripts so that key metadata can be extracted automatically. For photos, typical metadata include the time of capture, the resolution, information about the collecting device, and the geolocation. The metadata and the data volunteered by the data collector at the time of upload are used to build a database of information linked to the collected data and to map the data that have geolocation. The local SDI is supported and augmented by a cloud-based SDI, which enriches the information available in the local SDI by adding a further layer of data richness. This is achieved by integrating the data collected with the LfE app and other apps that EEFIT may use to collect data. The LfE app de facto replaces the need for paper forms, which were used in the past. The integration of the SDI and the LfE app allows the user to collect disaster data at ease and to be guided in this process by the workflows that have been designed in the LfE app forms so that the data collected are standardised and can be easily compared. Once uploaded, the "data to maps" process is performed automatically by the SDI.

The SDI has 3 components: an Uploader - which consists of a set of easy forms that can be accessed both offline and online to upload data to either the local SDI or the Cloud-based SDI, a Metadata Extractor which analysed the data and populates a database, and a Mapper that uses the data in the database to produce daily maps of what has been observed in the field. This last component is still being developed at the time of writing. When there is no internet connectivity, the users will be able to see the locations that have been visited during daily deployments in the form of a trail of dots. Each of the dots represents the place where the geolocated data have been collected (e.g. geolocated picture of a damaged building). If internet connectivity is present, the user will be able to download the data collected with the LfE app by accessing the app dashboard online. Once these data are also uploaded, new data attributes will be linked to the collected data.

3 The Zagreb remote mission

3.1 The idea of a remote mission

It was a Sunday morning and the team was alerted to the Zagreb earthquake of 22 March 2020 not by the usual channels of the US Geological Survey or news reports, but by images appearing on social media platforms such as WhatsApp, sent by Croatian friends living in the UK. The questions that follow are typical of the realisation of any earthquake- what are the recorded ground motions, how badly affected are the buildings in the area, how many casualties and the displaced being cared for? What is different in the COVID era, is 'how' we are going to find out? How can we collect valuable data and truly learn from this event without travelling to the affected area? Can this be done entirely remotely? What would we compromise and is such a mission still benefit the international earthquake community?

Given the constraints of acquiring data remotely, the LfE Zagreb remote mission focused on two aspects of the earthquake: building damage and disaster response. In this paper, the work on collecting building damage data is highlighted. The main objective of the mission was to assess the effectiveness of remote earthquake reconnaissance surveys in collecting damage and consequence information and analysing this data.

The team consulted different media to collect data on the event remotely. These include resources that have been traditionally used by the reconnaissance teams in the pre-mission phase (i.e., Google Earth, Newspapers, Local institution websites, and personal contacts) and novel means of information like Social Media - and, more specifically Twitter, Facebook, Instagram, and GoFundMe pages, which were considered as potential alternative sources of data for damage assessment and post-disaster needs assessments. Some critical limitations were identified:

- Social media photos and videos released on the internet by non-technical users may not have the correct angle of capture, distance from the building and/or scale to allow for the full-façade assessment of the damage pattern.
- Trying to build a picture of the type of damage and its distribution using solely SM data is a complex endeavour because such resources are not geolocated and may even present the wrong geolocation.
- There is a persistent and inherent bias in terms of the demographic of users using these technologies, which impact the frequency of SM interaction. Social media are used only by users with SM accounts, which are predominantly from a younger demographic.
- The limitation of the using moderate resolution Sentinel data (10 m) could have been overcome by purchasing high-resolution data from a vendor.

Given the lack of reliable building damage information found online, we decided to explore how the tools that were being developed to allow the reconnaissance teams to collect data in the field in LfE could be used by a local team. The on-site damage collection - carried out in collaboration with the University of Zagreb, Faculty of Civil Engineering and the GARK team focused on assessing damage to properties in the near-fault region. This was the advent of the hybrid approach to earthquake reconnaissance.

3.2 The training and infrastructure

The training of the local team was done remotely. With training material provided beforehand, the local team was encouraged to download the Device magic app and to enlist under the LfE organization to be able to access the standardised form. Since Zagreb was still in partial lockdown when the online training was delivered, the local team was instructed to simulate a deployment without leaving their homes and to take pictures inside and outside their buildings. Since the data collected via the Device magic app, are stored within the device before being sent to the Device Magic dashboard and repository, the local team was asked to send a copy of the original data via the SDI. Using the Metadata Extractor of the SDI, it was possible to verify which data had geographic coordinates and to draft a plan of action for the local mission to ensure that all the data uploaded were geolocated.

3.3 The data collection on-site and data transfer to the remote team

The local mission was conducted from the 18/05/2020 to 22/05/2020 a total of 123 submissions were received on the app. The areas covered by the deployment and the location of the 123 submissions are shown in Figure 2.

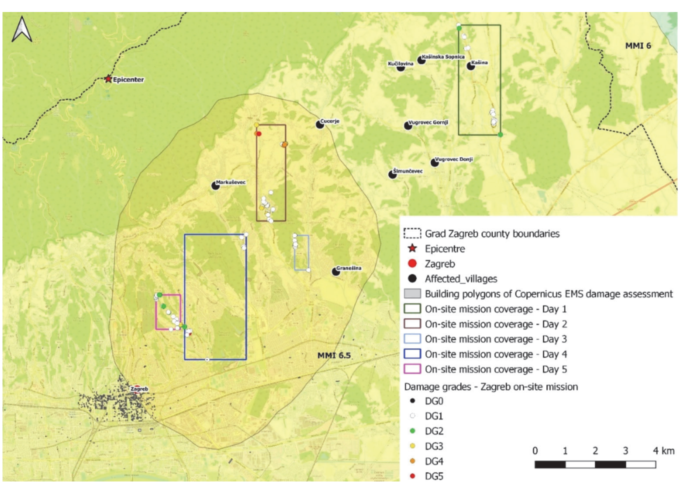

Figure 2. Overview map of the mission coverage. The submissions are color-coded according to the assigned damage degree

3.4 Results

Three rounds of assessments were conducted for the Zagreb EEFIT mission. The first round (defined as primary) includes the assessment done onsite and conducted by the students of the University of Zagreb. The secondary assessment was instead conducted by a team of experts with a remarkable track of experience in the field, entirely from remote and finally, the third assessment was provided by the same local team, who cross-checked damage set with the data collected by the HCPI Croatian Centre for Earthquake Engineering (Figure 3).

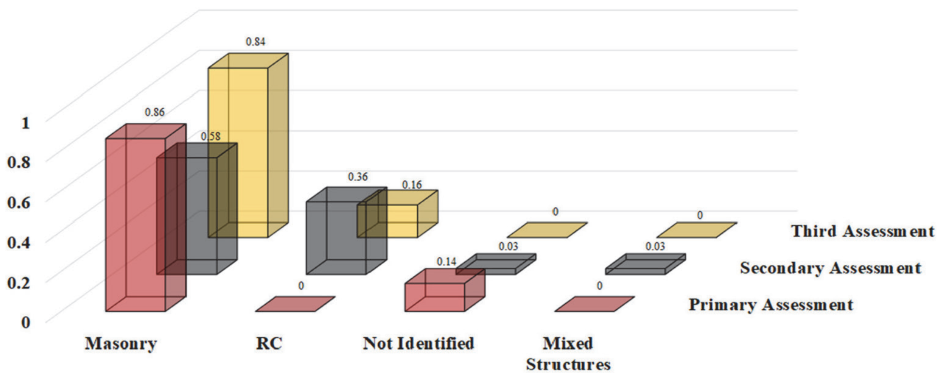

Figure 3. Results breakdown in terms of building typology assessment

There is a substantial visible discrepancy in terms of understanding of the building material between primary and secondary assessment, which levels up with the third assessment. The portion of RC buildings which were not identified properly during the primary assessment reappears in the third assessment re-adjusting the overall percentage of surveyed buildings. The team from remote spotted some mixed structures and also highlighted a small percentage of "not identified" buildings. The graph highlights the different level of experience of the two teams, whilst also highlighting the improvement of the local team achieved during the revision of the primary assessment results. A similar discrepancy can be observed in the overall damage assessment plots reported in Figure 4.

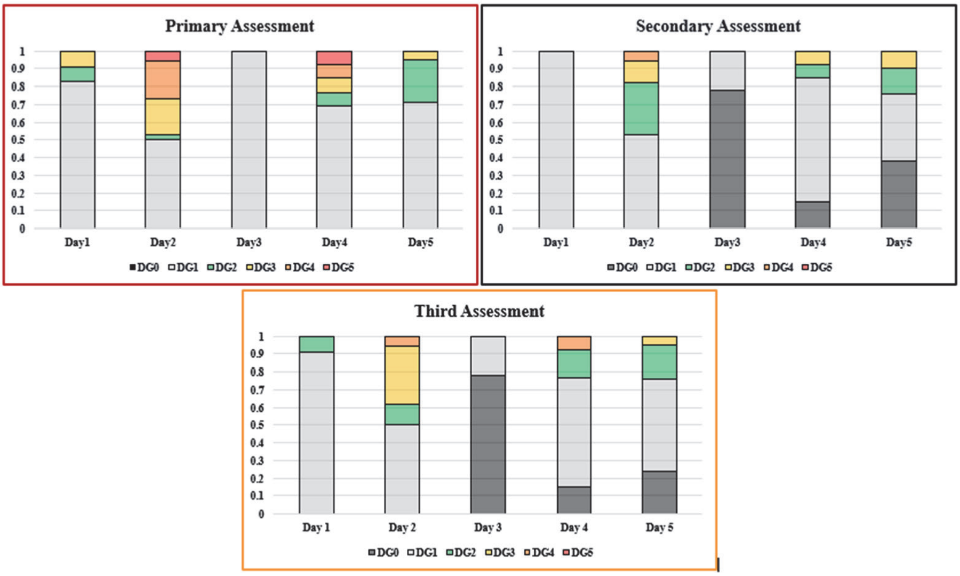

Figure 4. Results breakdown in terms of building damage assessment

The level of damage was overestimated in the case of the primary assessment, which is to be attributed to the level of experience of the team on site. Such discrepancy was levelled up - as per plot in Figure 3 with the third assessment, after the revision of results and comparison with the HCPI's datasets. Overall, the level of damage observed during this mission was relatively low - with no collapses spotted by the remote team and very few buildings considered as DG4.

Remarkably – a slight discrepancy between secondary and third assessment still exists in determining DG2 and DG3 – which it is believed to be a consequence of the photographic documentation accuracy, the only source upon which the remote team had to conduct their assessment.

4 Lesson learned

Our virtual mission was designed to mimic an on-the-ground mission and the LFE team dedicated a week (27/4- 1/5/2020) to complete different tasks which would traditionally be carried out in the field, e.g. damage area overview, building damage surveys, interviews with emergency managers and local academics. This mission was an opportunity for us to test what we can gather entirely remotely, and under COVID-19 conditions, therefore considering the implications of a multi-hazard event as well.

The team learnt some valuable lessons in terms of conducting a remote earthquake damage reconnaissance exercise under the restrictions imposed by the pandemic. The key ones are listed here.

Establishing a list of key institutions involved in the post-earthquake management and assessments is important, especially if official requests must be made for interviews and sharing of data.
Local knowledge and contacts are crucial. A good understanding of the local seismology, topography, building stock, and the general 'lay of the land' of the affected area is even more important than usual. Otherwise, the teams will have to rely entirely on remotely sensed imagery (satellite, drones, CCTVs, drive-throughs, and photographs) and without having visited the area, orientation and navigation can be problematic. Besides, the bird's eye can supplement but not entirely replace the value of the "boots on the ground".
Networking and technology can compensate for the lack of accurate information found on the Web. The methods also offer to verify what has happened in areas that are not so well covered by the media.
All team members need to be familiar with the background material before 'deploying'. It is not a simple data collection exercise as a critical interpretation and analyses of data needs to happen currently. There needs to be a clear delegation of tasks amongst the team members. Familiarity with the data is crucial in all circumstances. EEFIT missions are becoming more and more "data-rich" – and remote missions are even more data-dependent.
Mapping has been and continues to be a central part of reconnaissance missions.
Although the team were able to review images of damaged buildings online, a systematic assessment of the spatial extent of damage and the affected building types was not possible. Besides, though the City of Zagreb had carried out a preliminary building damage assessment, this data is not publicly available for review. One would assume this would be the case in many post-earthquake regions where the collected data will be proprietary. The team were fortunate in gaining the collaboration of local partners to help conduct a ground survey of buildings in the epicentral area.
Over 100 buildings were surveyed and the exercise, both in terms of the process of data collection and the information collected, were of tremendous value in helping the LfE team develop its damage assessment app and Spatial Data Infrastructure (SDI).
Training is essential and the LfE researchers were able to improve on the training material through the exercise.
The Zagreb mission also helped us understand the importance of attaining a comprehensive set of photographs through the app, to facilitate the remote secondary assessment.

5 Conclusions and future work

The pandemic landscape will change the way the earthquake community learn from real events and consider data collection in the future, bringing unforeseen challenges but also opportunities. The Zagreb exercise is proof of how well international networks can continue to operate and support one another even when a physical deployment on-site is not possible. This observation emphasises the importance of harnessing technological advancement to build tools that create a sustainable network of international researchers and allows them to work together not only on-site – as in the past – but also remotely, thus enlarging the numbers of experts that can be involved in damage reconnaissance assessments but also recovery. Lessons learnt from the Zagreb exercise was immediately translated to further development of LfE tools for the EEFIT Aegean Sea reconnaissance mission in November 2020, which adopted the same hybrid approach. The Aegean mission involving a large number of remote assessors surveyed over 400 buildings, fully demonstrating that the method can be upscaled to involve more researchers worldwide in the future. Indeed 'business as usual' in earthquake reconnaissance mission was achieved in both missions through technology and networking and may become the norm in the years to come.

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