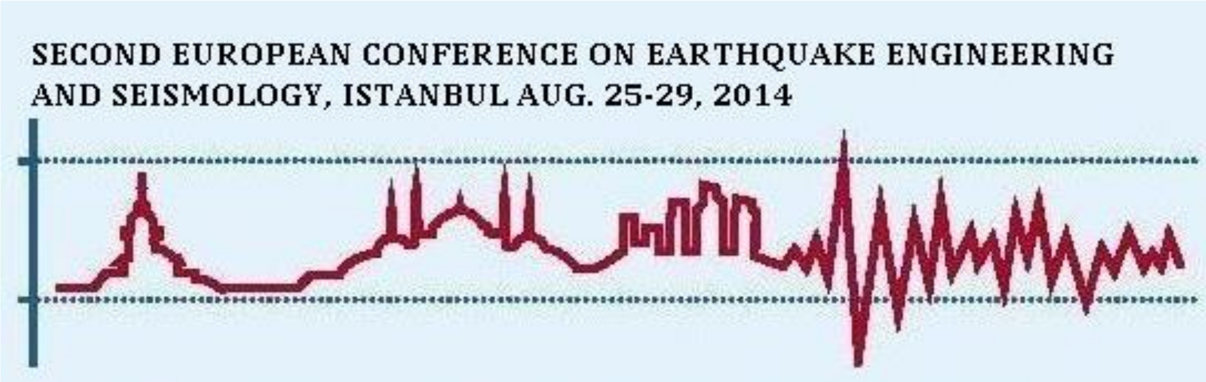

INTEGRATED DAMAGE ASSESSMENT SYSTEM USING MOBILE PHONE TECHNOLOGY DURING 2012 EMILIA EARTHQUAKE

Gian Paolo CIMELLARO[1] and Alessio VALLERO[2]

ABSTRACT

On May 20th and 29th, 2012 two earthquakes of 5.9Mw and 5.8Mw respectively have struck the Emilia Romagna region in Italy, causing 27 deaths and widespread damage. The epicenters were between Finale Emilia and Medolla. The damage assessment after the earthquake was managed from the Italian Emergency Authority, using printed forms (AeDES) which were filled by specialists on site. Since the use of smartphones is becoming more and more spread among the population, its utilization within the field reconnaissance has been proposed in this paper. An application that can be run by normal citizens on smartphones was developed, to give an initial damage evaluation of the area, which is going to be very useful when resources (e.g. the number of specialist is limited). A simplified version of the application was tested for the first time during 2012 Emilia earthquake to enhance the emergency response, showing the efficiency of the proposed method.

Keywords: smartphones, field reconnaissance, emergency management system, community resilience, disaster, recover

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INTRODUCTION

Over the past years the natural and man-made disasters with which the human society had to cope with had stressed the necessity to be prepared and to be able to recover in a short time from a sudden and unexpected change in the community technical, organizational, social and economical condition. The communities are organized social units with flexibility to adapt, to change and accommodate their physical and social environment. Their behavior during disasters depends on their dynamic social structure, their technical and economical resources and the capacity to restore normal operating conditions. The direct involvement of citizens in emergency response and recovery is very important, because if well coordinated they can improve the recovery process. In fact residents may help to identify an emergency and they can play a significant role in the recovery process. The ability of residents and professional emergency responders to directly exchange information during an emergency is necessary to provide a more accurate portrait of the severity of major disasters. Interaction and collaboration between citizens and technicians lead to improve the resilience of a given community (Cimellaro et al., 2010a,b).

"Mobile devices" and "Resilience" are two terms that nowadays regularly appear in the emergency management field. Mobile technologies and Internet provide means to use in a community when a response is needed, especially since individuals are becoming very comfortable with the use of technology devices. Mobile devices facilitate response in large scale emergencies by enabling individuals to report information. Using smartphones in the emergency management will help build community disaster resilience. In this paper, it is proposed a new procedure to obtain a first damage assessment of buildings right after the earthquake rapidly and efficiently.

LITERATURE REVIEW

In a society where information and telecommunications technologies have become so vital to every day's life, the nature of telecommunications policy must constantly evolve to meet new social developments (Mileti, 1999).

Mobile technologies can be harnessed to create a previously unavailable social benefit to communities and to individuals. It could be a revolution in the use of technology and infrastructure to help individuals and communities to respond and recover from disasters. Technologies such as smartphones and Internet can be better employed coordinating community response to major disasters more effectively. Advanced disaster management technology could provide a critical support system for emergency authorities during crises.

According to The Disaster Management Center of The University of Wisconsin, the term Disaster management can be described as "The range of activities designed to maintain control over disaster and emergency situations and to provide a framework for helping at-risk persons to avoid or recover from the impact of the disaster". However, "range of activities" infers a broad scale of applications which include, for example, pre-disaster activities that deliver an efficient response in the case of a natural disaster.

The development of a community response grid would offer a unique opportunity to join new technologies, governmental goals, and social benefits. Frequently in public policy related to communications and technologies, the potential social benefits of new technologies are ignored in favor of more immediate business, consumer, or governmental goals. Ultimately, policy decisions to develop and foster community response grids would bring significant benefits to governments, communities, responders, and residents faced with ever-present threats of natural disasters and terrorism by harnessing the power and presence of technology to change the way in which responders and residents are able to share information about and deal with crises. In any emergency, problems often derive from ''*collaborative problem solving*'' and other problems of coordination (Mileti, 1999). Coordination in terms of information sharing, communication, and collaborative action present enormous social and behavioral problems for emergency response (Kapucu, 2004). Major disasters are "occasions in which the boundaries between organizational and collective behavior are blurred" (Kapucu, 2004). As a result, communication and coordination among residents and responders are among the most pressing issues in an emergency (Haddow and Bullock, 2008).

Conceptually, the preparation for responding to emergencies can be seen as a cycle with information sharing and communication being keys throughout the cycle (Portsea, 1992, Pelfrey, 2005). "Sharing *information, willingness to collaborate, and shared values*" are vital bases of effective information sharing and communication in major disasters (Kapucu, 2004). For correct decision-making at any stage of natural disasters – from prediction to reconstruction and rehabilitation – a considerable amount of data and information is necessary. The most important procedures relating information from disasters are monitoring, recording, processing, sharing, and dissemination. Experience has proved that information technology simplifies the receiving, classifying, analyzing, and dissemination of information for appropriate decision- making. A critical component of any successful rescue operation is time. Prior knowledge of the precise location of landmarks, streets, buildings, emergency service resources, and disaster relief sites saves time – and saves lives. Such information is critical to disaster relief teams and public safety personnel to protect life and reduce property loss.

The ability of residents and professional emergency responders to exchange information directly during an emergency is necessary to provide a more accurate portrait of the severity and breadth of major disasters. The direct involvement of citizens is extremely important during the emergency, because it can improve the response and recovery process (Kweit and Kweit, 2004). "*Community engagement equips leaders to face the complex and ever-shifting realities of an extreme event*" (Schoch-Spana et al, 2007).

A higher number of resident responders (active residents), will allow decision makers to better allocate government resources where they are needed and supplement the limited resources, helping them to go further (Schoch-Spana et al, 2007). In the context of a community response grid, emergency response will firmly remain the job of professional emergency responders, except in the direst circumstances. The community members will generally be serving as support to professional emergency responders, helping the affected individuals in community support roles that fall outside the traditional functions of emergency response.

After a major disaster, community involvement through mobile devices is very important for increasing residents' trust of the emergency information and in promoting coordination among residents and responders.

Mobile-based emergency response systems are used by specialists during an emergency. This emergency system supports communications, data gathering, data analysis, and decision-making of emergency response. There are four main components in a mobile-based emergency system. They are (i) *inputs*, (ii) *processes*, (iii) *outputs* and (iv) *outcomes*. *Inputs* are the elements to be entered in the system (examples of inputs are the mobile user's details and emergency request data). *Processes* are all the elements necessary to convert or transform inputs to outputs (for example, a process includes disaster monitoring, and data analyzing). *Outputs* are the consequences of being in the system (for example warning messages) (Booker, 2010; Jagtman, 2010). *Outcomes* can take any or both of two forms benefits and/or risks, each should be well planned.

STANDARD EARTHQUAKE DAMAGE ASSESSMENT

One common scenario during disasters is that the activity of rescue and relief is not well-coordinated. Emergency authorities must receive and record the data related to damage of physical infrastructures (e.g. house, buildings, etc.) and then they must be processed to coordinate emergency response as fast as possible. The acquisition of damage reports starts from the citizens that require a first-level damage report – i.e. certificates of occupancy. Then the operative center organizes many technical teams to evaluate and perform the damage reports that are processed and organized according to their importance (Fig.1).

Figure 1. Standard damage assessment

Specialists and technicians from various regions perform the earthquake damage assessment of residential buildings right after the earthquake using AeDES printed forms to collect field data from the visual inspections. The certificate of occupancy (AeDES form) that was used in Emilia defines six outcomes of building usability: (A) usable building, (B) temporarily unusable (all or part) building but usable with emergency interventions, (C) partially unusable building, (D) temporarily unusable building for review with deepening, (E) unusable building, and (F) unusable building for external risk. Moreover, it is composed by nine sections: (1) identification of the building, (2) characterization of the building, (3) structural typology, (4) structural damage and emergency measures, (5) non-structural damage and emergency measures, (6) external risk from other structures and emergency measures, (7) soil typology and damage, (8) judgment of usability, and (9) other observations.

The final summary of the earthquake damage assessment for the inspected residential buildings after 2012 Emilia earthquakes in Italy using the data collected in the field with the AeDES forms are the following: 14,112 (36.4%) of A, 6,827 (17.6%) of B, 1,644 (4.2%) of C, 208 (0.5%) of D, 13,825 (35.7%) of E, and 2,110 (5.4%) of F.

The visual inspections in the field have been made by specialized teams. The standard damage assessment procedure (Fig.2) followed after the earthquake was the following:

1. Requests of certificates of occupancy with hardcopy forms made by citizens in the C.O.C. (Commissioner Operative Center) or C.O.M. (Mixed Operative Center);
2. Organization of technical teams;

Then for each technical team:

3. Registration of the team at the Direction and Control Center (Di.Coma.C.) located in Bologna;

For each day:

- Get the list of buildings to be investigated at the C.O.C. or C.O.M.;

For each building:

- Reach the building to be investigated;
- Fill the AeDES form (certificate of occupancy).
- Compile the summary form for the C.O.C. or C.O.M.;

- Reach the accommodation.
- Correction of the AeDES forms at the Di.Coma.C. (Bologna).

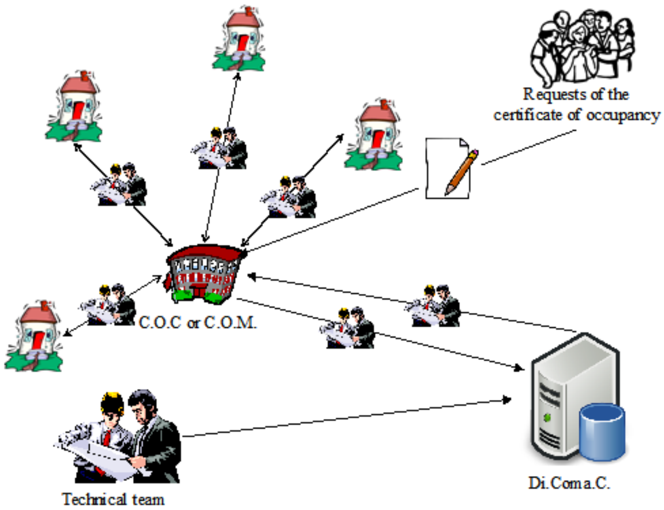

Figure 2. Standard procedure of earthquake damage assessment during 2012 Emilia Earthquake

PROPOSED EARTHQUAKE DAMAGE ASSESSMENT USING MOBILE PHONE TECHNOLOGY

A critical component of any successful rescue operation is time. Immediate knowledge of the precise location of landmarks, streets, buildings, emergency service resources, and disaster relief sites saves time – and saves lives. Such information is critical to disaster relief teams and public safety personnel to protect life and reduce property loss. Therefore, there is a need for a system that will improve the efficient resources allocation of rescue and relief in the disaster-affected areas “Mobile devices” and “Resilience” are two terms that nowadays regularly appear in the emergency management field. Mobile technologies and Internet provide means to use in a community when a response is needed, especially since individuals are becoming very comfortable with the use of technology devices. Mobile devices facilitate response in large scale emergencies by enabling individuals to report information. Using smartphones in the emergency management will help build community disaster resilience. In this paper, it is proposed a new procedure to obtain a first damage assessment of buildings right after the earthquake rapidly and efficiently.

Since the use of smartphones is becoming more and more spread among the population, a mobile phone application is developed, for an initial damage evaluation of the area affected by the disaster. The app, called EDAM (Earthquake Damage Assessment Manager), is run by *non-specialists* and it is going to be very useful especially when specialists are limited. A simplified version of the application has been tested for the first time after 2012 Emilia Earthquake to show the efficiency of the proposed method in improving the emergency response and comparing with previous data collection. The use of technology enables residents and responders to work together in community response to emergencies. Residents could report incidents and receive emergency information that would facilitate coordinated responses with emergency services. They could employ mobile devices like smartphones to provide information, GIS coordinates and pictures. Multiple platforms (mobile devices, Internet) and content types (text, pics, video) ensure that community response grids will function with surviving infrastructure during and after an emergency, while supporting two-way communications among residents and responders. Professional emergency responders could be collecting information via smartphones, residents could be reporting and receiving information via website, and communities could be sharing information simultaneously to respond to a crisis of any magnitude. Professional staff could separate out suspicious or low priority reports, assigning appropriate resources to the major problems and then automatically fill any form they need, like AeDES form. In this way it’s possible to collect all the informations quickly and automatically, with an easy mechanism for sending them.

Thanks to this new possibility, the input from structural engineers would also provide a more accurate portrait of the severity and breadth of disasters. A coordinated response from emergency services could be designed to use available resources with the option of requesting assistance from neighboring jurisdictions or secondary support services. The first responders need to communicate quickly, effectively, efficiently and frequently. Efficient, rapid and effective communication between mobile units and professional emergency responders is a key factor to respond successfully to the challenges of emergency management.

The proposed platform can support teams of professional emergency responders in the first hours after the disaster by using smartphones-based infrastructure and scale up to handle a much larger number of users with a more robust backend. It is a set of pluggable, mobile-based disaster management solution, that provides solutions to problems caused by the disaster and it is designed to help during the relief phase of a disaster.

The idea is to consider citizens who have a smartphone as a network of mobile sensors that can rapidly collect the first emergency response information immediately after a seismic event to improve community resilience through its recovery.

Since the use of smartphones is gaining interest in people, this damage assessment system was implemented as a smartphone application using Google's Android and Apple's iOS operating systems, with a future planned extension for the BlackBerry devices.

There are several mobile development environments in the market. One of which is *Android*, created by the Open Handset Alliance. *Android* is an open and comprehensive platform for mobile devices. It is designed to be more open than other mobile operating systems so that developers, wireless operators, and handset manufacturers will be able to make new products faster and at a much lower cost. The result will be a more personal and more flexible tool to the user. Another mobile operating system is iOS, developed and distributed by Apple Inc. It was originally unveiled for the iPhone but now it has been extended to support also other Apple devices, like iPod Touch, iPad, iPad Mini and second generation Apple TV. Unlike Android, Apple does not license iOS for installation on non-Apple hardware, but despite this the market is almost equally divided with Android (Fig.3).

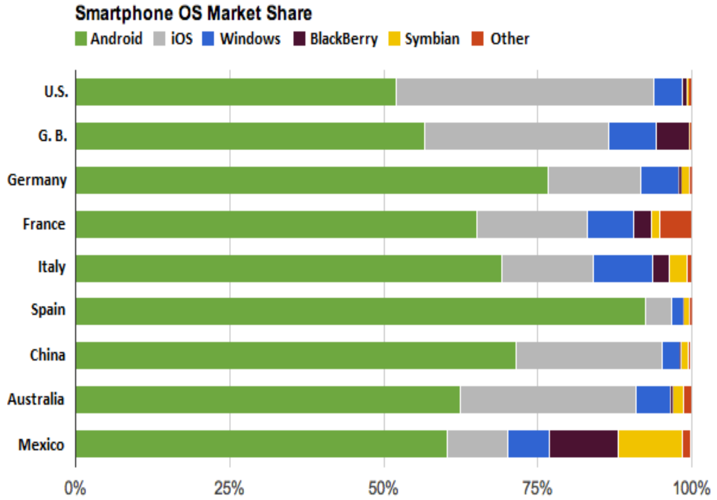

Figure 3. Smartphone OS Market Share

For this reason, this two mobile development environment were used in the implementation of the damage assessment system.The application is user-friendly and it reduces the bureaucratic procedures while it simplifies the evaluation and the acquisition of the certificates of occupancy.

Immediately after a seismic event, citizens collect different types of information by using the implemented application on smartphones: citizen's personal data, structural damages, location and features of buildings and infrastructure damages. The part about the insertion of citizen's personal data (name, last name, age, occupation, mobile number) also allows to digitally signing the document which can be downloaded in *pdf* after filling all the form. It is also required the user's position with respect to the building (inside or outside).

SURVEY ON BUILDING EARTHQUAKE DAMAGE ASSESSMENT

The possibility to collect the earthquake damage assessment of the non-specialist citizens was taken in account before realizing the proposed platform. Therefore, a survey was carried out among non-specialists to understand if they were able to identify structural damages in a building subjected to an earthquake (Scura et al., 2013). People were asked to match 36 pictures of damaged buildings (mainly from 2009 L'Aquila earthquake) with 22 type of failure mechanisms. The survey was made first in Turin (Italy) and then in Buffalo (USA). In both cases, the age's sample was between 18 and 30 years (which is the age range in which the highest number of people uses smartphones). The comparison of the survey between the two sites revealed no significant differences in the comparison between Turin and Buffalo.

The different failure mechanisms have been ordered in according to the level of difficulty in indentifying them for the two locations. Overall, according to the survey the percentage of error in the damages' identification by non-specialists is very small. However, it was decided not to rely on their judgments, because even a small error in percentage could falsify the damage assessment.

Therefore, it was decided to focus on smartphones cameras power. The function of taking pictures of damaged buildings was included in the application and it was asked to citizens to take pictures of the most important part of the buildings.

Those parts are obviously the most critical from the structural point of view and are useful for specialists to give a post-event damage assessment. In detail, the parts pointed by the application are: *the entire facades; external and/or internal corners; boundaries between adjacent buildings; bottom of each facade; top of each facade; access; roofs; ground around the perimeter of the building; internal walls; ceilings; floors; stairs and/or elevators; everything that is different from the usual (fractures, deformations, displacements)*. Regarding the position, the application allows loading automatically coordinates (WGS 84 system) as it is geo-referenced trough the GPS localization of the device.

Additionally, people can fill different fields such as *province, municipality, village or locality, address*. The system in fact allows the localization of buildings directly on a map. Regarding the building topology, EDAM (Fig.4). provides collecting the following information: *site, number of underground plans, number of not underground plans, and use of the building*.
It's also possible to draw a digital sketch of the building (e.g. plan view, lateral view, etc.) directly on the screen.

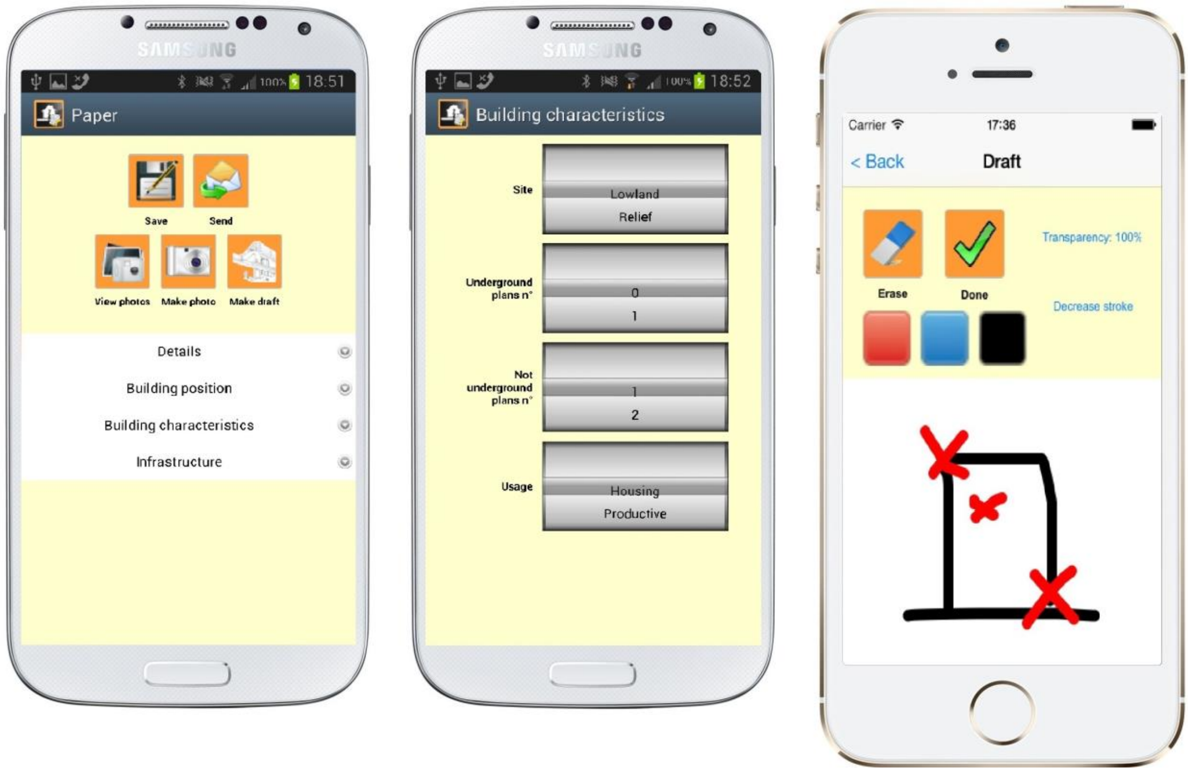

Figure 4. From left to right: Android Paper data, Android building characteristics and iPhone sketch view

Regarding the infrastructure damages, the application allows collecting information about: (i) ground fractures along the building perimeter, (ii) water and gas leakage and (iii) power outage. All the collected information is filled in a form which is prepared in pdf format directly from the app. Therefore, the application allows saving data and sending them directly to the centralized server of the operative center together with the attached pictures whenever an internet connection is available (Fig.5). In this way, the collected data can be digitally stored in a database and/or printed once they have been received.

Figure 5. Example of Collected Data

Once received in real-time all data from mobile sensors (of non-specialists), specialists and technicians at the operative center analyze these data and make a first damage assessment. Once obtained a complete map with the localization of the buildings and a first damage evaluation, thanks to the interaction between ordinary citizens and specialists (e.g. technicians), emergency authorities have an overall view of the areas affected by the earthquake. In this way, the operations of technicians for a more detailed damage assessment (AeDES forms) can be planned accordingly, improving the post-event recovery phase as well as its recovery and efficiency. Therefore, in this paper it is proposed a new procedure to obtain a first damage assessment during emergencies more rapid and efficient by removing all bureaucratic procedures, reducing the damage evaluation time; organizing the recovery phase. The proposed method is defined in a step-by-step procedure as follows:

1. Download EDAM;
2. Collecting data by citizens by using EDAM and sending them to an Operative Center;
3. Requests of certificates of occupancy in digital format made by citizens directly sending collected data;
4. First damage assessment by technicians at the operative center by means of collected data analysis;
5. Organization of technical teams;
6. Second more efficient and more detailed damage assessment following the common procedure to establish a final judgment of building usability.

APPLICATION OF THE DIGITALIZED EARTHQUAKE DAMAGE ASSESSMENT

A simplified version of EDAM was tested in the post-earthquake response of 2012 Emilia Earthquake in order enhance the data collection of the emergency authorities and compared with previous method and by the citizens of the town of Mirandola that just after the seismic event requested the damage assessment for their building by following the existing standard procedure. In detail, they were provided with a smartphone on which the implemented application was installed and they were asked to use this application for scientific research purposes. In this way it was possible to test the efficiency of the proposed method comparing with the standard procedure. 24 households were selected and the digitalized form was send to a centralized server located in the Operative Center. The data collected in digitalized form has been analyzed by five professional civil engineers and for each building; a first damage evaluation was requested using only the data provided through the smartphone. The most probable damage evaluation for each building was selected by comparing the five damage evaluations. Five different evaluations have allowed taking in account of the biased judgment of every single operator. The final damage evaluation related to the building was then compared with the results of the field reconnaissance obtained by the AeDES forms that were filled in by technicians after the seismic event.

RELIABILITY OF THE PROPOSED METHOD

It is evident that there are few differences between the results of the AeDES forms and the damage evaluation obtained from the analysis of data collected by means of the App were expected. The percentage of accuracy *A* of the proposed method shows the goodness of the proposed procedure Eq.(1).

$$A(\%) = \frac{N_p}{N_{TOT}} 100 \qquad (1)$$

where N_p=number of buildings with the same damage evaluation using the two methods, while N_{TOT}=total number of evaluated buildings. From the analyzed data it was obtained that N_p=21, while N_{TOT}=24, therefore the final percentage of accuracy is 87.5%. Even though the analyzed sample is very small due to the difficulty in convincing people in filling up the digitalized form, because they already filled the standard paper form, however the percentage of accuracy of the proposed method is very high.

Once obtained a complete map with the localization of buildings and a first damage evaluation, the specialists at the Operative Center can have a first overall view of damage in the entire area affected by the earthquake. In this way the emergency management operations of structural engineers can be optimally planned using the limited recourses of personnel. It is important to mention that the field damage evaluation using the AeDES forms of specialists cannot be avoided with the proposed procedure, but the post-event damage evaluation can be managed in a more efficient way

In Fig.6 is shown a sketch of functionality using as indicator the damage knowledge Q_{DK} of the buildings in Mirandola right after 2012 seismic event. The damage knowledge is null when the seismic event happens (May 20th). Then by following the standard damage assessment, there is a complete recovery in terms of functionality after almost 7 months (December). Instead, following the proposed digitalized earthquake damage assessment, it is possible to reach a very high level of damage knowledge just after a week. Consequently the full damage knowledge will be reached by following a more efficient (exponential curve) procedure thanks to well organized teams of specialists. In conclusion, by comparing the standard damage assessment with the proposed damage assessment method it can be observed that the damage knowledge in the area of Mirandola will reach full knowledge (100%) more rapidly than with the standard procedure. Indeed, the implemented App can be used during the response phase of a disaster especially when time is crucial.

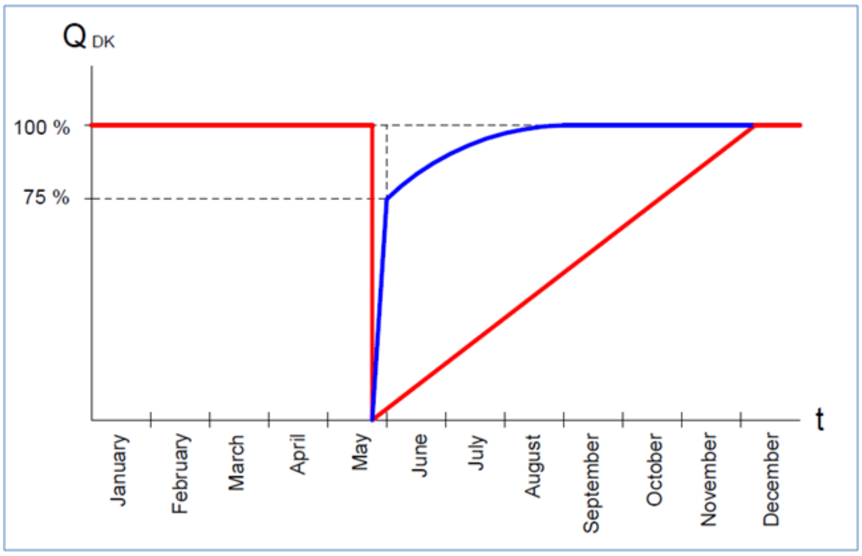

Figure 6. Comparison in terms of recovery

CONCLUSIONS AND FUTURE DEVELOPMENTS

As disasters are likely to increase across in the world, as more people that are vulnerable and are exposed to extreme natural and man-made events, and as cities continue to grow, there is a need at both local and national levels of an efficient disaster management system to better manage Resilience of communities. The direct involvement of citizen is extremely important during emergency, because they can noticeably improve both the response and the recovery phase. Residents may help to identify an emergency and they can play a significant role during the recovery phase. The combination of computing, networking, storage and content capture capability of smartphones can lead to new ways of sharing data. It can be used as a new opportunity for interaction between government, citizens, responders and other non-government agencies in emergency situations and therefore it improves the services of the government in emergency situations. With a smartphone every citizen is a potential reporter of emergency information, a potential responder to provide community support and a potential recipient of information that might prove life saving. There is the need for mobile technologies to assist specialists to collect information and making decisions during a disaster anytime and anywhere. In this paper a smartphones application is developed that can be run by non-specialists. It can be used for an initial earthquake damage assessment of the area affected by the disaster and it is going to be very useful especially when number of specialists is limited. The app is designed to help during the relief phase of a disaster to improve the recovery phase in terms of rapidity. Indeed a simplified version has been tested during 2012 Emilia Earthquake, and results clearly show the efficiency of the proposed method. However, it is important to mention that the earthquake damage assessment on site of professional engineers cannot be avoided with the proposed procedure; but the entire post-event damage assessment can be managed in a more efficient way.

ACKNOWLEDGEMENTS

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