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The street, an area exposed to earthquakes (the Lorca case, Spain 2011)

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Abstract

The Lorca earthquake (Spain, 11-05-2011) caused considerable damages, including a building collapse. This earthquake killed 9 persons affected outside the buildings, on the street, and more than 300 people injured. Studying this specific human exposure requires an adapted methodolgy. This article proposes a dynamic and spatio-temporal approach of individual mobility during the seismic crisis. Its application on Lorca case shows spatial and temporal variability of individual exposure level in the street during the hours following the shake. Not really studied until now, this specific human exposure deserves more attention particularly in zones of moderate seismicity, like Euromediterranean area.

1 Introduction

On May 11. 2011, exactly two months after the Fukushima disaster in Japan, a double earthquake shook Lorca, a city located some 60 kilometers southwest of Murcia in southern Spain. The earthquake mostly concerned the urban city centre of Lorca where 60,000 of the 90,000 city residents live (Figure 1). The Lorca earthquake was not one of the deadliest in the Mediterranean context but however shows several features making it an unprecedented one.

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Figure 1 Location of Lorca and map of Lorca's city centre. SPOT source provided by « © l'Instituto Geográfico Nacional de España »

The Iberian peninsula had never experienced such a deadly earthquake since 1956 when an earthquake killed 13 in the southeast of Spain, near the city of Granada (Solares 2012). In 2011 the magnitude Mw 5.2 quake occurred around 18.47 local time (16.47 GMT) and another magnitude Mw 4.6 tremor had occurred almost two hours before. With an epicentre intensity of VII (EMS 98) the quake killed 9 and wounded 300. A building totally collapsed and 1,164 other buildings were severely damaged. The economic loss was estimated in 2011 at €1,200 million by the municipality of Lorca (Oterino *et al*. 2012). The victims were hit out on the street next to buildings. Casualties were not wounded or killed by buildings collapsing on them but by the fall of cornices, balconies and other facade elements (Martínez Moreno *et al*. 2012).

The tremor duration was very short (a few seconds). It developed a 0.37 g maximum acceleration (recorded in the city 3 kms away from the epicentre). This has been the strongest acceleration recorded in Spain since the first accelerometers were installed in the region in 1984 (Rodríguez *et al*. 2011). The site effects, the shallow focal depth, the strong acceleration as well as the relatively high vulnerability of infrastructures seem to be the main factors explaining the reason for observed damage (Díaz 2012). This probably helped to concentrate the damage in the city of Lorca while this damage was hardly visible a few kilometers away from the city.

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Given the reasons for casualties and above all the location of individuals during the tremor we focused our study on the populations and their specific exposure in time. Yet the Lorca casualties were found outside the buildings while they are usually located in the ruins of damaged buildings. This leads us into modifying the most frequent approach for the analysis of earthquakes which emphasizes the study of structural failures. In the case of Lorca the public thoroughfare in the vicinity of buildings was the main exposed area. Our work aims at studying the individual exposure characterizing the Lorca case.

2 Individual exposure to earthquakes : latest developments

Relying on an analysis studying the reasons for casualties in the literature (in 2.1) we intend to examine why the public thoroughfare could constitute a particular area of exposure (2.2) and how this affects the way we address the event's social dimension compared to a more classical approach to vulnerability (2.3).

2.1 Origin of the casualties during an earthquake

According to Coburm (1992), as far as the urban environment is concerned 75% of the death toll is due to buildings collapsing, which represents more than 1.5 million dead between 1900 and 1992 (N=1,528,000 dead). This is verified in the Euro-Mediterranean countries where we can notice that most of the casualties resulted from building collapse (Galindo-Zaldívar *et al*. 2009; Tapan *et al*. 2013; Alexander 2011). However some necessary aspects need to be considered.

A collapsed building causes many casualties in the same place. This can be noticed for example in the case of the San Giuliano di Puglia earthquake in Italy in 2002 where among 29 dead 25 were due to the collapse of a school (Vallée and Di Luccio 2005). Similarly and still in Italy during the 2012 earthquakes 12 people lost their lives in the collapse of 5 factories. We can thus understand that most research intends to minimize the impact of a tremor on buildings using paraseismic constructions. Those were generalized in particularly sensitive areas by way of a paraseismic legislation and a systematic reinforcement of buidling standards.

The long European history however leaves ancient real estate heritage notedly dwelling in mountains or rural areas, a great number of urban historical centres (Guardiola-Víllora and Basset-Salom 2015; Moreno González and Bairán García 2012), as well as a great number of religious buildings and historical monuments (Martínez 2012; Milani 2013). Some

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earthquakes that succeeded each other in the 2000's in Turkey (2002, 2004, 2010, 2011) or in Italy (2009) for example caused much damage and many ancient buildings collapsed. Besides the practice of self-build according to which buildings are designed following local building practices without taking paraseismic standards into account could also have been the reason for some damage (Ellidokuz *et al*. 2005; Doğangün 2004; Celep *et al*. 2011; Tapan *et al*. 2013; Alexander 2011). Through these examples religious buildings appear to be the weakest facing earthquakes. This could be observed during the recent events in Italy (Martínez 2012; Milani 2013) and also during the Lorca earthquake. In this latter case 33 historical buildings have suffered damage that was economically speaking very hard to quantify. Damage is visible on domes, abutments, arches and decorative elements which suffered in several cases rotations and loss of balance (Martínez 2012).

Beyond these particular buildings and even if recent constructions are submitted to paraseismic standards some incorrect practices leave houses fragile. This is the case for instance with the use of short pillars or floors with various flooring heights, particularly for masonry constructions (Bechtoula and Ousalem 2005; Tibaduiza *et al*. 2012). Thus even if Euro-Mediterranean countries are not located on the most active faults in the world some ancient and more recent buildings are very sensitive to tremors that can hit their very structures or make some facade elements fall towards neighbouring streets and reach the population in various ways.

Existing studies on death causes during an earthquake show that crushed or asphyxiated victims are the most common (Ramirez and Peek-Asa 2005). However some analyses of specific events find out interesting conclusions and slightly moderate comments.

During the Liege earthquake in Wallonia (Belgium) on November 8. 1983 around 01.49 a.m (local time) most damage was linked to the fall of numerous chimneys (Camelbeek *et al*. 2006). Other construction elements such as cut stone pediments or chimney covers also fell. The fall of all those objects caused much damage to roofs and vehicles parked at the foot of the buildings but this could have been the reason for many more deaths if the quake had happened during the day. Therefore the study authors come to the conclusion that in Wallonia « the first cause of mortality in a low intensity earthquake is the fall of non-structural elements that are incorrectly fixed or little resistant and that are placed high up : chimneys, decorative facade elements, partitions and interior dividing walls which are simply built on the floor but not fixed » (Camelbeek *et al*. 2006).

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Besides, following the Darfield (Canterbury, United Kingdom) earthquake in 2010 non-structural elements which suffered much damage were studied. During the quake only two people were severely wounded, one of them because of a chimney fall. Considering the state of the streets next to the buildings, full of ruins, it seems obvious that the main determining factor explaining the small number of casualties was that the quake happened at 04.35 a.m. (Dhakal 2010).

Even if building collapse is one of the main factors of mortality during an earthquake population exposure on the public thoroughfare and in the vicinity of buildings should then be regarded as a factor that should be considered and more specifically in regions with moderate seismicity. Considering the study of the Afyon quake (Turkey) in 2002 even if the death toll was higher inside than outside of buildings the difference was not statistically significant in the words of Ellidokuz *et al*. (2005). For this very earthquake other reports underlined that numerous non-structural elements of the buildings suffered severe damage. The most frequently observed problem comes from the poor quality of partitions which were not drawn on the initial architectural plans and were added later (Tapan *et al*. 2013).

In the Lorca case only one building collapsed and did not injure anybody inside. The people affected by this quake were hit on the public thoroughfare next to buildings. Here again the wounds are not explained by building collapse but by the fall of cornices, balconies or other facade or roof elements (Martínez Moreno *et al*. 2012).

2.2 Exposure on the public thoroughfare

Putting people at the centre of our studies means considering carefully the new environment people have to face following an earthquake. Several reports stemming from psychologists or doctors list the types of wounds and traumas caused by earthquakes. Some try to understand what were the origins of the wounds (Ellidokuz *et al*. 2005; Armenian *et al*. 1997; Chou *et al*. 2004). Even if they are a minority others try to describe people's behaviours during the crisis as well as the reasons for those behaviours by assessing the way danger is perceived (Bolton 1993; Weiss *et al*. 2011; Goltz *et al*. 1992). But to the best of our knowledge there is no existing work in the field of seismic hazard establishing a relation between people's behaviours and the dangers to which they are exposed when on the public thoroughfare during the protection and evacuation phases.

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Following an earthquake such as the Lorca one people have to adapt to a more or less altered environment. The awareness of the new situation and following decision-making processes are linked to the individual and collective assessment of this new environment (Weiss *et al*. 2011). But in a troubled situation (notedly with disturbances in electric and phone networks) this assessment is mainly done physically by walking to the area and watching what happened which increases individual mobility. And those journeys can happen next to weakened buildings leading to an increased individual exposure.

In order to analyze individual exposure on the public thoroughfare we thus needed to understand how people travel across the area after the tremor until they are totally out of danger. For that and to carry out our study we took inspiration from the approach proposed by Time Geography which considers individuals and their daily journeys and activities over time and space. Those works and methods have been developed since the 1960's to evaluate the daily mobilities of a population at the scale of a territory, usually an urban area (Chardonnel and Stock 2005; Thevenin *et al*. 2007). So to study and get the best representation of people's journeys in their environment we used the concept of spatio-temporal trajectories developed by Time Geography. This approach provides for a representation of mobility as a succession of places (or positions) and journeys in a finely-defined time and space. It then looks perfectly adapted to analyze people's journeys in crisis time (André-Poyaud *et al*. 2009) and has already been tested for other types of high-speed phenomena : flash floods.

For a dozen years works have been developed to better understand the processes of alert and people's adaptations in an environment altered by a sudden rise of water (Ruin and Lutoff 2004; Ruin 2007; Ruin *et al*. 2008; Creutin *et al*. 2009; Ruin *et al*. 2013; Calianno *et al.* 2013). A specific methodology to collect and analyze data was developed in the framework of those studies. Analyzing several hydrometeorological episodes the study found out that people's mobility and their position on the public thoroughfare were determining factors in populations' exposure (Ruin 2007). In this way the fact that people may, must or want to move during a flood can put individual lives in danger. Is it a similar situation for earthquakes ? We suggest to use the mobility analysis method in a situation of flash floods to implement it to the Lorca seismic event and thus explore the conditions for exposure in a seismic crisis time.

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2.3 Exposure VS Social vulnerability

This focus on the notion of exposure requires some theoretical explanations in the field of the geography of risk.

The literature on the social approach of risks - notedly in geography – largely develops the notion of vulnerability but not the notion of exposure very much. According to Reghezza, « *The approach centred upon vulnerability leaves exposure with a secondary role, notedly because of the difficulties met in characterizing the interaction between the element exposed and the event* » (Reghezza 2006). Our objective was to face these difficulties and enter this analysis of human exposure fluctuations in the time and space of a seismic crisis. We then retained the definition of exposure provided by Leone as a spatial and temporal coincidence between a hazard and an individual (Leone 2007).

So as to meet the objective it was necessary to consider a dynamic rather than a static approach. Yet it comes to analyzing how people get exposed after an earthquake according to their journeys and to the way the quake could alter the built environment. Analyzing exposure then requires a dynamic approach to take both the spatial and the temporal dimensions of people's journeys and of the threat into account (Chardonnel and Stock 2005). In our case the temporal window analyzed corresponded to the time needed by individuals surveyed to evacuate the wrecked city. The spatial dimension is determined by the scope of damage, very concentrated in the urban centre in the Lorca case (Alfaro *et al*. 2011; Tibaduiza *et al*. 2012). This definition of the spatio-temporal window observed drove us to a more accurate definition of the concept of evacuation : evacuating requires to get out of the area hit by the quake and thus to reduce one's exposure in getting away from buildings weakened by the earthquake. Consequently the limit of the time window considered corresponds to the evacuation of the city for each individual observed, which allowed us to temporally define what we consider as a seismic crisis.

Works centred upon the crisis period are not new. Research conducted in the late 80's and early 90's highlighted the importance of addressing seismic crisis periods (Quarantelli 1982; Goltz *et al*. 1992; Bolton 1993). These studies – mainly quantitative – built from significant samples mainly focus on individuals' main actions, on the damage endured and the reasons for evacuation. They bring about statistically valid information helping us understand what the affected individuals mainly did but this information is disconnected from the time and place in which it happened. They then do not allow to analyze a likely difference in exposure

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according to the activities performed that is to say to assess whether those activities lead to increasing or decreasing human exposure or whether they have no influence on exposure.

3 Analysis methodology of dynamic exposure

The spatio-temporal window retained for the analysis included the seismic crisis period as it occurred in the urban city centre of Lorca. We are going to focus on a sample of individuals who were inside the city when the tremor hit Lorca and until they were evacuated. When anybody interviewed gets out of the city we consider that they are no more in a seismic crisis period and the collection of data for these people is then finished.

We present here the method retained to collect data and the processing required to analyze dynamic exposure in the Lorca case.

3.1 Data

Data was collected in two phases. The first mission took place four days after the quake. It allowed to make participating observations, to make contacts and produce graphic material (pictures and movies) in this immediate post-crisis period. The second mission was conducted nine months after the event to make interviews. This interval with the event could let the population get out of the trauma period and leave time for recovery after the event. If they had precise memories of what happened the individuals interviewed could then express themselves with hindsight without the emotional dimension (fear, anxiety) taking over the story of the events.

We carried out 20 interviews among the population using qualitative enquiries that relied on how people reacted during the crisis. These interviews enabled to collect and map all the journeys each interviewee made between the first tremor (May 11. 2011 at 17.05 local time) and the evacuation of the city.

We performed a snowball sampling looking for the widest diversity of spatial situations (despite the limited number of interviewees). Yet a great deal of spatial parameters can influence people's behaviours such as the place of residence, the workplace, the situation when the first or second tremor hit. Considering more classical vulnerability parameters noted in the literature we also attempted to get a diversity of interviewees in terms of age and gender (Cutter *et al*. 2000). Each interview lasted between 1 and 3 hours. In all we interviewed 8 men and 12 women aged 24 to 80, 9 with children to support. In total with these

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people we collected a database gathering 229 activities and 115 journeys during the seismic crisis period.

To collect data we adapted an interview grid created for the analysis of mobility behaviours during flash floods (Ruin *et al.* 2013) . This grid is based on a chronological scale in which time is divided in a succession of places (or positions) and journeys. For each of them we asked several qualitative details which at any time were linked to a precise space and time for each interviewee. We thus collected the addresses, the time schedules, which activities were performed and with who. For the journeys we noted the mode of transport used, how and why the itinerary was adapted (for example a detour to see the state of a property), the abnormal characteristics of the itinerary like traffic jams for example. This grid allows to work with precise time schedules (« I remember calling my son at 20.14 ») or durations by default (« I do not know what time I got there but I usually do this trip in 15 minutes »).

As we filled the grid with the interviewees we drew their itinerary, the places they usually go to and the places where they had experienced the earthquake on a map (Figure 2). Using the map during the interviews allowed people to better remember the details of their journey and to be more precise with time schedules. This also allowed them to better remember the way journeys were modified by the event (for example to avoid streets that were blocked or cut).

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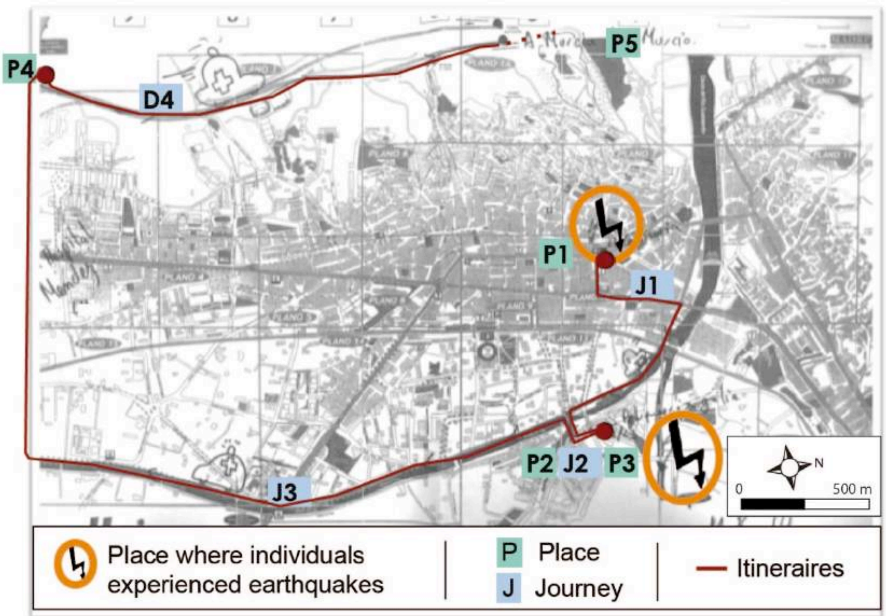

Figure 2 Example of the itinerary map drawn during one of the enquiries. Base map : shopkeepers' book.

3.2 Processing

From the data and maps collected this way two types of processing were applied : a spatial analysis of the journeys and new dangers of the built environment following the earthquake ; a temporal analysis of the succession of people's journeys and their resulting exposure.

3.2.1 Spatial analysis of exposure

From the 20 interviews carried out among the population we performed a digitalization of the journeys. With a view to identifying spatial consistency between the individuals and the hazards – and exposure then – we crossed two layers of information using the Qgis[1] software. We provide details here of those two layers and the related information.

a) Individual journeys

This layer represents all the journeys performed by the 20 interviewees. The digitalization protocol described here was defined to standardize this layer.

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[1] QGis is a free GIS (Geographic Information System) software

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All individuals walk in the same places : we supposed that individuals walking on the same road, in the same square or in the same open space walk exactly in the same place. This simplification offers greater data homogeneity from a spatial point of view.

Evacuation : because damage was very much localized in the Lorca case, when somebody evacuates the itinerary record is precise within the city boundaries but beyond it is simplified by a straight line to the destination place without any exact digitalization of the itinerary outside the city.

Getting into or coming out of a building : for journeys from the inside to the outside of a building we determined that the time it takes to get out is one minute when an individual is located higher than the ground floor. For example if people living on the fourth floor asserted that they went out just after the tremor the itinerary within the building was represented and lasts 60 seconds.

b) Characterizing damaged buildings

The second layer represents the altered environment and the characterized hazards from the buildings weakened by the tremor which may partially or totally collapse in case of an aftershock.

Following the second earthquake several teams of architects, engineers and volunteers were in charge of an emergency evaluation of the state of the buildings in Lorca and the surroundings. The objective of this first evaluation was to estimate the safety and habitability of the buildings and to detect the buildings which were extremely hazardous for the population.

Following each evaluation a coloured mark was applied at the entrance of buildings to indicate hazardousness. A green colour indicated that the residents could come back into the building because it did not suffer significant structural damage. A yellow mark was used for buildings requiring repairs but which could possibly be occupied, the building structure showing no hazard. Buildings in red presented severe structural and non-structural problems and could not be occupied. Finally buildings in black – also called ruined buildings – were considered irrepairable and were the first demolished. Access was then totally forbidden for the public.

In our analysis of individual exposure we retained buildings classified red and ruined, defined as « fragile » by the first evaluation (Figure 3). They were yet the ones that presented an important danger for people approaching them. Information on buildings identified as fragile

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during this first inspection were provided by the *Servicio de Urbanismo de Planeamiento y Gestion de Lorca (SUP)*[2]. Here we did not integrate data regarding emergency improvements to the structures in the days following the earthquake so as to obtain the closest state to the situation experienced by Lorca residents just after the tremor.

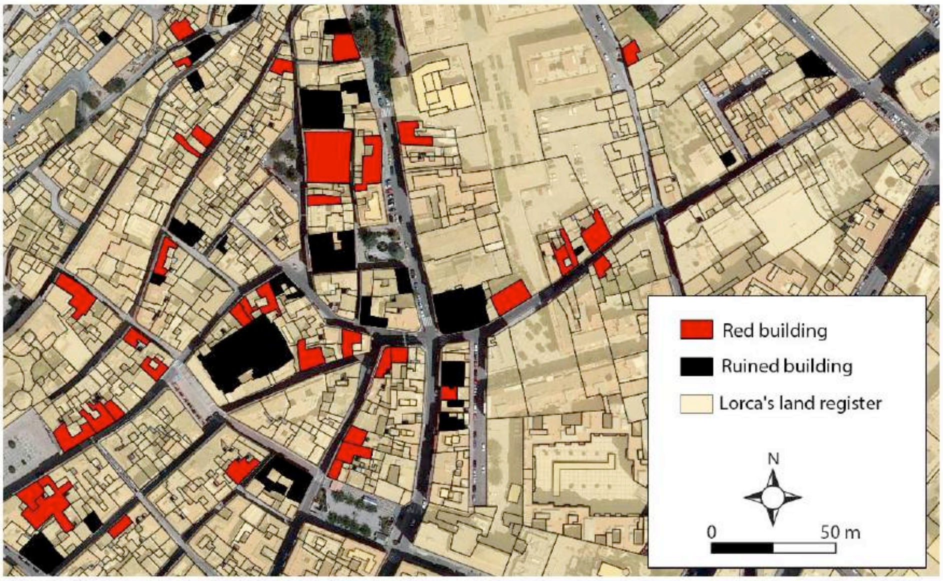

Figure 3 Extract from the maps of buildings classified in red or black (ruined). IGN land register data. Map base : PNOA images *del Instituto Geografico Nacional*. Evaluation of buildings : Source Servicio de Urbanismo de Planeamiento y Gestion. Production : Marc Bertran Rojo 2014.

3.2.2 Temporal analysis of exposure using actograms

The temporal analysis of interviews was based on the use of a specific tool : actograms. The latter are a form of graphic representation that is widely used in medicine or biology. (Thinus-Blanc and Lecas 1985) but also to analyze people's daily activity schedules in the approach of Time Geography (Thévenin *et al*. 2007). Actograms are matrixes into which each individual is represented by a line and each column symbolizes a time step defined according to the subject of the study. Cells indicate with a code and/or a colour the type of activity

[2] Servicio de Urbanismo de Planeamiento y Gestion de Lorca in charge of developing and implementing urban planning tools defined in the general plan for urban territorial planning.

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performed by the individual for each time step. Regarding the thematic issue of risks this tool was already used to analyze mobility in a hydrometeorological crisis period (Ruin *et al.* 2013).

Actograms then show a succession of activities organized from temporal information relating to a single individual. The superposition of actograms from a group of people at the same temporal scale allows vertical reading (per column) and to know the number of individuals performing the same activity (or moving) at the same time. Adding the cells from each column we obtained the number of individuals moving and those not moving for each time step.

In our case the information contained in the actograms had a one-minute time step. We were aware that this choice led to a bias linked to the accuracy of somebody's memory in a state of panic. However given the great number of very short journeys – in the range of one minute – we opted for this fine time step. Working with a time step in the range of 5 minutes would have compelled us to overestimate the duration of very short journeys or to forget them. For example a one-minute journey consisting in getting out of home would have been considered as a 5 minute journey or would have been integrated into the next activity, which in all cases constitutes an important bias.

4 Results

Results are presented in two parts : the first one deals with the exposure areas to consider for the evacuation phase in a post-seism altered environment ; the second focuses on the classification of exposure situations to see how the latter are distributed over time.

4.1 Analysis of exposure areas (methodological proposal)

Here we consider how individual exposure can be increased or decreased by people's journeys next to weakened buildings during the evacuation phase.

4.1.1 Evaluation of the impact area

Human exposure being considered as the spatial and temporal coincidence between an individual and a possible hazard we observed here how this spatio-temporal coincidence occurred for the interviewees in Lorca.

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The exposure situation supposes that the individuals considered are in the vicinity of buildings becoming hazardous following the tremor. But what does this « vicinity » mean ? Which distance can we consider people get exposed to the fall of facade elements on the public thoroughfare ? When they touch the facade ? When they walk one to ten metres away from it ?

To clarify these elements we studied the distances reached by the debris of elements falling off a building or resulting from a complete building collapse after the Lorca seism. In order to calculate this debris area for each building classified fragile we studied the images collected on the internet in the days following the earthquake, photographs (35 pictures) and videos from TV news or private individuals.

The idea was to use these pictures to measure the maximum distance reached by the debris which came off the buildings. This distance is defined as the furthest point from the facade where debris approximately the size of a brick can be observed (110 x 70 x 230 mm). This size was used to set a limit and not take small parts into account for they can result from the fracturing of the debris impacting the ground. The point from which distance was calculated was the facade of the building from which the debris came off. Two examples of how the maximum impact distance was studied are given below.

Each had distinctive features but we tried to collect as many reliable references as possible from which we could deduce the width of the impact area. There was still some uncertainty linked notedly to the different photograph perspectives. We preferred to underestimate impact distances rather than overestimate them to avoid exaggerating situations when results were interpreted.

First example : a cornice (Figure 4**)**

We had five photographs at our disposal for this case (two of them are provided as an example here). A reference point corresponding to the coloured logo of a restaurant present on both photos allowed us to link both pictures (yellow arrow on figure 4). First we identified the brand and model of the car (Hyundai Tiburon) on the first photograph which let us define its total width (1.73 m according to the manufacturer) which was used as a benchmark. Still on the same picture we could notice that the biggest debris were spread on a distance similar to the size of the car on the traffic lane beyond the parked cars. On the second picture we could see that the width of the car was similar to that of the pavement (i.e 1.73 m wide). Adding

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these three distances we could conclude that the maximum impact distance was roughly 5 metres.

Figure 4 An example of the maximum impact distance evaluation. The yellow arrow provides for a common point of reference for the three pictures (restaurant logo). Photographs by : 1 Andrés Ribón, 2 Marc Bertran Rojo.

Second example : Collapsed building (Figure 5**)**

We wanted to calculate the maximum impact distance of a single collapsed building. This case being rather spectacular photographs and movies were largely available. The impact area covered the whole street width. It was then 7 metres wide or even a little more as the building collapsed into the display window of the shop across the street (Figure 5). However we preferred to round the estimation to 7 metres.

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Figure 5 An example of the maximum impact distance evaluation. Photographs by : 1 Marc Bertran Rojo, 2 (Google Street).

We implemented this method to the 9 cases of the buildings for which we could collect sufficient information. This methodology provided us with a rough estimate of the impact area for each precise case. Nevertheless the small number of cases did not allow to create a statistically representative average.

We wondered whether the height of the building could influence the facade elements' impact area. However in the 9 cases observed the relation between the height and the impact area was not confirmed (Rojo 2014). For 3 and 4-floor buildings the most frequent value characterizing the impact area was 6 metres. In the case of Lorca 92% of fragile buildings had less than 4 floors. So it seemed relevant to set a maximum impact area of 6 metres for all buildings regardless of their height.

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4.1.2 Exposure areas and exposure sections

It comes here to comparing the impact areas as they were defined and people's journeys. With this in mind exposure areas were created using a 6-metre buffer area around fragile buildings (red and ruined). The methodology provided hereafter describes the way those areas impact people's journeys and thus increase their exposure.

So as to estimate how much individuals met exposure areas we considered that all the individuals walked in the middle of the public thoroughfare. The primary reason for this choice is that safety instructions recommend to keep away from buildings. The farthest point from the buildings is the very centre of the street. In addition we used videos and photographs made by the population after the tremor to check whether these instructions had been followed during the Lorca seism. The majority of the pictures we could collect on this subject (20 photos and videos) yet confirmed this type of behaviour. This was notedly explained by the fact that after the earthquake the pavements were more or less cluttered with debris of all sizes which naturally forced them to walk away from the buildings.

Among the 115 journeys listed in total 86 were retained to analyze their exposure : journeys made between both tremors (and just before the strongest tremor) were not taken into account. We chose to work only with journeys made after the second tremor because weakened buildings were listed only after the second earthquake. Figure 6 shows the way a journey is made across exposure areas to generate sections of exposure taken into consideration in the following analyses. This operation was performed under the supervision of a GIS using a geoprocessing tool (intersection).

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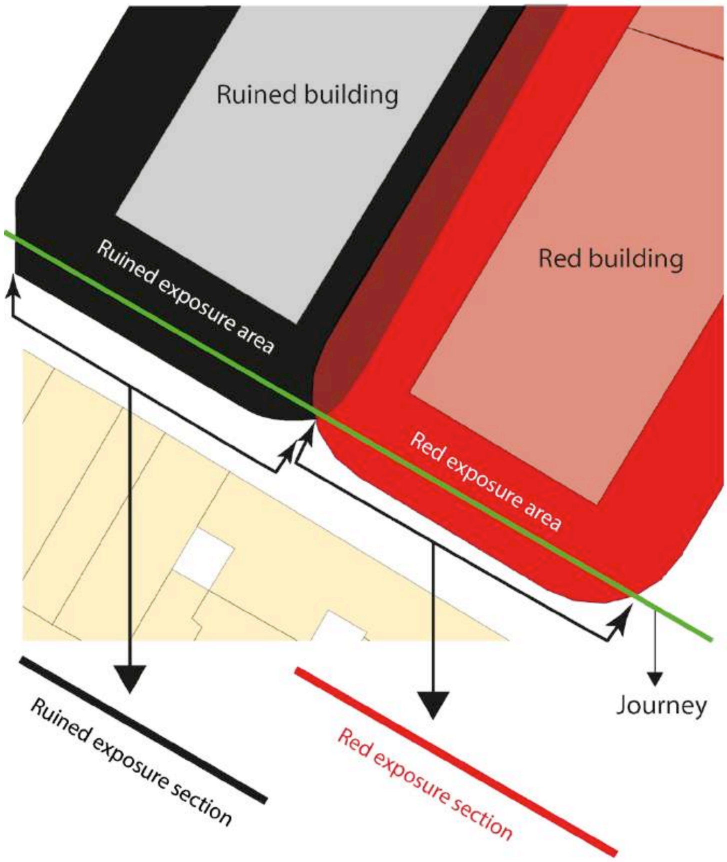

Figure 6 Production of exposure sections from an « intersection » geoprocessing tool between the journeys (lines) and exposure areas around fragile buildings (ruined or red).

Among those 86 journeys 32 were made across « ruined » areas and 39 across red building related areas at least once (it is yet likely that a single journey was made across several exposure areas).

Among the 20 interviewees only 3 of them never travelled across any area of exposure (in blue, Table 1). In most cases journeys were made across several areas of exposure. Regardless of the number of journeys we counted how many times individuals were exposed as an individual can get exposed several times during a single journey. In total we obtained 151 exposure sections among which 49 ruined exposure sections and 102 red exposure sections.

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Then we noticed that 5 people totalled up almost 100 exposure sections and that one of them totalled 29. The dimension of the exposure sections vary according to the facade length. On a total of almost 100 kilometer journeys in the city after the seism journeys within the exposure areas covered 3.6 kilometers (1.1 kilometer in ruined building exposure areas and 2.5 kilometers in red exposure areas).

At this point we could wonder why an individual did not walk next to fragile buildings while others were exposed several times. We wanted to analyze whether there was a correlation between the number of added exposure sections for each individual (column 3) and the total distance walked or the number of journeys (columns 4 and 5). The objective here was to define which was the best exposure indicator. We then relied on Table 1.

Individual (ID)	Exposure sections :			Total distance for each individual (in metres)	Number of journeys for each individual	Distance per journey (in metres)
	red	ruined	red and ruined			
1	17	12	29	4784	8	598
2	17	5	22	5388	4	1347
3	18	1	19	18292	7	2613
4	13	1	14	10808	7	1544
5	6	4	10	2457	8	307
6	2	7	9	9043	9	1005
8	5	3	8	6917	5	1383
7	5	3	8	813	3	271
9	6	1	7	1804	5	361
10	3	3	6	3088	4	772
11	3	3	6	4938	4	1235
12	2	2	4	3019	1	3019
13	2	1	3	3128	8	391
14	0	3	3	149	3	50
15	1	0	1	1031	2	516
17	1	0	1	2087	2	1044
16	1	0	1	405	1	405
19	0	0	0	78	2	39
20	0	0	0	397	2	199
18	0	0	0	4	1	4
TOTAL	102	49	151	78630,0	86	

Table 1 This table summarizes the spatial and temporal convergence between people's mobility after the second tremor and the weakened buildings following the same seism. Lines in blue correspond to individuals who never travelled across any impact area. The last four columns show an increasing colour gradient equal to a distribution per centiles. The highest values are coloured in red and the lowest in green.

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This table is in descending order according to how many times people were exposed to fragile buildings (red and ruined are in this case considered indifferently) so as to highlight the most critical situations. It shows the sections of exposure to buildings classified red, ruined and the addition of both red and ruined (columns 2, 3 and 4). Besides it lists the total distance for all their journeys, the total number of journeys made by each individual and the distance per journey (columns 5, 6 and 7). The colours allow to rapidly see the order of values in each column : the highest values for each column are represented in red and they progressively decrease, they turn to orange, yellow and green for the lowest values.

We can notice that while individuals moving a little do not usually travel across exposure areas, it is less clear that those who move the most are the most exposed. The number of journeys done does not look determining as regards human exposure after a seism. For example individual 2 made only 4 journeys but the second individual is the most exposed while individual 13 made twice more journeys but his/her combined exposure is largely less. Distance neither looks to be an explanatory variable of human exposure. We can for example notice that the individual who travelled a maximum distance (ID 3) was 10 times less exposed that the one who travelled less than a third of this distance (ID 1). On the contrary we can notice that some people were greatly exposed without travelling long distances (individuals 7 and 9 for example). This analysis shakes up the general idea according to which the more journeys or the bigger distance, the greater exposure. Considering exposure after a seism other factors ought to be considered.

Conditioned by the small sample we did not further extend the analysis of how influential is the location of buildings that generate the greatest exposure. However we noticed that among the 20 individuals a lot of them travelled on the same streets, either because they are wide or because they lead to open spaces in the city, or even because they are the city's exit roads. We can see that some fragile buildings on these roads generated a great number of exposure sections.

These results require validation with a bigger sample. Furthermore a deep analysis of activities and journey motivations in a seismic crisis period must be carried out to understand the complexity of factors taking part into the generation of human exposure.

4.2 Space classification according to induced exposure

As a supplement to the previous results the approach proposed here aims at defining the categories of situations that correspond to a specific exposure so as to better understand how

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individual exposure changes over time and space. These situation categories are not associated with precise places but rather to some features of those places, notedly hazard sources. In this way we sought to model the temporal evolution of human exposure in an indirect way by observing people's locations in those specific situations. With this aim in mind we considered the four following situation categories : inside the buildings, on the public thoroughfare, in open spaces and outside hazardous areas (outside Lorca). These spatial categories let us translate the hazards individuals get exposed to after a tremor.

4.2.1 Definition of the types of exposure situations

We depict here the four situation categories considered. The aim of this section is to get an overview of the events' sequences through the behaviours of the interviewees' sample and to identify the collective reactions leading to a fluctuation in human exposure.

Inside

People are inside the buildings whatever their type (houses, blocks, etc.) or the associated social functions (homeplace, workplace, at friends' or others). When an individual falls within this « inside » category an aftershock can generate a partial or total building collapse and directly affect the individual. As we already mentioned in the case of Lorca only one building collapsed during the seism without any casualties inside it.

Public thoroughfare

The public thoroughfare corresponds to the exteriors of buildings. This space is almost exclusively used to travel but it can become a meeting place for individuals.

Considering that most people wounded and all people killed were located on the public thoroughfare we can associate this space with the highest exposure in the case of Lorca.

Open spaces

These spaces are found inside the city but unlike the previous ones it is very difficult or even impossible that the population gathering here be put at risk by a building or debris.

The nature of these places may vary a lot : squares, gardens or wastelands for example. In these places exposure can be considered as almost nil. In some cases however in order to go to or leave those places people need to travel across hazardous areas (public thoroughfare) and walk next to fragile buildings likely to become a threat in case of aftershocks. In addition those places have limited capacity : the greater the number of people, the less secure places

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they are. Some people standing on the sides of those places will be more exposed for they will be directly near the surrounding buildings. Finally in some cases (as for example parvis as on the Square of España in Lorca) one of the sides of the square is built up with very high and fragile religious buildings (Martínez 2012). Exposure there is then not nil.

Outside hazardous areas

With the help of PNOA's aerial orthoimages and the land register we defined a polygon around the city. Anybody walking beyond this limit was outside Lorca and out of danger wherever they were : inside a house, on the public thoroughfare or in an open space. This category is yet characterized by a total decrease of human exposure because the seism had a very limited spatial impact.

4.2.2 Fluctuation of exposure over time

The graph in Figure 7 shows the location of 20 interviewees according to their situation of exposure as the crisis developed. Each line of the graph corresponds to the number of individuals present in each space category counted using the actograms. The sum of all individuals present in each space always equals 20. The red arrows indicate the time of the first and second earthquakes as well as a magnitude Mw 3.9 aftershock. Looking at the « low » curve (in yellow) we can notice an important number of short journeys largely corresponding to the journeys made immediately after the seism. These journeys allowed people to get out of the buildings after the tremor. On the same curve we can notice several situations reported in the interviews. A few minutes after the first tremor some individuals went back inside their home because they thought they were out of danger. This phase is well-known to psychologists and identified as a denial phase which in some cases affects the perception of external reality. These unconscious mechanisms help some people put a rather shocking situation into perspective allowing them to better control their fears or anxieties (Páez *et al*. 1995). Other individuals went out of the buildings because there was a rumour of an aftershock or to watch the damage done by the first seism or even to exchange on the event with people on the street.

The second tremor made people who had remained inside the buildings get out immediately when this was possible or a few minutes later when they had people to look after (elderly people notedly) or if they were panic-stricken. This phenomenon is clearly visible on the graph with a substantial decrease in the number of people present inside a building.

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We then can observe the behaviour consisting in gathering family members to plan for evacuation. Sometimes this gathering can increase the exposure for one or several family members. This phenomenon can be observed by looking at the curve corresponding to the « inside » situation after the main seism. Yet the people who went back into the buildings after the earthquakes did it to help their close families and friends evacuate. Within one minute after the main seism a majority of people were on the public thoroughfare where the deadly accidents and serious injuries occurred (13 in 20 people). Very rapidly (a few minutes on average) we can notice an increase in the number of people present in these open spaces and so *a priori* protected from the potential fall of building elements.

Until the city was completely evacuated some individuals went back again into the buildings after the second tremor. However this action was immediately followed by a complete evacuation of the city. It was not an action to protect close families and friends but a last effort to organize oneself before evacuation : looking for the keys of the car or of the second home for example.

Evacuation mainly started almost two hours after the main seism ; then the number of evacuated individuals increased regularly until 7 hours after the tremor.

We can notice with this figure that the individuals did not feel the need to go to an open space after the first seism and preferred to stay on the public thoroughfare. On the contrary, following the main seism most of the witnesses decided to rapidly reach open spaces rather than stay on the public thoroughfare. This difference in behaviour seems to be directly linked to the intensity of the seisms.

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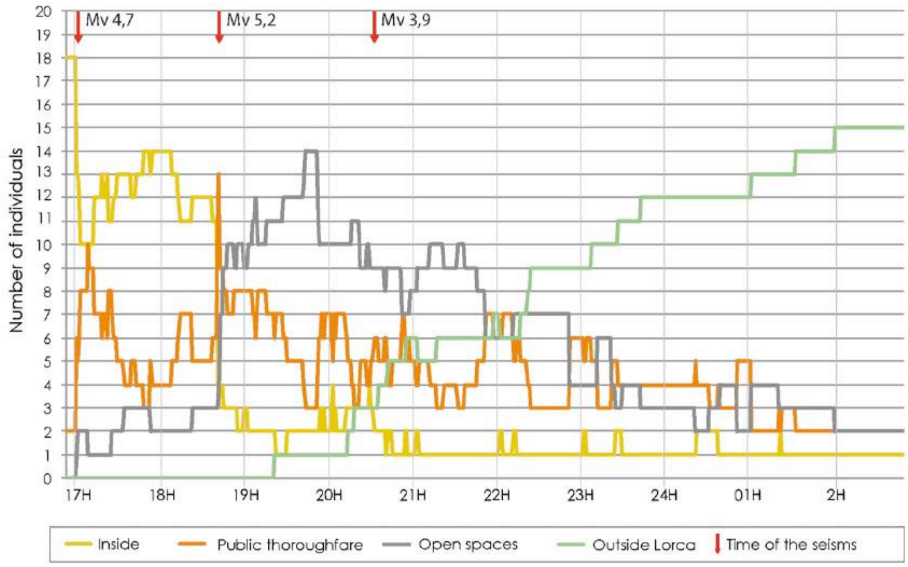

Figure 7 Evolution of the location of individuals in various categories of spaces during the seismic crisis (inside, public thoroughfare, open spaces and outside Lorca).

From this analysis completed by the interviews we propose in Figure 8 a mobility model during a seismic crisis period. This model allows to understand that the evacuation of the city is the outcome of a complex series of journeys more or less subjected to exposure. It compares individuals' locations and their mobility over time as well as their specific exposure. This exposure is assessed starting from the case of Lorca. Time on the abscissa is specific to each individual which means that the time it takes to travel from the inside to the outside of the city varies according to individual constraints. The model also represents two types of journeys according to the objectives pursued by individuals : on one side the journeys corresponding to protection (black arrows) and on the other side those linked to evacuation (blue arrows). As long as individuals stay inside the buildings, on the public thoroughfare or even in open spaces in some cases they remain exposed. Their exposure only decreases when they are outside the city. In the case of Lorca we can say that the public thoroughfare is a more exposed place than inside the buildings.

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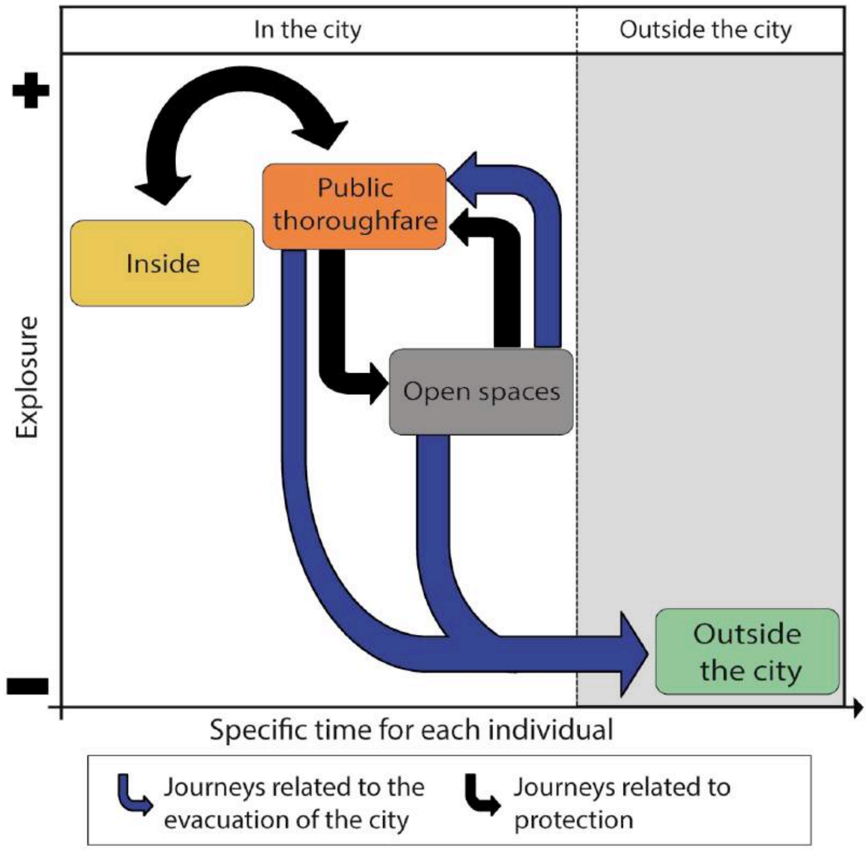

Figure 8 According to Géorisque (Rojo *et al*. 2013), a conceptual model of mobility in connection with exposure in a seismic crisis period. A model built from the analysis of the seismic event on May 11. 2011 in Lorca, Spain.

5 Limits and perspectives

It is difficult to collect significant samples on the type of subjects that we sought to study here with a sufficient level of detail to address our initial questions. Identifying witnesses several months after the event was not easy. Yet 9 months after the seism the reconstruction of the city had not started. The first building rebuilt was inaugurated on July 3. 2013, i.e more than two years after the earthquake. A big percentage of Lorca's population was still living outside the city. Besides, though the emotional dimension was lessened over time it was still present and sometimes interfered with the interviews.

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Nevertheless the analyses carried out from the 20 interviews could provide substantial information on the journeys and time schedules of these journeys and offer the opportunity to carry out analyses going beyond the sole analysis of interviews. Likewise the method retained allows to project all the accounts on the same spatial and temporal scale and thus to compare them.

In this way the Lorca seism highlights that the outside of the buildings is also a high exposure space and the facade elements can be at the origin of substantial hazards. In terms of safety recommendations in countries of low seismicity where the risk of building collapse remains limited it would be necessary to emphasize the behaviours that need to be adopted during and after a seism. Yet for the time-being information leaflets stop when an individual is in an open space. But the analysis of Lorca shows that the population should not only be informed on the reaction when the earthquake occurs but also on the best decisions to allow an evacuation of the city reducing potential individual exposure to a minimum. In this way limiting journeys in the city, prioritizing large avenues instead of the shortest routes, knowing in advance which exit roads are best adapted to each person and home could be interesting instructions to integrate.

As regards paraseismic building standards we can see that they are modified according to events (Aribert 2002) and zoning maps for seismic risks integrate a bigger section of the territory in each review (Frechet 1978; Martin *et al.* 2002; SISMORESISTENTS 2003). Ever stronger seisms are expected and in a greater number of regions. This analysis is equally confirmed in France, Italy or Spain. Considering the Lorca case we can say that the Spanish paraseismic standards were implemented because only one building collapsed. The typical building techniques used in Spain such as concrete cornices at the top of buildings are however elements that proved very fragile and hazardous. When those elements are stronger than the main structure itself the building response to the earthquake is conditioned by those elements. Several examples have become topics among technicians and architects and the substantial number of reports published provide further evidence (Alfaro *et al*. 2011; Diez and Sanz Larrea 2011; Martínez 2012; Tibaduiza *et al*. 2012). We showed that even if the victims were hit at the time of tremors several factors were converging to increase the number of casualties. Yet stronger aftershocks would have certainly made a greater number of unbalanced facade elements fall, possibly wounding pedestrians on the public thoroughfare. So we think the priority is to make populations exposed to earthquakes aware of the hazards

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that threaten them also during the evacuation phase. It is also important to better integrate instructions into the paraseismic standards that could make non-structural elements more secure.

This work is moreover a methodological proposal for the dynamic analysis of human exposure during moderate seisms that can be notedly observed in a Euro-Mediterranean context. Imported and adapted from a methodology initially created for another risk (flash floods) the approach shows that methodologies can be transferred from a hazard to another. This possibility is highly interesting in the case of seisms which remain less frequent in Europe than floods. This work of adaptation (from flash floods to seisms) is likely to be implemented to other seismic events. The results obtained could be comparable with those presented here for the Lorca case.

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Bibliography

Alexander, D. E. 2011. "Mortality and Morbidity Risk in the L'Aquila, Italy Earthquake of 6 April 2009 and Lessons to Be Learned." In *Human Casualties in Earthquakes*, edited by R. Spence, E. So, and C. Scawthorn, 185–97. Advances in Natural and Technological Hazards Research 29. Springer Netherlands. http://link.springer.com/chapter/10.1007/978-90-481-9455-1_13.

Alfaro, P., M. González, D. Brusi, J. A. López Martín, J. J. Martínez-Díaz, J. García Mayordomo, B. Benito, et al. 2011. "Lecciones Aprendidas Del Terremoto de Lorca de 2011." *Enseñanza de Las Ciencias de La Tierra* 19 (3): 245–60.

André-Poyaud, I., F. Bahoken, S. Chardonnel, L. L. Charleux, S. Depeau, F. Dureau, M. Giroud, C. Imbert, E. Quesseveur, and K.K. Tabaka. 2009. "Représentations Graphiques et Indicateurs Des Mobilités et Des Dynamiques de Peuplement : Contribution Bibliographique," October. http://halshs.archives-ouvertes.fr/halshs-00470407.

Aribert, J.-M. 2002. "Notions spécifiques pour un code de dimensionnement parasismique des constructions mixtes acier-béton." *Construction métallique* 39 (3): 5–17.

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-115, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 10 May 2016
© Author(s) 2016. CC-BY 3.0 License.

Armenian, H. K., A. Melkonian, E. K. Noji, and A. P. Hovanesian. 1997. "Deaths and Injuries due to the Earthquake in Armenia: A Cohort Approach." *International Journal of Epidemiology* 26 (4): 806–13.

Bechtoula, H., and H. Ousalem. 2005. "The 21 May 2003 Zemmouri (Algeria) Earthquake: Damages and Disaster Responses." *Journal of Advanced Concrete Technology* 3 (1): 161–74. doi:10.3151/jact.3.161.

Bolton, P. A. 1993. *The Loma Prieta, California, Earthquake of October 17, 1989: Public Response*. US Government Printing Office.

Calianno, M., I. Ruin, and J. J. Gourley. 2013. "Supplementing Flash Flood Reports with Impact Classifications." *Journal of Hydrology* 477 (January): 1–16. doi:10.1016/j.jhydrol.2012.09.036.

Camelbeek, T., A.M. Barszez, and A. Plumier. 2006. "Le Risque Sismique et Sa Prévention En Région Wallonne." http://orbi.ulg.ac.be/handle/2268/18333.

Celep, Z., A. Erken, B. Taskin, and A. Ilki. 2011. "Failures of Masonry and Concrete Buildings during the March 8, 2010 Kovancılar and Palu (Elazığ) Earthquakes in Turkey." *Engineering Failure Analysis* 18 (January): 868–89. doi:10.1016/j.engfailanal.2010.11.001.

Chardonnel, S., and M. Stock. 2005. "Time-Geography." *Echelles et Temporalités*, 89–95.

Chou, Y-J., N. Huang, C-H. Lee, S-L. Tsai, L-S. Chen, and H-J. Chang. 2004. "Who Is at Risk of Death in an Earthquake?" *American Journal of Epidemiology* 160 (7): 688–95. doi:10.1093/aje/kwh270.

Coburm, A. W., R. J. S. Spence, and A. Pomonis. 1992. "Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse." In *Proceedings of the Tenth World Conference on Earthquake Engineering*, 10:5989–94. http://books.google.fr/books?hl=fr&lr=&id=uHtDvBvWGREC&oi=fnd&pg=PA5989&dq=factors+determining+human+casualty&ots=KxZ3Dq2VfR&sig=t0-JDpnKHk-e3l_bOH8TPHaq4-c.

Creutin, J.D., M. Borga, C. Lutoff, A. Scolobig, I. Ruin, and L. Créton-Cazanave. 2009. "Catchment Dynamics and Social Response during Flash Floods: The Potential of Radar Rainfall Monitoring for Warning Procedures." *Meteorological Applications* 16 (1): 115–25.

Cutter, S.L., J.T. Mitchell, and M.S. Scott. 2000. "Revealing the Vulnerability of People and

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-115, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 10 May 2016
© Author(s) 2016. CC-BY 3.0 License.

Places: A Case Study of Georgetown County, South Carolina." *Annals of the Association of American Geographers* 90 (4): 713–37.

Dhakal, R. P. 2010. "DAMAGE TO NON-STRUCTURAL COMPONENTS AND CONTENTS IN 2010 DARFIELD EARTHQUAKE." *Bulletin of the New Zealand Society for Earthquake Engineering* 43 (4). http://www.nzsee.org.nz/db/Bulletin/Archive/43(4)0404.pdf.

Díaz, J. J. J. 2012. "Lorca: el terremoto del 11 de mayo de 2011." *Enseñanza de las Ciencias de la Tierra* 19 (3): 362–64.

Diez, A.A., and C. Sanz Larrea. 2011. "Why Was It so Damaging?" In *2011 International Conference on Multimedia Technology (ICMT)*, 6670–79. doi:10.1109/ICMT.2011.6002759.

Doğangün, A. 2004. "Performance of Reinforced Concrete Buildings during the May 1, 2003 Bingöl Earthquake in Turkey." *Engineering Structures* 26 (January): 841–56. doi:10.1016/j.engstruct.2004.02.005.

Ellidokuz, H., R. Ucku, U.Y. Aydin, and E. Ellidokuz. 2005. "Risk Factors for Death and Injuries in Earthquake: Cross-Sectional Study from Afyon, Turkey." *Croatian Medical Journal* 46 (4): 613–18.

Frechet, J. 1978. "Sismicité Du Sud-Est de La France et Une Nouvelle Méthode de Zonage Sismique." Université Scientifique et Médicale de Grenoble. http://tel.archives-ouvertes.fr/tel-00635869.

Galindo-Zaldívar, J., A. Chalouan, O. Azzouz, C. Sanz de Galdeano, F. Anahnah, L. Ameza, P. Ruano, et al. 2009. "Are the Seismological and Geological Observations of the Al Hoceima (Morocco, Rif) 2004 Earthquake (M=6.3) Contradictory?" *Tectonophysics* 475 (January): 59–67. doi:10.1016/j.tecto.2008.11.018.

Goltz, J.D., L. A. Russell, and L.B. Bourque. 1992. "Initial Behavioral Response to a Rapid Onset Disaster: A Case Study of the October 1, 1987, Whittier Narrows Earthquake." *International Journal of Mass Emergencies and Disasters* 10 (1): 43–69.

Guardiola-Víllora, A., and L. Basset-Salom. 2015. "Escenarios de Riesgo Sísmico Del Distrito Del Eixample de La Ciudad de Valencia." *Revista Internacional de Métodos Numéricos Para Cálculo Y Diseño En Ingeniería*. Accessed March 4. doi:10.1016/j.rimni.2014.01.002.

Leone, F. 2007. "Caractérisation Des Vulnérabilités Aux Catastrophes â€™ Naturelles â€™ :

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-115, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 10 May 2016
© Author(s) 2016. CC-BY 3.0 License.

Contribution À Une Évaluation Géographique Multirisque (mouvements de Terrain, Séismes, Tsunamis, Éruptions Volcaniques, Cyclones).” Université Paul Valéry - Montpellier III. http://tel.archives-ouvertes.fr/tel-00276636.

Martin, CH., PH. Combes, R. Secanell, G. Lignon, D. Carbon, A. Fioravanti, and B. Grellet. 2002. “Révision Du Zonage Sismique de La France. Etude Probabiliste.” *Rapport GEOTER GTR/MATE/0701* 150.

Martínez, J.D.H. 2012. “Efectos Del Terremoto de Lorca Del 11 de Mayo de 2011 Sobre El Patrimonio Religioso. Análisis de Emergencia Ys Enseñanzas Futuras.” *BOLETÍN GEOLÓGICO Y MINERO* 123 (4): 515–36.

Martínez Moreno, F., A. Salazar Ortuño, J. Martínez Díaz, J. A. López Martín, R. Terrer Miras, and A. Hernández Sapena. 2012. “EsLorca: Una Iniciativa Para La Educación Y Concienciación Sobre El Riesgo Sísmico.” *BOLETÍN GEOLÓGICO Y MINERO* 123 (4): 575–88.

Milani, G. 2013. “Lesson Learned after the Emilia-Romagna, Italy, 20–29 May 2012 Earthquakes: A Limit Analysis Insight on Three Masonry Churches.” *Engineering Failure Analysis* 34: 761–78. doi:10.1016/j.engfailanal.2013.01.001.

Moreno González, R., and J. M. Bairán García. 2012. “Evaluación Sísmica de Los Edificios de Mampostería Típicos de Barcelona Aplicando La Metodología Risk-UE.” *Revista Internacional de Métodos Numéricos Para Cálculo Y Diseño En Ingeniería* 28 (3): 161–69. doi:10.1016/j.rimni.2012.03.007.

Oterino, B. B., A. R. Medina, J. M. G. Escribano, and Patrick Murphy. 2012. “El terremoto de Lorca (2011) en el contexto de la peligrosidad y el riesgo sísmico en Murcia.” *Física de la Tierra* 24 (0): 255–87. doi:10.5209/rev_FITE.2012.v24.40141.

Páez, D., E. Arroyo, and I. Fernández. 1995. “Catástrofes, Situaciones de Riesgo Y Factores Psicosociales.” *Mapfre Y Seguridad* 57: 43–45.

Quarantelli, E. .L. 1982. “Sheltering and Housing after Major Community Disasters: Case Studies and General Observations.”

Ramirez, M., and C. Peek-Asa. 2005. “Epidemiology of Traumatic Injuries from Earthquakes.” *Epidemiologic Reviews* 27 (1): 47–55. doi:10.1093/epirev/mxi005.

Reghezza, M. 2006. “Réflexions Autour de La Vulnérabilité Métropolitaine: La Métropole

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-115, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 10 May 2016
© Author(s) 2016. CC-BY 3.0 License.
Natural Hazards and Earth System Sciences
Open Access
Discussions

Parisienne Face Au Risque de Crue Centennale.” Thèse de doctorat en géographie de l’université Paris X, soutenue le 5 décembre.

Rodríguez, L.C., E.C. Herrero, A.I. Álvarez, J.M.M. Solares, R.C. Villar, J. J.M. Díaz, B. Benito, et al. 2011. “Informe del sismo de Lorca del 11 de mayo de 2011.” Informe Técnico. July. http://digital.csic.es/handle/10261/62381.

Rojo, M.B. 2014. “Correr entre los escombros - Courir entre les débris La mobilité individuelle en période de crise sismique: facteur d’exposition humaine dans le cas du séisme de Lorca (Espagne 2011).” Grenoble: Université Joseph-Fourier-Grenoble I. Correr entre los escombros - Courir entre les débris La mobilité individuelle en période de crise sismique: facteur d’exposition humaine dans le cas du séisme de Lorca (Espagne 2011).

Rojo, M.B., E. Beck, C. Lutoff, and P. Schoeneisch. 2013. “Exposition sociale face aux séismes : la mobilité en question. Le cas de Lorca (Espagne) – Mai 2011.” *PLUM*, Georrisque, .

Ruin, I. 2007. “Conduite À Contre-Courant. Les Pratiques de Mobilité Dans Le Gard: Facteur de Vulnérabilité Aux Crues Rapides.”

Ruin, I., J. D Creutin, S. Anquetin, and C. Lutoff. 2008. “Human Exposure to Flash Floods-Relation between Flood Parameters and Human Vulnerability during a Storm of September 2002 in Southern France.” *Journal of Hydrology* 361 (1-2): 199–213.

Ruin, I., and C. Lutoff. 2004. “Vulnérabilité Face Aux Crues Rapides et Mobilités Des Populations En Temps de Crise.” *La Houille Blanche*, no. 6: 114–19.

Ruin, I., C. Lutoff, B. Boudevillain, J.D. Creutin, S. Anquetin, M.B. Rojo, L. Boissier, et al. 2013. “Social and Hydrological Responses to Extreme Precipitations: An Interdisciplinary Strategy for Post-Flood Investigation.” *Weather, Climate, and Society*, September, 130903161559003. doi:10.1175/WCAS-D-13-00009.1.

SISMORESISTENTS, COMISSIÓ PERMANENT DE NORMES. 2003. *Norma de Construcción Sismorresistente: Parte General Y Edificación. NCSE-02*. Edicions Multinormas.

Solares, J. M. M. 2012. “Sismicidad pre-instrumental. Los grandes terremotos históricos en España.” *Enseñanza de las Ciencias de la Tierra* 19 (3): 296–304.

Tapan, M., M. Comert, C. Demir, Y. Sayan, K. Orakcal, and A. Ilki. 2013. “Failures of

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-115, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
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Structures during the October 23, 2011 Tabanlı (Van) and November 9, 2011 Edremit (Van) Earthquakes in Turkey." *Engineering Failure Analysis* 34: 606–28. doi:10.1016/j.engfailanal.2013.02.013.

Thévenin, T., S. Chardonnel, and É Cochey. 2007. "Explorer Les Temporalités Urbaines de L'agglomération de Dijon."

Thevenin, T., S. Chardonnel, and E. Cochey. 2007. "Explorer Les Temporalités Urbaines de L'agglomération de Dijon. Une Analyse de l'Enquête-Ménage-Déplacement Par Les Programmes D'activités." *Espace Populations Sociétés. Space Populations Societies*, no. 2007/2-3: 179–90.

Thinus-Blanc, C., and J. C. Lecas. 1985. "Effects of Collicular Lesions in the Hamster during Visual Discrimination. An Analysis from Computer-Video Actograms." *The Quarterly Journal of Experimental Psychology Section B* 37 (3): 213–33. doi:10.1080/14640748508402097.

Tibaduiza, M. L. C., N. L. Zarzosa, J. Irizarry, J. A. Valcarcel, A. H. Barbat, and X. G. Suriñach. 2012. "Comportamiento Sísmico de los Edificios de Lorca." *Física de la Tierra* 24 (0): 289–314. doi:10.5209/rev_FITE.2012.v24.40142.

Vallée, M., and F. Di Luccio. 2005. "Source Analysis of the 2002 Molise, Southern Italy, Twin Earthquakes (10/31 and 11/01)." *Geophysical Research Letters* 32 (12): L12309. doi:10.1029/2005GL022687.

Weiss, K., F. Girandola, and L. Colbeau-Justin. 2011. "Les Comportements de Protection Face Au Risque Naturel : De La Résistance À L'engagement." *Pratiques Psychologiques*, Psychologie sociale appliquee a l'environnement, 17 (3): 251–62. doi:10.1016/j.prps.2010.02.002.