Review Paper:

Advances in rapid assessment of damaged buildings by earthquakes

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Abstract

This study presents a review of the methodology of rapid damage assessment by earthquakes in buildings, with its origin, general base, links with other similar methodologies and its international use.

In addition, it also presents other methodologies to assess damage based on imagery, laser and radar scanners with a possible future use to evolve rapid damage assessment. Rapid damage assessment methodology evidences advantages to reach its objectives and recommendations for structural analysis and design. This methodology is useful for cases with buildings that have obvious damage after earthquakes, but not in cases without obvious loss of structural resistance facing aftershocks.

Keywords: Rapid Damage Assessment, Structures, Earthquakes, Satellite imagery, Drone.

Introduction

The cost of damages and casualties from disasters occurring in the ten year period from 1976 to 2014 have increased from US$14 billion to US$140 billion [91]. Assessment of damages caused by disasters of this magnitude in cities or towns with dense populations needs to be performed quickly in order to determine whether buildings are stable or must be evacuated to protect lives of people.

Implementing techniques to estimate casualties, deaths, economic losses and helping to manage resources for emergencies using a large-scale[144] (1:10.000 to 1:25.000) would neither focus on individual buildings nor on usability or habitability in homes.

Rapid Visual Screening (RVS) is a procedure for qualitative and superficial assessment of structural behaviour. RVS could apply to structural vulnerability assessment before earthquakes and also to assess damage by earthquakes.

Zones affected by earthquakes need rapid assessment for different purposes. These purposes are interpretations of landing movements[68], detection of damage[137], assessment of sanitary situations and health needs[166] and even mental health[52].

Other purposes are social impact[118] and economic impact to requirement versus institutional response capacity[174], to establish accessibility of homes and the magnitude of reconstruction[170], effects of continuity in hospitals[28], bridge inspections[192] and also the assessment of immediate usability of buildings.

Structural assessment after earthquakes on buildings are, in general, Rapid Damage Assessment (RDA), Detailed Evaluation Method (DEM) and Engineering Assessment. RDA is for buildings not designated to provide public services in emergencies (hospitals, vital lines like buildings for public transportation, communications, etc. and public security). DEM is for buildings with emergency attention and for buildings with restricted use after an RDA. Engineering Assessment is for buildings with Restricted Use after a RDA or after a DEM[39].

Classification of techniques

Methods for assessment of damages to buildings by earthquakes are shown in Table 1.

Classification of methodologies according to development time: Techniques for assessment damages to buildings, according to development time referent the moment of occurrence of earthquake, could be divided as:

1) Predictive assessment of damages which includes assessment based on seismic parameters and different scenarios with approximate results of collapsed buildings. These techniques include predictive RVS and predictive engineering. Predictive RVS uses vulnerability functions of different types of buildings and techniques of predictive engineering use numeric models in specific buildings. Probabilistic estimation of damages after earthquakes could use information based in Predictive RVS as a case presented by Cardona and Bernal.[38]

2) Posterior of earthquakes which includes tele-detection with imagery from satellites, aerial images from planes and Unmanned Aerial System (UAS)[100]; traditional RVS over individual buildings with human teams (RDA and DEM); engineering assessment with numeric models and field trials.

It is important to note that engineering assessment will be different depending on whether buildings have previous instrumentation or not. Structural Health Monitoring (SHM) is an engineering assessment for instrumented buildings and seismic vulnerability assessment is for non-instrumented buildings.

Table 1
Method of assessment of building damage

Variable time		Time in min./ hours	Time in days	time in weeks			Time in months
				Tele-detection		Posterior RVS	
Predictive RVS[5,9,18,70,98,116,127,134,135]	Earthquake		BREC[71,129,145-148]	Visual interpretation[117,180]		RDA for homes[10,19,37,40,41,80,102,136,142,161,188]	Engineering of instrumented buildings[12-16,20,34,35,44,72-74,96,162,195]
Predictive Engineering of not instrumented buildings[12-16,20,44,72,73,162,195]			DEM for emergency attention buildings[19,21,27,156,157,167]	Automatic interpretation[95,97]	With previous and posterior images[1,3,4,78,85,88,126,150,177,179,180]		
					With posterior images only[62,100,119-121,180]	DEM for homes[19,21,133]	
Probabilistic estimation of damages[7,38,138,164]					DSM[122,152]		
Engineering of instrumented buildings[36,60,61,124]							

Classification of methodologies according to type of imagery: Techniques for assessment earthquake damage to buildings according to type of imagery, could be divided as: 1) Visual interpretation and 2) Automatic interpretation. This methodology could be different when the assessment use, images or data previously to earthquake and when the assessment makes or not a Digital Surface Model (DSM) after earthquakes with or without other previous DSM for comparison[120].

Rapid damage assessment

Detailed assessment for buildings is complex, expensive and it cannot be used in all buildings in an affected area[175]. Rapid Damage Assessment (RDA) has been created for this purpose based on a RVS. This kind of evaluation uses sidewalk surveys designed to record external visual qualifications and in some cases, interior visual qualifications. Because resources are normally limited, this methodology is used nowadays to assess damage by earthquakes.

Assessing a big amount of private use buildings and others with an important function of management of emergency is necessary in urban areas. Wrong assessment with RDA, such as, declaring uninhabitable habitable buildings increases shelters unnecessarily; or declaring habitable buildings at risk of collapse increases victims of aftershocks[125].

RDA aims to establish immediate habitability in buildings after earthquakes, it could contribute data for other purposes like fatalities and casualties in general. RDA is not useful to establish requirements of immediate emergency actions.

Beginning of methodology RDA: Beginning of RDA could be established in European Middle Age[153], in earthquakes of Ferrara (Italia) 1570-1574 (VIII[109] M_w 5,8[186]) with assessing buildings[94] for mandate by Duke Estensi to architect Pirro Ligorio (1503-1583)[49]. For early modern period[153], the International Conference of Building Officials of 1979 published a general methodology for assessing disasters[102], it is not specific for earthquakes, but has a similar form to RDA. A Japanese method was published for assessing, with three stages of damage in concrete structures[142].

Documents with remarkable importance for beginnings of RDA are publish in 1988 by American Society of Civil Engineers (ASCE) for Federal Emergency Management Agency (FEMA). These documents aim to advance the manual Seismic Evaluation of Existing Buildings ASCE 31-03 [99] to a prestandard Handbook for Seismic Evaluation of Existing Buildings FEMA-178 and standard for the American National Standards Institute, Handbook for the Seismic Evaluation of Buildings FEMA-310[73]. With current importance, the Applied Technology Council (ATC) from USA published in 1989 Procedures for Post-earthquake Safety Evaluation of Buildings (ATC-20)[19] commissioned by FEMA, California Governor's Office of Emergency Services and California Office of State wide Health Planning and Development[22]. This document includes procedures for RDA and DEM, but it not include engineering assessment.

General base of RDA: The ATC-20 guides with procedures to assess safety after earthquakes in common buildings in USA. It aims that two evaluations to the same building should have the same basic conclusion in terms of safety of habitability. One reason to have more methodologies based in ATC-20 is adaptation to local conditions in different countries, for example, common buildings. Collapses, foundation displacement, inclination, severe damages in structure or walls, fallings of non-structural elements, fissures or cracks and existence of other hazards are included. These criteria have different degrees of damage from no damage to severe.

Buildings with public use in emergencies should not be evaluated with RDA. The time span used for a RDA is relative to personnel in charge, but this lapse is reasonable between 10 and 75 minutes plus time to translate the personnel between buildings, compilation of data, analysis and reports[70,75]. The time span for a DEM could take up four hours and the engineering assessment usually takes weeks[18].

Some earthquakes-damaged buildings may be subject to fire. These buildings reduce their strength and stiffness due to high temperatures[45], however, RDA cannot be applied in these cases because these buildings need expensive numerical model.

Experiences of RDA: Just for appreciating the amount of damaged buildings in need of assessment, here three Colombian cities are shown as examples, Cali with population of 1'822.871, Pasto with 352.326, Bogotá, D. C. with 7'181.469, cities in a country with population of 44'164.417 in census[55]. Miyamoto[135] estimates that in urban zone of Pasto, 60% of buildings could be damaged with a degree of non-habitability and these 58.500 buildings should be assessment. Herrera et al[98] estimated that 94,6% of buildings of Valle de Aburrá have damages and that these buildings need to be assessed after an extreme-earthquake scenario. Plus, earthquake in Gorkha (M_w 7,8)[57] Nepal (2015), with 66.506 homes in a population of 271,061, in a country with 5'427.302 of homes for a population of 26'494.504[42], produced 498.852 collapsed buildings and other 256.697 partially damaged buildings[86]. Aftershocks of this earthquake lasted many days, one of them for 17 days after with M_w de 7,3 with 200 deaths more and 2,500 injured more and increase damage[83]. This situation show the necessity that assessment of damage must be rapid.

The Mexican Centro Nacional de Prevención de Desastres (National Centre of Disaster Prevention) has a rule and a manual for RDA[37]. It includes the Red Nacional de Evaluadores (RNE) (National Network of Evaluators). The RNE is compound by Civil Engineers and Architects with technical knowledge related to damages and earthquakes. In the event of disasters, the RNE invokes its members.

Although, in general, this methodology is similar in different countries, in Canada, poorly scoring buildings show a likely appropriate behaviour, in contrast highly scoring ones require the evaluation of more experienced engineers[161].

Due to earthquake in municipality of Lorca (Spain) in 2011 (M=5,1[108]), consequences of earthquake and performance of the Protección Civil were analysed.[155,165] Two hundred evaluators, in couple teams, used on an average 43 minutes to fulfil each RDA for 7.862 buildings. These RDA lasted one week according to their public plans. According to this experience, one could estimate that for Colombian estimates of damages in Pasto[135] and Valle de Aburrá[98], it requires participation of 1.488 and 8.423 evaluators respectively. Likewise, accepting that the Instituto Distrital de Gestión de Riesgos y Cambio Climático (IDIGER) (Local Institute of Risk Management and Climate Change)[103] reaches keeping 3.000 voluntary evaluators[104] and accepting evaluating of 60% of buildings in an extreme event according to Miyamoto[135], Bogotá will require three months to develop all necessary RDA.

It is important to point out that despite the fact that in Lorca, the acquisition of satellites images within the SAFER program of the E. U., the interpretation results were available just one week after. That is the reason why the field teams were more effective and the use of UAS has to receive more attention in the future.

Allali et al[10] show a technique with machine learning of fuzzy logic with a data test composed by RDA of earthquake in Boumerdes (Argelia) with M_w 6,8[139], reaching 90% of precision over conclusions of evaluators.

RDA from institutions: Results from RDA have importance for governments and they create rules and procedures based on these results. These nexus between results of RDA and rules affect to economic heritage and economy of a countries. It also affect psychosocial situation on people, attention of homeless people, immediate investment for demolish and future investment in repairs and reconstructions. There are officials documents for RDA, among others in Italy[29], Pasto (Colombia)[135], Manizales (Colombia)[23], Bogotá (Colombia)[23], El Salvador[11], México[37], Spain[82], Argentina[171], Guatemala[50], Chile[101,141] and Venezuela[159].

In Spain by real decree[92,93], for homologations and up integrating of emergency plans from territories, these plans must have immediate and punctual procedures to assess damages by catastrophes. Carreño et al[39] show an analysis of applications of RDA in former Yugoslavia, U.S.A., Japan, Mexico, Italy and Colombia. This analysis conclude that in spite of differences, the RDA is similar in these countries and these RDA have similar basic difficulties. The Grupo de Evaluación de Daños (Damage Assessment Group) as part of Plan Especial de Protección Civil ante Riesgo Sísmico (Special Civil Protection Plan for Seismic Risk)[172] in Murcia (Spain) has the main objective to validate in three days or maximum five days in extreme cases, the habitability of homes with structures type frames[58] or walls[59]. Classification of degree of damages is with code of colours: Green (habitable with no damages or irrelevant damages), yellow (restricted use with moderate structural damages), red (not habitable with severe structural damages) and black (collapse risk)[79]. For green cases is recommended a new DEM, but for others cases this DEM is mandatory.

El Salvador has the Comisión Evaluadora de Riesgos (CER) (Risk Assessment Commission)[187] with protocols and training procedures manual for professional post-earthquake evaluators[151]. The continuously updated database is part of an approved system by CER. The duration of each RDA by three evaluators takes from 15 to 60 minutes. The designed form for this purpose has fields for supporting final recommendation of habitability and other fields with other purposes. In the manual[151], there is no evidence of need for future use in recommendations in structural analysis and design.

In Guatemala[50,137], there are documents for RDA; a form with two pages includes estimates for global damage, sketches, requirement of specialized visit, habitability, safety procedures. Although not common in others countries, Guatemala includes approval of the visit of a community leader or owner. Others countries include a signature as a witness to the visit, but no approval. This form includes protocols for evaluator team training and management and an unusual possibility of flooding

The Annexed A in Chilean norm of seismic design of buildings NCH433of96 is not mandatory[105], but it defines criteria and procedures for damages assessment and guides in structural recovery, it refers without being explicit, damages grades of mild, moderate and severe[37]. It includes instructions for technical damage assessment based in experiences from Japan, Turkey and U.S.A. among others. Chile has a network of volunteers as part of the Unidad de Evaluación Estructural Rápida (Rapid Structural Assessment Unit)[169]. Chilean RDA form[141] shows that if external inspection shows a severe damage, an internal inspection should not be done and the buildings should be marked as unsafe.

The evaluator kit has a minimum, evaluator safety, length and slope measurement and a basic calculator. The ratings slopes are less than 1.7%, greater than 3% and the range. These deformations, although they are plastic, could be compared with limits of elastic drift in other Latin-American countries like Colombia and Ecuador with 1%[162] y 2%[132] respectively. Chile has a guide[101] based in the GUÍA AIS[80] by Asociación Colombiana de Ingeniería Sísmica (AIS).

The Colombian document base for RDA is Guía Técnica para Inspección de Edificaciones Después de un Sismo [24], it was updated and improved in GUÍA AIS[80] including a form[25]. This document includes the year of construction with periods based in validity period of Colombian laws. Limits of these periods are 1984, 1997 and it is easy to think that 2010 will be included with the current rules. This document has also included 1930 due to the importance in the construction of tall and complex buildings worldwide[47]. Although generally RDA has three classes of global damage with label of colour green, yellow and red, Colombia without the proposed RDA of San Juan de Pasto[136], it includes four degrees of damages with labels with their colours. These degrees of damage are habitable for none or mild damages (green), restricted use for moderate damages (yellow), non-habitable for strong damages (orange) and no habitable with collapse risk for severe damages (red).

City of San Juan de Pasto (Colombia) with phase I of the program PREPARE[135] supported by OFDA - USAID[184] estimates that with an earthquake with Aa in rock of 0.25g, deaths may be up to 5.200 people, 43.000 injuries and 58.500 buildings not habitable (60% of all). Phase II of PREPARE shows a new proposal of form for RDA[136]. This form proposal simplifies the form in AIS.[25] To facilitate future studies with live load, this form uses types of buildings based in uses from the valid Colombian norm. This document uses structural systems which are easy to identify in a sidewalk for RDA. The global damage classification for internationalization purposes only has three degrees of damage: habitable, restricted use, non-habitable with green, yellow and red respectively and without orange.

City of Manizales (Colombia) based in GUÍA AIS[24,80] has a new version of form including a field manual[23] and procedures of RDA[149]. This document has specific structural topics for floor hard to identify like steel profile without shear connectors (shear stud or others). It changes year of construction from 1930 to 1950 and 1984 to 1982; qualification of collapse from yes, partial or no for total, superior to 50%, inferior to 50% and no; from none, mild, moderate, strong and severe to percentages of damage in different structural elements, and so on minor changes. It includes more discriminants for habitability, separating global stability, geotechnical, structural and non-structural threats. Risk of habitability (low, low after preventive measures, high and very high) depends on data filled in forms. This link between inserted data and final grade is not general in other RDAs studied, but the link is less strong with RVS of FEMA-154[70].

To support information management, fieldwork in evaluation, less time to collect data and to increase reliability, applications for tablets y smartphones have been developed[102,188]. The software with Machine Learning “Evaluación del Daño Sísmico en Edificios EDE” (Seismic Damage Assessment for Buildings) seeks to contribute to the solution of problems derived from different degree of damage in RDA for the same building[40,41].

Similarly, an automatic real-time system has been developed to assess damage in Bogotá (Colombia)[38]. It works with a network of accelerometers in rock, modelling the dynamic response of soil and creating accelerograms in surface, a probabilistic map of damages for collapse and human deaths and finally sends an automatic email and SMS (Short Message Service) to authorities with relevant information.

AR (augmented Reality) has been tested to assess damages.[112,113] Training courses are held like IDIGER for the Grupo de Ayuda para Inspección de Edificaciones después de un Sismo (Inspection Assistant Group for Buildings after Earthquakes)[104]. This experience shows an exercise of training in RDA to the same building, with more than 300 engineers and architects, these results have important differences. The evaluators rated the general condition of the building with 40% restricted use and 40% habitable. For geotechnical problems, the evaluators rated with 47% with restricted use and 33% with habitable. For problems in non-structural elements, the evaluators graded the building with 42% habitable and with 38% restricted use. For structural damages in the more affected storey, evaluators graded the building with 48% restricted use and 33% habitable. For global damage and habitability, the evaluators rated 46% restricted use, 21% non-habitable and 26% habitable[156].

DEM: DEM is defined in ATC-20[21], this methodology qualifies habitability in buildings[19] for emergency care and in buildings with questionable RDA and RDA rated with restricted use or unsafe. It is an RVS. It has a difference with teams in RDA; teams in DEM have two structural engineers or one structural engineer plus a builder inspector. DEM is more detailed than RDA. RDA uses six basic criteria, but DEM uses 21. RDA rates the possibility of collapse and foundation problems with single criteria, but DEM separates the collapse and foundation. RDA join all damages to structural components and DEM separates roofs and floors, vertical support elements, diaphragms, walls and precast connections. RDA unites the hazards of falling objects, but DEM separates parapets, cladding, ceilings, partitions, elevators, stairs, electric and gas system. RDA uses a single criterion for geotechnical assessment, but DEM uses slope failures and ground movements. RDA has unique criteria for other not-specific problems, but DEM uses four possibilities of not-specific problems.

A particular case of DEM is for health care-oriented buildings because it directly affects earthquake victims [157]. The particular situation is the need for verification of structural and non-structural components in addition to verification of components for vital services. Results of DEM in hospitals, for example, may be in unusable building due to failures of water, gases and fire systems. The cases of this type of results are Olive View Hospital affected by earthquake of Northridge (M_L 6,7) de 1994[27,167] and other cases in Chile (M_W 8,8)[133].

Predictive RVS

Qualitative studies of damage prediction with RVS are conservatives [18]. The main basis of these studies is the information crossing between structural typologies with a single parameter for description of the earthquake[116], usually peak ground acceleration[160]. The RVS cannot represent the complete characteristics of the same type building (number of storeys, diaphragms, architectural entrances and ledges, changes on materials etc.), neither more characteristics of earthquake (frequencies, lapse of time with strong movement, amplitude etc.) and nor complexity of geological zone and soil of foundation.

The ATC for FEMA developed FEMA 154 [75] and FEMA 155 [70] with different versions, these documents have been the support for other documents in different countries. Buildings evaluated under the criteria of these documents have a rating of zero to seven. The purpose is to identify possible preliminary threats for future evaluation of professionals experienced in seismic design or the estimation of good seismic performance. The forms of RVS according seismic zones[185] with FEMA 154 characterize buildings in two classes, buildings with a good seismic performance and buildings with the need of a detailed evaluation for professionals experienced in seismic design. The threshold grade is two; buildings lower than this threshold have a poor seismic performance and they need to evaluate again for qualified personal.

The evaluation process begins with a basic rate for each type of structure and continues to apply modifiers that increase or decrease the initial rate. These modifiers depend on height, irregularities, year of construction versus validity of rules and their updates.

The RVS give a knowledge about seismic risk in buildings.[8,43,135] This is a simple and effective method previous to earthquakes, with sidewalks with forms used for RDA and DEM. In this methodology personnel experienced and training review different aspects, age of construction, materials, number of storeys[6], weak storeys, excessive loads, pounding effect, topographic effect, visual quality of construction[9], structural typology, seismic zone, soil conditions, plane and vertical irregularities, short column etc. These kind of studies include data collection to manage risk[134]. Sidewalks surveys and numerical models of different types of structures are the basis for ratings on this methodology.

Including the year of construction in this methodology is due to the increased risk when the population in the houses increases before the building codes[111]. Victims of more than 1100 strong earthquakes in XX century are more than million and half, more of them for collapsed buildings with more than 90% of direct deaths[115]. It has a clear relation of the fact that buildings before construction codes do not have seismic provisions[171] and that these buildings are responsible for the most part of victims and damages[196].

Riaño et al[164] showed a study with future utility for Predictive RVS, it has a 3D simulation in a big scale of earth crust of 100x50x18,75 Km^3 around Bogotá D. C. (Colombia). It uses a distribution of V_s, scenario with earthquake Quetame (M_L 5,7[173]), a model of digital elevation with 30m of resolution or ground sample distance. The calculus was made with a supercomputer with 19.200

processors, for more than de 665 million of nodes and more than 626 million of finite elements of size of minimum 10 m.

Montaña[138] showed an academic exercise of estimation damages for Bogotá D. C. (Colombia). It is a probabilistic analysis of earthquake occurrence and the probability of damages to typical structures in that city versus earthquake magnitude ranges.

Probability damage is an adaptation of Hazus[77], the exposition model is an random distribution with cadastre information in ranges. These ranges are previous to CCCSR-84[163] (70%) from 1985 to 1999 (20%) and posterior to 1999 (10%).

Miyamoto[135] for city of Pasto used two scenarios (day and night), peak ground acceleration of 0,25g, exposition model with 36 homogeneous zones and 22 special buildings, eight structural types with fragility curves similar to Hazus[77] and Openquake[191]. Estimations are 31% and 29% of buildings with a rate of insecure with labels in yellow and red. This percentage represent around 30.500 and 28.000 buildings respectively.

Herrera et al[98] showed an analysis for Valle de Aburrá (Colombia), It has six seismic scenarios with different intensities, hypocenters, geological failures, magnitudes 6,05 to 7.86 and vulnerability curves for types of structures. Results with more critical scenario have 1'0324.588 homeless people and 331.100 buildings with moderate and severe damages.

Damage assessment with imagery

Emergency answer and safety assessment have support in data, their visualization in 3D representation with geolocalization and sequence[76]. Kortowo campus of Warmia and Mazury University (Poland) has a 2 km^2 test field to assess the accuracy of the image measurements. Testes were performed with camera Phase One iXU-RS 1000 of 101 MP and the Light Detection and Ranging (LiDAR) Riegl LMS-Q680i to 400 kHz with pulses NIR with 25 pts/m^2. The fly altitude was 220 m over ground and a ground sample distance (GSD) of 2 cm. The accuracy achieved in terms of root mean square error was 3,2 cm for images with camera Phase One and less than 2 cm for LiDAR[84].

Sources for generating images: Satellites contribute terrestrial views for assessment and prediction of natural hazards[7,33,46,89], but it pays little attention to the development of methodologies to detect minor damages in buildings[121]. Examples of use of this kind imagery are the earthquake in Ban (Iran) in 2003[189], other uses being for natural hazard with VIEWS™ system.[3,88,128]

Synthetic Aperture Radar (SAR) images combine information from many scans creating a "single virtual scan", it uses Differential Interferometric and Persistent Scatterer Interferometry techniques to improve accuracy[53]. The advantages of SAR over optic sensors are that SAR does not depend on light and atmospheric conditions[78].

LiDAR images are analogue to radar[65], but using laser. Its use is associated to temporal-space detection of changes in 3D with high precision[150]. It needs data in different moments to classification. The ecology classifies the works in multi-temporal if moments have a time of difference greater than one month and hyper-temporal if the time of difference is less[66]. The best precision vertical/ horizontal register by Glennie[90] is 5/20 cm and 15/75 cm for airplanes flying at 500 m and 3.000 m altitude respectively[90]; this accuracy may improve if the altitude is lower like in UAS.

Red Green Blue (RGB) images are captured in the visible electromagnetic spectrum with wavelength of 0,4 to 0,8 μm. These images in a digital form have assigned a model of "colour" perception where each pixel is formed with a triplet with components red, green and blue.[48,158] For a different use, RGB is generally transformed to other non-perceptual models like HSV, HSB, HIS and a new RPT proposal[56].

RGB-Depth (RGB-D) images combine colour information from RGB sensors with distance information from laser measurements. These images are also called time-of-flight-based (ToF) in small devises like smartphones.[26,32,63,81,106,107,110,114,131,143,193,194] Multispectral images have information from different ranges of electromagnetic radiation, generally combine visible radiation with other infrared and ultraviolet radiation.[130,154]

Visual interpretation technique: This technique uses satellites or aerial imagery, data, GIS system and experienced human operators. It require long process[180] so this methodology is not part of the RDA technique.

Lei et al[117] demonstrate the use of high-resolution aerial imagery, visual interpretation and interpolation for collapsed houses in the Wenchuan earthquake (China M=7,9[108]). It reports collapsed houses when the situation is difficult to repair. Despite the high-resolution images, it is possible to identify collapsed houses, but is difficult to identify the degree of damage. This work gives credibility to the precision in the visual interpretation because the computer interpretation at the time was in an exploration stage.

Automatic interpretation techniques: Automated machine learning with supervised and unsupervised (self-organization) techniques[123] is the common process for damage assessment and image-based object classification[31]. Gümüşbuğa[95] shows UAS technologies for disaster emergency response, aerial traffic needs, aircraft selection, algorithms for real time aerial-routs and training for personnel in simulated scenarios.

Hermosilla and Ruiz[97] proposed and compares building detection methods for image-based object classification with thresholds and shadows in buildings. It includes a complexion index to measure the percentage of real buildings that are in the same place with automatic detection of buildings in urban and industrial areas. Index reaches 100%, which is very important for RDA with automatic interpretation, because the data extracted from the images should assign to the same building[85].

Techniques with previous and posterior earthquakes images: It is important to consider that with images with different dates, there could be changes in the elements such as demolitions, dismantling and repairs[126]. Furthermore, if UAS is used, the morphology of the study area is important for optimal flight planning[64].

Gamba et al[85] showed analysis of RADATT project[67] due to RADATT which is geared towards estimates of the extent of earthquake damage. Some problems encountered are that a simple image comparison is not robust enough for the presence of noise, different light and weather conditions and the position of the sensor. The procedure includes the detection of collinear edges, the grouping of edges with intersection around 90° and configuration of the outline to represent hypothesis of quadrangular buildings. This methodology was satisfactory in earthquakes of Irpinia (Italy Nov. 23th, 1980 M=6,0[108]), Umbria (Italy Oct., 1997 to May, 1998 M=6,0 [108]) and Egión (Greece June 15th, 1995 Ms=6,3 [108])[176].

Tong et al[177] used high resolution stereo images from satellite IKONOS[17] with GSD of 1,1 m in ground and precision of 1,5 m in altitude. This methodology proposed estimates of the areas of damage using the vertical component. It manages to detect a collapsed individual building. In addition, it manages to detect how many storeys have collapsed. The study area was Dujiangyan (China) affected by earthquake Wenchuan in 2008[190].

Tu et al[179] compared the semantic features in WorldView-2 satellite imagery scenes to 50 cm of pixel[87] of an earthquake using Support Vector Machines (SVM). This method was used on Longtou Hill in Yunnan (China) affected by the Ludian earthquake (Ago. 3, 2014 Mn 6,1)[30].

Matsuoka and Nojima[126] showed a damage analysis method based on seismic intensity functions for Japan, images before and after earthquake with 30 m of precision from ALOS satellite. ALOS uses SAR and human ground damage assessors. Results on the correlation and backscatter difference at 2.000 random pixels for each zone with different damage rates were assessed on the ground by human assessors in the Kobe earthquake (1995). It also applies the model with good results to the images of the same satellite in Pisco (Peru) after earthquake (2007).

Tu et al[180] showed a method for different degrees of damages using GIS with satellite imagery before earthquake. It generates vector buildings with area and height; it compared previous earthquakes images with posterior earthquakes images. It calculates height with shadows detection and it estimates damage with roof texture with an SVM. This method was tested with good performance in Beichuan (China), correlating with another method show in Tong et al.[178]

Adams and Huyck[4] described the use of the methodology developed to be applied in Marmara (Turkey) with moderate resolution images, but it was applied in Bormedes (Algeria) and Bam (Iran) with submetric high resolution images from the IKONOS satellite.

Techniques with only posterior images: These techniques detect damage-building zones based on the extraction of images features only with post-earthquakes images and GIS[180]. Dong et al[62] used of identification of two patterns of straight lines (mean length and slop) in 2D images. This could have different degrees of damages in specific "windows" (image sector) analysed.

Li et al[121] detected holes in rural houses caused by earthquakes using supervised machine learning with only posterior earthquakes images. The images were taken from UAS. Hua et al[100] showed collapsed buildings using imagery from UAS and give recommendations for assign the limited resources for rescue process.

Li et al[119] detected building collapse using high sub-metric vertical resolution images, morphologic texture and spectral information to characterize debris of collapse of built-up structures. It was tested in Jiegu Country (China) affected by earthquake Yushu[30]; it shows effectiveness for fast detection, but there is no validation with more images for different areas with more scenes with different degree of damage.

Li and Tang[120] used spectral and morphologic information with images from UAS and external shape vectors from previous high-resolution satellite images and manual interpretation. It classifies buildings as almost intact, slight damage, partial collapse and totally collapse. It has simulations with earthquakes in Wenchuan (China M=7,9[108]) and Ya'an (China M=6.6[108]) for verification with good results.

Techniques with DSM comparison: DSM generally comes from laser measurements, 2D or stereo images matching, traditional surveying and blending of them. Pang et al[152] classified objects into buildings and non-buildings based on the gradient histogram (HODOL). Buildings show regularity in HODOL diagram and other objects show irregularity. This study is not intended to detect damage, but its ability to distinguish between buildings and non-buildings could be used in automatic urban image analysis.

Liu et al[122] used LiDAR and 3D-shape signature. It calculates 100.000 times in each type building from random exterior points. It uses distance, slope, area, volume, aspect and Delaunay Triangulation[2] in isolated buildings with four roof types. 3D-shape signature comes from histograms with 50 intervals of each parameter. It uses 0.99 as a threshold between damaged building and not damaged buildings. This technique could continue developing for RDA, especially for isolated buildings without DSM before earthquake.

Other techniques for damage assessment

After RDA and/or DEM, these could have numerical model structural engineering studies performed by more experienced staff. Quantitative engineering studies in buildings non instrumented are known as seismic vulnerability. These studies are based in FEMA 154[72], FEMA 310[73] and updates of ASCE 41-17[12] and the FEMA 178[44]. In general, these studies seek to establish a level of seismic performance. It could start with an RVS-like verification with experienced engineers and subsequent phases need foundation-soil and material testing, lineal and no lineal numerical models[195], static and dynamic analysis[168] and others. To establish typical budget to repair one could use FEMA 156[74] and FEMA 157[96]. Recommendations of structural repairs could use FEMA 356[13], FEMA 273[34] and FEMA 274[35].

Colombian engineering studies for buildings with moderate and severe damages must follow the rules shown in Reglamento NSR10 (seismic Colombian code)[162], specially chapter A.10; alternatively these studies could based on ASCE 41-06[14] updated in ASCE 41-17[15], FEMA-356[13], ATC-40[20] and ASCE 41-13[16].

The safety levels defined in FEMA 356[13,140] and FEMA 310[73] refer to performance for immediate occupancy, safety of life and prevention of collapse over a 50-years life cycle. The specific hazard is a probability of exceedance in 50%, 20%, 10% and 2%. In contrast, RDA and DEM give a habitability recommendation without characterizing hazard.

Structural Health Monitoring (SHM) are studies with buildings instrumented for damage assessment. Marulanda et al[124] identified the damage with changes on static and dynamic structural characteristics, model analytically the global behaviour and interpret data, but this technique does not do destructive test[36]. Doebling et al[60] showed that SHM methods use changes in natural frequencies, modal shapes, dynamic measures of flexibility and update of the stiffness matrix. Doebling et al[61] defined the pre-earthquake state as an initial state without damage. Conclusion details are level 1 for damage existence, level 2 for localization of damage, level 3 for severity and level 4 for remaining cycle life. With a SHM implemented before the earthquake and operating after the earthquake, it is possible to automate the interpretation of data in real time and allow it to be included as a non-RVS-based RDA technique.

The International Search and Rescue Advisory Group (INSARAG) created in 1991 by the Urban Search and Rescue (USAR) teams includes guidance documents for the preparation, cooperation and coordination of assistance in a disaster area with structural collapse[145]. Structural evaluation required for INSARAG is for scope, location and type of damages for the rescue of alive victims, but it is not for establish habitability as RDA does. USAR groups, also known as BREAC[129], are under cover OCHA[182]. They do activities for administration, search, rescue, medical assistance and logistic assistance.

Guides INSARAG[147] establish a requisite for USAR teams in levels Median and Heavy, a member known as structural engineering.[146,148] This member must provide practical solutions for structural instability, structural safety and how unsafe structure becomes safe, monitors and coordinates implementation to shore up and remove structure layers. Technologies for technical rescue are being developed and are part of calculation tools for aftershocks with residual structural capacity (observed damage versus remaining capacity)[71].

A relevant case supporting the for these technologies is the collapse of World Trade Center in New York (11S) in 2001 where 343 members of the Fire Department of New York lost their lives[51,183], part of the 3.000 deaths[1]. Despite search and rescue is the "speciality" with the most technological advances and more attention for USAR teams[54], the Twin Towers collapsed over rescue personnel, but rescuers did not have information about remaining structural capacity of affected structures.

Conclusion

RDA with years of construction based on validity of the seismic codes shows direct contribution in estimation of seismic performance of buildings. The data from RDA forms are systematizable. It is useful for future recommendations in seismic structural analysis and design and good practices construction techniques. Results show that the RDA can be used in training of machine learning to contribute to appropriate decision making.

RVS-based RDA is an excellent tool for non-habitability decision making for earthquakes-affected buildings with visible structural problems. It saves lives and defines the demolitions necessary to prevent future casualties by aftershocks. However, for buildings with important-loss of seismic capacity, but not obvious, RVS-based RDA does not warn of the danger of loss of life in aftershocks. Personnel not properly trained to develop RDAs, evaluating buildings with no apparent earthquakes deterioration, will not ensure that meeting the criteria of two RDAs in the same building with different evaluators had the same basic conclusion.

Collecting and analysing aerial and/or satellite image measurements data could contribute as an alternative RDA method of determining habitability in earthquake-affected buildings. A problem in the assessment of earthquake damage with previous and subsequent images is that if the acquisition dates are distant, there could be change in the buildings evaluated. Although the previous and posterior imaging methods show better results than the posterior imaging only methods, many areas with no previous imaging or low-resolution previous imaging require posterior imaging-only methods.

SHM-based RDA contributes to disaster prevention when it detects damage in a timely manner and becomes an excellent RDA technique for emergency care buildings because its methodology takes a relatively short time to obtain reliable results. The RDA carried out by USAR teams does not intend to conceive habitability, but needs a study of the remaining resistance in collapsed buildings or in buildings with severe damages.

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(Received 14th October 2020, accepted 08th January 2021)

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