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Mobile applications in crisis informatics literature: A systematic review

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ABSTRACT

How members of society interact during disasters has significantly changed because of technological innovations and new media evolution. The modality changes in crisis communications, such as the popular rise of mobile applications use, may pose risks to the public if not properly studied, with results adopted and utilised. Crisis informatics, as an emerging field of research, studies the socio-technical advancements in disaster management. The purpose of this review is to summarise the involvement of mobile applications (apps) in crisis informatics literature and to scope needs and opportunities for further research on citizen's use of mobile apps during disasters.

This review uses a scoping process to identify and analyse 49 crisis informatics articles that focus on mobile apps in disaster situations. The study investigates the various mobile apps that engage with the crowd during disaster situations. Findings show that apps used in disasters can be general-purpose apps or built-for-disaster-purpose apps. This review further focuses on the built-for-disaster-purpose apps and shows the various interactions these apps foster with the public and the apps' value-added contributions throughout the disaster life cycle.

Communication during disasters between the public and authorities has become more dispersed. To fully augment disaster resilience through technology it is important that future research should engage in user-centred studies to gain more insights from the citizens' on using mobile apps. This study highlights three areas of need for future research: engagement of apps prior disaster response stage, public behaviour and motivation towards the use of apps, and usability of mobile apps.

1. Introduction

Communication is a crucial component in managing disasters, as communication can aggravate or alleviate the impact of disaster situations [30,74]. In disaster scenarios, numerous people and agencies become linked, creating complex information demands in constrained supply capacities, thus generating large and unique problems [5]. How members of society interact during disaster situations has significantly changed because of technological advancements and new media evolution [4]. With the ubiquitous presence of social media and mobile devices in our networked world, the influence of Information and Communications Technology (ICT) on social phenomena cannot be ignored [52].

Crisis informatics, as termed by Hagar [31], is "broadly defined as the interconnectedness of people, organisations, information and technology during crises. Informatics often relates to the development of new uses for information technology and focuses on how people transform technology and how technology transforms people." Two important movements in communications have given rise to crisis informatics: (1) the shift from a top-down approach to bottom-up interaction, and (2) the growth of socio-mobile capacities [47]. The increasing interconnectedness of our society challenges the traditional one-way dissemination of disaster communications [4,70]. The rising trend of social media has created a communications world that has become "more complex rather than linear" (Andersen [4], p. 128).

In line with the growth of social media usage for disaster communications, mobile inventions and applications have also expanded. It is through these mobile technologies that users have unparalleled access to information [29,30]. This paper seeks to contribute to current research by reviewing the role of mobile applications (apps) in the crisis informatics literature and by framing opportunities for further research on citizen's use of mobile apps during disasters.

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This literature review followed the scoping review process by Arksey and O'Malley's [8]. The review process started with a broad question: 'Are mobile applications represented in crisis informatics literature?' Through the scoping process, the following questions were raised: What purpose do mobile apps serve in disaster situations? What interactions do mobile apps foster? What are the roles of the public when using these apps? In which stage of the disaster management cycle do the apps contribute? Findings from the 49 articles included in this review provided insights into the above questions. Furthermore, this review highlights three areas for future research: engagement with apps before the disaster response stage; public behaviour and motivation in the use of apps; and usability of mobile apps.

This paper is structured as follows. First, the paper contextualises the review by providing a background to the study, briefly discussing (1) the change in the communication landscape and (2) crisis informatics as a field of study. The paper then presents the methodology. The findings from the literature follow. Then the discussion section examines the findings in context to current and future research trends for mobile apps in crisis informatics. The paper concludes with a summary of recommendations for future research.

2. Background of the study

2.1. Communication during disasters

Most practices in disaster communication, whether stemming from crisis communication or risk communication traditions, have centred on an authority-centric 'push' culture where messages come from authorities and are principally distributed through mass media to the public [36,74]. Traditionally, communication is understood "as a planned activity conducted through the use of established strategies, regulations, and standardised plans" (Olsson [55], p. 115). A top-down approach is one in which the focus is on the transmission [55].

In this traditional 'push' culture, the authorities act as the focal point where they treat communication as an intentional activity [4,55]. Authorities can be the government or official organisations that have a mandate over the management of disaster situations; they can be international, national, regional or local in scale [25]. People assume authorities are ready to take responsibility, to maintain order and to safeguard society from the effects of disasters [19,25]. Traditional mass media during disaster communication uses one-to-many transmission [4]. The public has often relied on news media (i.e. radio and television) as their main source of detailed information on disaster situations; however, for alerting to reach the widest audience possible, news media alone is not sufficient [25]. In strategic alerting, as good practice, multiple channels are needed to promote reinforcement and redundancy [25].

However, the one-way disaster communication paradigm has been challenged by the changing media landscape. Through the years, different media channels allow people to communicate with each other in various ways during crises (see Table 1). Reuter et al. [73] pointed out that social technologies are already integrated into our societal infrastructure. Social-software assisted cooperation has aided in crisis management in four categories [73]. The categories are (1) crisis communication – quickly communicating with citizens for individual needs, (2) self-help communities – cooperation through emergent groups, (3) integration of citizen-generated content – integration of information from various social software sources and (4) inter-organisational crisis management – cooperation among professional organisation communities. These various types of social-software assisted cooperation, along with emerging technologies such as mobile phones and location-based media, have the potential to enhance crisis management [73].

Table 1
Communication paradigms.

Interactions	Description	Examples
One-to-one	Individuals communicate with each other	Telephone call, SMS messaging
One-to-many	A single source distributes information broadly	TV broadcast, radio broadcast
Many-to-many	Participants can publish and receive broadly with one-another	Social media platforms: Facebook, Twitter

Communication during disasters is moving towards the crowd [9]. 'Movement towards the crowd' means that members of the public no longer act simply as passive recipients of information; but rather, the crowd can self-organise, communicate as a network, and provide ongoing assistance amongst each other during disaster events [59]. This movement is a great opportunity to improve independent community resilience. However, multiple complexities arise with this many-to-many interaction from the crowd. For example, too much information can cause strain on the collective or authority-based capacity to manage the disaster [49]. Despite the increased complications, the presence of social media technologies may be advantageous during disaster events because such technologies also have many beneficial attributes such as greater capacity and interactivity [36].

2.2. Crisis informatics

Crisis informatics, as a growing research field of interest, seeks to understand online behaviour in social computing during disaster events [58]. The 2010 Haitian earthquake acted as the tipping point for demonstrating the value of ICT and new media in crisis communications [24,90]. Crisis informatics looks into the socio-technical aspects of disaster management with a particular focus on the interaction between the people and organisations involved [37]. The study of crisis informatics aims to contribute to scientific knowledge and society by updating theories, developing informed policies, and innovating technologies to better improve disaster resilience [62,65].

Even before the 2010 Haitian earthquake, some studies already noted the changing media landscape. As early as the 2005 Hurricane Katrina, researchers observed the emergence of online forums following the disaster [59]. Further interest in crisis informatics emerged as social media platforms, such as Facebook, gained in popularity. For example, after the 2007 Virginia Tech Shooting, many of those affected sought social media information during and after the mass shooting event [89]. Early academic publications on crisis informatics also emerged from the 2007 Southern California Wildfires [85], the 2009 Red River Valley Flood [60], and the 2009 H1N1 pandemic [13,61].

However, crisis informatics gained more traction as the Haitian 2010 Earthquake amassed a vast scale of spontaneous digital volunteerism [46]. Partly because of the Haitian diaspora, volunteers across the world came together with technology skills through social media to collaboratively work on crisis maps to aid relief efforts. For the first time, the United States of America government agencies used social media extensively to gain and coordinate knowledge for disaster management [90]. The wide-scale acceptance of new media technologies by the public, as well as by the authorities, legitimised crisis informatics as an area of research. Since 2010, an increased volume of academic research has explored crisis informatics. For example (See Fig. 1), the initial search for relevant crisis informatics articles for this review

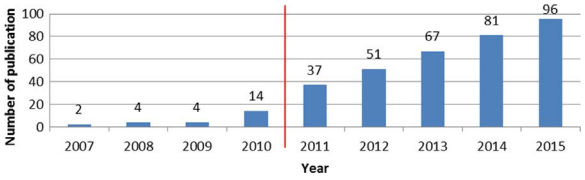

Fig. 1. Increase in crisis informatics publications post 2010.

Table 2
Crisis informatics themes of study.

Themes	Description	Examples of papers
Social media analytics	Literature quantitatively or qualitatively assesses data produced by the public through social media to understand socio-behavioural phenomena. These studies often involve recommendations on improving quality mining of social media data (such as Twitter tweets or Facebook posts) during the immediate timeframe of the disaster.	[10,16,14]
Adaptation and utilisation	How individuals and organisations adopt and use social media and technologies during disaster situations	[38,42,45]
Information sharing behaviour	Looks at the socio-behavioural aspect of information sharing of people and organisations during disasters. It looks at the motivations behind information seeking and sharing to allow crowdsourcing to work.	[80,79,59]
Improving technical capacities	Focuses on technological aspects. These papers present technological developments and innovations to improve disaster management capabilities. The studies look at a wide technical range: from infrastructure to modalities that will be resilient during disasters.	[84,2,81]

resulted in 356 publications between the years 2007–2015; of which the most publications (93%) occurred after the year 2010.

In addition, since the 2010 Haitian earthquake, research has more frequently integrated the varied fields of technology, society, and disasters. Some articles have systematically analysed and compared studies from different focus areas, including collective behaviour and social media in disasters [20], crowdsourcing and emergency management [46], Twitter communication and stakeholder expectation in various disaster situations [56] and on algorithms for processing social media messages [40]. Similarly, this review contributes to the literature by providing insights from systematically analysing mobile apps in crisis informatics research.

Crisis informatics integrates three main topics: (1) disaster management, (2) ICT, and (3) socially generated and processed content. Crisis informatics covers a broad scope of disciplines, and it branches into several themes of study. Currently, there are no demarcated boundaries on these themes. Depending on the discipline lens, different research areas are highlighted (e.g. [65]). From a thematic analysis of 373 unique publications, we have identified broad themes (See Table 2). These themes are not mutually exclusive and may overlap.

3. Methodology

This review used the ‘scoping’ typology. Scoping reviews, also known as mapping reviews, aim to frame the nature of existing literature on a particular topic [63]. Scoping reviews have been conducted and accepted in the information systems field. For example, Sjøberg et al. [83] and Venkatesh et al. [88] published well-cited scoping studies that have helped frame the literature in their respective fields of software engineering and technology adoption [43,63]. The scoping review usually starts at a broad level, follows the research trend and develops inclusion/exclusion criteria to scope the size and nature of a particular topic [43,63]. This study followed Arksey and O’Malley's [8] five-step scoping review process: (1) defining the research question, (2) identifying relevant studies, (3) selection of articles, (4) charting the data, and (5) analysing and collating the results.

The purpose of the review was to find research opportunities for mobile apps in the crisis informatics literature. Unlike other systematic literature typologies, in scoping reviews, the research questions are allowed to be generic [43]. The review started with an overarching question: ‘Are mobile apps represented in the crisis informatics literature?’.

The scan for relevant academic publications started with using the EBSCO Discovery Service – a unified indexed search service that simultaneously searches through multiple indexed databases and collections. The search covered the period starting the year 2000 until the end of the first quarter of 2016. Additional searches were conducted on Scopus and Web of Science to ensure coverage of major publications on the topic. Only peer-reviewed journals and conference proceedings in English were considered. Table 3 summarises the literature search results. Search criteria included the keywords ‘crisis informatics’ and ‘mobile'. The search also included variants of these keywords. Alternate searches for 'crisis informatics' used a search combination of 'disaster management' (or 'emergency management' or 'crisis management') and 'social media' (or 'web 2.0', or 'citizen science', or 'crowdsourcing'), without ‘crisis informatics’. Substitute keywords for 'mobile' included the words: platform, device, instrument, tool, and phone. The initial search produced 1166 results.

Table 3
Summary of literature search results.

	EBSCO discover	Scopus	Web of science	Total
Initial search criteria results				
‘crisis informatics’ AND ‘mobile’	19	75	23	117
(‘disaster management’ or ‘emergency management’ or ‘crisis management’) AND (‘social media’, or ‘web 2.0’, or ‘citizen science’, or ‘crowdsourc*)	348	495	206	1049
Total	**367**	**570**	**229**	**1166**
Total articles after removal of duplicates	93	259	21	373
Total articles after Exclusion Criteria 1	44	189	13	246
Total articles after Exclusion Criteria 2	**6**	**43**	**0**	**49**

Further filtering removed duplicates within and between databases. The process reduced the number to 373 unique publications. We then employed two rounds of inclusion-exclusion criteria to filter relevant documents. Fig. 2 summarises the inclusion-exclusion process. While the numbers of articles are listed, we are of the view that the qualitative aspects reported in the articles regarding the usability and utility of the disaster apps to be more important than the number of articles.

The first inclusion-exclusion criteria looked at the types of disasters discussed in the literature. The definition of ‘disaster’ adopted in this review comes from the crisis informatics perspective: “disaster situations are a result of hazards with varying predictabilities in a time-pressured environment. The increase in uncertainty during crises often leads to complex response efforts with broad societal consequences.” (Liu [46], p. 392).

Differentiating disasters from non-disaster crises, crises are usually

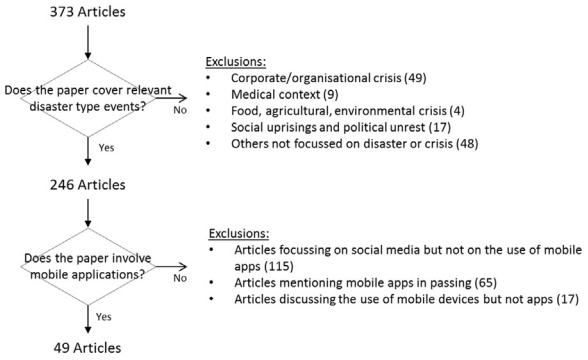

Fig. 2. Inclusion and exclusion criteria.

seen from the perspective of an organisation [24]. This review considers disasters from a societal perspective rather than that of a single organisation. Based on this criterion, this review excluded articles relating to corporate crises; such as those of public relations problems, social media fiascos, and product recall situations. This review also excluded articles that were in the medical organisational context; where articles focused on hospital management and social media use in the medical community.

Furthermore, the disruptions included in this study were those characterised by short term, imminent time-pressures rather than 'slow' catastrophes characterised by long emergent times spans. As such, articles on food shortages, agricultural and environmental problems were excluded from the review. The study also excluded articles delving into political unrests and uprisings; where the articles focused on using technology for the purposes outside disaster management, such as for election campaigning, for tracking political unrest, for propaganda dissemination, and for pushing for political change.

Any other articles that did not put emphasis on disasters were also excluded. The disregarded articles had an array of topics too varied to discuss in detail, but some excluded topics involved e-learning, smart cities and web-design, among others. In total, 127 articles were excluded. The 246 articles included for further review related mostly to natural disasters and terrorism.

The second inclusion-exclusion criteria determined whether the materials contained sufficient mobile apps content. On occasion, the articles mentioned mobile apps only in passing and did not dwell on the apps in the discussion. For example, Twitter is a popular topic of interest in crisis informatics literature. Twitter has been highly accessible through the web and mobile apps. Journal articles would mention 'mobile apps' as a context for the use of Twitter, but the focus of the article would be on the analytics of the content of the tweets rather than on the use of the app; this review excluded such publications. Some articles, on the other hand, discussed the role of mobile phones during disaster situations but again do not explicitly delve into the apps; the review also excluded such publications. Only articles that discussed the use of mobile apps in disaster situations were included. After subjecting the materials to two rounds of inclusion-exclusion criteria, the total number of articles was reduced to 49.

The 49 articles were subjected to thematic analysis. Through thematic analysis, the data collected were coded in a structured and comparable manner according to emerging themes (Flick [23], pp. 305–332). Thematic coding makes it possible to gather new insights and perspectives related to the themes throughout the review process; the coding process involves sequentially building summaries for each article, but allows for continuous rechecking and modification as further coding and interpretation is conducted (Flick [23], pp. 305–332). The thematic analysis revealed how mobile apps are situated in the crisis informatics literature. The analysis prompted significant sub-questions: What purpose do mobile apps serve in disaster situations? What interactions do the mobile apps foster? What are the roles of the public when using these apps? In which stage of the disaster management cycle do the apps contribute? The next section presents the answers to these questions.

4. Findings from the literature

This chapter presents the findings regarding mobile applications in the 49 articles selected from the crisis informatics literature. First, an overview of the articles included in the study is provided. Then this chapter focuses the discussion towards the nature of the apps: (1) the different mobile apps encountered and the interaction these apps foster between the public and authorities; (2) the public's multiple roles as users of these mobile apps; and (3) finally the various contributions of mobile apps in the disaster cycle.

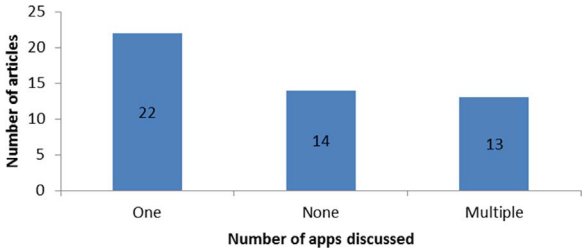

Fig. 3. Number of apps discussed per article.

4.1. Summary of the articles

The 49 articles included in the review showed a varying level of detail in their discussion of mobile apps for disasters (see Fig. 3). 22 of the 49 articles focused on presenting a particular mobile app, discussing in detail the app's system architecture or its critical disaster management features. The next 14 articles discussed overarching theories and concepts on mobile apps during disasters without focusing on any particular mobile app. Also, 13 articles named and compared multiple disaster-focused apps highlighting some key observations between various applications. Appendix A summarises the apps mentioned in each of the articles.

The findings in the study display a comparable pattern to Poblet et al.'s [66] review of web-based and mobile-based disaster crowdsourcing platforms. According to Poblet et al.'s [66], there are two technology-approaches in platform functionality development: (1) data-oriented and (2) communication-oriented. Similarly, In the 49 articles reviewed, multiple papers concentrate on providing a proof of concept of data-oriented functionalities and communication-oriented functionalities for the apps.

For example, on data-oriented functionalities, some discussion focuses on technical data capacities such as enhancing geo-referenced data quality (e.g. [86]), as well as systems for mining and processing of multimodal data (e.g. [2]). On the other hand, other papers discuss communication-oriented functionalities where the focus is on building seamless interaction between stakeholders. These include resilient alerting/notification services (e.g. [75]), structures for bridging seeker-supplier information (e.g. [82]), and systems for streamlined crowdsourcing (e.g. [48]). In most of the papers, however, data- and communication- oriented functionalities are discussed complementarily as part of a whole architecture (e.g. [51]).

The articles have varying depths of discussion based on the objectives of the papers. Objectives of the papers vary: some provide a detailed analysis of an app, some present a prototype app, some compare different apps, and some discuss theoretical concepts of a disaster app. Appendix A lists the papers included in this review and the objectives of each paper. Because of the varying depth of discussion of the articles (detailed analysis of an app, broad comparison of apps, or theoretical discussion of apps) comprehensive appraisal of the technical functionalities of these apps or the apps' effectiveness are not within the scope of the review. However, the study provides categorisations, descriptions, interactions, and purposes of these apps.

4.2. Mobile apps and interactions fostered

Mobile apps used in disaster situations may be made specifically for disaster purposes and may also be apps used for normal day-to-day activities. Apps used during disasters can be broadly categorised as (1) general-purpose apps, or (2) built-for-disaster-purpose apps.

4.2.1. General-purpose apps in disasters

During disaster situations, the public uses various apps that are not built solely for the purpose of disaster management. For example, the public uses social media apps or news apps to find information pre-,

Table 4
Interaction and description of general-purpose apps used during disasters.

Interaction	General-purpose apps
One-to-one	• Messaging apps where a person can send personal message to another
One-to-many	• News apps where a news agency publishes news to the public • Weather apps where a meteorological agency publishes weather information
Many-to-many	• Social media apps such as Twitter, Facebook, etc. • Messaging apps where a group of people can send messages to each other

during- and post-disaster events. Table 4 describes the nature of the general-purpose apps mentioned in the review; apps that have facilitated communication or information dissemination during disasters.

During disasters, social media apps like Twitter and Facebook are popularly used to gather and communicate information; people tend to favour familiar platforms that they have frequently used before the disaster occurrence [30,53]. However, disaster management authorities have concerns in promoting the use of general-purpose platforms for emergency situations, as many issues arise such as privacy, information quantity, and content quality [77]. To circumvent these difficulties, multiple efforts have been made to create apps specifically to channel curated emergency information needs of the public and authorities [77].

4.2.2. *Built-for-disaster-purpose apps*

From the 49 articles considered in this review, 35 articles discussed apps built specifically for disaster management purposes. From the 35 articles, a total of 57 built-for-disaster-purpose apps were named; ranging from popularly used Ushahidi mobile-version mapping platform, to experimental or prototype apps, to tested but discontinued apps. Appendix B lists the apps included in this review.

4.2.2.1. Purposes of the built-for-disaster-purpose apps. These built-for-disaster-purpose mobile apps usually have an array of multiple features; however, the apps typically serve a primary objective. The purposes of the apps revolve around operations and activities that arise when disasters occur. The review finds five purposes for built-for-disaster-purpose apps: (1) crowdsourcing, (2) collaboration, (3) alert and information dissemination, (4) information collation, and (5) user-generated notification during disasters. Table 5 summarises these; Appendix B lists the purpose of apps included in this review. The first three purposes focus on enriching situation awareness through gathering information with the public's involvement; while the last two focus on resilient delivery of critical information between authorities and the public.

These five purposes are not mutually exclusive for the built-for-disaster-purpose apps. Some apps may incorporate multiple purposes:

Table 5
Purposes of built-for-disaster-purpose apps.

Purpose	Description	N*
Crowdsourcing	To organise and collect disaster-related data from the crowd	16
Collaborating platform	To serve as a platform for collaboration during disasters	13
Alerting and information	To disseminate authorised information before and during disasters	13
Collating	To gather, filter and analyse data to build situation awareness	9
Notifying	For users to notify others during disasters	6

* Number of built-for-disaster-purpose apps in the review. ΣN = 57.

for example, CrowdMonitor [48] gathers information from social media as well as incorporating volunteered information. Most of the apps, however, adhere to an identifiable primary purpose.

The purpose of the largest group of apps (16 of the 57 found in the review) is to facilitate crowdsourcing during disaster situations. The apps are usually intended as part of a system to organise crowdsourcing efforts. Most of these apps were designed for crowdtasking activities; the crowdtasking process starts with a call for defined action where participants are asked to perform tasks [77]. Examples of such apps include TweetClicker and ImageClicker, which both helped assess the typhoon situation in the Philippines by requesting volunteers to tag the relevance of tweets and images of the disaster [67]. Crowdtasking apps can be used for post-disaster damage assessment or pre-disaster risk assessment as well; as an example, 'Damage Tracker' collects damage information for evaluation after a disaster [33].

Another purpose for disaster apps is to act as a collaborating platform. Collaboration apps, in contrast to crowdsourcing apps, provide an open avenue for communities to work together during disasters. Apps are used as platforms to foster 'self-help communities', as defined by Reuter et al. [73], to collaborate from public to public. Examples, from this review, include a platform where donation seekers can link-up with suppliers [82]; and open-source platforms for crisis mappers such as OpenStreetMaps mobile [84].

Providing alerts and information is also a common purpose for a built-for-disaster purpose app. The objective of such apps is to disseminate information. The primary interaction is one-way; usually originating from the authorities to the public. Examples of such apps are the American Red Cross Apps and the Federal Emergency Management Agency (FEMA) App; which were developed by their respective agencies.

Built-for-disaster-purpose apps purpose can also be for collating information. Academic publications explore how mobile apps can improve and enrich disaster information by utilising information already provided by the public. Apps collate publicly available social media data, without necessarily engaging the public, and then repackage the information for easier consumption. For example, XHELP gathers data across social media platforms; the app monitors, filters, analyses, and presents cross-platform social media data using dashboards [72].

Finally, the last purpose is more localised to the user and his or her network; the app affords users the capability to notify others of their situation when a disaster occurs. The origination of the notification comes from the user to disseminate information to another person, organisation, or network. Usually, it is a common characteristic of these apps to have the ability to retrieve the user's GPS position automatically; so users can quickly communicate this information to others [75]. HelpBridge, ELERTS, and Emergency Alert are examples of notification apps.

Appendix B lists more examples of the apps and their purposes.

4.2.2.2. Interactions of built-for-disaster-purpose apps. Similar to the general-purpose apps, the built-for-disaster-purpose apps foster interaction between and within the public and the authorities. Table 6 shows the various interactions the built-for-disaster-purpose apps provide. Aside from fostering one-to-one, one-to-many, and many-to-many communication; we observed that the built-for-disaster-purpose apps also promote other types of information flow between the authorities and the public. For example, some apps start with a single source's call for information from the public to contribute data which will then be processed centrally to gain a better awareness of the disaster situation. In this case, the interaction is 'one-to-many-to-one'. In some instances, the apps data-mine publicly displayed information via social media sites to make it usable for the authorities. In this case, the app cultivates a 'many-to-one' processing of information from the public for the benefit of the agency collecting the data. The 'many-to-one' is a one-way interaction also known as crowd-harvesting; the app harvests crowd data with or without the public's consent [46]. Other

Table 6
Interactions and descriptions of built-for-disaster-purpose apps.

Interaction	N*	Built-for-disaster-purpose apps
One-to-one	2	• Notification apps where a person can send information to authorities
One-to-many	17	• Alert and information apps where authorities communicate to the public • Notification apps where a person can send emergency information to his/her contacts
One-to-many-to-one	8	• Crowdtasking apps where a source requests volunteers to send information; information is then processed centrally.
Many-to-one	12	• Processing apps where a central source gathers information from the public.
Many-to-one-to-many	8	• Crowdsourcing apps where information from the public is aggregated then redistributed to the crowd.
Many-to-many	11	• Community apps where interest groups (e.g. neighbours or firefighters or mappers) can share information with each other.

* Number of built-for-disaster-purpose apps in the review. ΣN = 57.

apps, on the other hand, try to foster mutual interaction by redistributing the aggregated information to the public; making it a "many-to-one-to-many" interaction corroborated by the app.

4.3. The public as app users

The increasing interconnectedness of our society challenges disaster communications, requiring them to become more complex because of the evolving dynamics between the authorities and the public in their various roles [4,70]. Communication tools contribute to the interaction between stakeholders during disasters. Officials are sometimes wary of social media and new technologies, primarily because of the concern for information integrity [1,12]. Despite this apprehension, according to Adam et al. [2], authorities (agencies, organisations and responders) find benefit in using smartphones during disasters. Mobile apps provide the authorities additional capabilities to receive real-time situation awareness reports, to request updates from citizens and to provide a timely response.

In earlier literature, the public is often only seen as information recipients, who request assistance or receive updates and advisories through their mobile phones [2]. As social media evolves and as technologies become more mobile, the citizens are now also seen as potential participating sensors that could give information or perform tasks to aid in disasters. From the various articles we have reviewed, the public is usually perceived to take on the following functions: (1) as victims, (2) as targeted receivers of information, (3) as in-situ sensors, and (4) as offsite volunteers (see Table 7).

The apps foster various multiple interactions, from simple one-way communication to the complex interactions between the public and the authorities. The level of complexity of the interactions relates to how the app recognises the public as its users. For example, if the app treats users only as disaster victims or as passive recipients of information then the app focuses on strengthening its one-to-one or one-to-many communication capabilities. If the app fosters a one-to-many-to-one or a many-to-one interaction, the main objective of the app is to support capabilities for gathering or crowdsourcing of information; it treats the public primarily as sensors or volunteers rather than simply as receivers of information or as victims needing help. Other apps try to foster an enriched interaction that supports complex connections between many stakeholders; these apps interact with the public in multiple roles during disasters.

Table 7
Cross-tabulation of public's role and apps interaction.

Interaction	N*	Public as victims	Public as information receivers	Public as in-situ sensors	Public as offsite volunteers
One-to-one	2	X			
One-to-many	17	X	X		
One-to-many-to-one	8		X	X	X
Many-to-one	12			X	X
Many-to-one-to-many	7	X	X	X	X
Many-to-many	11	X	X	X	X

* Number of built-for-disaster-purpose apps in the review. ΣN = 57.

4.4. Apps in the disaster cycle

ICT developments, such as mobile apps, look to improve disaster management by fostering interactions to minimise uncertainty and to augment capabilities. Improving disaster resilience can happen throughout the various stages of the disaster cycle. Houston et al. [36] conducted a comprehensive review of academic and non-academic literature and found that social media use exists throughout the disaster life cycle. A similar finding has been observed in this review of mobile app use in disasters; 49 articles discuss app use throughout the various stages of the disaster life cycle. Table 8 summarises the various contributions mobile apps provide at the stages of the cycle found in this review. Articles were not limited to discussing just one stage of the disaster cycle; often the discussion overlaps between phases. However, the majority of the literature focuses on the response stage, mainly because of interest in the data generated during disaster response.

5. Discussion

The 49 documents reviewed include different descriptions, purposes, interactions, and contributions of built-for-disaster-purpose mobile apps. All the apps try to foster better information exchange between and within the public and authorities during the disaster life

Table 8
Apps' contributions in the disaster cycle.

Disaster cycle	%*	Mobile apps contributions
Mitigation/Reduction	26%	Crowdsourced damage assessment Crowdsourced hazards monitoring
Preparedness/Readiness	26%	Disaster risk education and preparedness learning Gathering of digital volunteers prior disaster occurrence Providing early warning notifications
Response	82%	Fast and wide distribution of information Diffused data gathering – crowd as sensors Fast and timely processing – crowd as microtaskers Localised distribution of alerts and warnings
Recovery	26%	Seeker-supplier interaction for donation/ information Providing recovery information post-crisis Crowdsourced disaster effects/damage assessment

* % of total 49 articles discussing the role of mobile apps at the particular stage.

cycle. However, from the review, there are still research gaps in advancing complex interaction between public and authorities through these built-for-disaster-purpose apps. To ensure that these apps will be valuable to the public-at-large there are three fundamental areas of further research needed: (1) engagement with apps before the disaster response stage, (2) public role, behaviour, and motivation towards apps use, and (3) usability of mobile apps.

5.1. App engagement prior disasters

Existing literature in crisis informatics revolves mostly around the response and recovery stages [62,66]. The reviewed publications have highlighted how the use of mobile apps can improve situation awareness during disaster response. Some of the articles have also emphasised that building disaster resilience capacities should be integrated not only during the response stage but throughout the disaster life cycle. Various stages of disaster management from preparation to mitigation need the involvement of information, communication, and technologies [31].

In particular, this study highlights the importance of the preparedness phase; where awareness of and familiarity with the apps must be established before a disaster to ensure full utility. For apps to be useful to the public in the succeeding phases of the disaster management cycle, the users must already be acquainted with the apps before the disaster event. Disasters and their management scale differently depending on the type, size, and complexity of the situation. Any technology meant for disaster management must be familiar to users on a regular basis. Otherwise, it will be of limited use during larger and more complex disaster situations [53]. It must be acknowledged that the potential user population of disaster tools may or may not be familiar with the technology when the need arises [6].

From this review, we have observed that during disasters, the public can potentially interact through existing general-purpose apps or through specially built apps for disaster purpose. As such, research on engaging the public to use apps before disaster occurrence has two general directions (see Fig. 4): (1) integrating disaster management capacities into existing and popular platforms or (2) attracting interest and retaining continued use for built-for-disaster-purpose apps.

5.1.1. Augmenting disaster capability on popular platforms

The public tends to use platforms that are familiar and trusted [30]. Various publications have researched the use of general-purpose apps such as Google, Twitter, and Facebook in disaster situations [15–17].

The increased frequency of traffic during disasters to popular online sites such as Facebook, Twitter, and Google has driven these entities to consider and integrate disaster functionalities in their respective web- and mobile- platforms. For example, Google Public Alerts, a platform for disseminating emergency information, seamlessly integrates with ‘Google Search’, ‘Google Maps’ and ‘Google Now’ [26]. Subscription to ‘Twitter Alerts' help Twitter users receive relevant and reliable

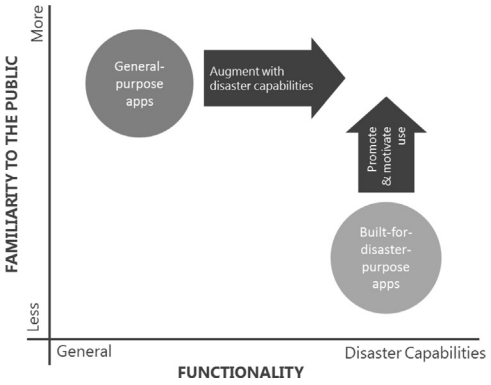

Fig. 4. Research directions on engaging apps for disasters.

information during disasters [64]. The Facebook ‘Safety Check’ feature allows Facebook users near a major crisis to publish a notification regarding their safety status [22].

These disaster features are only adjuncts to the main functionality of the apps. General-purpose apps are not built for disaster purposes. However, they may have extended functions that can be activated during disasters. For example, the main intention of the Facebook app is not for a Safety Check but rather for social media purposes. Despite not being designed specifically for disaster-context use, Google, Twitter, and Facebook may be deemed more useful when disasters strike as users are familiar with these apps. People tend to favour familiar platforms that they have frequently used before the disaster occurrence [24].

The review did not find any content from the 49 articles that investigate these extended disaster functionalities by Google, Twitter, and Facebook. This paper has not further considered the discussion on general-purpose apps as the findings from the literature show that the majority of academic publications on mobile apps on crisis informatics literature concentrate on built-for-disaster-purpose apps. The prominence of popular apps – in particular with the pioneering disaster functionalities executed by Google, Twitter, and Facebook – is a noteworthy area for further disaster research exploration.

5.1.2. Promoting the built-for-disaster-purpose apps

In the past few years, the level of use and acceptance of social media platforms during disasters has been established. Often during disasters, the public uses readily available platforms (such as Twitter or Facebook) due to their ease of use, simplicity, and familiarity [6]. The use of built-for-disaster-purpose apps is less common. Despite the plethora of available apps in the market, only a few have been deemed good enough to be downloaded and used by the public. “Only 1% of all mobile applications have been downloaded more than one million times and, once downloaded, one in four mobile applications are never used again” (Hoehle and Venkatesh [34], p. 435).

Multiple built-for-disaster-purpose apps are currently being developed to address the emergency information needs of the public and authorities [77]. All stakeholders should be aware of and exposed to such tools even before a disaster. If the built-for-disaster-purpose apps are to be useful during disasters, the app must be supported and endorsed by authorities and also promoted to and accepted by the public as a preparedness tool.

Efforts must then be carried out in the preparedness phase to facilitate the access, knowledge, and use of technology for disaster situations [6]. It is a challenge to gain the interest of both the authorities and the public. On the one hand, the authorities must overcome possible apprehension about adapting to new technologies and be invested enough to put their resources behind a complex information communication channel. On the other hand, the apps also need to be attractive enough to the public to achieve critical mass for maximum impact.

So far, research has focused on the theoretical concepts and technical structures of mobile apps during disasters. In the future, research must transcend this to study societal acceptance of such technologies. For example, after presenting the proof-of-concept of their mobile app, Auferbauer et al. [9] highlighted the need to ensure the full utility of their mobile app by studying user uptake and acceptance further and finding barriers of entry to user involvement.

5.2. The public's motivation and role in using apps

Most of the articles reviewed (23 of the 49) presented theoretical or model app systems, and the majority of these studies recruited participants for experimentation or prototyping with the assumption that users have accepted the technology. However, the studies recognise possible issues of testing in isolated situations. In actual conditions, there is a possibility of low acceptance of the technology systems, especially if the technology does not function in a way that is

Table 9
Communication emphasis and authority-public interactions of reviewed apps.

	Interactions	Public as victims	Public as information receivers	Public as as in-situ sensors	Public as offsite volunteers	N
Traditional	One-to-one	X				2
	One-to-many	X	X			17
Authority centric	One-to-many-to-one		X	X	X	8
	Many-to-one			X	X	12
Public centric	Many-to-one-to-many	X	X	X	X	7
	Many-to-many	X	X	X	X	11
Total number of apps						**57**

predictable to the user [13]. However, limited literature has looked into the public's behaviour towards disaster mobile apps.

In information systems research, studies on technology acceptance for emergency purposes usually focuses on authorised responders as intended users and not the general public. For example, police in Finland [44], firefighters in the United Kingdom [54,69], and emergency centre operators in New Zealand [68]. Only a handful of studies [3,41] evaluate technology applications from the perspective of civilians as the targeted users; “despite the growing awareness of untapped potential of affected population in a disaster situation, their inclusion in disaster management is extremely limited” (Gunawan and Fitrianie [28], p. 1).

The premise for ICT developments in disasters has been moving towards the crowd. Members of the public are no longer seen as helpless and unpredictable agents; rather citizens may have the capability to do life-saving work [18]. Although multi-modal disaster communication is becoming more popular, the information direction flow for most disaster mobile applications still flows one-way [66]. As also seen in this review, a significant proportion of the apps still employ one-way communication (see Table 9).

A large proportion of the articles still approaches apps from an authority-centric and command-and-control perspective. Apps with limited interactions (one-to-one and one-to-many) still retain the traditional one-way communication paradigm which limits the public to the role of victims or passive information receivers. The many-to-one and one-to-many-to-one interactions, on the other hand, try to utilise information from the public but still centralise on the authorities’ interest in gathering information, without adequately fostering two-way communication with the public. Only 17 of the 57 apps mentioned in the review focused on citizen-centred communication, in which the apps promote complex two-way interaction and treat the public with multiple possible roles during disaster situations.

The partiality towards traditional communication and authority centredness of the articles in this review contrasts with the general crisis informatics literature. Crisis informatics acknowledges the redefined approach to crisis information from "the top-down control and command approach […] towards community-based grassroots strategies" (Hagar [31], p. 12). Research on mobile apps for crisis informatics must acknowledge the change in communication paradigm in order to advance research that integrates the public's interests. With mobile apps, the authorities' intentions, interest, and involvement are significant; however, the public's motivation behind downloading, adapting, and the use of the technology are also critical to ensure the full realisation of the apps' purpose.

Academic research on the public's use of mobile technologies for crisis communication is fairly young. Mobile app distribution to the public, in general, is a recent phenomenon. Both iTunes Apps Store and Android's Google Play (formerly known as Android Market) were launched in 2008 [50]. Comparatively, more considerable research has been conducted on mobile technologies used in the health industry. “Health communication colleagues have conducted considerable research on more broadly defined mobile health (mHealth) communication processes, technologies, and campaigns” (Bean et al. [11], p. 70). The field of mHealth provides a parallel body of literature that could provide insight into research on disaster apps. Some examples from the mHealth literature include user-centred design of apps [78] and the socio-technical approach to technology evaluation [57]. Further research is needed to look into the public's motivation and adaptation of disaster mobile applications.

5.3. Usability of mobile apps interface

The built-for-disaster-purpose apps support activities and operations that arise when disasters occur: such as crowdsourcing, collaborating, alert and information dissemination, information collating, and notifying. The majority of the papers in the literature have focused on (1) data-oriented functionalities: how dispersed data is produced, gathered, and processed or (2) communication-oriented functionalities: how interaction will be fostered between various stakeholders or both. This review observes an orientation in the literature (See Fig. 5) that is not discussed as frequently. Only a few papers have addressed the visualisation and interface capacities of mobile apps. 18 of the 49 articles reviewed mention “user interface”, but only to a limited extent. Only Estuar et al.’s [21] paper discussed app user interface as the main topic.

Even if data- and communication-functionalities are in place, mobile apps for disasters must be intuitive at first usage; as users must be able to operate the device and access information in complex disaster situations [53,75], and often while under stress. For example, using maps and images may enhance users’ awareness as opposed to using text formats [48,71]. “New media tools have much potential for encouraging preparedness, knowledge, and involvement in crisis response by making the topic visual and interactive” [87]. An ideal built-for-disaster-purpose app should have data, communication, and also interface functionalities working seamlessly.

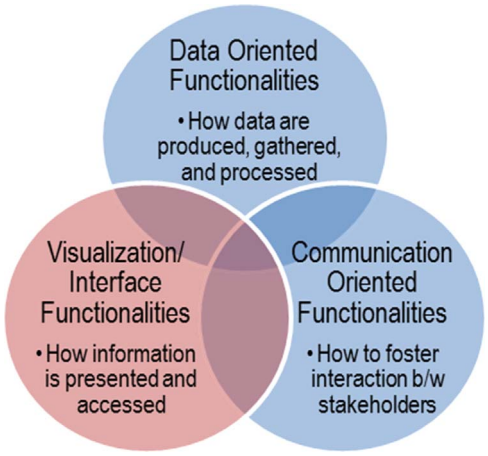

Fig. 5. Disaster mobile apps main functionalities.

Academic research on the usability of mobile apps, in general, has just recently started [34]. Furthermore, most of the usability literature centres on social media apps as these are the applications that are most frequently used by the public [35]. However, effective interface design is of immediate and relevant concern for disaster apps; Romano et al. [75] noted that designers of emergency response mobile apps do not particularly focus on usability.

However, good interface design is even more relevant in crisis situations. Taking account of the decision-making qualities of users in stressful scenarios is important when designing information systems for emergency management. Individuals may react differently when under high stress [32]. Extreme time pressure and high stakes create conditions of high stress where individuals may experience degradation in information-processing and decision-making abilities [76].

In disaster situations, users may be put in scenarios where the apps may influence life-critical outcomes; therefore, a sound basis for design and development plays a critical role in the success of the system [39]. Mobile platforms such as iOS and Android provide user experience guidelines that help developers to create applications with a user-friendly common interface [7,27]. From these, numerous studies have been conducted on adoption and usability of mobile applications but mostly in a context outside disaster apps (e.g. [35]). However, the dynamic disaster management environment imposes particular demands, requiring that users can operate apps as intuitively and accurately as possible while under stress. Ensuring usability of disaster apps is another area of research that needs to be further explored.

6. Conclusion

Disaster communication is shifting from the authority-centric archetype and moving towards a paradigm that integrates and engages with the public. Mobile technology is at the frontier of innovation in improving public preparedness and in strengthening the engagement link between citizens and authorities during disasters. This literature review found 49 articles that discussed mobile applications in the crisis informatics literature.

The findings from this review answer the following questions. *What purpose do mobile apps serve in disaster situations?* The articles revealed five thematic purposes for built-for-disaster-purpose apps: Crowdsourcing, Supporting collaboration, Alerting and providing information, Collating information, and Notifying. *What interactions do the mobile apps foster?* The disaster apps promote different interaction dynamics between one and many. However, the largest proportion of apps focused on the one-to-many authority centric flow. *What are the roles of the public when using these apps?* The review also saw that the public has multiple roles as users of mobile apps during disaster events; the roles of the public can be as victims, information receivers, in-situ sensors, or as offsite volunteers. *In which stage of the disaster management cycle do the apps contribute?* Mobile apps can assist in various parts of the disaster management cycle, but the majority of the apps discussed in the articles covered in this review are designed for the response stage.

A comprehensive appraisal of the technical functionalities of these apps was not within the scope of the review due to the varying detail the articles provide and the variability of their approach from reviewing existing apps to developing their own proof-of-concept apps. However, the findings from the questions above reveal some areas for future research. Three of these research directions are highlighted in this paper.

First, future research needs to acknowledge that apps used during disasters can be general-purpose or built-for-disaster-purpose. As such, research on engaging the public to use apps before disaster occurrence has two general directions: (a) integrating disaster management capacities into general-purpose apps, as well as (b) attracting interest and retaining continued use for built-for-disaster-purpose apps.

Second, the use of social technologies such as social media and mobile apps are already integrated into our societal structure. Research on mobile apps for crisis informatics must acknowledge the current authority-centric communication paradigm but also the recent changes to a more citizen-centric communication. To fully realise the potential of mobile apps for disasters, it is important that future research engages in citizen-centred studies to gain more insights into users' needs, motivations, expectations, experiences, and limitations when using disaster apps.

Third, the majority of the literature has focused on data-oriented and communication-oriented functionalities. However, just as significant, as these two orientations, is the presentation and visualisation of information in the mobile apps' interface. In the dynamic disaster environment, the usability of these disaster apps is critical. Research is needed to investigate and ensure the usability of mobile apps for disasters.

Funding acknowledgement

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Appendix A. Summary of the articles reviewed

Article #	Author	Year	Title	# of built-for-disaster-purpose apps discussed	Name of mobile apps discussed	Objective of the paper
1	Adam	2012	Social media alert and response to threats to citizens (SMART-C)	One	SMART-C	Presentation of the SMART-C system
2	Adam et al.	2012	Spatial computing and social media in the context of disaster management	One	SMART-C	Discussion of spatial computing and social media from the perspective of the SMART-C system
3	Ai et al.	2015	A dynamic decision support system based on geographical information and mobile social networks: A model for tsunami risk mitigation in Padang, Indonesia	One	DDSS	Presentation of a system for early tsunami warning
4	Auferbauer et al.	2015	Moving towards crowd tasking for disaster mitigation	Multiple	American Red Cross Apps PulsePoint RE-ACTA	Presentation of RE-ACTA app; includes discussion of similar apps

5	Besaleva and Weaver	2014	CrowdHelp: m-Health application for emergency response improvement through crowdsourced and sensor-detected information	Multiple	American Red Cross Apps CrowdHelp GeoCommons Help Call iTriage Ushahidi	Presentation of CrowdHelp; includes review of other applications
6	Besaleva and Weaver	2013	Applications of social networks and crowdsourcing for disaster management improvement	Multiple	CrowdHelp Ushahidi	Presentation of CrowdHelp; includes review of other applications
7	Boulos et al.	2011	Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples.	None		Review of different domains on mobile applications
8	Brussee and Pouwelse	2015	Survey of robust and resilient social media tools on Android	None		Review of robust social media tools on Android
9	Camarero et al.	2009	Disasters 2.0 application of Web 2.0 technologies in emergency situations	One	Disasters 2.0	Presentation of a social portal (architecture) that integrates and shares user generated information
10	Cooper et al.	2015	Twitter as a potential disaster risk reduction tool.	None		Review of Twitter and other tools for crisis management
11	Crowe	2011	The social media manifesto: a comprehensive review of the impact of social media on emergency management.	None		Explanation of social media use and discussion of mobile phone movement
12	Estuar et al.	2014	Validating UI through UX in the context of a mobile-web crowdsourcing disaster management application	One	eBayanihan	Usability study of a mobile app
13	Frommberger and Schmid	2013	Crowdsourced bi-directional disaster reporting and alerting on smartphones in Lao PDR	One	Mobile4D	Presentation of Mobile4D
14	Gibson et al.	2014	Combining big social media data and FCA for crisis response	Multiple	American Red Cross Apps ATHENA-App CrowdHelp Ushahidi	Presentation of ATHENA app; includes discussion of various apps
15	Gómez et al.	2013	A review on mobile applications for citizen emergency management	Multiple	*Generic discussion of multiple apps*	Review of mobile applications for citizen emergency management
16	Goolsby	2010	Social media as crisis platform	None		Review of social media and other platforms for crisis mapping
17	Handmer et al.	2014	Updating warning systems for climate hazards: Can navigation satellites help?	One	QZSS Mobile	Discussion on how satellite navigation helps warning systems; app for interpreting and displaying info
18	Havlik et al.	2013	Robust and trusted crowd-sourcing and crowd-tasking in the future internet	One	MDAF	Evaluation of volunteer networks supported by smartphones
19	Hodapp et al.	2013	Damage tracker: A cloud and mobile system for collecting damage information after natural disasters	One	Damage Tracker	Presentation of the Damage Tracker system and mobile app
20	Imran et al.	2015	A processing social media messages in mass emergency: A survey	None		Review of crowdsourcing
21	Karnatak et al.	2012	Spatial mashup technology and real time data integration in geo-web application using open source GIS – a case study for disaster management	None		Presentation of a geo-spatial integrated architecture for mobile disaster management
22	Link et al.	2013	Twitter integration and content moderation in GDACSmobile	One	GDACSMobile	Presentation of the GDACS and GDACSMobile system
23	Liu et al.	2011	Going beyond citizen data collection with Mapster: A mobile + cloud real-time citizen science experiment	One	Mapster	Presentation of Mapster

24	Ludwig et al.	2015	Crowdmonitor: Mobile crowd sensing for assessing physical and digital activities of citizens during emergencies	Multiple	CROSS CrowdHelp CrowdMonitor DIADEM Mobile4D Ushahidi	Presentation of CrowdMonitor system and app; includes discussion of various crowd sensing apps
25	Ludwig et al.	2015	CrowdMonitor: Monitoring physical and digital activities of citizens during emergencies	Multiple	CROSS CrowdHelp CrowdMonitor DIADEM Mobile4D Ushahidi	Presentation of CrowdMonitor system and app; includes discussion of various crowd sensing apps
26	Markenson et al.	2014	American Red Cross Digital Operations Centre (DigiDOC): An essential emergency management tool for the digital age	None		Discussion of the concept of a digital operations centre; with a mobile apps component
27	Meissen and Fuchs-Kittowski	2014	Crowdsourcing in early warning systems	One	Unnamed prototype	Presentation of a prototype and discussion of the role of crowdsourcing in early warning systems
28	Meissen and Fuchs-Kittowski	2014	Towards a reference architecture of crowdsourcing integration in early warning systems	One	Unnamed prototype	Presentation of prototype; an integrated architecture for crowdsourcing in early warning systems
29	Mocanu et al.	2012	Ubiquitous multi-agent environmental hazard management	One	JADE	Presentation of a model that integrates the robustness of JADE and the Android OS
30	Moreira et al.	2015	An experimental evaluation of a crowdsourcing-based approach for flood risk management	None		Presentation of a modest evaluation system for verifying Volunteered Geographic Information
31	Murthy et al.	2014	Capacity building for collecting primary data through crowdsourcing - An example of disaster affected Uttarakhand State (India)	One	MANU	Presentation of a damage assessment app – MANU
32	Poblet et al.	2014	IT enabled crowds: Leveraging the geomobile revolution for disaster management	Multiple	CrisisTracker Imageclicker OpenStreetMap mobile Sahana TaskMeUp Tweetclicker Ushahidi	Review of approaches and tools to crowdsourcing
33	Poblet et al.	2014	Crowdsourcing tools for disaster management: A review of platforms and methods	None		Review of platforms and methods
34	Reuter et al.	2015	SOMAP: Network independent social-offline-map-mashup	Multiple	Disaster Alert Earthquake Alert! ELERTS Hurricane Hound MobileMap Outbreaks near me Real Time Warning SOMAP ubAlert	Presentation of SOMAP; includes discussion of other mobile apps
35	Reuter et al.	2015	XHELP: Design of a cross-platform social-media application to support volunteer moderators in disasters	Multiple	Hands2Help Ushahidi XHELP	Review of social media use and proposes a platform
36	Reuter et al.	2015	Social-QAS: Tailorable quality assessment service for social media content	None		Presentation on how tailorable QAS can assist the use of citizen-generated information

37	Romano et al.	2016	Designing mobile applications for emergency response: Citizens acting as human sensors	Multiple	ELERTS Emergency Alert FEMA HelpBridge Motorola Alert My112 SafetyGPS SignAlert	Review of apps and presents the usability test of an app
38	Schimak et al.	2015	Crowdsourcing in crisis and disaster management – challenges and considerations	One	RE-ACTA	Presentation of RE-ACTA; includes discussion of the relevance of crowdsourcing
39	Schulz et al.	2012	Crisis information management in the Web 3.0 age	Multiple	Incident reporter Report classifier	Discussion of linked open data, crowdsourcing and presents applications that utilise them for emergency management
40	Shams et al.	2015	On integrating social and sensor networks for emergency management	None		Review of existing management systems; introduces an architecture proposal
41	Shih et al.	2013	Democratizing mobile app development for disaster management	Multiple	Donate-N-Request WeReport	Presentation of architecture and discussion of prototypes
42	Slavkovikj et al.	2014	Review of wildfire detection using social media	One	Firemash	Presentation of a platform for wildfire detection; reviews current systems for using social media for fire detection
43	Soden et al.	2014	Resilience-building and the crisis informatics agenda: Lessons learned from open cities Kathmandu	One	OpenStreetMap Mobile	Presentation of a case study using OpenStreetMap in Nepal
44	Stollberg and De Groeve	2012	The use of social media within the Global Disaster Alert and Coordination System (GDACS)	One	GDACSMobile	Presentation GDACSMobile and discussion of Twitter search
45	Szczytowski	2014	Geo-fencing based disaster management services	None		Presentation of architecture, use case, and trial
46	Weaver et al.	2012	Applications and trust issues when crowdsourcing a crisis	One	Unnamed prototype	Presentation of a system
47	Willems	2012	Sustainable futures for learning in a climate of change: Mobile apps, social media, and crisis informatics during emergencies and disasters	None		Discussion on m-learning, apps, crisis informatics and mobile social media
48	Yang et al.	2014	Disaster mitigation by crowdsourcing hazard documentation	One	Hazard documenter	Presentation of a case on app use for hazard documentation
49	Zheng et al.	2011	Applying data mining techniques to address disaster information management challenges on mobile devices	One	ADSB	Presentation of a native mobile system; argues for native mobile apps vs. mobile browsers

Appendix B. List of apps included in the review

	App name	Primary interaction	Primary purpose classification
1	ADSB	Many-to-one	Collating reports
2	American Red Cross Apps	One-to-many	Alerting and information
3	ATHENA-App	Many-to-one-to-many	Collating reports
4	CrisisTracker	Many-to-one	Collating reports
5	CROSS	One-to-many-to-one	Crowdsourcing
6	CrowdHelp	Many-to-one	Collating reports
7	CrowdMonitor	One-to-many-to-one	Crowdsourcing
8	Damage Tracker	Many-to-one	Crowdsourcing
9	DDSS	One-to-many	Alerting and information
10	DIADEM	Many-to-one	Crowdsourcing
11	Disaster Alert	One-to-many	Alerting and information
12	Disasters 2.0	Many-to-many	Collaborating platform
13	Donate-N-Request	Many-to-one-to-many	Collaborating platform

14	Earthquake Alert!	One-to-many	Alerting and information
15	eBayanihan	Many-to-many	Collaborating platform
16	ELERTS	One-to-one	Notifying
17	Emergency Alert	One-to-many	Notifying
18	FEMA	One-to-many	Alerting and information
19	Fire Mash	One-to-many	Alerting and information
20	GDACSMobile	Many-to-one-to-many	Collating reports
21	GeoCommons	Many-to-many	Collaborating platform
22	Hands2Help	Many-to-one-to-many	Collaborating platform
23	Hazard documenter	Many-to-one	Crowdsourcing
24	Help Call	One-to-many	Notifying
25	HelpBridge	One-to-many	Notifying
26	Hurricane Hound	One-to-many	Alerting and information
27	Imageclicker	One-to-many-to-one	Crowdsourcing
28	Incident reporter	Many-to-one	Collating reports
29	iTriage	One-to-many	Alerting and information
30	JADE	One-to-many-to-one	Crowdsourcing
31	MANU	Many-to-one	Crowdsourcing
32	Mapster	Many-to-one-to-many	Crowdsourcing
33	MDAF	Many-to-one-to-many	Crowdsourcing
34	Mobile4D	One-to-many-to-one	Crowdsourcing
35	MobileMap	Many-to-many	Collaborating platform
36	Motorola Alert	One-to-many	Notifying
37	My112	One-to-one	Notifying
38	OpenStreetMap mobile	Many-to-many	Collaborating platform
39	Outbreaks near me	One-to-many	Alerting and information
40	Prototype - Meissen & Fuchs-Kittowski	Many-to-one	Crowdsourcing
41	Prototype - Weaver et al.	Many-to-one	Collating reports
42	PulsePoint	One-to-many	Alerting and information
43	QZSS Mobile	One-to-many	Alerting and information
44	RE-ACTA	One-to-many-to-one	Crowdsourcing
45	Real Time Warning	One-to-many	Alerting and information
46	Report classifier	Many-to-one	Collating reports
47	SafetyGPS	Many-to-many	Collaborating platform
48	Sahana	Many-to-many	Collaborating platform
49	SignAlert	Many-to-many	Collaborating platform
50	SMART-C	Many-to-many	Collaborating platform
51	SOMAP	Many-to-many	Collaborating platform
52	TaskMeUp	One-to-many-to-one	Crowdsourcing
53	Tweetclicker	One-to-many-to-one	Crowdsourcing
54	ubAlert	One-to-many	Alerting and information
55	Ushahidi	Many-to-many	Collaborating platform
56	WeReport	Many-to-one	Crowdsourcing
57	XHELP	Many-to-one-to-many	Collating reports

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