Comparison of vulnerability methods at urban scale in of view of their application to the city of Oran (Algeria)

A. SENOUCI
GEORAN -Univ. Es-Senia, University of Sciences and Technology of Oran, Algeria

P.Y. BARD
ISTERRE, Joseph Fourier - Grenoble 1 University, France

M.N. FARSI
National Earthquake Engineering Centre (CGS), Algeria

E. BECK & S. CARTIER
PACTE UMR 5194 CNRS, Joseph Fourier - Grenoble 1 University, France

SUMMARY:
The Algerian legislation, through the amendment to the 90/29 law related to urban planning after the 2003 Boumerdès earthquake, requests the urban planners to reduce the exposure to natural hazards. Vulnerability evaluation is indeed a good tool to raise the awareness of architects and urban planners about the need for seismic risk mitigation. This is however uneasy because of the combination of several aspects related to the inherited urban fabrics: historical dimension, unconformity with seismic buildings regulation, aging, current urban challenges, complexity and difficulty of urban intervention. Assessing the vulnerability of a city thus requires considerable resources, increasing with its size and the level of sophistication of the method. In view of "optimizing" the limited available resources, we conducted a methodological comparison between three approaches to assess the vulnerability at urban scale: the Italian GNDT method (1988), the European RISK-EU method (2003) and the French VULNERALP method (2005). The present study will highlight their differences and similarities, identifying the key input information, the associated reliability and their respective contribution to the end result. An important goal is in particular to quantify the degree of reliability of the vulnerability index values that can be derived from the actually available data in Oran. This comparison shows that the importance of a given parameter depends on the method considered. This in turn allows discussing various possible options by identifying the key parameters to collect during future urban surveys, and comparing the use of one "preferred" single method or the simultaneous use of different methods, in order to better combine robustness, reliability and cost-effectiveness.

Keywords: Vulnerability, urban scale, vulnerability parameters, survey

1. INTRODUCTION

Several methods for vulnerability evaluation at urban scale have emerged since the 80s of the last century. They are derived from each other and adapted to particular context. The choice of the most appropriate method to be selected arises for each urban vulnerability study. The present study is intended to compare three methods based on the use of a vulnerability index, GNDT 2 (Benedetti et al., 1988; Méditerranée CETE, 2008), RISK-EU LM1(Milutinovic and Trendafiloski, 2003; Giovinazzi and Lagomarsino, 2004; Lagomarsino and Giovinazzi, 2006), and VULNERALP 2.0 (Guéguen et al., 2007; Dunand and Gueguen, 2012). The comparison is here limited to the parameters used to estimate the vulnerability index. As a first step, for each method, the relative importance of every parameter (i.e., factors taken into account for the evaluation of the vulnerability index) is assessed on the basis of their relative weight in determining the total score; this allows to identify the key parameters in each method and to set the ground for a quantitative comparison. The second step consists in comparing the actual technical content of the parameters. This comparative study is presented here only for masonry buildings, but the internal consistency of the methods probably allows to extend these results to reinforced concrete buildings.

2. COMPARISON OF PARAMETERS WEIGHTS

The GNDT method is the oldest one and was used as a basis to develop RISK-EU and VULNERALP. So, in this comparison these methods are formatted in the GNDT format. The transformation is more significant for RISK-EU than for VULNERALP, since the latter explicitly uses the same format as GNDT. Within the same method, the parameters do not have the same weight in the final vulnerability index. Thus the measure of this importance is based on the weight assigned to each parameter in each scoring system.

2.1. Weights of GNDT parameters

The scoring system of GNDT is based on four classes of increasing vulnerability, A, B, C, D. Class A=0 is the minimum vulnerability and Class D is the maximum score (45). To estimate the importance of the contribution of each parameter in the final vulnerability index, the maximum variability of vulnerability parameter (difference between the values of classes A and D, i.e., generally 45) is multiplied by the corresponding weight and expressed as a percentage of the maximum variability of the final index of vulnerability. In fact, for a masonry building, the index IV varies, before normalization from 0 to 382.5. In percentage terms this variation is equivalent to the variation of IV from 0 to 100% of vulnerability.

Table 1: Expression of the maximum variability of parameters IVi GNDT as a percentage of the maximum variability of IV

Parameters	Maximum variability of the value of the vulnerability index			
	Iv_i^{max}- Iv_i^{min}	Weight	% of IV max	Hierarchy
1 – Resisting system type	45	1	11,8	**II**
2 – Resisting system quality	45	0,25	2,9	**IV**
3 – Conventional seismic strength	45	1,5	17,6	**I**
4- Location and soil condition	45	0,75	8,8	**III**
5 – Horizontal structures	45	1	11,8	**II**
6 – Plan shape	45	0,5	5,9	**III**
7 – Regularity in elevation	45	1	11,8	**II**
8 – Maximum distance between walls	45	0,25	2,9	**IV**
9 - Roof	45	1	11,8	**II**
10 – Non structural elements	45	0,25	2,9	**IV**
11 – Preservation state	45	1	11,8	**II**
Total	382,5	8,5	100	

The hierarchy of parameters according to their impact on IV is illustrated in Figure 1 . Four groups are distinguished: the first contains only one parameter, n° 3 (Table 1). The second contains five parameters exhibiting an equal relative weight (n° 1, 5, 7, 9, 11) of 11.8%. The third group is formed by the two parameters: n° 4 and 6. They represent 8% and 5.9% of the final IV. The fourth group includes the three parameters n° 2, 8 and 10, which have a small impact because their lowest weight (2.9%).

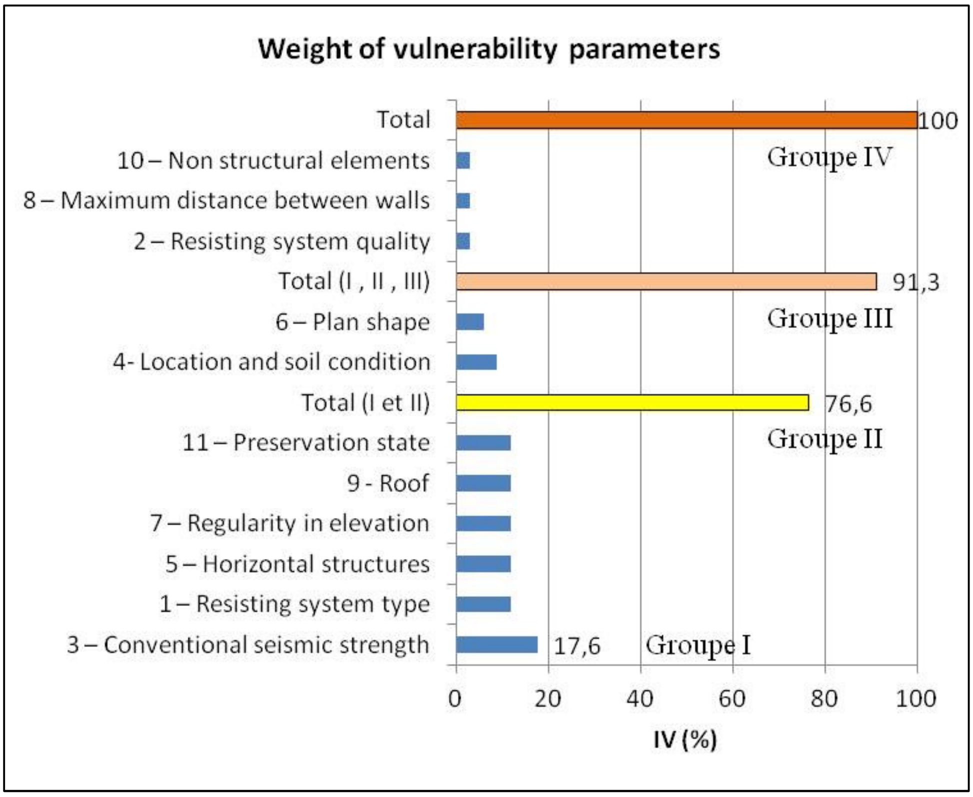

Figure 1: Relative weights of the 11 vulnerability parameters - GNDT Method

In the GNDT method, the key parameters that contribute the most (i.e., 75% of IV) are six. They belong to groups I and II (Table 1 and Figure 1): Conventional seismic strength (n°3), resisting system type (n°1), horizontal structures (n°5), regularity in elevation (n°7), roof type (n°9), and preservation state (n°11). The further consideration of the two additional parameters n°4 (location and soil condition), and n°6 (plan shape), allows to characterize up to 90% of IV total score. This kind of relative ranking allows to identify the parameters which should be given the highest priority in building surveys.

2.2. Weights of VULNERALP parameters

VULNERALP was derived from GNDT and adopts three levels of estimation of the vulnerability index IV. Level 1.0 is the most basic analysis. It is based on five parameters: resisting system type (n°1), location and soil condition (n°4), plan shape (n°6), regularity in elevation (n°7), and roof type (n°9). The level 1.1 uses the same parameters with more information. The index calculated in the first two levels is affected by an uncertainty interval because of the very rough analysis, and of the use of default values for non surveyed parameters (n°:2, 5, 8, 10, and 11). The level 2.0 includes all the GNDT parameters except n°3, conventional seismic strength, because the latter requires some mechanical analysis on the lateral seismic resistance. Only the level 2.0 is analyzed the present section, as it is the most comparable to GNDT. Levels 1.0 and 1.1 will however be included in the next section discussing the technical contents of each parameter. The relative weighting of the VULNERALP 2.0 parameters was estimated in exactly the same way as for GNDT, with the results show in Figure 2.

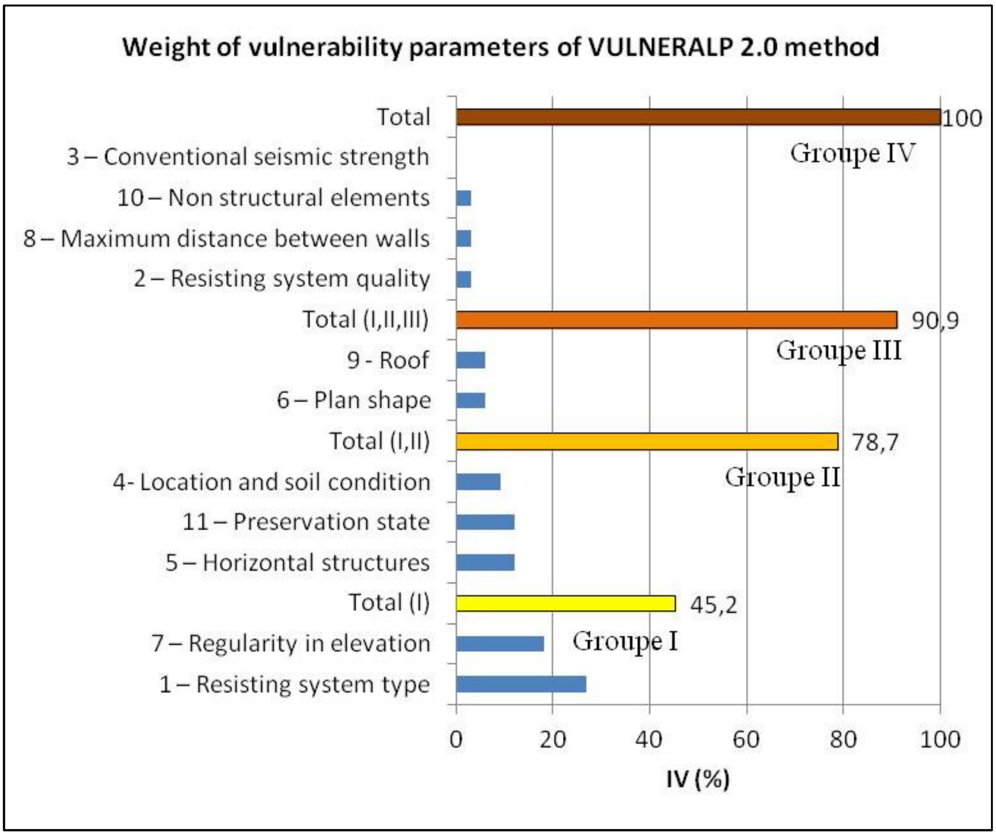

Figure 2: Relative weights of the 11 vulnerability parameters for VULNERALP2.0 method

The main parameters contributing up to 78% of VULNERALP IV are five, belonging to the first and second groups: n°1, 7, 5, 11, 4 (Figure 2). The addition of the two parameters of the third group n°6 and 5, the IV is determined up to 90%. The changes performed in the modifications from GNDT to VULNERALP have thus changed the original hierarchy of the GNDT parameters.

2.3. Weights of RISK-EU parameters

The scoring system RISK-EU LM1 has been translated into the GNDT format by grouping the so-called "modifying factors" ΔVm on the basis of their conformity / proximity to GNDT parameters (Senouci, 2012). The main difference of the RISK-EU approach compared to GNDT and VULNAERLAP is that it first assigns a "typological class" which indeed controls the major part of the final index V (Figure 3). Then the "modifying factors" ΔVm modulate this typological value, within some bounds that vary with the building type.

Establishing a hierarchy between the various "modifying factors" ΔVm, expressed according to their equivalence to the GNDT parameters, ha been achieved by scaling their effect to the total allowed variability, i.e., the Vmax-Vmin interval. This led to te identification of three main groups (Figure 4): The three parameters n° 7, 2 and 6 form the first group. The second group consists of three parameters n° 1, 4, and 11. The last group consists of one parameter n°4.

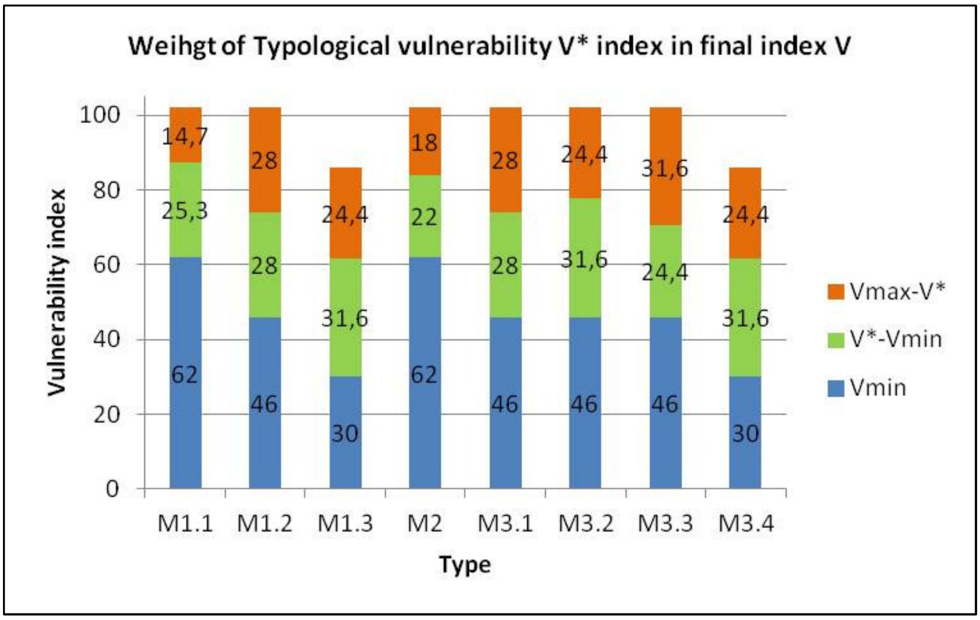

Figure 3: Range of variation of the vulnerability index V* (from Vmin to Vmax) for the main RISK-EU masonry typologies

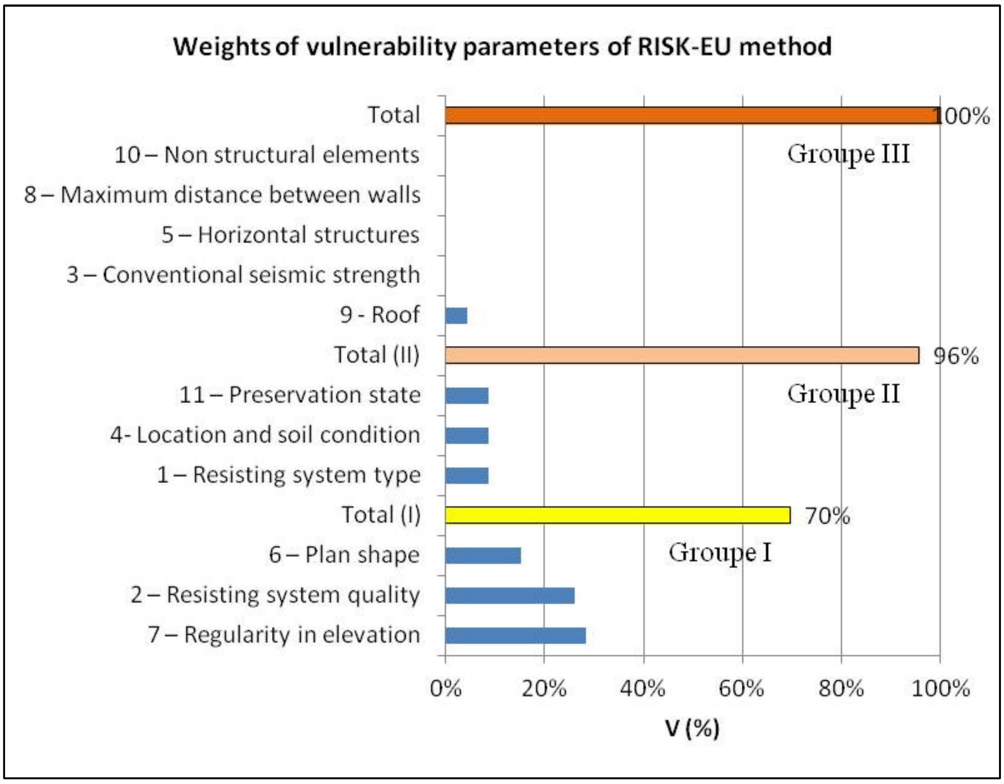

Figure 4: Weights of vulnerability parameters of RISK-EU method

The most important parameters in the RISK-EU approach beyond the typological class and its complement "number of floors", are thus three, which contribute to 70% of the final index V, regularity in elevation, resisting system quality, and plan shape.

3. COMPARISON OF PARAMETERS CONTENT

A detailed comparison of the definition and accounting of the 11 GNDT items would require much more space than allowed here. The focus will thus be given here only on the description and comparison of items n°1, 2, and 3, corresponding to the basic structural system. A full comparison can be found in Senouci (2012).

The RISK-EU scoring system differs from that of GNDT. The typological class defines the most part of the final index, from 60% to 80% for masonry building. It is then modulated by modifying factors ΔVm. The sum of the ΔVm has a limited influence (Figure 4). The maximum value of ΔVm to bring V up to Vmax varies from 14 to 31.6 depending on the typological class, while the minimum value to reach Vmin varies from -31.6 to -22 (Figure 3). In order to make these ΔVm comparable to GNDT values, these total modifying scores are expressed as a percentage. A positive sign corresponds to a vulnerability increase, while a negative score indicates a favourable situation leading to a decreased vulnerability. With the exception of rubble stone (M1.1) and adobe (M2) categories, the total modulation may reach 56 (Figure 3).

The differences between the technical contents of GNDT and VULNERALP parameters are maximum for the "downgraded" levels 1.0 and 1.1 of the VULNERALP approach. These two levels correspond to base level analysis when only very little information is available (a case which often occurs in low to moderate seismicity areas, and was one of the motivations behind the development of the VULNERALP method). They allow the use of simpler and lighter building surveys when only limited resources (financial, time, manpower) are available. The main changes affect the parameter weights and the values assigned to vulnerability classes (A, B, C, D). VULNERALP uses EMS98 building typology (G. Grünthal, 2001) to assess the parameter n°1 (structural resisting system), which is also considered as a proxy for GNDT item n°3 (conventional seismic strength) : the building type is thus given a largely dominant role in the determination of the final index IV, as it can represent up to 30% of the IV value.
The main item entering the GNDT definition of this first parameter is the existence and quality of wall ties, which is addressed in VULNERALP by the second parameter ("quality of the resisting system"). Even if the assignment of weights is different between the two methods, this "basic structural system" group of GNDT items n°1, 2 and 3 finally receives an equivalent weight in both methods (33% vs 32%). This amount is determined by two parameters (n° 1 with 11.8% and 3 with 17.7%) in GNDT and by a single parameter (n°1 with 30.41%) in VULNERALP.

The main changes between Vulneralp 1.0 and 1.1 levels, and Vulneralp 2.0 and GNDT, pertains to the uncertainty of the vulnerability index. In the former, only a range of values (minimum, mean, maximum) is provided to account for the uncertainties inherently associated with the limited amount of available information for these basic analysis levels. The principle impact lies in the parameter n°1, since the type of construction is reduced to the combination of building material (i.e., masonry) and construction date. The typology is slightly refined in the level 1.1, consisting of three types, but remains rather rudimentary.

Table 2: Technical contents of parameters n° 1, 2 and 3 for the GNDT method

Method: GNDT 2						
n°		Vulnerability classes Iv_i				Weihgt
		A	B	C	D	
1	Classe Iv_i	0	5	20	45	1
	% IV	0	1,31	5,23	11,76	
	Elements of the survey	New construction standards Existing building codes	Chaining at all levels	Good connection between walls	weak connection	
2	Classe Iv_i	0	5	25	45	0,25
	% IV	0,00	0,33	1,63	2,94	
	Elements of the survey	1 - Brick masonry of good quality, tuff masonry or stone of uniform size 2 - Masonry has sacco homogeneous connection provided between the two faces	Brick masonry, tuff or cut stones inhomogeneous or "a sacco" inhomogeneous with good connection between two facing	1 - roughly squared stone cut or brick of poor quality, presence of irregularities 2 - Masonry has sacco, or tuff stone with regular seated but no connection between the two facing	- irregular masonry - Brick masonry of poor quality with inclusion of pebbles - Masonry has sacco and no connection between the two facing	
3	Classe Iv_i	5	5	25	45	1,5
	% IV	1,96	1,96	9,80	17,65	
	Elements of the survey	$\alpha \leq 1$	$0.6 \leq \alpha < 1$	$0.4 \leq \alpha < 0.6$	$\alpha < 0.4$	

Table 3: Variability of the contents of parameters n°1 and 2 according to the analysis level in the VULNERALP approach

Parameter		**Méthode VULNERALP 2.0**				Weight
		Classes de vulnérabilité de VULNERALP				
		Classe1	Classe2	Classe3	Classe4	
1	Classe Value	5	15	25	45	2,5
	% IV	3,38	10,14	16,89	30,41	
	Elements of the survey	Brick masonry, concrete block-after 2000	* Massive stone; * Brick masonry-concrete blocks (between 1970 and 2000)	* Simple stone (1945-2000) ; * Brick masonry-concrete blocks (1970-2000)	* Rubble stone; * Adobe (earth bricks) ; * Simple stone (before 1970); * Brick masonry- Concrete (before 1945)	
2	Classe Value	0	5	45		0,25
	% IV	0,00	0,00	0,03		
	Elements of the survey	renovated	* chaining with vertical angles and tie rods on each floor	* no vertical angles and chaining ; with tie rods at each floor * chaining with the vertical angles and tie rods * without wall ties to vertical angles and tie rods		

Tableau 4: Definition and values for parameters n°1 and 2 in the VULNERALP 1.1 approach

Parameter		Method: VULNERALP 1.1												Weight
		minimum values				mean values					maximum value			
1	Classe Value	5	15	25	45	10	20	25	35	45	15	25	45	2,5
	% IV	3,6	10,8	18,0	32,3	7,2	14,4	18,0	25,1	32,3	10,8	18,0	32,3	
	Elements of the survey	Concrete block- after 1970;	Stone masonry-all periods; Concrete-block before 1970;	Adobe- after 1970;	Adobe- before 1970;	Concrete block- after 1970;	Stone masonry- after 1970; Concrete block -after 1970;	Stone masonry- before 1970	Adobe- after 1970;	Adobe- before 1970;	Concrete block- after 1970;	Stone masonry- after 1970; Concrete block-before 1970;	masonry stone- before 1970; Adobe- all periods;	
2		0				15					45			0,25
		0				1,1					3,2			

Tableau 5: Definition and values for parameters n°1 and 2 in the VULNERALP 1.0 approach

Parameter		VULNERALP 1.0						Poids
		Valeurs minimales		Valeurs moyennes			Valeur maximales	
1	Classe Value	5	15	20	25	30	45	2,5
	% IV	3,58	10,75	14,34	17,92	21,51	32,26	
	Elements of the survey	1970-2000	Before 1970	1970-2000	1945 -1970	Before 1945	all masonry construction	
2	Val, classe Ivi	0		15			45	0,25
	% IV	0		1,08			3,23	

Table 6: Definition and values for the RISK-EU modifying factors corresponding to GNDT parameters n° 1 and 2

GNDT paramater		RISK-EU		
Typological vulnerability index	% V	61,6	87,3	
	Elements of the survey	Building type		
1	% V	-2	2	6
	% (V^{max}-V^{min})	-3,57	3,57	10,71
		Number of floors		
	Elements of the survey	Low (1÷2)	Medium (3÷5)	High (≥6)
2	% V	-12	0	12
	% (V^{max}-V^{min})	-21,4	0	21,4
	Elements of the survey	**Structural system** *Wall thickness ; *Wall distance; *Wall connections, * Connection of horizontal structures **Retrofitting Intervention**		

This comparison of the technical description and contents of the various items contributing to the determination of the vulnerability index– out of which only a short extract was presented here -, does show that the three compared methods use indeed the same concepts, but arranged in different manners leading to some variation in the description of elements, and in the assigned weights. After a thorough comparison of all items, (Senouci, 2012) concludes that the RISK-EU approach is the method that requires the least information (compared to VULNERALP 2.0 and GNDT. The price to pay is the larger responsibility of the investigator in selecting the appropriate RISK-EU classes and approach, compared to the two other approaches.

4. CONCLUSION

The three methods of vulnerability evaluation at an urban scale globally share the same parameters. However, some differences can be identified through a detailed analysis. GNDT adds a quantitative analysis (item n°3) to a qualitative approach, while RISK-EU and VULNERALP adopt a strictly qualitative approach. Noticeable differences also lie in the weight assignment to the different vulnerability items, resulting in a varying hierarchy between the key parameters.. RISK-UE is the method that requires the least information, but the reliability of which is essentially based on the investigator.

The GNDT survey forms and the associated guidelines involve highly detailed and relevant on formation. Considering the tight connections between the "mother" technique GNDT, and the "daughter techniques VULNERALP and RISK-EU, it is highly recommended for the field investigators using VULNERALP and./or RISK-EU techniques to spend enough time on reading and assimilating the GNDT documents, in order to leave the smallest possible room for "uninformed subjectivity".

This methodological comparison of GNDT, RISK-EU, and VULNERALP methods is a part of a PhD thesis work (Senouci, 2012). In this work, these three methods are also applied to a part of the city of Oran (Algeria) to compare their results in terms of damage estimates for different earthquake scenarios. The results show on one hand that the VULNERALP and RISK-EU methods are characterized by relatively small uncertainties, given the availability of all required data. The GNDT approach is impaired by the impossibility of calculating the mechanical parameter n°3, which results in a significantly larger uncertainty. On the other hand, an overall agreement could be observed in the spatial distribution of damage, despite some variation in the absolute damage levels from one method to the other: the identification of the most sensitive and vulnerable areas is relatively robust.

Acknowledgements
This thesis work was prepared jointly at the host laboratory ISTERRE in Grenoble (France) with funding from the USTO MB-Oran (Algeria) University. We are very thankful to the authors or main contributors of the different vulnerability approaches (S. Lagomarsino (DICAT, Genoa, Italy) and C. Negulescu (BRGM Orléans, France) for RISK-EU, and P. Guéguen (ISTerre, Grenoble, France) for VULNERALP), for their help and provision of the basic documentation of these methods.

REFERENCES

Benedetti, D., Benzoni, G., Parisi, M.A. (1988). Seismic vulnerability and risk evaluation for old urban nuclei. *Earthquake Engineering & Structural Dynamics*, **16: 2**, 183–201.

CETE Méditerranée. (2008). Comparaison de méthodes qualitatives d'évaluation de la vulnérabilité des constructions aux séismes. Plan séisme - action 2.4.7. Guide des méthodes de diagnostics de la résistance des bâtiments aux séismes (Etude). www.planseisme.fr/IMG/pdf/comparaison_methodes_ vulnerabilite_sommaire.pdf.

Dunand, F., Gueguen, P. (2012). Comparison between seismic and domestic risk in moderate seismic hazard prone region: the Grenoble City (France) test site. *Nat. Hazards Earth Syst. Sci.* **12:2**, 511–526.

Grünthal, G. (editor) (1998), European Macroseismic Scale 1998. Cahiers du Centre Européen de Géodynamique et de Séismologie, 7, Luxembourg, 99 pp.

Giovinazzi, S & Lagomarsino, S. (2004), A macroseismic method for vulnerability assessment of buildings, proceedings of the 13th World Conference on Earthquake Engineering. Vancouver, B.C., Canada, August 1-6, 2004, Paper ID 896.

Guéguen, P., Michel, C., LeCorre, L., 2007. A simplified approach for vulnerability assessment in moderate-to-low seismic hazard regions: application to Grenoble (France). *Bulletin of Earthquake Engineering.* **5:3**, 467–490.

Lagomarsino, S., Giovinazzi, S., 2006. Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. *Bulletin of Earthquake Engineering* . **4:4**, 415–443.

Milutinovic Z. V. and G. S. Trendafiloski (2003). WP4: Vulnerability of current buildings. Risk-UE project Handbook. September 2003. Risk-UE project report. 111 pp.

Senouci, A., 2012. Apport de l'étude de la vulnérabilité au séisme dans la requalification des tissus urbains-Etude de cas : la ville d'Oran. Univérsité des Sciences de la Téchnologie d'Oran Mohamed Boudiaf. In Presse