Environmental Modelling & Software 63 (2015) 156–169

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Loss estimation for landslides in mountain areas – An integrated toolbox for vulnerability assessment and damage documentation

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ARTICLE INFO

Article history:
Received 19 February 2014
Received in revised form
25 September 2014
Accepted 6 October 2014
Available online 30 October 2014

Keywords:
Loss estimation
Vulnerability
Damage assessment
Landslides
Documentation

ABSTRACT

Global environmental change includes changes in a wide range of global scale phenomena, which are expected to affect a number of physical processes, as well as the vulnerability of the communities that will experience their impact. Decision-makers are in need of tools that will enable them to assess the loss of such processes under different future scenarios and to design risk reduction strategies. In this paper, a tool is presented that can be used by a range of end-users (e.g. local authorities, decision makers, etc.) for the assessment of the monetary loss from future landslide events, with a particular focus on torrential processes. The toolbox includes three functions: a) enhancement of the post-event damage data collection process, b) assessment of monetary loss of future events and c) continuous updating and improvement of an existing vulnerability curve by adding data of recent events. All functions of the tool are demonstrated through examples of its application.

1. Introduction

Disaster costs are increasing globally. According to the European Environment Agency (EEA), as far as weather and climate related events are concerned, only in Europe and despite all the counter measures which have been taken, the overall damages have increased from EUR 9 billion in the 1980s, to more than EUR 13 billion in the 2000s (EEA, 2012). This is primarily due to increases in population, economic wealth and human activities in hazard-prone areas, as well as better reporting (EEA, 2012; Keiler, 2013). According to the Intergovernmental Panel on Climate Change (IPCC, 2012), the nature and the severity of the consequences following the occurrence of climate extremes or other hazardous phenomena depends not only on the process itself but also on the exposure and vulnerability of the elements at risk (Fig. 1). Climate change is responsible for changes in the frequency and magnitude of natural processes (Keiler et al., 2010), or actually, for changes in the inputs and the effect of processes (e.g. rainfall as an input to the process of flooding) and partially also for the occurrence locality, however, socio-economic changes also result in alterations of the spatial and temporal pattern of exposure (Fuchs et al., 2005, 2013) and vulnerability (Fuchs et al., 2012a; Keiler et al., 2012). Therefore, strategies for risk reduction should not only focus on hazardous process and structural protection works, but also, on reducing the exposure and vulnerability of the exposed system. Consequently, appropriate tools are needed so that scientists, authorities and other stakeholders may assess the possible loss under different future scenarios (Papathoma-Köhle et al., 2011). According to IPCC (2012), vulnerability is a key factor in disaster losses; however, it is not yet well accounted for, since data on disasters at the local level are limited (Totschnig and Fuchs, 2013) and thus, improvements in local vulnerability reduction are constrained.

There have been numerous debates regarding the definition of "vulnerability", since the specific term is used in various ways by scientists of different scientific backgrounds such as natural scientists, engineers, social scientists and climate change researchers (Glade (2003), Füssel (2007), Fuchs (2009), Hufschmidt and Glade (2010), Birkmann et al. (2013), Ciurean et al. (2013)). In natural science and as far as physical vulnerability is concerned, the most common definition of vulnerability is the one that was introduced by UNDRO (United Nations Disaster Relief Organisation) in 1984: "the degree of loss to a given element, or set of elements, within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1

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http://dx.doi.org/10.1016/j.envsoft.2014.10.003
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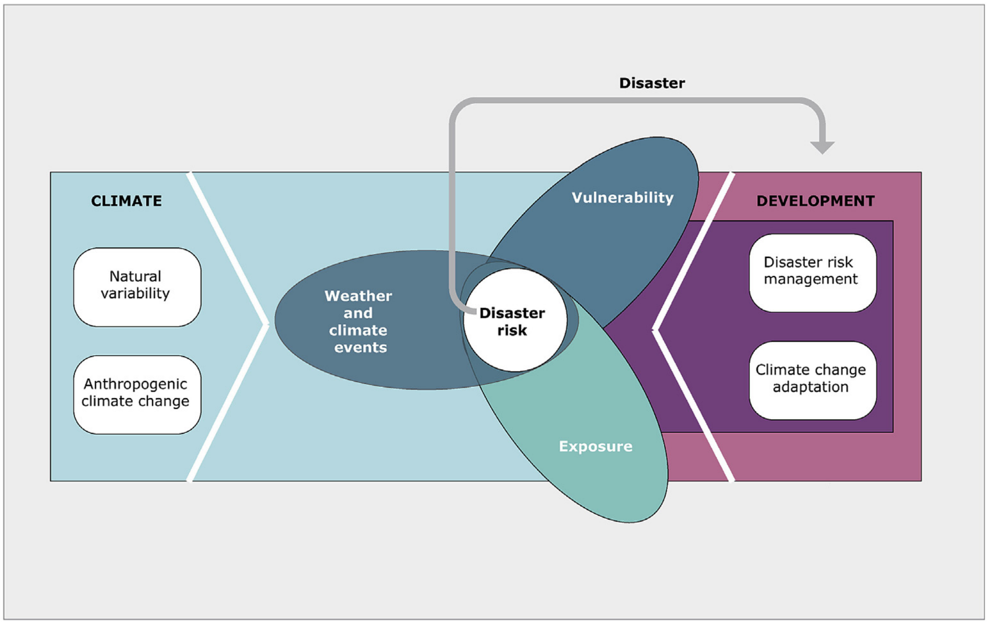

Fig. 1. Key concepts of disaster risk management and their interaction (modified from IPCC, 2012).

(total loss)". There is no universal method for assessing vulnerability (Fuchs et al., 2011); nevertheless, there are three dominant methods for assessing and assign values to it: vulnerability matrices (Papathoma-Köhle et al., 2012b), vulnerability indicators (Birkmann et al., 2013) and vulnerability curves (Fuchs et al., 2007a; Totschnig et al., 2011).

The use of vulnerability curves is common in the case of hazards that affect larger areas and a considerable number of buildings (e.g. floods and earthquakes, Apel et al., 2009). In these cases, the intensity of the process (water depth and ground acceleration respectively) can be assessed relatively easy for each building. Moreover, the reliability of the curve is high due to a rather high amount of available data. It is worth mentioning though, that a comparison of parametric (using indicators) and physically based modelling techniques (using curves) regarding flood vulnerability assessment showed that the parametric approaches are the most appropriate (Balica et al., 2013). Nevertheless, the authors of the specific comparative study indicated also the drawbacks of the parametric methods, such as high data requirements and high levels of uncertainty (Balica et al., 2013). On the other hand, for some types of hazards, such as rock falls or debris flows, the deduction of vulnerability curves is difficult due to the limited number of available damage data (Uzielli et al., 2008), the challenge in assessing the intensity of the process on individual buildings (Mazzorana and Fuchs, 2010) and the gaps in understanding the interaction between the process and the affected elements.

As far as debris flow and fluvial sediment transport (as one large group of landslides) are concerned, the main disadvantage of the vulnerability curves is the lack of reliable empirical data regarding building loss (Fuchs et al., 2012b; Papathoma-Köhle et al., 2012a, b). Although recently an increasing amount of studies focussing on vulnerability curves for this type of hazard can be found in the literature (see Fuchs et al., 2007a; Totschnig et al., 2011; Papathoma-Köhle et al., 2011 for an overview), these curves are mostly based on a limited amount of data related to building damages since such damages are rarely documented in detail (per building) or the information is not available due to e.g. data protection legislation. A second disadvantage is that, in order to develop a curve, information on the intensity of the process on a detailed scale (intensity per building) is necessary. However, this information is challenging to be recorded and expressed since the intensity of a process depends on more than one factor (Keiler, 2011). For example, in the case of debris flow, the intensity is often expressed as the debris deposition height, although more factors, such as velocity, viscosity, pressure, direction and duration of impact might influence the overall intensity of the process (Jakob et al., 2012). Additionally, the process behaviour may change as it progresses over time and in space. Due to the temporal and spatial variability of sediment concentration during individual events the dominant process in the central part of the deposition zone is regularly used to define the entire event characteristics (Hungr et al., 2001). Moreover, the buildings that are considered for the development of a vulnerability curve should have similar characteristics. These characteristics, however, will not be fully considered in their assessment of vulnerability (Holub et al., 2012). This means that the computation of the curve provides us with information regarding the potential loss rather than information on how this loss can be reduced. Another important issue is the transferability of the method. Vulnerability curves developed for European mountain regions may be applied to other parts of the world only if the type of housing is similar to the one that was used for the development of the original curve (Fuchs et al., 2012c; Lo et al., 2012). In any other case, a new vulnerability curve has to be developed. Moreover, existing curves are based on reported (often tangible) damage and not comprehensively on a broader damage definition (e.g., with respect to tangible and intangible losses). It is, however, almost impossible to validate them (Meyer et al., 2013). For this reason, it is clear that there is a need for better detailed reporting of damages at local scale. Finally, vulnerability curves – if derived empirically – have to be regularly updated with data on losses from recent events, and to be consequently adjusted to the increased basic population. In order to achieve this goal, hence, there is an urge for automatisation in the field of damage recording.

On the other hand, the advantage of the vulnerability curves, and the main reason why they are so popular among practitioners, is that they offer a quantitative rather than a qualitative result. By using vulnerability curves the potential economic loss may be expressed as an approximate value in relationship to the expected hazard intensity for each element at risk (Kienholz et al., 2004). For this reason, vulnerability values may describe the susceptibility of elements at risk facing different natural processes with different spatial and temporal distributions of process intensities (e.g., flow depths, accumulation heights, flow velocities and pressures). Practitioners can use the results of vulnerability curves not only to assess the financial costs of future events under different scenarios, but also for cost benefit analysis for protection measures (e.g., Fuchs et al., 2007b; Markantonis et al., 2012; Fuchs, 2013) and for the impact assessment of alternative risk reduction strategies, such as land use planning (Greiving et al., 2006) or local structural protection (Holub and Fuchs, 2009).

In this paper, an innovative toolbox for assessing the loss of potential future landslide events is presented. The toolbox uses a vulnerability curve based on local past damage data in order to assess the monetary loss of future events and at the same time is targeted at reducing the disadvantages mentioned above. The new toolbox has three functions (tools): 1) it ensures the automatisation of the recording of damages in an efficient way by supporting the damage documentation process after an event, 2) it can assess the monetary loss of potential future events, and 3) it improves and updates the curve by the inclusion of new damage data and a re-computation of the curve. Moreover, information on the condition and characteristics of the buildings is also recorded and may be used in the future to investigate the way that buildings with different characteristics react on the impact of debris flows or other torrential hazards.

2. State of the art

Loss estimation models have been developed in the past for various hazard types. The last decades, advances in information technology have significantly improved their functionality. Bendimerad (2001) suggests that loss estimation tools rely on the availability of two large datasets: data regarding the hazard itself (including information on the geology, geomorphology, soil conditions etc.) and data regarding the elements at risk (inventory of buildings and infrastructure, economic value of the elements, etc.). Bendimerad (2001), who focuses mainly on loss estimation tools for earthquake hazards, recognises also the central role of vulnerability curves within these tools. He defines these curves (sometimes referred to also as fragility curves) as “the functional relationship that provides the probability to reach or exceed a damage level as a function of the (earthquake) severity”. Finally, in the same study the advantages and possible uses of loss estimation tools are also listed: (1) accessibility (they can be used also by non-experts), (2) scenario analyses (the impact of different scenarios may be investigated), (3) special focus analyses (the focus may be on specific elements at risk or their components), and (4) customised applications (applications may be defined in order to satisfy specific user needs). In a review of methods for assessing the costs of natural hazards (including alpine hazards, drought, floods and coastal hazards), Meyer et al. (2013) underline the need for cost assessments for natural hazards, because they can be a powerful tool in the hands of decision makers, as well as insurance companies. They suggest that there is a variety of methods and terminologies for the estimation of costs related to natural hazards. As far as terminology is concerned, a glossary for cost categories was developed within the CONHAZ project. The CONHAZ project and cost assessments in general often include a variety of costs types (e.g. direct costs, business interruption costs, indirect costs, intangible costs or even risk mitigation costs). However, in the present paper the focus is clearly on direct costs related to property damage due to the direct physical contact with the hazard (Smith and Ward, 1998; in Meyer et al., 2013). Regarding direct costs, the review (Meyer et al., 2013) refers also to the damage functions (elsewhere referred to also as fragility or vulnerability functions) for single or multi parameters as the most frequently applied method for cost assessment. They suggest that the functions may take into account one or more parameters. A thorough review of damage/vulnerability functions especially for alpine hazards (floods, landslides, rock falls and snow avalanches) is also provided by Papathoma-Köhle et al. (2011). Particularly for torrent hazards, a considerable number of vulnerability curves can be found in the literature. For example, Fuchs et al. (2007a) based on damage data from a debris flow event in Austria computed a vulnerability curve, Akbas et al. (2009) applied a similar method in Italy and Totschnig et al. (2011) modified the approach introducing the term “relative intensity” (intensity expressed as debris height in relation to building height). Moreover, Papathoma-Köhle et al. (2012a) computed a vulnerability curve for the valley of Martell, which was later improved by including additional data from debris flow events in South Tyrol, Italy (Papathoma-Köhle et al., 2012b). Finally, Quan Luna et al. (2011), based on intensity information derived by numerical modelling, provided three vulnerability curves for debris flows expressing intensity, not only as deposit height, but also as impact pressure and kinematic viscosity respectively.

There is an overall (and empirically-based) conclusion that low process intensities result in low damage ratios and, therefore, low vulnerability, whereas high process intensities result in high damage ratios and consequently high vulnerabilities (e.g., Totschnig and Fuchs, 2013). Nevertheless, there is only limited information available on spatial characteristics of vulnerability within the concept of risk (Fuchs et al., 2012b). As far as medium process intensities are concerned, it is evident that damage associated with medium process intensities (deposit height 1–2 m) may vary significantly (Fuchs et al., 2007a; Totschnig et al., 2011). Therefore, there may be a dependency other than between process intensity and the damage ratio of the buildings exposed. It has been shown that the spatial distribution of geographical locations with either high or low damage ratios is not only an effect of changing process intensities, but also an outcome of the general land use pattern on each individual torrent fan, and the overall constructive characteristics of the elements at risk (Fuchs et al., 2012b). Nevertheless, a further analysis of data, such as the type and year of construction, would enrich our understanding beyond space; such information would be of particular interest with respect to the overall discussion on multi-temporal and spatial assessment of risk (Fuchs and Bründl, 2005; Keiler et al., 2005, 2006; Zischg et al., 2005) and with respect to advances in multi-temporal vulnerability assessments (Fuchs et al., 2011; Papathoma-Köhle et al., 2011) and multi-hazard vulnerability studies (Kappes et al., 2012a, b).

A wide variety of different approaches is available for the assessment of hazard, risk and vulnerability. In the literature, individual studies may be found that set their focus on vulnerability models and loss estimation. Most of them aim at the development of tools and maps to provide information for or to support decision making of stakeholders involved in natural hazard mitigation. An example is the study of Samarasinghe and Strickert (2013) that developed fuzzy cognitive maps for adaptive policy formulation for earthquakes in mountain ski areas, allowing the participation of the stakeholders in the modelling process. Another example of participatory modelling is the study of Giupponi et al. (2013). They developed a tool for flood hazards that explores and communicates vulnerability to floods and climate change to stakeholders, such as representatives of public administrators, businesses and NGOs. The stakeholders of this study may actively participate by identifying the most relevant issues to be considered as input variables to the model. However, the specific tool considers a range of indicators that are relevant to many vulnerability dimensions (e.g. social) and not only physical. On the other hand, there are studies and tools that concentrate not only on vulnerability but also on the hazard itself, such as a model developed by Serra et al. (2013) for wildfires in Spain. The model is focussing on the extent of clustering of wildfires and the development of risk maps that may provide a tool for preventing and managing vulnerability levels. In the literature, the elements at risk are usually the built environment and the population, however, there also studies concentrating on agriculture (e.g. Pogson et al., 2012). Last but not least, apart from a range of natural hazards, similar models have been also developed for man-made or technological hazards such as transportation of dangerous goods (Tena-Chollet et al., 2013).

Besides individual studies of different vulnerability assessments or loss estimation methodologies for specific hazards and areas, there are also loss estimation tools that include data for more than one hazard, as well as inventories for larger areas or countries such as the HAZUS model (USA), RiskScape (New Zealand), EconoMe (Switzerland) and CAPRA (Latin America).

HAZUS (Hazards United States) is a GIS (Geographic Information System) based on a loss estimation software package developed by FEMA (Federal Emergency Management Agency) for the USA that can identify and profile hazards, as well as estimating the losses and possible mitigation options considering the elements at risk in the hazardous areas. HAZUS contains inventories of buildings, essential facilities, transportation and utility facilities, as well as vehicles and agricultural products. It uses damage curves that can be chosen or developed by the user. HAZUS provides loss estimation for hurricanes, earthquakes and floods (Scawthorn et al., 2006).

RiskScape is an integrative risk assessment tool (Schmidt et al., 2011) which uses fragility functions for modelling risks from different natural hazards and for various elements at risk. The tool uses a software prototype for generating fragility functions from standard mathematical curves. Different types of fragility functions (empirical curves developed from historical data or synthetic functions (hypothetical curves) based on expert opinion developed independently) can be integrated in RiskScape. RiskScape uses a combination of both refining and adjusting the initial fragility curves to the situation for affected regions in New Zealand.

In Switzerland, an online risk assessment calculation tool EconoMe and its most recent version EconoMe-Develop have been developed for cost-benefit analysis of mitigation measures and have been in operation since 2008. The tool is used mainly for the prioritisation of mitigation projects by the Federal Office of the Environment (FOEN/BAFU) (Bründl et al., 2009). The specific tool is makes use of fixed (EconoMe) or user defined scenarios (EconoMe-Develop) regarding the hazard (avalanches, floods, debris flows, rock fall and landslides). The tool provides a calculation of exposure, consequence and risk analysis with and without mitigation measures (Bründl, 2012).

CAPRA (Comprehensive Approach to Probabilistic Risk Assessment) is a probabilistic risk assessment program developed for evaluating multi-hazard risk in Latin America. It is composed of modules of hazards, vulnerability and risk evaluation, as well as tools for cost benefit analysis and it is used for decision making. It provides disaster related information to a number of sectors such as health, education, transport, housing etc. (Marulanda et al., 2013).

Loss estimation tools like the ones described above require detailed damage datasets that may be derived only through adequate documentation of losses due to disastrous events. One of the main sources of uncertainty in the assessment of costs related to natural hazards is the lack of such datasets that may provide information not only about the past events and their characteristics (intensity, duration, extent, etc.), but also about the elements at risk, their condition prior to the event, the detailed amount of damage and the intensity of the process associated with each damage. In this respect, several authors suggest (e.g. Papathoma-Köhle et al., 2012b; Meyer et al., 2013) that improvements should be made in the collection of data following disastrous events and secondary data sets that may enable the calculation of natural hazard costs (e.g. object value). Many efforts have been done in the past for improvement and harmonisation of the collection of post event data such as DOMODIS (Hübl et al., 2002) and DIS-ALP (Berger et al., 2007), which focused on the documentation of mountain disasters. However, these initiatives gave an emphasis to the process and its characteristics rather to the consequences and detailed documentation of damage. Damage databases have been also developed by insurers or reinsurers (e.g. NATHAN of Munich Re and Swiss Re's Sigma; Barredo, 2009), as well as by national administrative bodies (e.g. StorMe; Burren and Eyer, 2000) at different scales. However, StorMe includes information regarding the event rather its consequences (Burren and Eyer, 2000). At global level, there is the EM-DAT database which is available on line and contains data on natural and technological disasters and their impact (casualties and costs). At national level, there are similar efforts: in Australia, the research team “Risk Frontiers” maintains a database with information regarding natural hazards and their impacts at national level and countries such as Germany (HOWAS) and countries from Latin America (DesInventar) also maintain databases for flood and natural/technological hazards respectively (Hilker et al., 2009). In Switzerland, there is the WSL damage database (Hilker et al., 2009) which focuses on economic damage and casualties. The recorded events are then available to official institutions responsible for land use planning, and protection measures. The financial damage is not only recorded for buildings but also for infrastructure, protective structures, forest and agricultural land (Hilker et al., 2009). The scale of the damage documentation is at community level (Hilker et al., 2009). However, to date, there is no standard for the documentation of losses related to natural hazards.

In Italy, the collection of natural hazards events and related information (damages and casualties) is made by means of the IFFI-system (Italian Landslide Inventory, APAT, 2007), particularly for landslides and rock falls. In the Autonomous Province of Bozen (South Tyrol), water related hazards and the related damage are documented by means of the ED30 system (event documentation for natural hazard events in the Department 30 – Hydraulic Engineering) (Zischg et al., 2007). Summarised information regarding affected persons, damages on buildings and infrastructure is inserted into the event documentation databases, in most cases without mentioning monetary values.

The main difference between the tool presented here and the existing approaches described above is that the presented tool is working on a local scale in contrast to HAZUS, RiskScape, etc. Moreover, the presented tool is tailored to the application in the European Alps due to the underlying loss data. Additionally, the tool can be used in the field by non-experts for rapid damage documentation and it can also improve itself automatically (updating of the existing vulnerability curve). However, the tool is focussing on the elements at risk and their characteristics without including hazard information (e.g. CAPRA). The presented tool contains not only damage information, but also (in contrast to HOWAS in Germany) information regarding characteristics of the buildings. This information is highly detailed and available on large scale. It includes information not only on the condition or floors of each building but also, on the presence of basement, characteristics of the surroundings and number, size and quality of openings, that is hardly available in any other existing database. RiskScape is currently developing such a database for New Zealand, still, the building characteristics are not as detailed as the ones presented here (RiskScape Website). In the case of HAZUS, information on elements at risk is collected per Census Block, which, although it is the smallest geographical unit of the United States it includes several buildings.

Despite the fact that documentation methods are slowly improving taking full advantage of the increasingly available technology and loss estimation tools, there are still gaps to be filled, such as scale issues, degree of detail, relationship between damage pattern and process intensity on individual objects, etc. In order to address these issues, we have to improve first the quality and reliability of datasets allowing a more reliable assessment of physical vulnerability. In more detail, there is still the need for improving the vulnerability input within the risk assessment process, increase the quality of damage data and data on elements at risk, as well as the degree of detail. This can be done by continuously recording the consequences of natural processes adequately on the built environment. In this way, the interaction between process and consequences can be better understood and the gained knowledge may then be used for the design of vulnerability reduction strategies. The tool presented in this paper contributes significantly to the improvement of these datasets and, consequently, to the improvement of the vulnerability component of the risk assessment process. In other words, the tool contributes to the successful capture of damage information and its transfer to valuable and reliable datasets that may be used for vulnerability and risk assessment.

3. The vulnerability function

A vulnerability function was computed based on empirical damage data of buildings in South Tyrol, Italy, that have suffered the impact of debris flow or fluvial sediment transport in the past. Based on event documentation (photos), the heights of the deposits were estimated and the estimated monetary damage per building was analysed. The degree of loss per building was also calculated by comparing the value of the building (in terms of reconstruction costs) to the monetary damage caused by the event. At the beginning, Papathoma-Köhle et al. (2012a) conducted a pilot study in the municipality of Martell. A building-precise assessment of the debris flow intensities and the monetary loss of most of the affected buildings of the 1987 debris flow event in the municipality of Martell was carried out. Overall, photographic documentation of 53 buildings was used out of the 69 buildings that were damaged or completely destroyed (Pfitscher, 1996), since, only for this amount of buildings adequate photographic documentation was available. By using photographic documentation, the extent of damage was translated into monetary loss, based on standard prices for renovation works (Kaswalder, 2009). The degree of loss for each building was then assessed, based on the overall building value (Papathoma-Köhle et al., 2012a). In order to improve the curve, more buildings that suffered damage due to debris flows or fluvial sediment transport in South Tyrol were added to the curve (52 additional buildings) in a later stage. The final curve, including all the buildings from the Italian Alps, is shown in Fig. 2 (Papathoma-Köhle et al., 2012b).

The vulnerability curve clearly shows that the higher the intensity of the process the greater the damage that an element at risk suffers. Papathoma-Köhle et al. (2012a, b) computed also a validation curve (blue curve in Fig. 2) using paid-out compensation data provided by the Department of Domestic Construction of the Autonomous Province of Bozen (South Tyrol) for the calculation of the degree of loss. The degree of loss for the development of the validation curve was expressed as the ratio of the estimated object value and the compensation that the building owners received in order to restore their building. The intensity values remained the same as the ones used for the initial vulnerability curve. The validation curve provided slightly higher degree of loss values for intensities 0–1.5 m and lower degree of loss values for intensities 1.5–3.5 m.

4. The toolbox

A toolbox was developed to support the risk management practice in regard to three main aims: (a) improvement of the damage data collection process on the field, (b) assessment of damage and loss for buildings prone to future events (scenarios), and (c) improvement of an existing vulnerability curve by using data of recent events.

Thus, the toolbox has three functions that were implemented as three separate but interlinked procedures (tools):

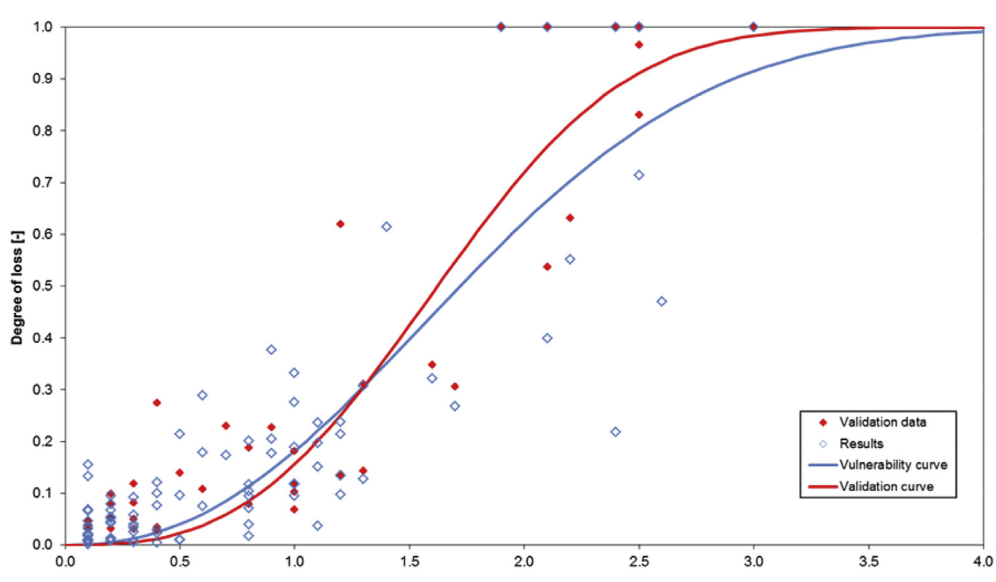

Fig. 2. The vulnerability function (blue curve) and the validation function (red curve) for debris flow events in South Tyrol (Papathoma-Köhle et al., 2012b). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1. A standardised method for improved and more efficient damage documentation and assessment in the field.
2. A method for damage and loss assessment of possible future events under different land use/hazard scenarios using the existing vulnerability curve.
3. Updating of the database and improvement of the curve by including additional empirical and well-documented damage data from recent events.

The toolbox considers mainly damage on residential buildings or buildings with similar characteristics without including specifications, such as sensitive inventories in industrial buildings. The three individual tools are connected to each other in terms of data and output exchange (Fig. 3). A starting menu prompts the user to the required tool, which is either damage documentation or damage calculation.

The first tool (damage documentation) offers a graphical user interface, which enables the documentation of physical damage on buildings caused by the impact of torrential hazards. With this tool, the majority of information regarding detailed damage patterns can be recorded into a database. On the basis of the input data, a mathematical function calculates the needed amount of restoration work and, eventually, the total monetary value of the restoration, as well as the total value of the building. In the calculation of the restoration costs, only the construction costs are calculated, based on the costs of an average building in South Tyrol. Content costs or special high value building features (e.g. expensive floors) are not considered. As a result, the loss ratio can be obtained for every assessed building. If, at a later stage, information on additional losses (from another hazard event) becomes available, the system re-calculates the existing vulnerability curve (third tool: update of existing curve), in order to take into account an enlarged sample of buildings and to increase the reliability of the function.

The second tool (loss assessment of future scenarios) calculates the monetary loss per building for a specific hazard scenario on the basis of the building value and the externally computed expected process intensity. The potential loss is subsequently calculated using the internal vulnerability curve, which is continuously updated by the third tool. Depending on the scale, this function can be used for individual objects but it can simultaneously be implemented into a GIS-procedure for loss assessment over wider regions. In the following paragraphs, all three tools of the toolbox are described in detail.

4.1. Damage documentation tool

Following a debris flow event it is important to estimate the cumulative damage on buildings and infrastructure. The individual damage has to be documented and calculated in a short time window after the event because (a) damage is usually restored as soon as possible by the local population after the event and (b) the government needs information about the losses immediately for priority setting of intervention and restoration works and for the information of the media. In parallel, insurance companies would like to have an efficient instrument for the rapid documentation of the losses. If a larger area is affected by the event, the damage documentation should be made as efficient and precise as possible.

The damage documentation tool consists of a form, which is represented by a graphical user interface in the software environment (Fig. 4) and guides the user through the data input.

The process characteristics are usually described in detail in the (separate) event documentation database. Here, the process characteristics are expressed in terms of mean deposition heights around the building. If the deposit height varies around the building, a further input form supports the user to document the process characteristics on all sides of the building.

The input values are stored in the database and are, therefore, available for subsequent computation steps, such as the implemented mathematical function which calculates the monetary value of the total construction costs of the buildings based on the official price index of the Autonomous Province of Bozen-South Tyrol (Autonomous Province of Bozen-South Tirol, 2012a). In 2012, the official prices of construction costs were € 342 per cubic metre of building volume, which is, respectively, € 1369 per square metre net living area. After the input of the ground plan area and the number of floors, the value of the building is calculated and inserted in the database.

Another mathematical function calculates the monetary value of the restoration costs by using the average hourly salaries and the general cost calculation guidelines for constructions of the Autonomous Province of Bozen-South Tyrol (2012b). This official database stores the necessary material costs and associated

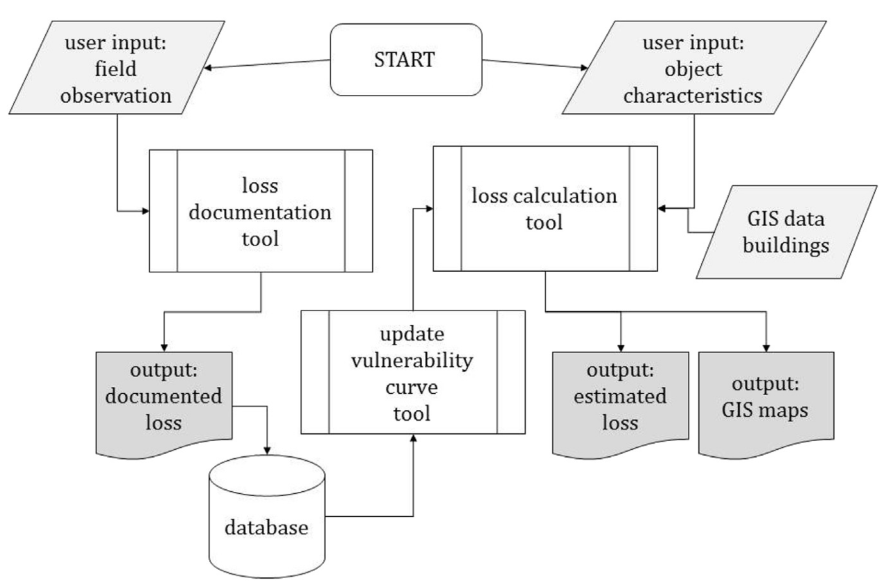

Fig. 3. The structure of the integrated toolbox.

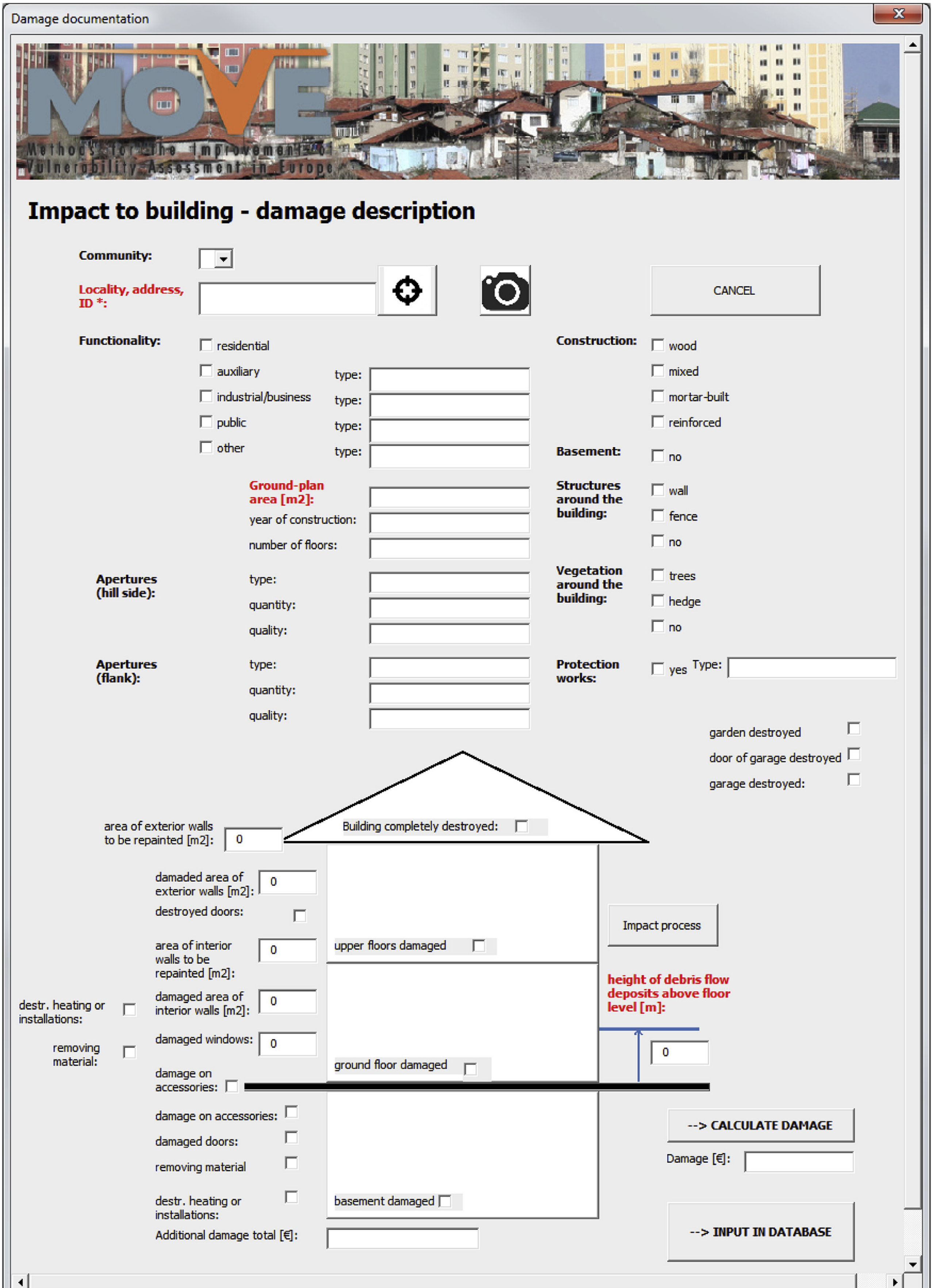

Fig. 4. The screen shot of the graphical user interface of the tool for damage documentation.

Table 1
Modified functional approaches for regression analysis of vulnerability. As Frechet distributions with different numbers of parameters were tested, a numeral suffix was used to distinguish between them. The RMSE for the Exponential, Weibull and Frechet functions is provided in the last column.

Distribution	Mathematical notation	Number of unknown parameters	Interval of the explaining variable	Root mean square error
Modified Weibull	$1-e^{-a\left(\frac{x+b}{b}-1\right)^{c}}$	3 a, b, c	$[0; +\infty)$	0.1318
Modified Exponential	$1-e^{-a\left(\frac{x+b}{b}-1\right)}$	2 a, b	$[0; +\infty)$	0.1437
Modified Frechet no. 1	$e^{-\left(\frac{x+b}{b}-1\right)^{-a}}$	2 a, b	$[0; +\infty)$	0.1355
Modified Frechet no. 2	$e^{-c\left(\frac{x+b}{b}-1\right)^{-a}}$	3 a, b, c	$[0; +\infty)$	0.1355

personnel working hours in standardised units. The data is accessible via an XML interface for use in any software, or in terms of a MS Access © database. The vulnerability tool uses the MS Access © tables of the price-index database for further computation. The official data sets were imported into the tool database representing the construction costs of this specific region. The mathematical function implemented in the tool considers the dimension of the building and the other input data (e.g. number of broken windows and doors, area of walls to be repainted, etc. see Table 1) to compute the necessary costs for each individual working step during the potential re-instatement of the building. Finally, the costs of each individual working step and the necessary material costs are summed up. After the input of the documented damages, the calculated costs are shown in the documentation form (Fig. 5). If the documented damage is connected with a GIS-dataset of the buildings, the results of the documentation tool can be shown in a map (Fig. 6).

The record set of the damage documentation for each building is subsequently complemented by two computed values: (a) the construction costs of the building and (b) the costs for repairing the damage due to the respective hazard event. These two values are then used by the tool for the assessment of loss of future events and for the update of the vulnerability function.

4.2. Loss assessment of future events

The tool for loss assessment of future events requires the input of information, such as the building category and functionality, the floor plan, the number of floors and the existence of a basement, the use of the ground flood and the upper floors, and additional information on auxiliary buildings such as garages, sheds and storerooms. Using this data, the tool calculates the total value of the construction costs using the official price index (Autonomous Province of Bozen-South Tirol, 2012a) as described above. Furthermore, since the expected process intensity is expressed as the height of debris deposits, this information is also needed. On the basis of this value, the tool computes the degree of loss using the vulnerability function (Fig. 5).

If the presence of a basement is unknown, the tool calculates two values. As a minimum value, the construction costs are calculated without considering a basement. In the maximum value, the construction costs of a basement the size of the first floor are considered. Additionally, based on the minimum and maximum construction costs, a mean value is also given. The tool calculates the potential damage by multiplying the degree of loss with the mean value of the construction costs.

This procedure was also incorporated as a GIS-procedure in the ArcGIS software environment. On the basis of an overlay of the GIS-dataset of the building characteristics (function, use of the building, ground plan area, floors) and the hazard maps (scenarios with process intensities), the potential losses caused by selected scenarios can be computed over large areas. The GIS-procedure uses the vulnerability function computed from the tool database.

4.3. Update of the vulnerability curve

The vulnerability curve derives from the degree of loss associated with an expected process intensity. After recording the new damage documentation data (including information regarding the value of the buildings, the intensity of the process and the loss height), the update module of the tool re-calculates the parameters of the stored vulnerability function. The degree of loss is expressed as the ratio between repairing costs (monetary damage) and construction costs (object value) in terms of a Weibull function (Formula 1 (Totschnig et al., 2011; Papathoma-Köhle et al., 2012a, b)).

$$y = 1 - e^{a\left(\frac{x+b}{b}-1\right)^{c}} \tag{1}$$

Where:

y: degree of loss
a, b, c: factors describing the shape of the Weibull-function
x: process intensity

The factors describing the shape of the vulnerability curve (a,b,c) are recalculated based on the newly recorded datasets. The function itself does not change. It is assumed that with a growing dataset and detailed and improved documentation of damage of individual buildings, the vulnerability curve will become more and more reliable.

5. Implementation and practical use

The toolbox was used into three different applications. The three tools (damage documentation, loss assessment of future scenarios, and updating of the vulnerability curve) have been implemented into a Microsoft SQL Server and ESRI ArcGIS. The system offers the graphical user interface for data entry and output (as shown in Figs. 4 and 5); it contains the knowledge base for calculating the total amount and costs of restoration works (extract from the official price list of construction costs), and the database for the insertion of damage documentation. The routines and functions for the cost calculation and the calculation of the vulnerability curve are also implemented in the database as server functions. The database forms are accessible via internet.

5.1. Damage documentation

During the damage documentation in the field, shortly after a hazard event, a mobile internet connection is not always possible.

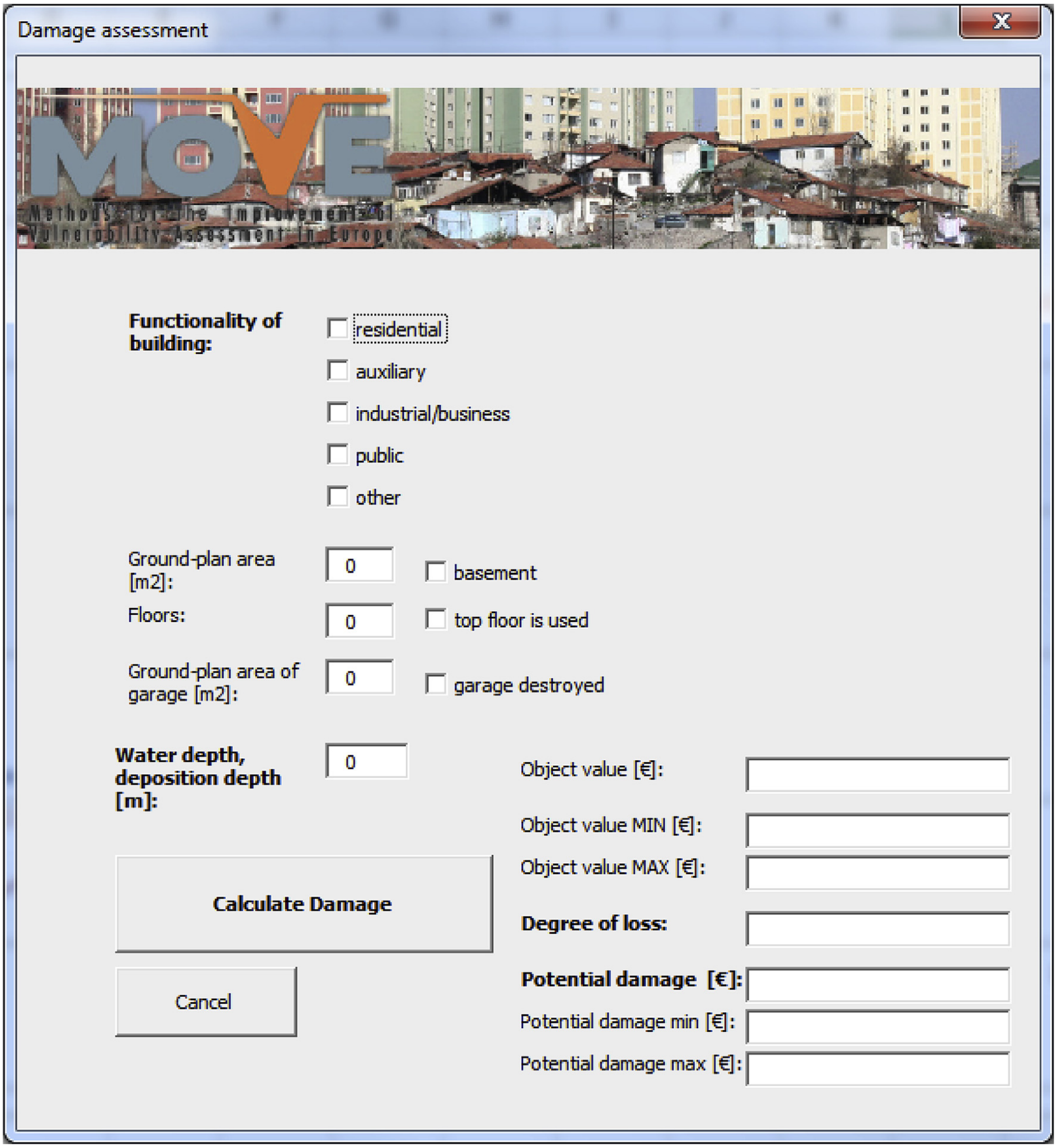

Fig. 5. Graphical user interface of the loss assessment tool.

Therefore, the tool was implemented into an MS Excel spreadsheet by using VBA and the same windows forms of the database. The spreadsheet contains the same graphical user interface as the database and stores the data in the same data format for an easy import into the database. The spreadsheet-based tool can be used on a tablet computer without internet connection.

The damage documentation tool was tested during the damage documentation in the consequences of numerous debris flow events in the area of Vipiteno/Sterzing, Autonomous Province of Bozen – South Tyrol, Italy (August 4th and 5th, 2012; refer to Zischg (2012) for details). A heavy rainfall event triggered more than ten debris flows. The debris flows damaged 52 mostly residential or residential/agricultural buildings. The physical characteristics of the debris flow events were documented by the official authorities of the Autonomous Province of Bozen – South Tyrol. The damage on the buildings and houses were documented during a field campaign five days after the event with the presented tool. The damaged buildings were surveyed and the damage was recorded using the damage documentation form shown in Fig. 4. The tool was used on a tablet computer and supported an efficient documentation and time-saving damage assessment; the 52 buildings were documented and the related losses subsequently estimated within one day. Besides the photographic documentation, the tool did not require post-field processing.

5.2. Loss estimation

The total sum of incurring losses caused by the event was estimated by the tool to be 1.3 Mio. €. The process intensities impacting the building envelopes were locally very high with deposition heights of more than 2 m, with a mean of 0.7 m and a median of 0.3 m. Two thirds of the buildings affected by the debris flow did not experience structural damage. Two buildings were totally destroyed. Eleven buildings experienced damage in the

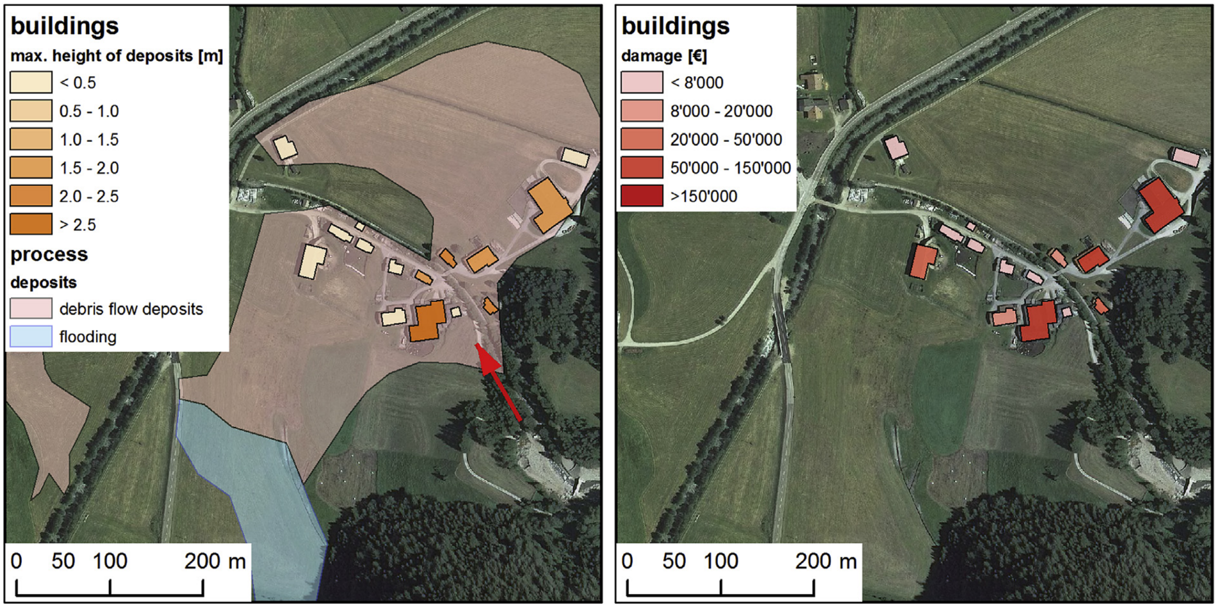

Fig. 6. Map of showing the spatial pattern of the process intensity distribution (left) and the monetary damage distribution (Fussendrass, community of Valle di Vizze/Pfitsch)).

interior because the debris entered into the building through broken windows or doors. The spatial pattern of the deposition height and flooding as well as the damage distribution in the specific area are shown in Fig. 6.

A comparison of the estimated loss (1.3 Mio. €) with the actual cost of this event is not possible because the estimation of the local authorities included also monetary losses regarding the content of the buildings and agricultural equipment.

5.3. Updating of the vulnerability curve

After recording the damage into the database, and after calculating the losses with the first two parts of the tool, the parameters of the vulnerability function were recalculated with the third part. The entire dataset consists of 271 documented damages: 136 from Austria (Totschnig and Fuchs, 2013), 34 from Martell valley (South Tirol, Italy) (Papathoma-Köhle et al., 2012a), and 100 damage from the Vipiteno/Sterzing and Pfitsch/Val die Vizze areas as described above.

The dataset is divided into a training dataset (80% of the original data) and a test dataset (20% of the original data). The test dataset was stratified as such that both datasets contained the same amount of high and low values (Fig. 7).

The training dataset, composed from a total of 217 cases, was further divided randomly into ten subsets of equal size (22 cases each) in order to cross-validate the different data models tenfold. Subsequently, we tested different possible loss functions for their power to fit best the training dataset. These functions had to comply with the mathematical requirements of (a) defining vulnerability as the dependent variable in a closed interval [0; 1]; (b) a steady and monotonic increase within the interval of its explaining variable (intensity); (c) steadiness with respect to higher orders within the defined interval; and (d) definition of its explaining variable either in the unbounded interval $(-\infty; +\infty)$ or in the half-open interval, bounded from below $[0; +\infty)$. Following Totschnig et al. (2011), an Exponential function, as well as a Weibull and two Frechet distributions were tested. These different functions were trained on the ten sub-samples of 22 data points (tenfold cross-validation), and as a result a Root Mean Square Error (RMSE) was obtained for each one of them (see Table 1).

As the modified Weibull distribution obtained the smallest RMSE (0.1318), this function was chosen to best represent the training dataset. In a second set of calculation, the Weibull function was tested taking the 20% residual test dataset. The RMSE increased slightly to 0.1358, which means that this function is able to project future (unknown) events with an accuracy of almost 87%.

In Fig. 8, the alteration of the Weibull distribution is presented in dependence on the amount of data considered. It is shown that, for the Martell event, the losses were slightly lower for small and medium process intensities up to 1.5 m deposition height, and

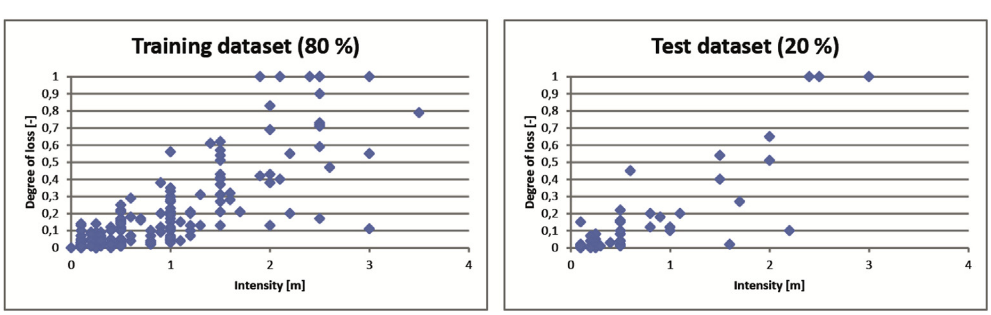

Fig. 7. The training and the test dataset used for the recalculation of the parameters of the vulnerability function.

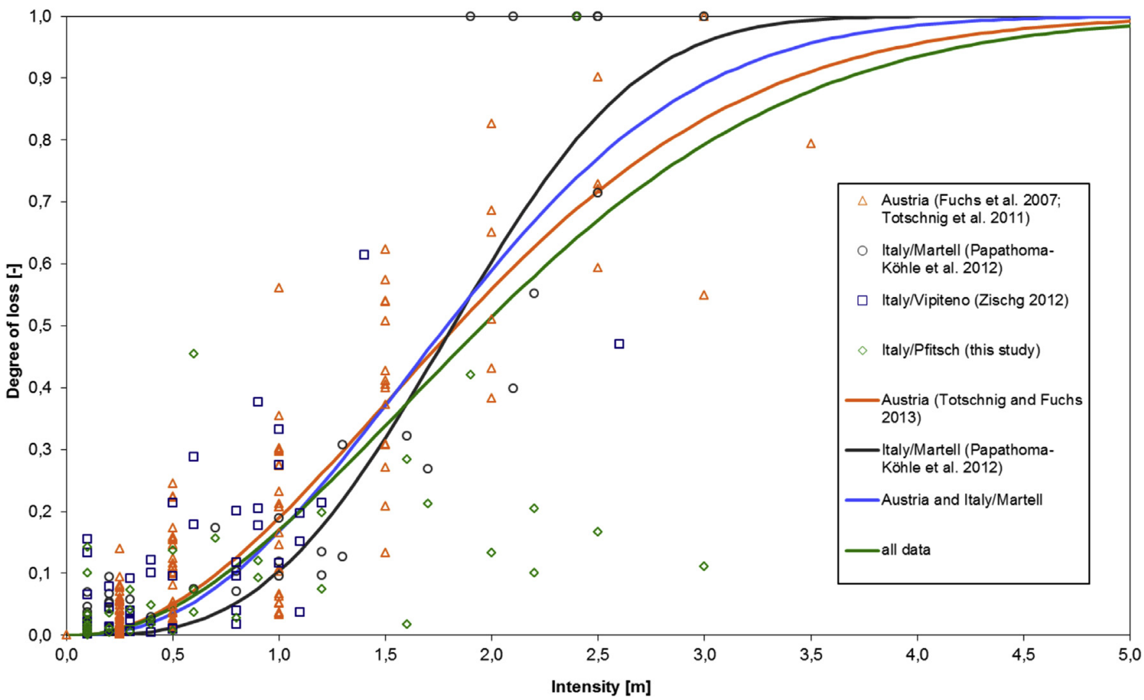

Fig. 8. Results of the recalculation of the vulnerability curve after the increase in the sample dataset. The green curve shows the vulnerability function calculated on the basis of all the data. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

slightly above the population for higher process intensities. The combination of different sample data (Austria, Martell case study and the damage from Vipiteno/Sterzing and Pfitsch/Val die Vizze) shows how the shape of the function is altered due to different values of the parameters a, b and c calculated according to Equation (1). In Table 2, the values of the parameters describing the Weibull function (a, b, c) for the different case studies and respective curves are shown.

In general, the results also show that the spread is considerable for medium process intensities. Therefore, if the vulnerability function is used to calculate damage on single objects, the results may over- or underestimate the real losses. The method implies consideration of a minimum number of some objects in loss assessments. However, it is difficult to set a minimum number of data, as more factors may influence the reliability of the curve. For example, the data points should represent cases of the full spectrum of values. In other words, buildings that have suffered very high degree of loss should be used as well as others that have suffered minimum loss.

6. Discussion

The toolbox presented herein offers a number of solutions to various challenges that decision makers and planners have to deal with, such as: a) future change (climate and socio-economic) and associated increasing of damage costs, b) reliable vulnerability assessment that will contribute to improved risk analysis, and c) better documentation of events and associated damage in large scale, etc. In the following paragraphs, the most important benefits and limitations of the present study are described. Finally, ideas for further development of the presented tool in the future are also outlined.

Table 2
The parameters a, b, c for the Weibull function for the different case studies/curves shown in Fig. 8.

	Austria (orange curve)	Austria and Italy/Martell (blue curve)	Italy/Martell (black curve)	All data (green curve)
a	−1.253	−1.138	−0.27	−1.671
b	2.438	2.177	1.287	3.189
C	1.892	2.202	2.974	1.746

6.1. Benefits

The greatest benefit of the toolbox is its multi-functionality. The toolbox presented here can be used for loss estimation, rapid damage assessment and documentation at local level, and improvement through continuous updating of the existing core vulnerability curve. The tool has the ability to self-improve and to work against one of the greatest drawbacks in the field of risk analysis, which is the lack of reliable and adequate data. The tool improves the data collection procedure by providing a user-friendly and standardised data collection method that does not require a high number of qualified personnel. The data collection can take place on site within a short time period after the event. Depending on the availability of an internet connection, the data can be stored directly in the database or in a spreadsheet.

The toolbox can also be used as a basis for cost benefit analysis. Once the overall monetary loss of a hypothetical event is assessed, the alternative monetary loss by using mitigation measures may also be calculated. In this way, the best alternative risk mitigation and management strategies can be chosen. The implementation of the functions in a GIS-procedure is unproblematic when a dataset of buildings including their functionality and extent is available. Through the integrated functions, the reconstruction values of each building can be calculated on the basis of the attributes of the input dataset. The function delineates the vulnerability value from the intersection between the buildings dataset and the hazard intensity map and, therefore, calculates the expected loss for every object exposed to the hazard. Using GIS, not only the assessment of potential losses on buildings over large areas is possible, but also, the databases can be easily updated and the results can be visualised. The vulnerability of the elements at risk is not calculated in a static way, but, through the connection to GIS, the spatial pattern of the vulnerability may be also visualised and, in this way, the relationship between the natural process and its consequences may be better investigated. Moreover, databases including loss data may be exported and used in other applications.

An important benefit of the toolbox is that it can be used by multiple users that are not necessarily experts or experienced specialists. Decision makers and stakeholders with different backgrounds, such as, scientists, technicians, and administrative personnel, may all make use of the advantages of the toolbox. The situation and damage pattern following a disastrous event may change very quickly due to the need of the authorities and the local population to bring the situation back to normal. The tool offers a quick way of documenting damage directly on site, so that the original situation of the damaged elements following an event can be directly recorded. An innovative element of the toolbox is that, apart from the recorded damage, it also records (and creates a database of) building characteristics that influence its overall vulnerability (vulnerability indicators). In this way, two of the most commonly used methods for vulnerability assessment (vulnerability curves and vulnerability indicators) are integrated in the same tool supporting rather than opposing each other. Furthermore, the scale that the toolbox is used at offers a great detail of the damage pattern. Until now damage databases are maintained mostly at community level and they miss great detail (e.g. damage and intensity per building). The toolbox also offers possibilities of improvement and expansion such as additional elements at risks (infrastructure, agricultural areas, and open spaces) and hazard types. However, the most important benefit that the toolbox can demonstrate through the present study is its capacity to actively support risk reduction strategies and climate change adaptation efforts.

Finally, an additional strength of the tool is that, although the core vulnerability curve itself cannot be transferred and used in another area with different characteristics and type of built environment, the tool itself may be immediately used by local data and start performing by tuning itself automatically to the local context.

6.2. Limitations and improvement

One of the most significant limitations of the tool is the difficulty of recording information regarding the intensity of the process on each building. The intensity of the fluvial bedload transport or debris flow has been expressed in this paper as the height of debris deposits. However, in many cases this height was assumed by looking at the size of destruction or at the stains that material and water have left on the walls of the building. Moreover, the intensity of the process depends, apart from the deposition height, also on other factors, such as the velocity, the viscosity and the direction of the flow that approaches the building. These factors are generally challenging to record for each affected building. However, in some recent studies (Quan Luna et al., 2011; Jakob et al., 2012), information regarding the velocity and the viscosity of debris flows has been acquired through modelling of past events. In the case of the presented tool, intensity of the process is recorded through improved documentation, establishing the link between event and damage documentation. Nevertheless, during the development of the tool many assumptions had to be made which increased the level of uncertainty. There are uncertainties associated with the input data (e.g object value, intensity assessment), and uncertainties associated with the model procedure (e.g. monetary loss assessment) that were not considered or quantified in this study. In more detail, sources of uncertainties are related to: a) the estimation of the process intensity, b) the estimation of the degree of loss, c) the value of buildings and d) the credibility of the existing data. However, the quantification of these uncertainties within the tool and recommendations regarding their reduction could be one of the potential future improvements. The quantification of uncertainties is very important for the end-users of the tool that, in this way, may get an indication of how well the tool is expected to perform. The uncertainties related to the development of the vulnerability curve which formed the basis of the tool presented in this paper have been quantified in a recent study (Eidsvig et al., 2014). However, their quantification is not yet included as a function of the tool.

Furthermore, the tool may be transferable to areas with houses of similar type of construction and similar construction costs. However, if the building types are different, a new vulnerability curve has to be developed. The database of the construction costs can be easily adapted to other regions, if mean values for the single restoration works are available there in a standardized format. The development of the curve is often prevented by data limitations. However, the tool itself with its rapid damage assessment function is expected to improve data availability.

Moreover, since the database at the moment contains only a limited number of documented cases, the function is calculated based on all building types available. Nevertheless, in the future, a growing set of documented data will allow the development of more than one vulnerability functions for the different types of buildings (use, type of construction etc.).

6.3. Outlook

A future development of the tool, apart from its applications in other areas, must include more elements at risk. A similar toolbox could include critical infrastructure, such as powerlines, railway and road networks, industrial or other important buildings, such as airports and railway stations. Moreover, the tool could also be used for the loss estimation of agricultural areas, based on the intensity of the process and monetary loss, which includes for example the cleaning costs, replanting and the harvest loss. The tool could be also adequately modified to be used for other hazard types, such as floods. Although this paper is focussing mainly on direct losses to the built environment, the focus of the risk reduction strategies is always the protection of the human life. In this respect, the toolbox could be expanded to include data regarding the population e.g. number of inhabitants, population density, characteristics of the population, such as health condition, income, mobility, and density during different times of the year and the day. Information on people could also be included in the documentation process (e.g. number of casualties per building etc.). Nonetheless, one of the most important developments of the existing toolbox could be the possibility of quantifying its uncertainties in order to enable decision making. As it was mentioned in the previous paragraph, work concerning the quantification of uncertainties has already been done and the next step is the integration of the quantification of uncertainties in the tool. Finally, the tool could be used remotely from unqualified users as a phone or tablet application in order to populate a central database with data by ordinary people (non-experts) that are located on the spot during or right after an event and may assist in the post-damage data collection and documentation. This would be a step towards solving one of the biggest problems in the loss estimation and vulnerability assessment field, which is the one of data availability.

7. Conclusion

A toolbox for loss documentation for landslide hazards is presented. The toolbox can be used by decision makers to assess potential losses of future debris flow events but also to document and record damage of real events in a rapid, sufficient and detailed way. The toolbox is a valuable instrument in the hands of stakeholders considering the on-going changes in the frequency and magnitude of hazardous events and also in the spatial pattern of the elements at risk. The tool offers also a solution to one of the most common challenges in risk assessment, which is the lack of adequate data. The databases included in the toolbox may be exported and used for other applications, but also the new data may be used to continuously update the tool and increase its reliability. Although the toolbox is an important step towards loss estimation at local level for debris flow hazards, there is still a need for continuous research in the field, in order to better understand the interactions between natural processes and the built environment, so that we are able to reduce the vulnerability of elements at risk and eventually the costs related to natural disasters.

Acknowledgements

The authors would like to thank Bruno Mazzorana from the Department of Hydraulic Engineering of the Autonomous Province of Bozen – South Tyrol, Italy. He supported the documentation of the damaged buildings following the debris flow events in August 2012 in the Vipiteno/Sterzing area and provided information on the process intensities. Furthermore, the authors would like to thank the reviewers and the editors for their valuable comments and suggestions to an earlier version of this paper. Funding for the presented research was provided by the Austrian Science Fund (FWF, L535-N10) and the EU project MOVE (Methods for the Improvement of Vulnerability Assessment in Europe; http://www.move-fp7.eu, contract number 211590).

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