

# Deliverable

## [D5.10 – Improving earthquake information in a multi-hazard context]

Deliverable information	
Work package	[WP5 – Data Gathering and Information Sharing with the Public and Policy-makers]
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Reviewer(s)	[Dr. Rémy Bossu, EMSC]
Approval	[Management Board]
Status	[Final]
Dissemination level	[Public]
Will the data supporting this document be made open access?	[Yes]
Delivery deadline	[28.02.2022]
Submission date	[23.02.2022]
Intranet path	[DOCUMENTS/DELIVERABLES/D5.10_Communication in a multi-hazard context]

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## Summary

Communicating event-related earthquake information, if created and disseminated appropriately, can prompt effective public response and, in turn, reduce injuries and lives lost from damaging earthquakes. In recent years, multi-hazard platforms have become common practice providing real-time information to the public. However, whether these platforms increase people's intention to take action and are understood correctly has not yet been analysed. We thus conducted four studies using mixed-methods within a transdisciplinary research approach. Altogether, our studies show that people demand for multi-hazard platforms but only benefit if they are designed thoughtfully. This is a prerequisite to exploit their potential and increase people's ability to handle (severe) hazards. First, a sophisticated design of hazard overviews and messages contains time and action indications so that people can at first glance distinguish which current hazards require for immediate actions and which still leave time to prepare. Second, incorporates interactive features, such as a sharing function or an "I am safe" button, allowing people to handle crises and contributing to the response activities. Third, considers personal factors that influence people's intention to take action and based on this understanding allows to tailor the communication products to their specific needs and skills increasing their ability to correctly interpret the information presented. Fourth, benefits from the co-design of communication products with experts from different fields, experimental testing, and consciously includes the target audiences in the development processes to increase the platforms' effectiveness and usefulness.

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## 1. Introduction

For urban areas and the population, exposure to natural hazards has doubled in the last 40 years. Thereby, earthquake is the natural hazard that accounts for the highest number of people exposed, and that causes high financial losses worldwide (Munich RE, 2015). Five of the largest natural disasters in the last twenty years have been earthquakes that caused altogether about 700,000 fatalities. Beside technical measures, communicating event-related earthquake information can prompt effective public response, and consequently, increase society's resilience towards earthquakes. With resilience we refer to *"the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions"* (United Nations, 2009)

A relatively new approach to increase society's resilience towards earthquakes is the communication of event-related earthquake information in a multi-hazard context. Triggered by the technical evolution that allows combining information about natural, technological and anthropogenic hazards, numerous (inter)national multi-hazard platforms have been established over the last years. Despite their increasing use to inform and warn the public, surprisingly, little research has been conducted evaluating their usefulness for the public. The aim of task 5.3 within the EU-Horizon 2020 project "Real-time earthquake rIsk reduction for a reSilient Europe" (RISE) thus was to analyze the existing multi-hazard communication means and to develop and test advanced designs that increase people's ability to take appropriate actions and prevent misinterpretation. We thus addressed the following overarching research question: *How should the communication of event-related earthquake information in a multi-hazard context best be designed to increase society's resilience?*

To this end, we conducted a case study in Switzerland. Compared to other European countries, Switzerland faces low to moderate seismic hazard and catastrophic earthquakes are expected to occur every 100 to 150 years (SED, 2019). This is one of the reasons, why the majority of the Swiss public is not prepared for earthquakes, and underestimates the potential damages. In such countries, people's motivation to download/use an application only informing about earthquakes is low. Therefore, worldwide it has become common practice to communicate information about low-probability via multi-hazard platforms to reach the public as a whole during emergencies. An

exemplary national service doing this is the Swiss Seismological Service (SED) at ETH Zurich. The SED does not only communicate earthquake information via their website and twitter account but also via the multi-hazard platforms MeteoSwiss (national weather app), AlertSwiss (national disaster app) and the Natural Hazard Portal (national natural hazard website). We thus explored whether the information provided on these platforms is understood correctly and designed new action- and time-oriented hazard overviews and messages which we tested with the public.

In this report, we first summarize the state of the art (chapter 2). Second, we explain our methodological framework (chapter 3) and provide an overview of the four studies we conducted (chapter 4). Third, we provide general recommendations for hazard and risk communication and specific recommendations for the design of (multi-)hazard platforms based on our results and best practices from the literature (chapter 5). The report ends with the limitations of our case study and future research needs (chapter 6). The scientific discourse is more precisely summarized in (Dallo, 2022).

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## 2. State of the art

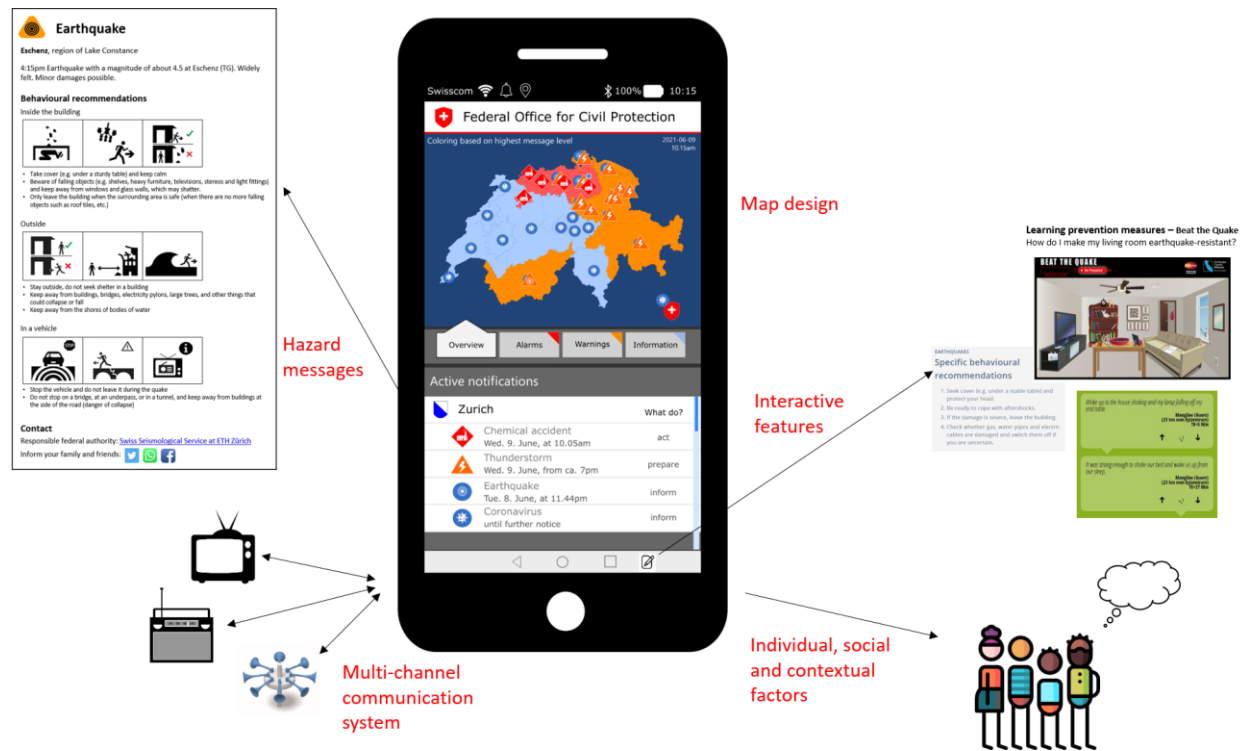
### 2.1 Multi-hazard platforms

Globally, there are several approaches to inform the public about different hazards via a single platform. Their aim is to communicate information about multiple hazards that is comprehensible, timely, consistent and harmonized. Additionally, people should be encouraged to stay informed and receive hazard information at an early stage of or immediately after an event, so that they can take (precautionary) actions if needed (European Commission, 2019; Zechar et al., 2016).

Previous studies have mainly focused on the technical and institutional capabilities regarding the implementation of multi-hazard platforms, and identified several challenges: (i) the absence of common methodologies and the difficulty to collect data in a coherent way for different types of hazards and risks; (ii) the comparability of hazardous events with each other, since they differ by their nature, intensity, return periods and effects on exposed elements; (iii) the comparability of anthropogenic and natural hazards; (iv) the lack of cooperation between the involved institutions, organizations and departments; and (v) the ensuring that the information on the different channels is consistent (Komendantova et al., 2014).

However, also questions with respect to the users' perspective of multi-hazard platforms arise. Are consistent and compatible hazard messages and maps correctly understood by the public? Which content does the public prefer? Are people overwhelmed with the information about the different hazards combined on one platform? Even if information about earthquakes and other hazards is embedded in frequently used weather apps, do people look at this information at all? Which individual, societal and contextual factors influence people's preferences for and ability to handle information provided on multi-hazard platforms?

In order to answer some of these questions, we had a detailed look at different (inter)national multi-hazard platforms (Annex A) (Groneberg et al., 2017; Helmerichs et al., 2017). In Figure 1, the various issues related to multi-hazard platforms are summarized, and in the sections 2.2.1 to 2.2.5, each issue is discussed in detail.



**Figure 1: Overview of the various issues that have to be considered when designing and operating a multi-hazard platform.**

### 2.1.1 Map designs

Most multi-hazard platforms consist of a map on the landing page. Maps as a key visual have various advantages: First, maps allow hazard and risk to be visualized across an entire region (Carpignano et al., 2009). Second, if well designed, graphics can better increase risk avoidance compared to numerical representations of risk only (Bostrom et al., 2008; Thompson et al., 2015). Third, maps are understandable for those who are not speaking the language in which a message is issued (Becker et al., 2019). However, using maps to communicate information also brings up some challenges. First, hazard maps are mainly designed for experts but still used to communicate with non-experts who are often unable to intuitively get the relevant information (Meissen & Voisard, 2008; Perry et al., 2016). Second, an inappropriate use of colors, symbols, or legends can lead to misunderstandings or even aversion to using the map (Keller et al., 1994; Marti et al., 2019; Thompson et al., 2015). Studies are limited assessing which map designs (e.g., hazard categories, map format) the public prefers, correctly interprets and perceives as useful for everyday life.

### 2.1.2 Hazard messages

On many multi-hazard platforms, people can click on the icons displayed on the overview map. After clicking on the icon, a subpage or information box with a hazard message pops up. Alternatively hazard messages are directly sent to the people as a push notification. In general, those hazard messages contain the following information: hazard, location, guidance, time and source (Bean et al., 2015). In addition, some of them also include information about the possible impacts (Weyrich et al., 2018), emergency numbers or triggered hazards.

People especially demand actionable instructions about the recommended behavior (Maduz et al., 2018; United Nations, 2006). So far, behavioral recommendations have mainly been included in text format. However, Bossu et al. (2018) uses pictured behavioral recommendations on the EMSC app (LastQuake) to inform their users what to do after an earthquake. This minimises language barriers and is intended to ensure a rapid understanding of the behavioral recommendations. In addition, graphical displays attract and hold people’s attention better than textual information

(Lipkus, 2007), which increase their motivation to act. However, unclear, unfamiliar and complex graphical displays can lead to misunderstandings (Lipkus, 2007). Moreover, graphical displays should not present more information than what is required for the purpose of the display (Canham & Hegarty, 2010).

### 2.1.3 (Interactive) features

Groneberg et al. (2017) categorized the content of disaster and emergency apps into **information** (e.g., push notifications, maps, news), **communication** (e.g., social media integration, “I am safe” button), **preparation** (e.g., emergency planning, behavioral tips, trainings) and **other** (e.g., language change, app rating, feedback).

Some studies have already assessed people’s preferences for some of these contents and interactive features. For example, the public expects that information about central contact points and emergency numbers is included in an app. Moreover, the option to generate a test message was appreciated, letting users know how it would look and sound. The possibility to share information about a current hazard situation with friends and family members was also wished by some persons (Bossu et al., 2018; Reuter et al., 2017). Further features are disaster toolkits, an alarm or an “I am safe” button. So far, such actionable features are still missing on many apps and future improvement is needed (Verrucci et al., 2016). It is important that future research engages in citizen-centred studies to gain more insights into users’ needs, motivations and experiences (Tan et al., 2017).

### 2.1.4 Multi-channel communication system

Until the nineties, public warnings and hazard information had been communicated via traditional channels, such as radio, television, sirens and loud speakers. Modern technologies including computers, smartphones and other digital applications have only been available for a few decades (Bachmann et al., 2015; Meissen & Voisard, 2008). The public appreciates to receive hazard warnings as push notification via apps because it is a distinct public alerting application whereas e-mail and SMS are general purpose tools for communication of all kinds (DemoSCOPE, 2019; econcept, 2011; Maidl et al., 2016; Seddigh et al., 2006). Moreover, Groneberg et al. (2017) showed that the most downloaded apps were mainly weather and first aid apps. This indicates that embedding information about earthquake in widely used apps might increase the group of recipients. During emergencies, however, people still prefer to receive the warnings/alerts also via the traditional communication channels such as radio and television (Maduz et al., 2018).

Modern communication means have various potentials. For example, responsible emergency managers enhance their technical information with data crowd sourced via social media or communication forums on apps (Bossu et al., 2018; Kox et al., 2018; Lacassin et al., 2019). Furthermore, vibrating alerts allow to inform hard of hearing and deaf persons about an emergency situation (Sillem, 2006). In addition, most people take their smartphones during an evacuation process with them (Leelawat et al., 2013), and most of them have internet access also outside home (Sung, 2011). Smartphones and other mobile devices thus represent potential tools to constantly inform and warn a large number of users (Colombelli et al., 2019).

Besides the potentials, the new communication means also create some challenges. Just to name a few, it is needed to adapt hazard warnings to the receivers’ needs and local circumstances (Meissen & Voisard, 2008). Furthermore, the missing individual’s comfort, mistrust and their unfamiliarity can hinder people from using them (Lovari & Bowen, 2019). Additionally, there are some technical challenges, namely related to hardware (e.g., battery life) and software (e.g., user-friendly surface) (Kurosu & HCI International, 2015). Moreover, temporary overload is possible as the example of the earthquake in Ridgecrest showed (Hobbs & Rollins, 2019).

To this end, a multi-channel communication system is recommended being able to inform and warn as many people as possible, and to compensate the failure of individual channels (Houston et al., 2015; World Meteorological Organization, 2018). Thereby, authoritative information and warnings should be consistent among the multiple communication channels in order to maintain trust and achieve a desired response by the public (Weyrich et al., 2019).

### 2.1.5 Individual, social and contextual factors

Different individual, social and contextual factors influence people's abilities to handle the information presented on multi-hazard apps. Even though theoretical behavioral models were tested to identify those various factors in the context of a single hazard, it is still unexplored which behavioral theories are better suited for multi-hazard communication approaches (Shreve et al., 2016).

On the individual level, the factors self-efficacy, personal beliefs, hazard experience, numeracy, outcome expectancy, personal responsibility, awareness, optimistic bias, normalization bias and mood were identified to influence individuals' choice to take (precautionary) actions (Becker et al., 2013). Regarding the demographic factors, females, minority group members and younger people see themselves to be more at risk of earthquakes than males, majority group members and older people respectively (Solberg et al., 2010).

On the social level, the sense of community and responsibility, community participation and social norms influence people's intention to take action (Atwood & Major, 2000; Becker et al., 2012; Solberg et al., 2010). In addition, after having received a warning message people tend to verify the content by talking to neighbors, friends etc. Furthermore, a study in the United States showed that households are most likely to take steps to prepare themselves if they observe the preparations taken by others (Wood et al., 2012).

The environmental context – political system, legal requirements etc. – plays a crucial role too. A lack of faith in institutions among members of the public, for example, can hinder communication investigations (Alexander, 2014). People trust more in information which comes from federal authorities than private agencies (Maduz et al., 2018). Furthermore, these factors vary from region to region and change from time to time. As a result, communication means can be effective at one place but not at another with differing circumstances.

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## 3. Methodology

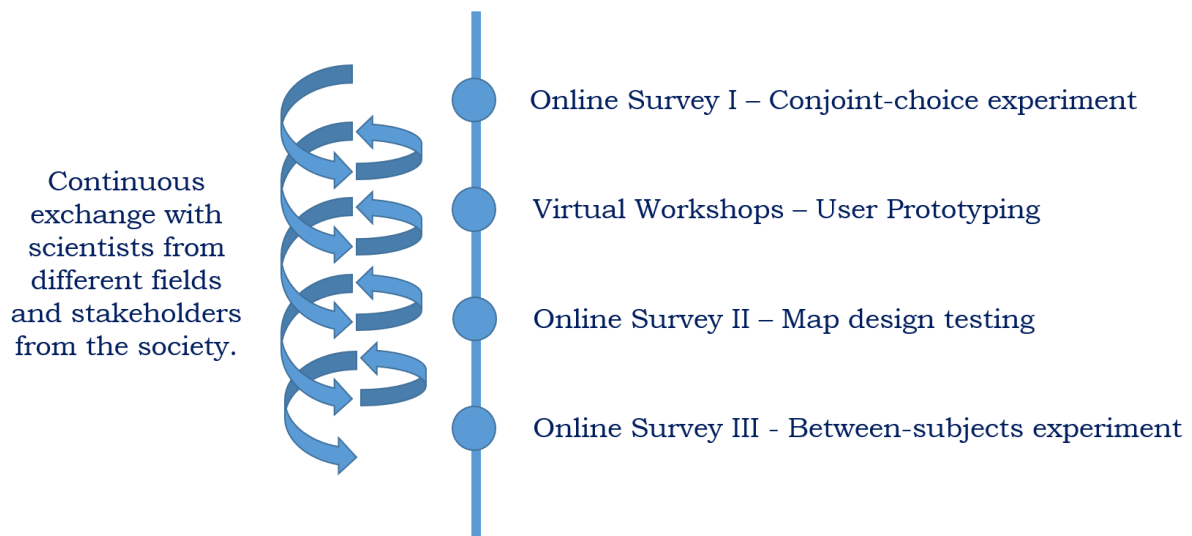
We applied a user-centred, mixed methods approach, with a major emphasis on user requirements driving technological developments. Throughout the project, we continuously collaborated with scientists from different fields and stakeholders from the society, thus following a transdisciplinarity approach<sup>1</sup>. In total, we conducted four studies (Figure 2) to better understand the communication of earthquake information in a multi-hazard context and to design action- and time-oriented hazard overviews and messages, and in consequence, to deduce practical recommendations.

We applied several outreach activities to ensure the scientific as well as non-scientific impact of our research efforts (Jacobi et al., 2020): co-creation of knowledge with key stakeholders through workshops and other events, open-access papers in scientific journals, individual contact with actors involved, presentation at conferences, non-scientific reports for the federal authorities,

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<sup>1</sup> Dallo, I. and Marti, M.: How to best involve different stakeholders in the design process of products and services to communicate multi-hazard information?, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-815, <https://doi.org/10.5194/egusphere-egu21-815>, 2021.

social media presence (mainly twitter), contributing to federal working groups and experience via the platform and newsletter of the EU-project RISE.



**Figure 2: Overview of the four studies** which we conducted in parallel to our continuous exchange with scientists from different fields and stakeholders from society.

## 4. The four studies

In the subchapters 4.1 to 4.4 we describe the objectives, methods and main findings of each study separately. We further provide links to (peer-reviewed) publications to dig deeper in the subject matter.

### 4.1 Study I: What defines the success of maps and additional information on a multi-hazard platform?

#### 4.1.1 Objectives

This study aimed at answering the following questions:

- *Does the public prefer and actually use multi-hazard platforms to get information about the current hazard situation?*
- *Which elements of the home page design does the public prefer, correctly interpret and perceive as useful?*
- *What contents of the hazard messages attached to the maps on home pages does the public prefer?*

#### 4.1.2 Method

For our study, we conducted a survey with a conjoint-choice experiment (N=810). Such choice experiments were first developed in marketing research in the 1970s (Bansak et al., 2018) and are now also applied in other research fields, such as health (Darby et al., 2008), food consumption (Huber et al., 2019) and political science (Beiser-McGrath & Bernauer, 2019). In general, participants are put in a hypothetical choice situation in which they are confronted with bundles of relevant product attributes (Rinscheid & Wüstenhagen, 2019). The levels of these attributes are varied randomly across participants and tasks, allowing for an estimation of the relative importance of each attribute (Hainmueller et al., 2015). By observing the stated preferences regarding the alternatives presented, it is possible to examine the relevance of certain product attributes and their characteristics to individual choices. Compared with single-profile designs, paired-profile designs induce more engagement and less satisficing among participants, maximising the external validity about real-world causal effects (Hainmueller et al., 2015).



### 4.1.3 Main insights

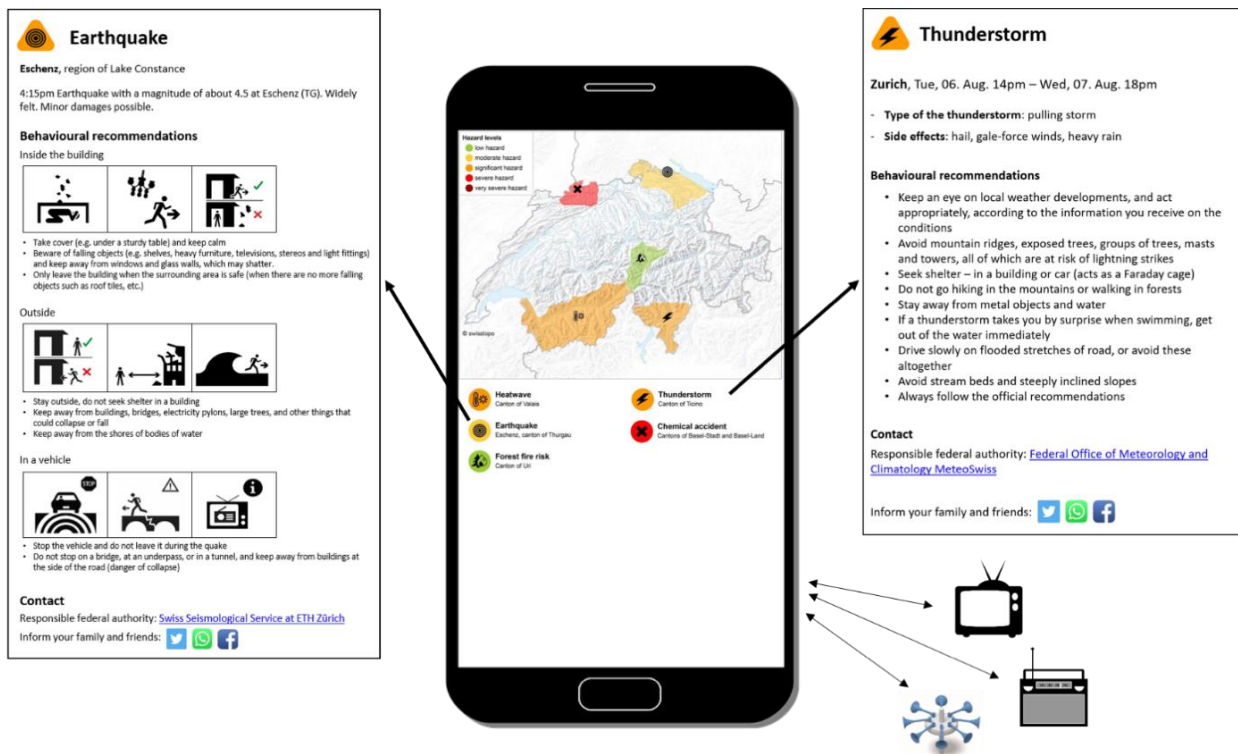
The main results are that the public prefers (Figure 3)...

- ... a **single map** on which all current hazards are displayed.
- ... **textual information** about the current hazards below the map.
- ... hazard classifications with **four or five categories**.
- ... a combination of **pictured** and **textual** behavioral instructions for unpredictable hazards such as earthquake. For predictable hazards such as storms, they prefer written behavioral recommendations.
- ... hazard messages with a **sharing function**.

We further showed that...

- ... people who **trust** in actors involved in the communication process are more motivated to seek for further information and to take (precautionary) actions.
- ... people with high **numeracy skills** answer more map interpretation questions correctly.
- ... people who have never **experienced** any hazard yet struggle more to understand the provided information.
- ... people's **risk perception** influences their design preferences, i.e. people with a high risk perception perceive single maps as more useful and the hazard categories "alert, warning, information and clear".
- ... people with high levels of trust and risk perception **rate** the hazard messages **overall better**.

To conclude, the results indicate that the design of information provided on multi-hazard platforms indeed affects public's preferences. Therefore, in parallel to the continuous improvement of scientific-technical products, the communication and perception of these products should be systematically examined.



**Figure 3: Participants' preferred start page design and favored hazard messages.** The earthquake message on the left is adjusted (combination of pictograms and textual instructions) based on the participants' remarks. The symbols on the bottom right represent the need for a multi-channel communication strategy to inform as many people as possible.

#### 4.1.4 Find out more

- **Peer-reviewed publication:** Dallo, I., Stauffacher, M., & Marti, M. (2020). What defines the success of maps and additional information on a multi-hazard platform? *International Journal of Disaster Risk Reduction*, 49, 101761.
- **EGU20 Conference presentations:** Dallo, I., Stauffacher, M., & Marti, M. (2020, May). Understanding public's preferences for information provided on multi-hazard warning platforms. In *EGU General Assembly Conference Abstracts* (p. 1420).
- **German report:** Dallo, I. & Marti, M. (2020). Multi-Gefahren-Plattformen – Präferenzen der Bevölkerung. URL: <https://ethz.ch/content/dam/ethz/special-interest/usys/tdlab/docs/research/multigefahrenplattform.pdf> [18.01.2021]

## 4.2 Study II: Why should I use a multi-hazard app? Assessing the public's information needs and app feature preferences in a participatory process.

### 4.2.1 Objectives

This study aimed at answering the following questions:

- *Which hazards would the public combine with earthquakes on a multi-hazard app?*
- *Which types of information about the hazards does the public want on a multi-hazard app?*
- *Which features does the public wish for a multi-hazard app?*

### 4.2.2 Method

Users are often asked to test a prototype of a product (Alperowitz et al., 2017; Monteiro-Guerra et al., 2020; Nass et al., 2018). Thereby, developers gain insights by observing users' responses to a prototype and by talking to them about the experience. In comparison to the testing of already established prototypes, the intention of "user-driven prototyping" is to gain understanding by observing users when creating prototypes (Bootcamp Bootleg D.School, 2018; Roberts et al., 2016). This approach allows to gain an understanding of users' thinking and reveals needs and features that developers may not have thought of. To this end, it is important to ensure that users can be creative but still have a realizable prototype in the end (Bootcamp Bootleg D.School, 2018). We thus decided to conduct user-driven prototyping workshops as we wanted the participants to reflect on, discuss, and exchange with others which types of information and features they perceive as beneficial to be embedded in a multi-hazard app.

In total, we conducted seven workshops of four to five participants each. The procedure of the virtual workshops was a result of two test runs that allowed us to identify which tools best fit the purpose of our workshops and how we could facilitate interactions between the participants. At the end, they consisted of four parts – an introduction phase, group work, a plenary discussion, and a closing phase. During the group work, the participants were split into two groups and they discussed which hazards they would combine, which information they want on a multi-hazard app and which features should be available.

### 4.2.3 Main insights

The main results are that the public prefers (Figure 4)...

... the combination of **multiple hazards** on an app. To this end, not only combining natural hazards but also anthropogenic and socio-natural hazards.

... only the **most relevant information** should be provided on the app and a **forwarding function** forwards the users to the official website to access more detailed information. People define the following as relevant information: location, time, hazard severity, behavioral recommendations and the contact details of emergency services.

... **short-term & real-time information** (containing behavioral recommendations & contact numbers)

... features such as **push notifications, button to ask for help, sharing feature, chat forum, 'I am Safe' button, report button.**

... **interlinking/using existing apps**, such as sending push notifications via general-purpose apps (e.g., weather apps) and communicating specific information on disaster apps.

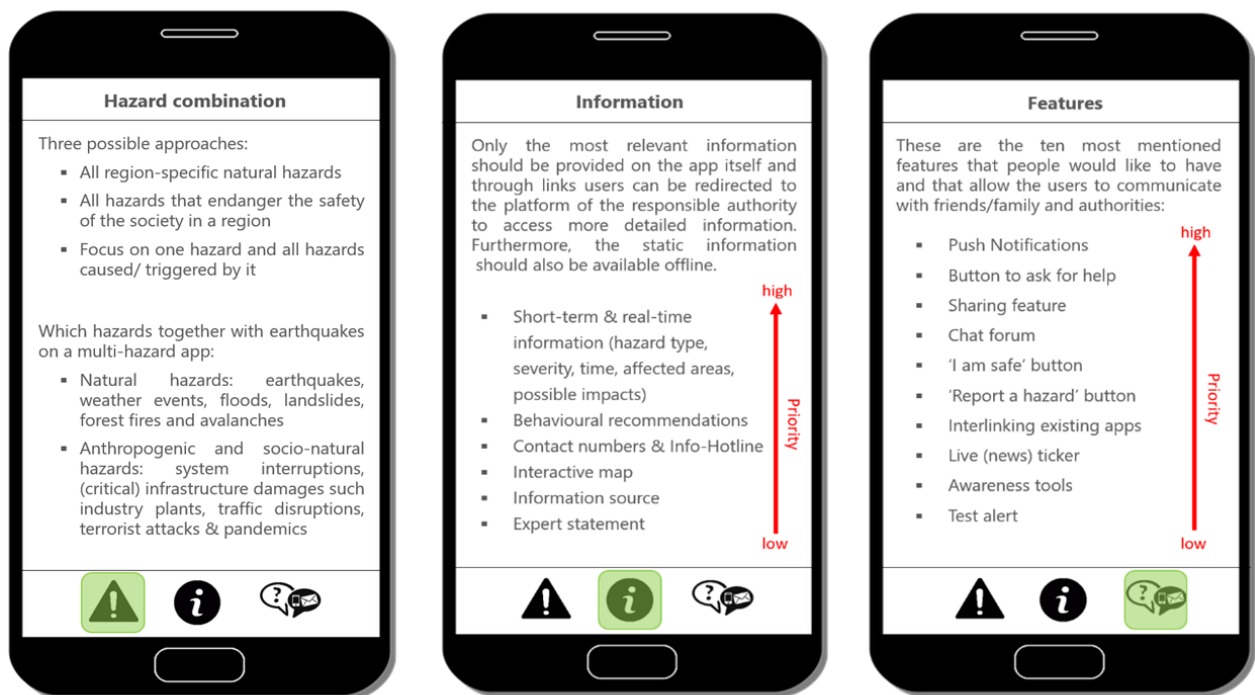
The main challenges people mentioned were...

... concern about **data protection** and security.

... **information overload** due to too much hazard information.

... tradeoff between **low battery consumption** and the amount of available information/interactive features.

... receiving push notifications even when the **app is not running**.



**Figure 4: Recommendations for the hazard combination, the information content and available features on multi-hazard apps.** In the display on the left, we listed the three possible approaches to combining multiple hazards that we derived from the discussions. In the middle and the right displays, the types of information and the features that should be available on multi-hazard apps are listed, respectively, in descending order of number of mentions.

#### 4.2.4 Find out more

- **Peer-reviewed publication:** Dallo, I. & Marti, M. (2021). Why should I use a multi-hazard app? Assessing the public's information needs and app feature preferences in a participatory process. *International Journal of Disaster Risk Reduction*, 57, 102197. doi: 10.1016/j.ijdr.2021.102197
- **EGU21 Conference presentations:** Dallo, I. and Marti, M.: How to best involve different stakeholders in the design process of products and services to communicate multi-hazard information?, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-815, <https://doi.org/10.5194/egusphere-egu21-815>, 2021.
- **German report:** Dallo, I. & Marti, M. (2020). Multi-Gefahren App: Wieso sollte ich sie nutzen? URL: <https://ethz.ch/content/dam/ethz/special-interest/usys/tdlab/docs/research/multigefahrenapp-informationsinhalte.pdf> [31.05.2021]

### 4.3 Study III: An analysis of the earthquake map on the MeteoSwiss app with regard to comprehensibility and its potential for improvement

#### 4.3.1 Objectives

This study aimed at answering the following questions:

- *What are the overarching challenges to be considered when providing an earthquake map on a multi-hazard platform?*
- *How is the current earthquake map on the MeteoSwiss app understood by the public and which demographic, sociographic and cognitive factors influence its comprehensibility?*
- *What are the needs and expectations of the public with regard to the graphic design and content of an earthquake map on a multi-hazard platform?*
- *To what extent would individual elements (colours, legends, information texts) of an earthquake map have to be changed so that the public would understand the map better, and how can the temporal dimension be represented in the design of the earthquake map?*

#### 4.3.2 Method

As a pre-study before the survey, we conducted interviews with the public in order to identify which information and elements on the earthquake map on the MeteoSwiss app are understood and which lead to confusion. Additionally, we interviewed four experts – from MeteoSwiss, the Swiss Seismological Service at ETH Zurich, and a company focusing on user-centred app design –, what helped us to come up with improvement suggestions of the information currently presented. We used the insights from these interviews to set up a survey with the aim to test the interpretation of the current earthquake map and to check whether our adjusted maps based on the expert interviews are preferred by the public. In total, 356 people filled out the survey, representing the German-speaking part of Switzerland.

#### 4.3.3 Main insights

The main results are that (Figure 5) ...

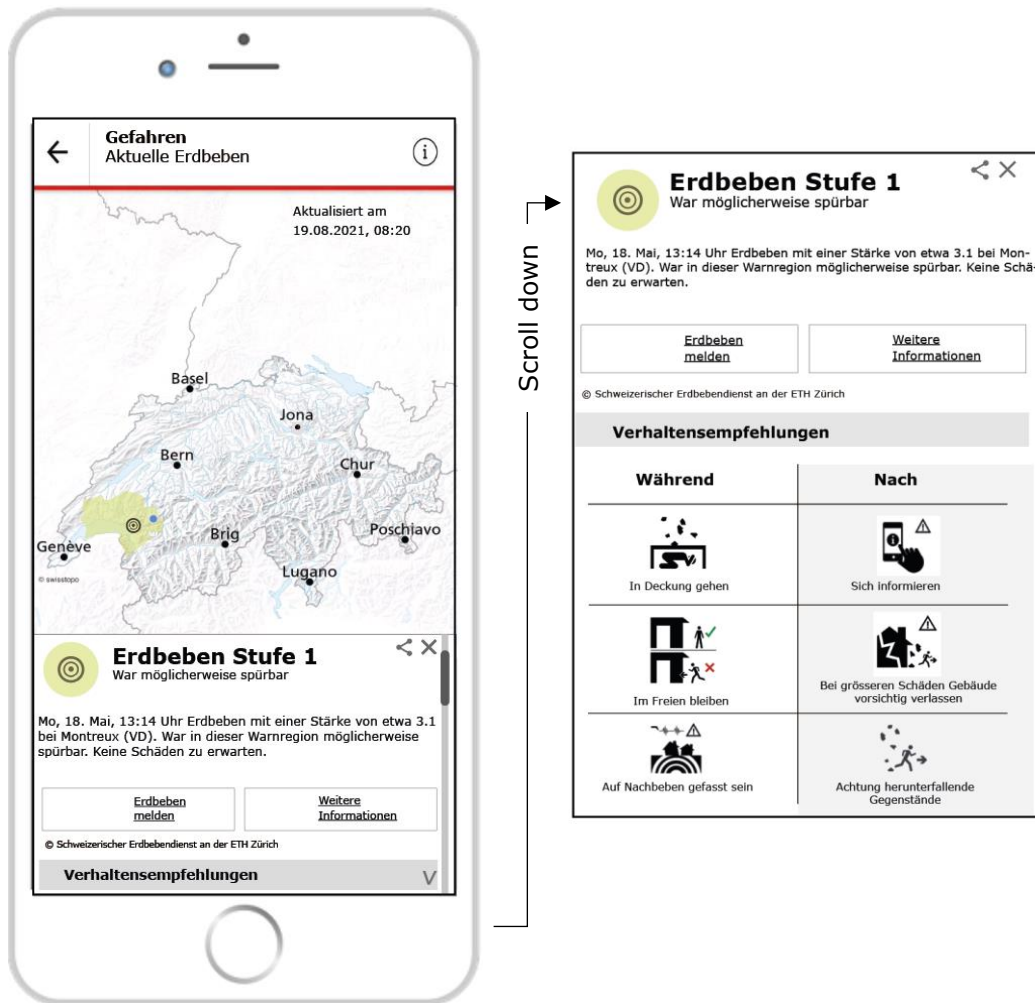
... when communicating earthquake information together with other natural hazards on one platform, especially **the time-related aspects are misleading**. For the weather-related hazards (e.g., storms, heatwaves, floods), warnings are mainly provided before an event. This in contrast to earthquakes, where post-event information is presented. Many people currently do not understand this and think the earthquake information is a forecast too. A time slider allowing people to go backwards and forwards or with a text element highlighting that the information provided on the map shows earthquakes that occurred in the past may minimize this misunderstanding.

... when the authorities decide to have **consistent danger levels** they have to make sure that the names of the levels are clear and do not imply that the event will happen in the future. For example, the hazard level “moderate danger” is ambiguous for people as they are not sure whether this is a hazard assessment of an ongoing/past event or an estimation of the impact of a future event.

... one has to clearly differentiate between the **icon of the epicenter and the person’s location**. We recommend using a blue circle for the user location that is used by google maps, and not a red circle, for example.

... in times with no recently felt earthquakes, a map with a **gray background is misinterpreted**. People think that the seismic stations are not working or that they do not have to worry about earthquakes. A neutral map (e.g., basic map with hill shades) with no borders or the regional borders is a much better solution.

... the complementary textual information should contain the location and time of the earthquake, its expected impact, behavioral recommendations for during and after the shaking, the possibility to report an earthquake, and the source of the information.



**Figure 5: A possible map and information text for earthquake information** provided for example on a national weather-app (e.g., MeteoSwiss).

#### 4.3.4 Find out more

- **German Master's Thesis:** <https://www.polybox.ethz.ch/index.php/s/vaBmjfUr0AgaVtS>

### 4.4 Study IV: Actionable and understandable? Evidence-based recommendations for the design of (multi-)hazard overviews and messages

#### 4.4.1 Objectives

This study aimed at answering the following questions:

- *How should multi-hazard overviews and hazard messages be designed to increase people's intention to take action and their correct interpretation of the information presented?*
- *Are the generally preferred designs also the ones which increase people's intention to take action and their correct interpretation of the information?*
- *Do personal factors influence people's intention to take action and their correct interpretation of the information presented on multi-hazard overviews and hazard messages?*

#### 4.4.2 Method

For this study, we first conducted five virtual workshops with scientists and practitioners [N=15] from different fields to co-produce knowledge about how to best design the hazard overviews and

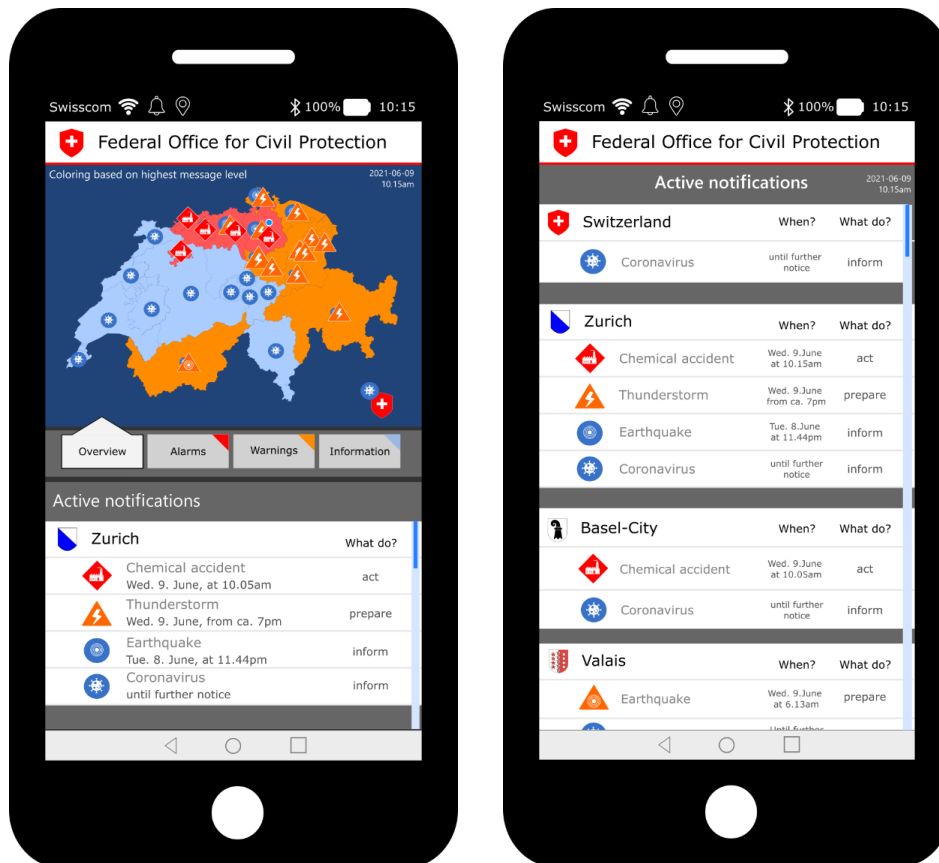
the hazard messages. The collected suggestions of improvement from the experts allowed us to refine the designs. Second, we conducted an online survey with the public [N=601] to test whether the refined designs meet the public's needs and expectations.

The survey consisted of four questions blocks (QB). In QB1, the participants were introduced to a scenario, before they were randomly assigned to one of the twelve hazard overviews. With three question sets we assessed their interpretation skills, intention to take action and design perception. Afterwards in QB2, the participants were randomly assigned to one of the twelve hazard messages. Also for the messages, we assessed participants' interpretation skills, intention to take action and design perception. We further asked them whether some relevant information is missing on the message and which elements are especially useful for them [two open-ended questions]. In QB3, we assessed participants' experimental and instrumental attitudes, self-efficacy, injunctive and descriptive norms and perceived digital-based information overload. Further, we assessed participants' general and negative hazard experiences for all hazards displayed on the hazard overview (Sullivan-Wiley & Short Gianotti, 2017). In QB4, we assessed the sociodemographic characteristics gender, age, work position, living place and highest educational degree.

#### 4.4.3 Main insights

The main results with respect to the *multi-hazard overviews* are the following (Figure 6):

- ... Providing a **time indication** (before, during or after) and an **action keyword** (inform, prepare, act) for each hazard on the overview ensures that people understand which hazards are urgent and ask for immediate action. Further it triggers people to access further information and minimizes their misconception that the earthquake post-event messages are forecasts as most of the weather-related hazard messages are.
- ... If **clearly defined**, the choice of the **hazard categorization** has no effect on people's understanding and perception of the information and their intention to take action.
- ... Information presented in a **list** is better understood, perceived as better structured and clearer than the same information presented on a map. However, participants liked the **map** better than the list.
- ... A **map supported with textual information** is perceived as most useful and trustworthy.



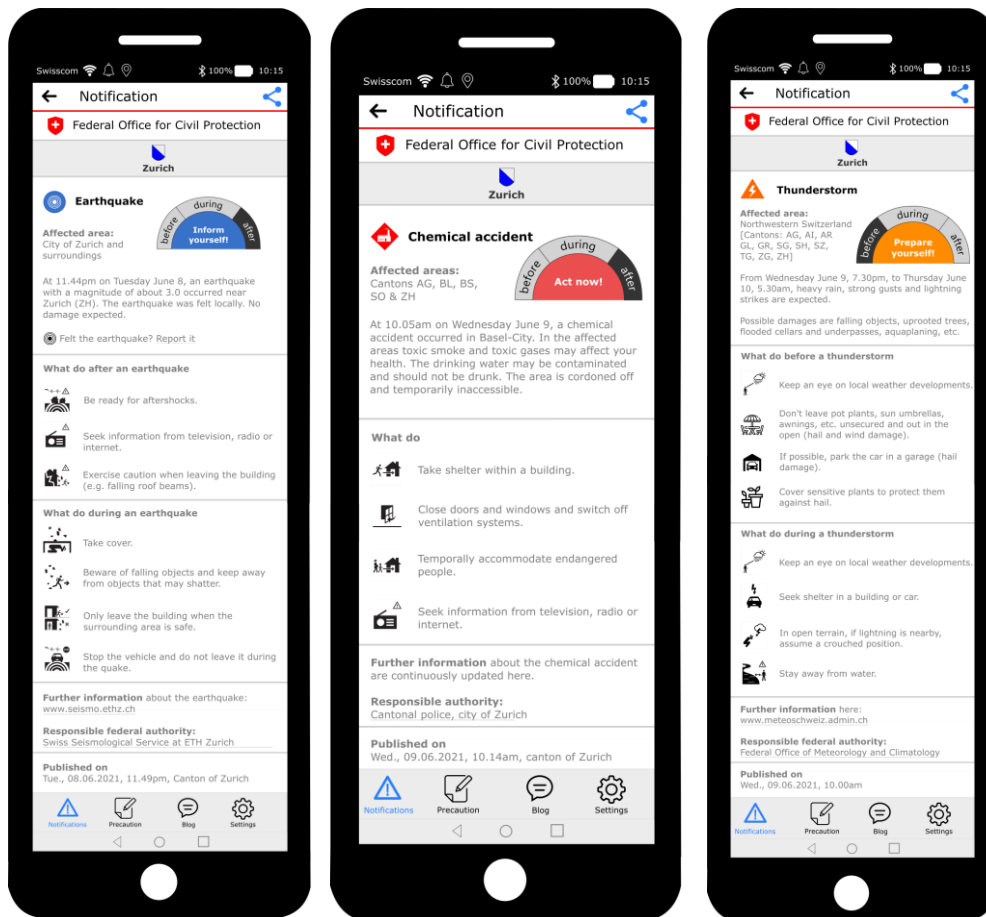
**Figure 6: The two hazard overviews that are correctly interpreted and increase people's intention to take action.** We recommend that people can switch between the two formats as they each have their advantages and in combination best meet people's needs and skills. The hazard categorization can also be replaced by "no to little danger, moderate danger, significant danger, high danger, very high danger", as the two categorizations had the same effects.

The main results with respect to the *hazard messages* are (Figure 7):

... We identified **two misconceptions**. First, people think that the most important recommended action is the one at the top of the list. Second, people struggle to understand whether the potential impacts listed in the forecast messages will actually occur or not. Further research thus is needed to explore how to best communicate the corresponding uncertainties and probabilities.

... We confirm the **importance of the information elements**: hazard type and level, affected areas, time, behavioral recommendations, possible impacts and source. In addition, we **recommend adding a time- and action-related icon** as our study showed that such an icon motivates people to take action and ensures that they understand whether it is information before, during or after an event.





**Figure 7: Exemplary messages for three different hazards: earthquake, thunderstorm and chemical accident.** The half-circle icon on the top right increases people’s intention to take action and further ensures that they understand whether it is a message before, during or after an event.

We further showed that various personal factors have a significant influence on people’s intention to take action and correct interpretation of the information provided:

- ... People who have already **experienced a hazard** have a higher intention to take action and are more eligible to interpret the information.
- ... The higher people’s **perceived self-efficacy** the higher is their intention to take action, are their interpretation skills as well as their positive perception of the hazard overviews and messages.
- ... High levels of **instrumental attitudes**<sup>2</sup> and of injunctive norms lead to higher intentions to take action.
- ... High levels of **experiential attitudes**<sup>3</sup> lead to a better general perception of the overviews and messages.
- ... **Men and younger people** are more skilful in interpreting the information.
- ... **Women and housewives/househusbands** and **retired people** have a higher intention to take action.

#### 4.4.4 Find out more

- **Peer-reviewed publication:** [under review in International Journal for Disaster Risk Reduction; (Dallo et al., n.d.)]

<sup>2</sup> Instrumental attitudes are “the attitudes about the outcomes of the behavior” (Vinnell et al., 2021).

<sup>3</sup> Experiential attitudes are “the attitudes about the experience of enacting the behavior” (Vinnell et al., 2021).



## 5. General and specific recommendations

We derived general and specific recommendations on how to best communicate event-related earthquake information on a multi-hazard context from the results of our four studies and best practices from the literature. We further critically reflect our insights and provide suggestions for future research.

### 5.1 General recommendations

We here provide general recommendations on how to best communicate hazard and risk information to the public and other stakeholder from society.



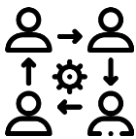
#### Knowing your audience

To design user-centred and effective communication products and services, one has to know its audiences. Through various qualitative and quantitative methods (e.g., focus groups, workshops, surveys with experiment settings), people's needs, expectations and abilities can be assessed.



#### Building trust

Trust in the actors involved in the communication process is essential to ensure that people also trust the hazard messages and are willing to take action. In Switzerland, as several surveys have shown, the public trusts most in federal or cantonal authorities and to a lesser extent in private institutions or information shared via social media. But this differs from country to country or even from region to region.



#### Building relationships

The collaboration with the involved stakeholders is indispensable. Especially, when operating a multi-hazard platform, the authorities providing the hazard information, the operators of the platform and the emergency services have to collaborate to ensure effective, consistent and efficient communication.



#### Communication channels

The public wants to receive push notifications via apps on mobile devices, but supported by other channels such as television, radio or public messages. Furthermore, cell broadcasting is an efficient communication mean too (e.g., United States, New Zealand) to warn affected people. In Europe, the Council of the European Union has adapted the directive of the European Electronic Communications Code in 2018 with the target that all EU member states must establish a civil defense alert system – cell broadcasting or/and a mobile app – by June 2022 (Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 Establishing the European Electronic Communications Code (Recast)Text with EEA Relevance., 2018). This target aligns well with the public's needs.

Japan further installed satellite-linked telecommunications equipment as a backup to terrestrial communications (Yamori, 2020), which should be considered while developing emergency infrastructures.

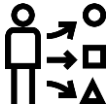


#### Multi-hazard platforms as an entry point

The public demands platforms that provide information about the regionally relevant natural, anthropogenic and technological hazards. Especially for low probability and infrequent hazards, people would not download a single-hazard app. Thus, communicating earthquake information on multi-hazard platforms allows reaching a wider audience, in particular in countries with low to moderate

seismic hazard. Even though not all people have a mobile device, people using one can act as a multiplier and warn people without a mobile device.

However, people wish that only the most important information is directly available on the multi-hazard platform (e.g., real-time information, behavioral recommendations, and emergency numbers). Through links, the users can then be redirected to the official website of the responsible authorities to access further information.



### **Actionable and personalized information**

The responsible entities should give actionable and personalized information by providing behavioral recommendations for various situation (e.g., inside a building, outside, in the car), by communicating the possible impacts and by giving local and contextual information. This increases people's intention to take action.



### **Map design and textual information**

We recommend i) to use no gray coloring for indicating that there are currently no active hazard messages as people interpret "gray" as there is no data available; ii) to use clearly distinguishable icons for the epicenter of the earthquake and the user's location; iii) to use intuitively understandable icons for the hazards; and iv) to show the regional borders and name the capital cities to facilitate the geographic orientation.

People prefer a single map on which all current hazards are displayed. However, we have shown that lists with written text is better understood wherefore we recommend combining a map with textual information.



### **Message content**

Regarding the hazard messages, we confirm the importance of the information elements: hazard type and level, affected areas, time, behavioral recommendations, possible impacts and source. In addition, we recommend adding a time- and action-related icon since our results showed that such an icon motivates people to take action and ensures that they understand whether it is information before, during or after an event.



### **Consistent messages with a single voice**

Consistent messages across the different hazards as well as across the different communication channels are important. The latter increases people's trust in the information and willingness to take action. Further, consistent messages ensure that people understand the information also for hazards they are not that familiar or only occur rarely.



### **Interactive features**

The implementation of interactive features has many advantages. First, people can contribute to the hazard assessment (felt reports), spread the messages (sharing function) and facilitate the crisis response (communal support activities). Second, interactive features allow them to exchange their feelings and experiences (chat forum), to communicate that they are safe ('I am safe'-Button) and to ask for help ('I need help'-Button).



### **Being aware of misinformation**

Try to prevent the emergence of misinformation, by testing the maps and information provided to the target audiences beforehand. Additionally, have some strategies in place to fight misinformation.



### **Iterative, user-centred design process**

By consciously and continuously including the end users' perspectives in the development processes of communication services and products one can increase their effectiveness and usefulness. Needs and expectations can change over time due to new technologies, social networks or institutional requirements.

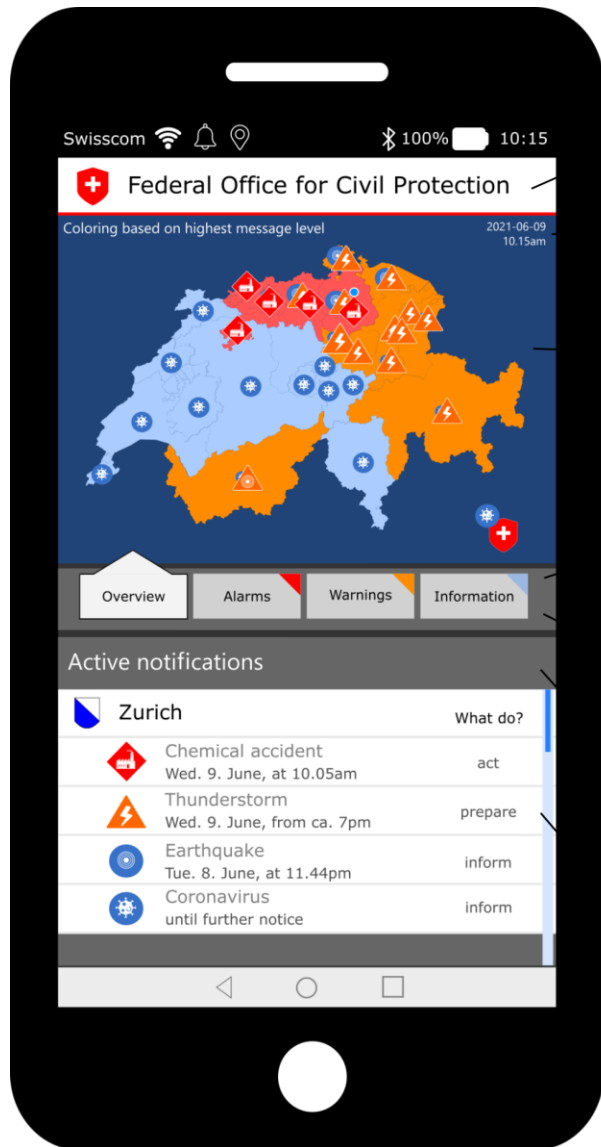


### **Transdisciplinarity approach**

We recommend applying a transdisciplinary research approach when designing communication products and services by collaborating with scientists from different fields as well as involving different stakeholders from the society such as cantonal and national authorities, practitioners and the public.

## **5.2 Specific (design) recommendations**

In the following, we provide specific recommendations for the design of (multi-)hazard overviews and hazard messages, which we took from (Dallo, 2022). These recommendations should help scientists and practitioners working in the field of hazard and risk communication develop and operate actionable, understandable and well perceived event-related (multi-)hazard overviews and messages.



**Trusted source** at the top of the overview so that people directly see that it is information from an official authority.

**Timestamp** so that people see at first glance that it is real-time information.

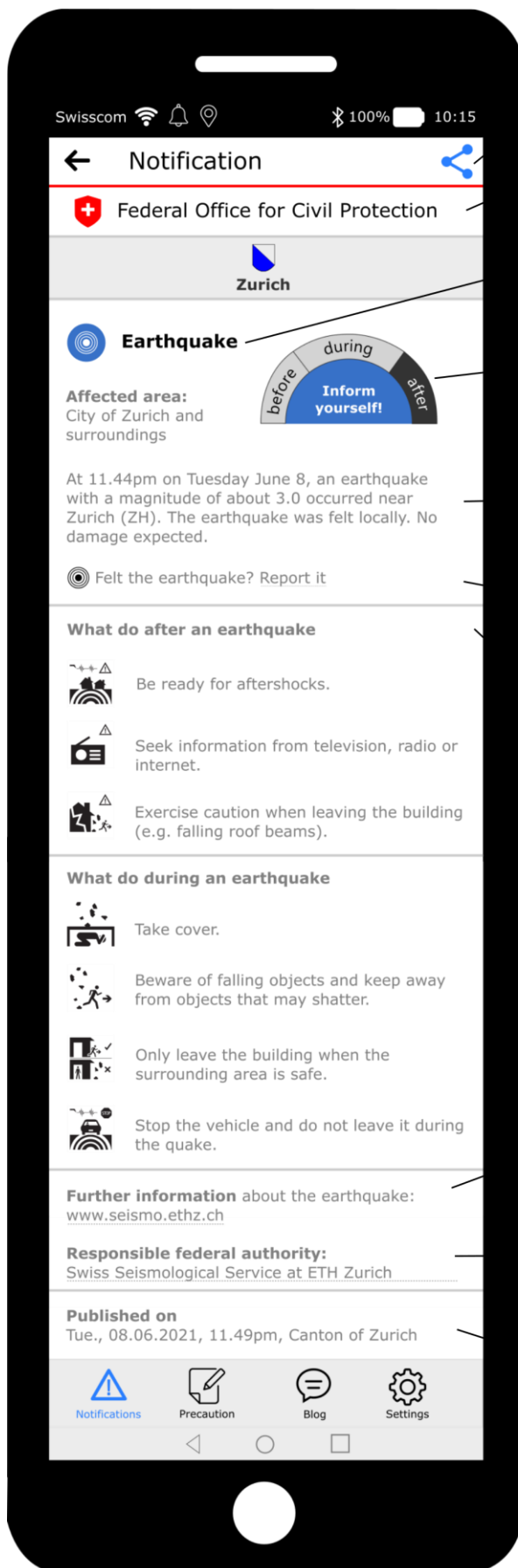
**Single map** displaying all active hazard notifications. The **hazard icons** on the map are appreciated as they show where the hazard "hotspots" currently are.

**Map selection** so that people can look at the information (e.g., hazard category) they are interested in. This further allows one to provide an **overview of all hazard categories**.

When the **hazard categories** are **well defined** and **clear**, it does not matter whether to have for example information/warning/alert or no hazard/little hazard/moderate hazard/high hazard/very high hazard.

Location-based **textual information**, listing the active hazard notifications for a **user-preferred region**.

**Action and time indications** already on the start page prompt people to open the hazard messages and allow them to understand whether it is information before, during or after an event.



**Forwarding feature** as the first thing that many people want to do is to inform their relatives and friends.

**Trusted source** at the top of the message so that people directly see that it is information from an official authority.

Information about the **hazard type, hazard level and affected areas**.

**Action- and time-related icon**, highlighting which action people should take (prepare, inform, act) and whether it is information before, during or after an event.

**General description** of the event (e.g., time of occurrence, specific characteristics of the hazard) and the **possible impacts** (that may be) caused by the event.

**Interactive features** such a report button, an "I am safe" button or "I need help" button.

**Behavioral recommendations** trigger people to take action. One must be aware that people tend to believe that the most important action is the one at the top of the list. Additionally, a combination of visual and textual behavioral recommendations is wished by the public and allows people not speaking the language in which the message is provided to understand what they can/should do.

**Link** which allows people to **access further information** on the official websites of the responsible authorities.

**Contact details of the responsible authorities** in case people have specific questions. For severe events, also **emergency numbers** should be listed.

**Publication date** so that people know whether the information is still relevant or not and when the message was disseminated.

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## 6. Conclusion

### 6.1 Cross-disciplinary reflections

Beside the communication of event-related earthquake on multi-hazard platforms, the scientific community is also exploring the potential of earthquake early warnings (EEW), operational earthquake forecastings (OEF) and rapid impact assessments (RIA) (Dryhurst et al., 2021). In 2020/2021, the first generation of the European Seismic Risk Model (ESRM) has been publicly launched (Crowley et al., 2020) and numerous countries, such as Switzerland and Italy, are establishing rapid impact assessment systems, allowing to estimate the expected losses minutes to hours after an event (Wyss & Rosset, 2020). Operational (loss) forecasting is still debated in the community whether to communicate it to the public or not. New Zealand and the US already provide OEF information to the public and other stakeholders (Becker, Potter, McBride, et al., 2020) and the potential to make OEF publicly available in other countries is planned (Jordan et al., 2011; Jordan & Jones, 2010; Woo & Marzocchi, 2014). The future challenge is to combine this information with event-related information already provided to the public. Thereby, questions arise such as how can earthquake forecast information and event-related messages be combined? Or how does earthquake early warnings and rapid information after an event be linked to avoid confusion?

The experiments we conducted were only based on hypothetical scenarios. Thus, future studies are needed to test the developed hazard overviews and hazard messages also in real hazard situations. In Switzerland for example, the existing two multi-hazard apps could be extended with the time- and action-related icons. After a real event, one could then assess the understanding and usefulness of the adjustments with for example a pre-prepared questionnaire. This in turn allows to make further adjustments based on the users' feedback.

Our samples were representatives for Switzerland regarding gender and age. However, we did not specifically assessed the needs of vulnerable groups (e.g., persons with disabilities). But, especially these groups are most affected by (natural) disasters (Lome-Hurtado et al., 2021; Ye & Aldrich, 2021; Zúñiga et al., 2014). Thus, future studies should assess whether the designed communications are also suitable for these groups or whether they need other interactive features of further information tailored to their, for example, physical abilities.

We have not taken into account the potential of alerts provided by privately operated services. Google, for example, is already testing respectively providing earthquake alerts to the public in some countries (Stogaitis, 2020). However, Google is not yet coordinating their alerts with responsible national authorities. Further, major streaming services, such as Netflix, consider to send emergency alerts to their users (Grothaus, 2019). However, information from such private operators is often questioned since the public's trust in these institutions is comparably lower, at least in Switzerland (Dallo et al., 2020). An option could be that the responsible federal entities collaborate with the private services and offer them to spread the official (federal) messages via their channels because there is no doubt that more people can be informed in this way.

In addition to providing information on multi-hazard apps, responsible entities can also benefit from the potential to rapidly disseminate event-related information on social media. Two studies, one in Japan and one in the US, showed that twitter plays a crucial role for the public to deal with disasters (Ruan et al., 2020; Yamada et al., 2018). Moreover, especially in countries where no public service is communicating regularly information to the public, social media platforms allow people to handle the situation by their own (Fallou et al., 2020). However, the penetration rate of Twitter for example is high in Japan and the United States and in all other countries rather low (Statista, 2021), and public's trust in the information available on social media is also rather low (Dallo et al., 2020; Flizikowski et al., 2014; Lacassin et al., 2019). Therefore, it is indispensable that the information comes from an official authority and is consistent with the information on the

other channels, such as the messages on the multi-hazard app. Further, social media also facilitates the rapid spread of misinformation. Thus, responsible entities should have strategies ready to prevent or immediately fight misinformation to avoid inappropriate public behavior. Future research is needed to establish tools to ensure the information spread on social media is reliable and does not lead to reactions that worsen an emergency situation. In general, it is recommended to distribute relevant hazard information via multiple channels to enhance resilience and to reach different target audiences with varying needs.

Further, when communicating real-time hazard and risk information to the public legal and ethical issues have to be considered too. Regarding the legal aspects, the earthquake in L’Aquila in 2008 (Alexander, 2014; Cocco et al., 2015) and the volcanic eruption in New Zealand in 2019 (Lewis, 2021; Mutter, 2021) show that it is indispensable to clearly define roles and responsibilities not only with respect to the monitoring and analyses but also for the communication. In many European countries, such as Switzerland (Art. 2 & 3 VWAS), the natural hazard institutions are allowed to give behavioral recommendations but only civil protection has the mandate to give behavioral instructions that people must follow. Further, it is crucial that such events do not inhibit scientists from communicating information to the society but rather motivate them to better collaborate with stakeholders from society and jointly communicate within the legally defined framework. Regarding the ethical issues, one can differentiate between internal and external ethics (ALLEA, 2013). The internal ethics define good research practice, e.g. complying with GDPR (General Data Protection Regulation) or considering FAIR data principles (findable, accessible, interoperable and reusable) (Di Capua & Peppoloni, 2021; Wilkinson et al., 2016). The external ethics refer to the ethical issues of the relations between science and society (ALLEA, 2013) and of disaster justice (Lukasiewicz & Baldwin, 2020; Shrestha et al., 2019). For various scientific disciplines international and national guidelines have been developed (e.g., AGU, 2017) to avoid, for example, the misuse of scientific data, technologies or inventions. A recent study by Di Capua and Peppoloni (2021) has shown that many scientists are aware of these ethical implications but do not know how to consider them in their practical work. Thus, future efforts are needed to increase the consideration of ethical implications and to support scientists in doing so.

## 6.2 Closing words

Our research effort is a first, comprehensive approach to analyse how to best design the communication on multi-hazard platforms to enhance their benefit, comprehensibility, and popularity. Based on these studies, we derived recommendations for stakeholders working in the field of hazard and risk communication and provide a basis for the intended development of a European civil defense alert system, including mobile apps and cell broadcasting, by June 2022.

Due to technological evolutions, multi-hazard platforms have been developed worldwide and are widely used not only by professionals but also by the public. Users have high expectations regarding the design and functionalities of such platforms because they are used to high-quality and mature products offered by private companies. However, the Swiss public generally trusts federal and cantonal authorities so they want to receive official messages from them. In consequence, there is a need for authorities to design useful and accessible communication materials for, among others, multi-hazard platforms.

Overall, the responsible authorities sometimes have to make a trade-off between the preferred design and the comprehensibility of the information, but often small tweaks can make a big difference. We show in particular that people prefer a single map with textual information added below a map and that textual formatted in lists are best understood. A time and action indication on the multi-hazard overview and the hazard messages thereby increases people’s intention to take action and ensures that they know what they should do and when they should take the actions (forecast vs. post-event information). Further, interactive features facilitate people to handle an emergency by warning their loved ones, informing emergency services that they need help or reporting damages to the responsible authorities, thus contributing to the mitigation of the

hazard. Moreover, a better understanding of people's personal factors allows to tailor the communication products to their needs, abilities and resources. And it is important to consider that these factors change, and thus public's needs, change from country to country and may also change with time and new technical developments

Testing and evaluating these communication materials participatory is thereby indispensable because well-intentioned designs are not always the ones that actually work best to increase peoples' understanding of the information provided and their ability to take protective actions. Further, the technological inventions and developments are still evolving rapidly, which must be monitored and taken into account for the continuous improvement of the multi-hazard platforms. Moreover, peoples' wishes sometimes conflict with their concerns; many users ask for more personalized information but worry about data privacy and security, wherefore compromises are needed. These requirements can best be met by authorities by involving their users in the design process of multi-hazard platforms.

We were only able to gain these insights by applying transdisciplinary research, more precisely by involving scientists and practitioners from different fields during the design process and by testing the designs with the public. Thus, we encourage researchers to consciously include the various stakeholders in the development processes to increase the effectiveness of the communication platforms and to test these iteratively. As icon inventor Martin LeBanc once said: *"A user interface is like a joke. If you have to explain it, it's not that good."*



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