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VULNERABILITY DATA COLLECTION AND DEFINITION OF SEISMIC RISK FOR CITIES IN PALESTINE

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Abstract. *This paper investigates the web with GIS functionality (WebGIS) realized by Eucentre (EUropean CENtre for Training and Research in Earthquake engineering) for SASPARM 2.0 (Support Action for Strengthening PAlestine capabilities for seismic Risk Mitigation) project [1]. The end users of the WebGIS are citizens, students, practitioners, governmental and non-governmental institutions. The platform represents a very useful and intuitive tool to load and manage data collected during the survey of residential buildings. Both practitioners and citizens can collect structural data for residential buildings by using two forms, different from each other only in terms of detail. The forms are organized into sections and they allow to identify the main geometrical and structural features of the surveyed buildings. The forms can be compiled directly on WebGIS or through two apps specifically created for Android operating system 4.0 and following. The apps enable the compilation of the fields also when internet connection is not available: data are stored on smartphone or tablet and then sent to the Web portal once internet connection is available. Starting from collected data, the seismic risk of each building is evaluated. In particular, the seismic demand to which each building is subjected to is defined from the hazard curve. In the specific case study of Nablus, the hazard curve is obtained by referring to the "West Bank and Gaza Strip: Seismic Hazard Distribution Map". For what concern the structural vulnerability, it is quantified through fragility curves. Fragility curves are defined for five damage levels [2] by using the mechanical method SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment) modified in order to represent the building environment in Nablus. By combining the hazard and the vulnerability of each building, it is possible to calculate the seismic risk.*

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1 INTRODUCTION

Earthquakes are one of the most catastrophic natural events, both in terms of casualties and economic losses. Nevertheless, the mitigation of seismic risk, which comes from the convolution of hazard (i.e. the measure of the shaking severity), exposure (i.e. the scale of the impact of the damage) and vulnerability (i.e. the measure of how a structure is prone to be damaged by the ground shaking), is possible. Since hazard and exposure cannot be reduced, the vulnerability is the only element on which it is conceivable to mitigate the seismic risk. This awareness highlighted the need to identify a process that estimates the seismic vulnerability of Palestinian residential buildings in Nablus, the city taken as a case study in the SASPARM 2.0 project [1]. The final product of SASPARM 2.0 is a WebGIS with multiple functions.

Collecting geometrical and structural data of residential buildings is one of the main WebGIS functions. Data are collected by using two forms defined according to the building environment of Nablus. The forms are different from each other only in terms of detail: practitioners compile the form with more details and citizens an easier one. The users can decide to fill in the forms directly on the WebGIS, at the tab dedicated to them (i.e. tab *Building Form – Practitioners* and tab *Building Form – Citizens*), or through two apps downloadable from the tab *Downloads* of the WebGIS. Once selected the building at the tab *Map* (see Figure 1), the WebGIS allows to check corresponding data.

Another function of the WebGIS is to determine the seismic vulnerability of buildings (i.e. tab *Fragility*). In particular, the seismic vulnerability is defined by fragility curves calculated through the mechanical method SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment) ([3] and [4]). SP-BELA is an analytical procedure implemented initially to assess the seismic vulnerability of Italian building stock. In the specific case of Palestine, SP-BELA has been modified to best perform the building environment of those territories. The fragility curves are determined for five damage levels (i.e. *DL1*…*DL5*) according to EMS98 (European Macroseismic Scale) scale [2] and associated to each building in relation to its structural type and its number of storeys.

Then, the hazard is defined as the probability of occurrence of an earthquake exceeding a certain threshold of intensity magnitude (i.e. PGA) in a given area and in a certain time window (i.e. tab *Hazard*).

Once defined both the vulnerability and the hazard, the WebGIS calculates the seismic risk of the selected building (i.e. tab *Risk*) for three different time windows, and suggests a series of retrofit measures (i.e. tab *Retrofit*) to reduce its seismic vulnerability and consequently the risk ([5] and [6]).

The above is described in detail in the next paragraphs where also a brief description of the building environment present in Nablus is proposed.

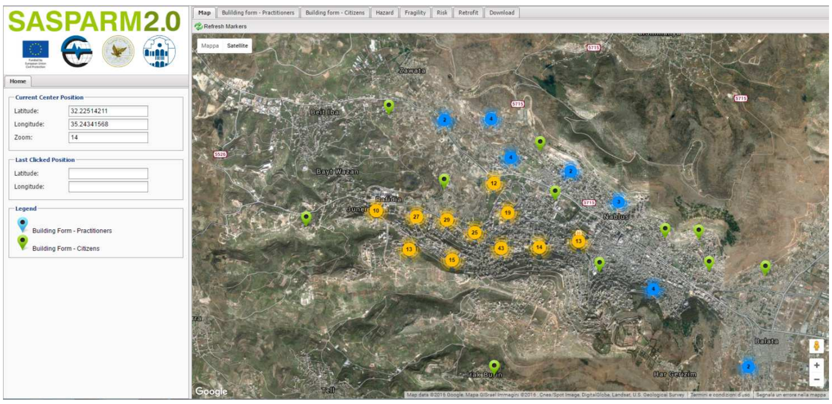


Figure 1: Tab *Map* - Screenshot of the initial view of the WebGIS that allows to select surveyed buildings.

2 BUILDING ENVIROMENT IN PALESTINE

In order to define survey forms adequate to assess the vulnerability of buildings, it has been necessary to identify the main structural types in the city of Nablus. Here the buildings are mainly new construction (see Figure 2) but seismically vulnerable as designed according to pre-code seismic standards. The latter, in fact, has been introduced only nowadays, when Palestine adopted the Jordan Code [7] which is very similar to Eurocode [8]. Figure 2 shows the buildings distribution in Nablus in relation to their year of construction: it has been obtained on the basis of data collected through the forms for practitioners filled in during the project that ended the 31st of December 2016 [1].

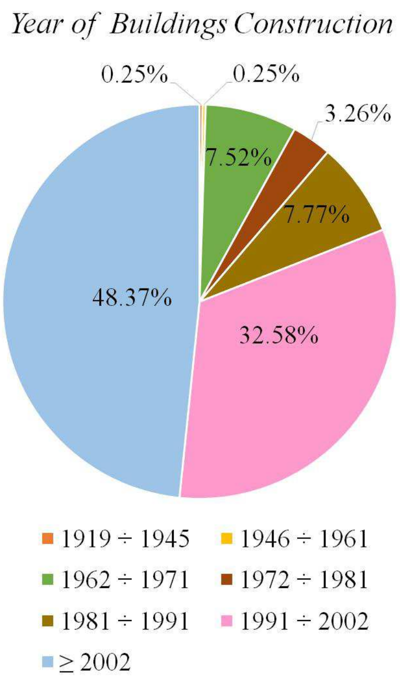


Figure 2: Distribution of buildings in Nablus in relation to their year of construction.

Nablus residential buildings can be grouped in four main structural classes:

- masonry buildings;
- reinforced concrete frame (RC) buildings;
- RC soft storey buildings (*pilotis*);
- RC shear wall buildings.

Masonry buildings are more regular both in plan and in elevation than RC ones. They have generally not more than 4 storeys and 1 or 2 bays in X-Y directions. Generally, masonry walls can be of two types:

a. the concrete is sandwiches between two surface layers of masonry stones, thus resulting in a wall thickness around 400-500 mm;

b. the masonry stones are installed row-by-row and then concrete is cast behind them via suitable framework, thus resulting in a wall with one-side masonry stones and the other side concrete surface. In recent days, concrete hollow blocks are generally used in lieu of framework so as to provide permanent support for the masonry walls. Such method generates a wall with concrete blocks on one side and masonry stones on the other side with filling concrete in between. This type of walls can have a thickness up to 350 mm.

For what concerns slabs, two types of slab construction are used. The first is a two-way solid slab with typical thickness around 200-250 mm. The second, instead, is a composite steel-concrete construction made of steel joists as supporting beams for the solid slabs. The result is a slab with typical thickness around 100-120 mm with simple reinforcement. While in the first type slab spans might range 4-5 meters, in the second type spans may range 5-7 m in both directions. Figure 3 shows some examples of masonry buildings in Nablus.

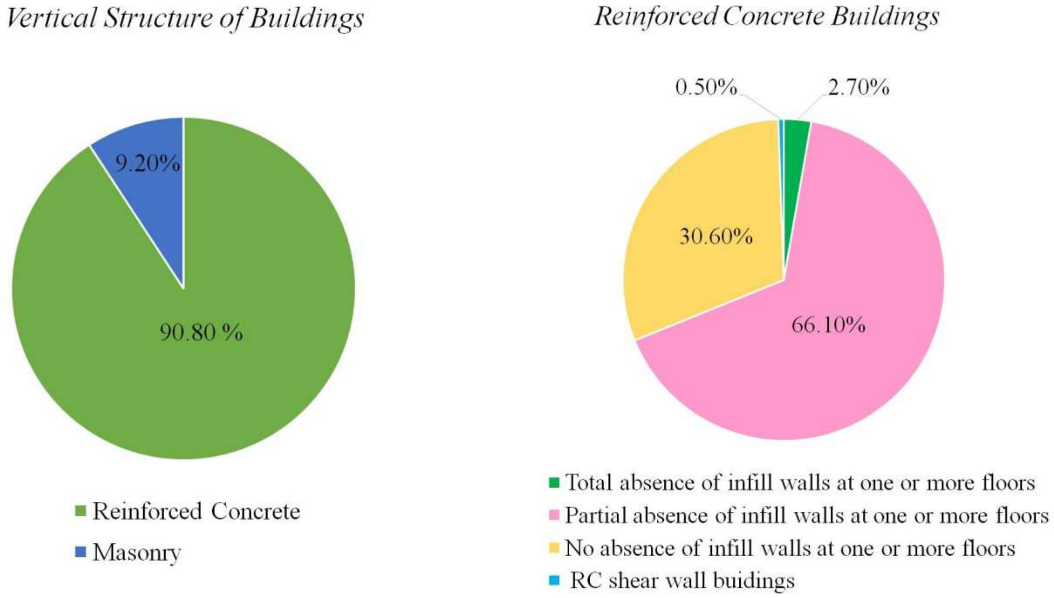
Figure 3: Masonry buildings in Nablus.

RC buildings can reach 15 storeys and have generally 2 or 3 bays in both directions. The resistant structural system can be either frames or shear walls, with consequent variation on the vulnerability level. The structural vulnerability, in fact, is higher for frame buildings than for shear walls ones, especially if frame buildings misses cladding partially or totally at one or more floors (i.e. soft storey buildings). Outer infill walls can be made of either three layers (i.e. hollow concrete blocks of 100 mm thickness, weak concrete layer of about 130 mm thickness, and stone layer of about 70 mm thickness) or only one layer thick from 150 to 200 mm, composed of hollow concrete blocks. Finally, slabs can have a one or two way ribbed slab system according to the plan dimensions of the building. Figure 4 shows some examples of the different types of RC buildings in Nablus.

(a) (b) (c)

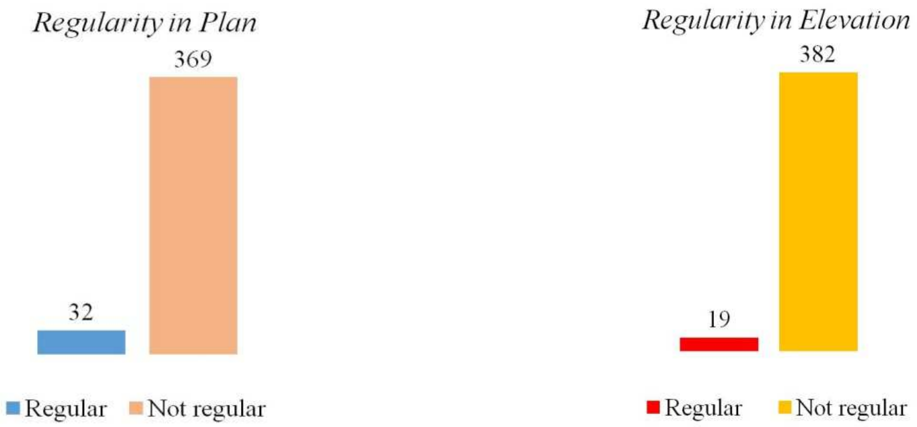
Figure 4: RC buildings in Nablus – (a) RC frame building, (b) RC soft storey building, and (c) RC shear wall building.

Figure 5 and Figure 6 document data collected by practitioners until now. In particular, pie-charts show that RC frame buildings are most common in Nablus (see Figure 5(a)) and that a large part of them has partial or total absence of infill walls (outer/inner) at one or more floors (i.e. soft storey buildings) (see Figure 5(b)). This causes a higher level of structural vulnerability, especially in case of irregularity of the building both in plan and in elevation. The irregularity, in fact, is a really common characteristic of Palestinian buildings, as shown in Figure 6. The latter, in fact, indicates the number of surveyed buildings in Nablus that are irregular respectively in plan (see Figure 6(a)) and in elevation (see Figure 6(b)).



(a) (b)

Figure 5: Distribution of structural types in Nablus - (a) Vertical structure of buildings, and (b) RC buildings.



(a) (b)

Figure 6: Distribution of buildings - (a) Regular/not regular in plan, and (b) Regular/not regular in elevation.

3 DATA COLLECTION

According to the different structural types in the city of Nablus, survey forms were created to collect geometrical and structural data to calculate the seismic vulnerability of residential buildings. In particular, the redacted forms are two and targeted to:

- citizens;
- practitioners.

The forms are different only in level of detail and allow to make a quick assessment of seismic performance of the building. Herein, buildings are considered as structural units of ordinary construction type (such as masonry, RC frames or walls) used for housing and/or services. Therefore, the forms are not suitable for monumental or specialized types (such as industrial depots, sport constructions, theaters, churches, etc.).

The forms can be compiled directly on the WebGIS platform at the tab *Building Form – Practitioners* and tab *Building Form – Citizens*.

Both forms start with a section devoted to information on the compiler, followed by the section named *Identification of the building*. Both sections are displayed in Figure 7.

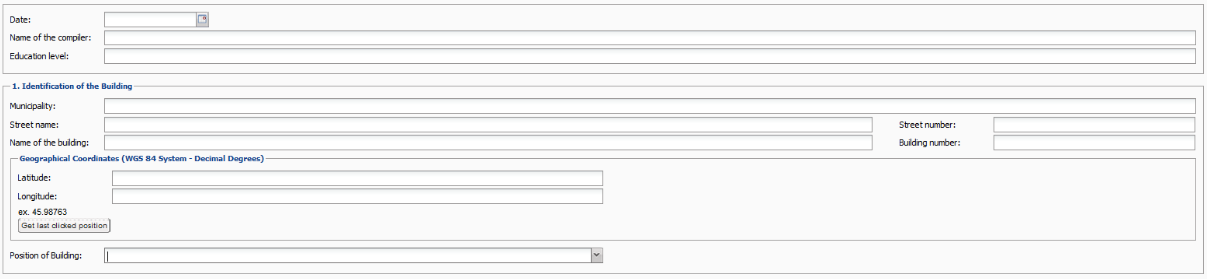

Date:
Name of the compiler:
Education level:
1. Identification of the Building
Municipality:
Street name:
Street number:
Name of the building:
Building number:
Geographical Coordinates (WGS 84 System - Decimal Degrees)
Latitude:
Longitude:
ex. 45.98763
Get last clicked position
Position of Building:

Figure 7: Sections for compiler information (from tab *Building Form – Practitioners*) and for the identification of the building.

The section *Identification of the building* allows to locate the building across the street name and number, and geographic coordinates expressed in terms of WGS84 (World Geodetic System 1984) system. Since the behavior of a building depends also on its position towards others buildings (i.e. structural aggregates), the compiler shall specify whether the structure is an *isolated building*, *internal building*, *end building* or *corner building*, as shown in Figure 8.

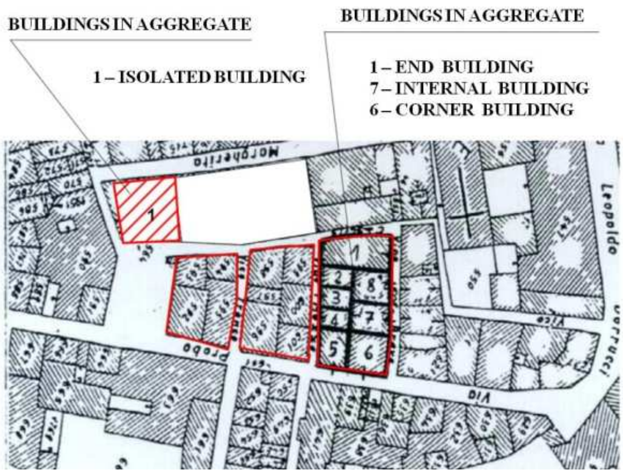


Figure 8: Buildings in aggregate and different types of location.

The section *Description of the building* allows to describe the building in terms of numbers of storeys, year of construction and year of eventual structural upgrade, exposure (i.e. number of units, percentage of use and occupants), and type of property (i.e. public or private). In the same section, in addition to the previous information, practitioners shall indicate the average of floor height and average of floor area to get more precise geometrical measure to use in case of structural modeling. The section *Description of the building* is reported in Figure 9.

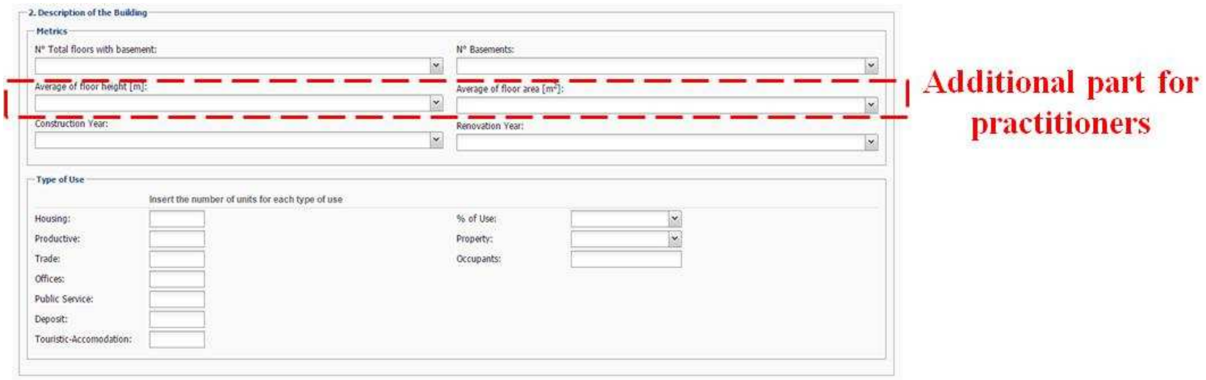


Figure 9: *Description of the Building*.

After defining the building from a geometrical point of view, the next step regards the identification of structural properties. This can be done in the section *Structural data* where citizens and practitioners have to compile different parts. As illustrated in Figure 10, practitioners have to define both the vertical and horizontal structure of the building (including the eventual presence of RC shear walls). Citizens, instead, have to focus only on the vertical structure. Finally, both citizens and practitioners have to indicate if the building misses inner/outer infill walls, partially or totally, at one or more floors. The lack of cladding, in fact, drives to the occurrence of the weak story mechanism in case of medium or high intensity ground shaking.

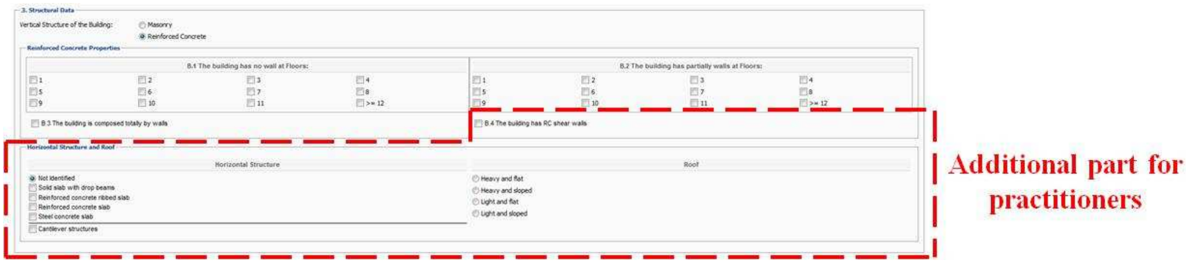


Figure 10: *Structural Data*.

The sections *Regularity* and *Geomorphological Data* can be found only in the tab *Building Form – Practitioners*. They regard respectively the regularity of the building (both in plan and in elevation), the morphology of the site and the category of the soil foundation on which the building was constructed. The criteria for the definition of the structural regularity and the type of soil foundation are described in Eurocode 8 [8]. Figure 11 shows sections *Regularity* and *Geomorphological Data*.

Finally, for both practitioners and citizens, the form ends with the sections *Notes* and *Photos*, to record more detailed information on the surveyed building that cannot be caught from the sections described above.

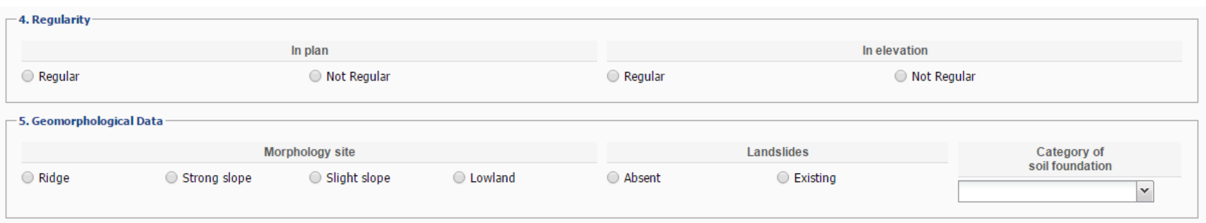
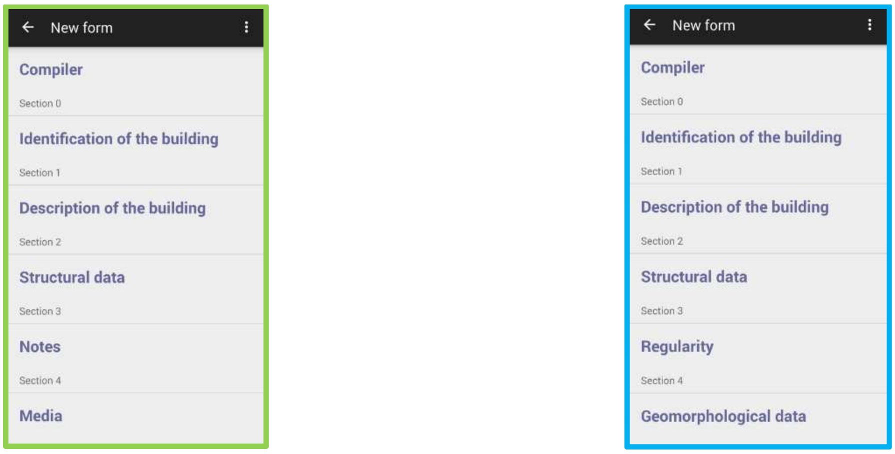


Figure 11: *Regularity* and *Geomorphological Data*.

As well as on the WebGIS, citizens and practitioners can fill in the forms also by using two apps for smartphones and tablet with Android system, downloadable from the tab *Downloads* in the WebGIS platform. The apps reflect exactly the forms for practitioners and citizens implemented in the WebGIS, and allow a quick and easy data entry, even without internet connection. Once internet is available again, the apps will send the loaded data to the WebGIS platform. Figure 12 shows the home page of the apps for citizens (see Figure 12(a)) and practitioners (see Figure 12(b)).

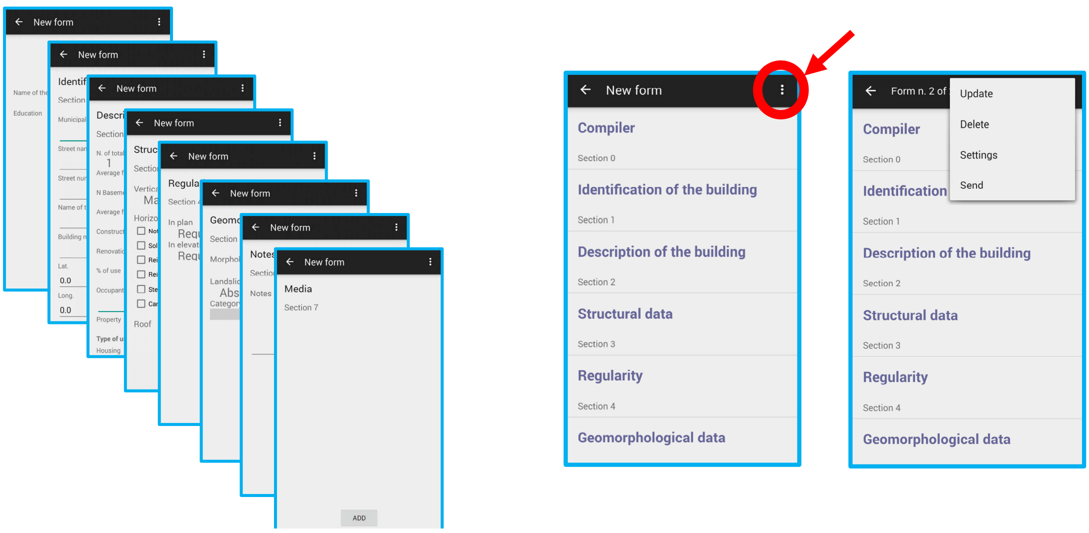
The user has to fill in all the sections of the form as the ones reported in Figure 13(a). The compiler can save, upload or delete the form at any time only by clicking the button in the upper right, as showed in Figure 13(b). In the same list shown in Figure 13(b), the button *Send* can be selected once completed the form.

After having sent the form, in relation to the compiler, the form will be available on the WebGIS platform at the tab *Building Form – Citizens* or *Building Form – Practitioners*.



(a) (b)

Figure 12**:** Home Page of the SASPARM 2.0 app for: (a) citizens and (b) practitioners.



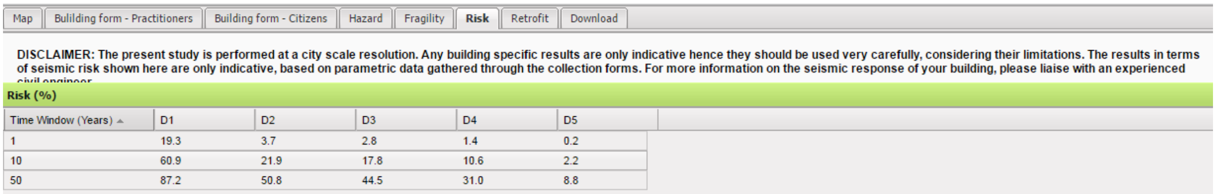
(a) (b)

Figure 13: (a) Sections to insert data in the SASPARM 2.0 app for practitioners and (b) Operations on the apps.

4 ESTIMATION OF SEISMIC RISK

The seismic risk quantifies the probability of reaching or exceeding a damage level for a building subjected to an earthquake of a certain intensity. As well as the importance of the structure and the number of people who occupy it (i.e. exposure), the seismic risk is mainly related to the vulnerability of buildings and to the hazard of the area where the building is located. Since the hazard is an intrinsic property of the site, the seismic risk can be reduced only acting on the structural vulnerability. In case of new buildings, the level of vulnerability can be reduced by using standards which provides appropriate design criteria to limit the building propensity to be damaged by seismic event. For existing buildings, instead, the limitation of the damage can be obtained through retrofit measures that depend on the structural type and the level of vulnerability of the building itself.

As already reported in the §2, the seismic code has been introduced in Palestine only recently. The awareness on seismic risk, and hence on the necessity of adopting a seismic code, increased thanks to SASPARM FP7-Project [9] which was undertaken by the same partnership that carried out SASPARM 2.0 [1]. As a consequence of the very recent adoption of a seismic code, most of Palestinian buildings has a high level of vulnerability from which it follows a high seismic risk. The seismic risk of a selected building is reported in the tab *Risk* of the WebGIS. In particular, as it is shown in Figure 14, the risk is expressed in probability and calculated for three time windows (i.e. 1, 10, and 50 years). The following paragraphs describe the procedure and the assumptions used to determine the local hazard and the structural vulnerability, whose combination defines the seismic risk.


Map | Bulilding form - Practitioners | Building form - Citizens | Hazard | Fragility | Risk | Retrofit | Download

DISCLAIMER: The present study is performed at a city scale resolution. Any building specific results are only indicative hence they should be used very carefully, considering their limitations. The results in terms of seismic risk shown here are only indicative, based on parametric data gathered through the collection forms. For more information on the seismic response of your building, please liaise with an experienced civil engineer

Risk (%)

Time Window (Years)	D1	D2	D3	D4	D5
1	19.3	3.7	2.8	1.4	0.2
10	60.9	21.9	17.8	10.6	2.2
50	87.2	50.8	44.5	31.0	8.8

Figure 14: Tab *Risk* - Risk values related to a selected 8-storeys RC frame building, not regular both in plan and in elevation and recently built.

5 HAZARD MODEL FOR NABLUS CITY

The hazard is a parameter that depends exclusively on seismicity of the area. Precisely, the hazard represents the estimation of the expected level of seismic intensity in a certain area and for a given observation period. The definition of seismic hazard occurs through the hazard curve. In particular, the curve relates the severity of shaking, in this case defined by the *PGA* (peak ground acceleration), with the *AFE* (Annual Frequency of Exceedance), which correspond to the inverse of the T_r (return period).

The logarithm of a ground-motion parameter and the logarithm of the corresponding annual frequency of exceedance can be assumed to be linearly-related, at least for return periods of engineering interest, and represents the hazard curve. The negative gradient of the log–log hazard curve is referred to as *k* in this paper, following the definition in Part 1 of Eurocode 8 [8]. Thanks to the approximation of linear trend, to define the hazard curve it is sufficient to determine the *PGA* value, corresponding to a return period T_r, and the negative gradient of the log–log hazard curve *k* that passes through the reference point. The point on the curve here considered corresponds to T_r of 475 years. The hazard curve is then defined by the relation (1):

$$AFE = AFE_{475}\left(\frac{S \cdot PGA_{475}}{PGA}\right)^{k} \quad (1)$$

where AFE_{475} e PGA_{475} are the annual frequency of exceedance and the PGA corresponding to the return period T_r of 475 years while S is the soil factor. Once defined the hazard curve, it is possible to calculate the seismic demand related to PGA for any return period T_r.

For the case study of Nablus, the "West Bank and Gaza Strip: Seismic Hazard Distribution Map" shown in Figure 15 is considered: it displays the PGA corresponding to a return period T_r of 475 years. Since the gradient k of hazard curve is unknown, the value of k is assumed equal to 3 as suggested in the Eurocode 8 [8]. In summary, the parameters that allow to calculate the hazard curve in the equation (1) are:

- AFE_{475}=1/475;
- PGA_{475}=0.24g;
- k=3;
- S=1 (soil A), 1.2 (soil B or C), 1.4 (soil D o E).

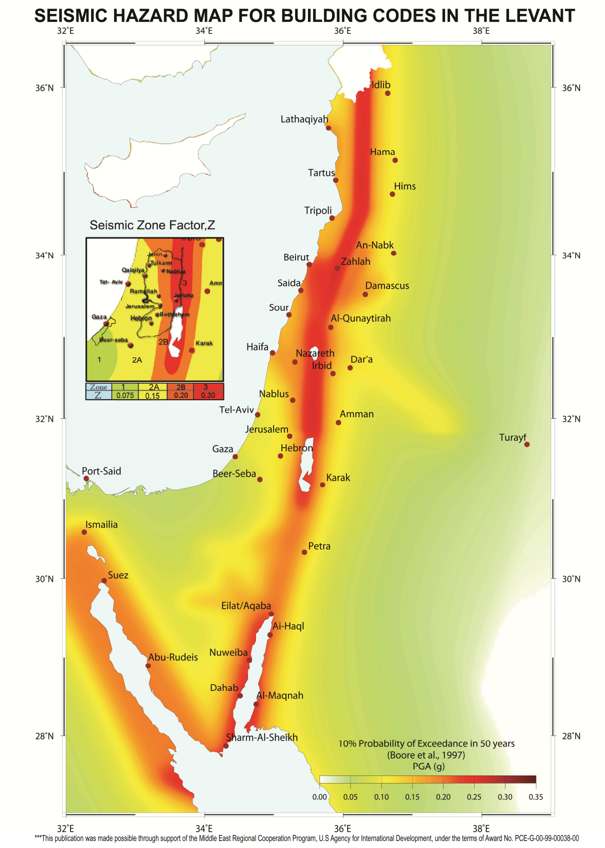


Figure 15: Seismic hazard map for building codes in the Levant [9].

Figure 16 shows tab *Hazard* of the WebGIS corresponding to the selected building and it displays the hazard curve for a soil "C". Since the type of the soil can be specified only in the form filled in by practitioners, the hazard curve related to the forms compiled by citizens is determined by considering the soil type "B".

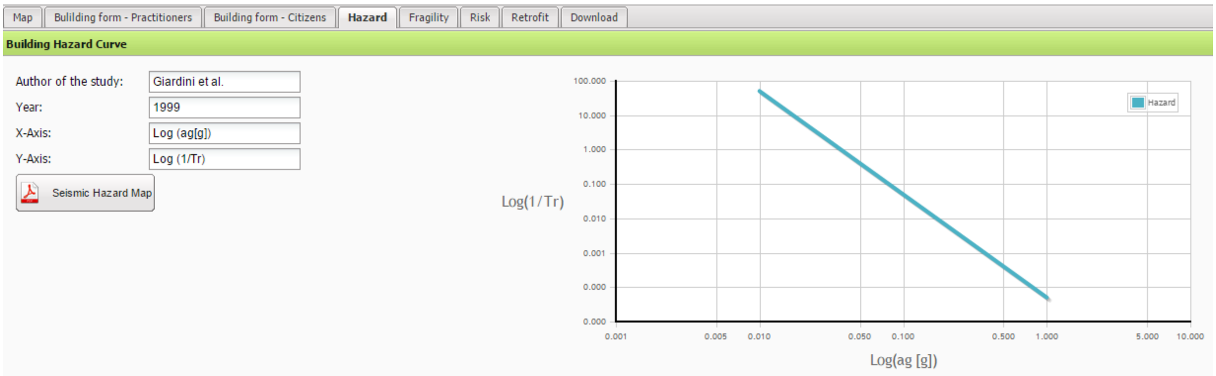


Figure 16: Tab *Hazard* – Hazard curve for soil "C".

6 DEVELOPMENT OF ANALYTICAL FRAGILITY CURVES FOR DIFFERENT BUILDING TYPES

From survey data collected as described in the §3, fragility curves can be calculated by using SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment) method ([3] and [4]). The curves are determined as functions of each structural type and then associated to each building in relation to the number of storeys. SP-BELA was implemented to investigate the seismic behavior of masonry buildings [3], RC frame buildings [4], and precast buildings [10] on the Italian territory. Since it is really versatile, SP-BELA can be modified to represent any building environment, as done for the city of Nablus.

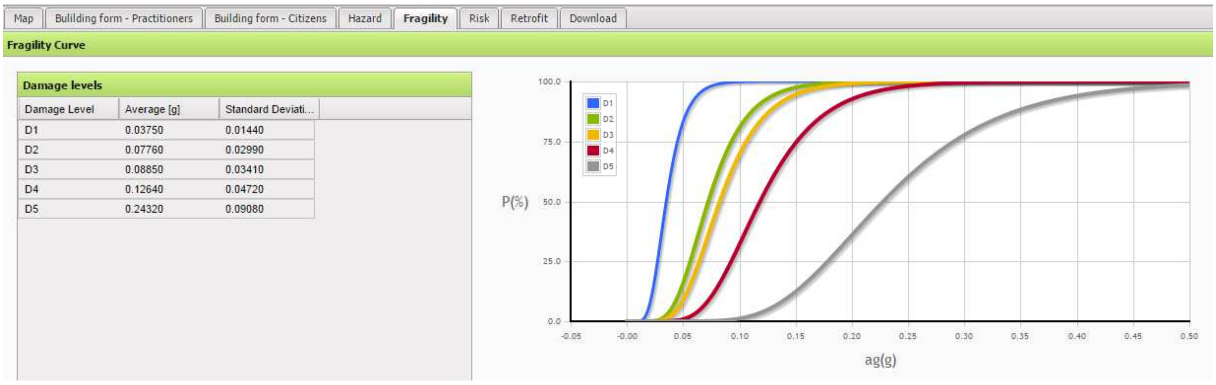
Initially, the procedure took into account three different limit states: *LS1* (light damage), *LS2* (significant damage) and *LS3* (collapse). Recently, according to EMS98 scale [2], the fragility curves are instead calculated for five damage levels: *DL1* (slight damage), *DL2* (moderate damage), *DL3* (extensive damage), *DL4* (complete damage), and *DL5* (collapse). To do that, it was necessary to find a relationship between the previous three limit states, which can be numerically identified, and the five damage levels. To this purpose, observed damage data available for Italy have been used, since damage data for Palestine are not available.

SP-BELA allows to define fragility curves by comparing the displacement capacity of representative building classes with the displacement demand for the considered damage levels. The first step of the procedure is to generate a sample of buildings that is representative of the analyzed structural type by using Monte Carlo method. Afterwards, a non linear static analysis is carried out on each building of the sample to determine the structural behavior under seismic action. The final product is a pushover curve on which limit conditions (i.e. *LS1*, *LS2* and *LS3*) are identified in terms of the displacement of a pre-selected control point. The pushover curve refers to a MDOF (Multi-Degree of Freedom) system from which it is possible to define the properties of an equivalent SDOF (Single-Degree of Freedom), thus obtaining the capacity curve. The latter describes the behavior of a SDOF that is equivalent to the original MDOF in terms of period of vibration, displacement capacity and dissipation capacity. Through the equivalent SDOF system the displacement capacity is obtained. The displacement spectrum, corresponding to the various ground shaking intensity (i.e. PGA), is then used to define the displacement demand. By comparing the displacement demand with the displacement capacity, it is available to define the proportion of buildings, belonging to the sample, that survive the considered limit conditions. By varying the ground shaking intensity, it is finally possible to build all the points of the fragility curve for each limit state.

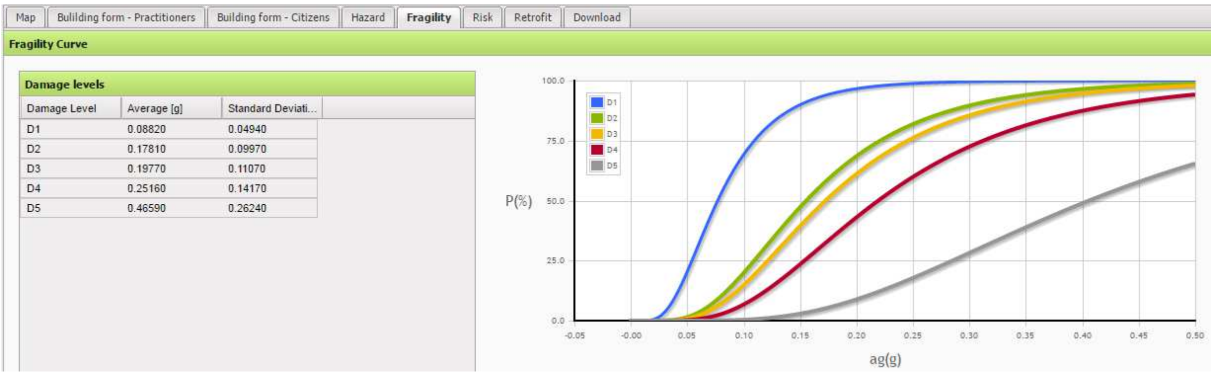
By using the survey data and the procedure described above, fragility curves can be determined for masonry buildings [11], RC frame buildings ([11] and [12]), and RC soft storey buildings ([11] and [12]).

For RC shear wall buildings, the lack of information to best represent this structural type didn't allow to calculate fragility curves directly through SP-BELA method. In fact, the fragility curves of RC shear wall buildings are defined from the ones of RC frame buildings with the same number of storeys [11]. Precisely, a correction factor has been identified and applied to the average value of the fragility curves of RC frame buildings while the coefficient of variation remains constant. The considered correction factor is equal to 1.3 and it has been evaluated by comparing the fragility proposed by HAZUS [13] for concrete frame with unreinforced masonry infill walls buildings and for concrete shear wall ones.

Figure 17 displays respectively the fragility curves of: (a) 3-storeys masonry buildings, (b) 7-storeys RC frame buildings, and (c) 10-storeys RC shear wall buildings, all located in the city of Nablus.



(a)



(b)

(c)

Figure 17: Tab *Fragility* – Fragility curves for: (a) 3-storeys masonry buildings, (b) 7-storeys RC frame buildings, and (c) 10-storeys RC shear wall buildings.

7 RETROFIT MEASURES

Palestinian buildings, herein represented by the ones of Nablus, present a high level of vulnerability.

To improve the structural behavior of buildings even in case of low or medium intensity ground shaking, the WebGIS suggests possible structural rehabilitations ([5] and [6]) at the tab *Retrofit* on the basis of vulnerability conditions detected through data compiled in the forms.

The tab *Retrofit,* as shown in Figure 18, is organized to identify in a simple way all possible retrofit measures towards any structural deficiency (e.g., soft storey mechanism, irregularity both in plan and in elevation, etc.).

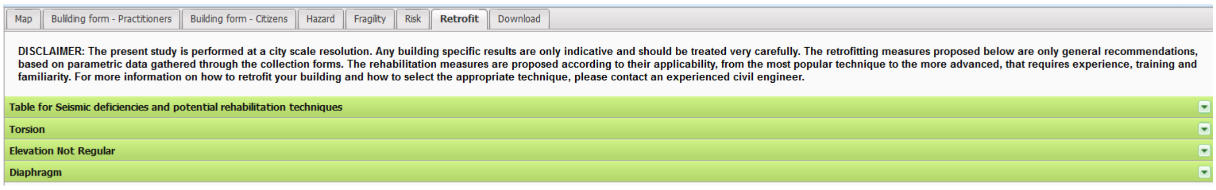


Figure 18: Tab *Retrofit* – Retrofit measures suggested for any structural deficiency.

8 CONCLUSIONS

This paper describes the WebGIS developed for SASPARM 2.0 project [1]. The WebGIS allows to estimate the seismic risk of residential buildings in the city of Nablus by combining the structural vulnerability with local hazard. The data required to define the seismic vulnerability of buildings are collected by citizens and/or practitioners who shall fill in two survey forms. The forms can be compiled directly on the WebGIS or through two apps developed for smartphones or tablet. According to collected data, the WebGIS calculates the seismic vulnerability of each building with the analytical method SP-BELA. The structural vulnerability is then combined to the local hazard, thus obtaining the seismic risk for three observation time windows. In relation to the structural deficiencies, the WebGIS proposes also different retrofit measures with the aim of reducing the seismic vulnerability of the selected building and consequently its seismic risk.

The SASPARM 2.0 WebGIS is a simple and intuitive tool, open to all and suitable to any type of user. Through the site, a massive amount of data on vulnerability of the building stock can be gathered with no cost. Although it started as an instrument to be used on the Palestinian territory, the SASPARM 2.0 WebGIS could be modified to extend its use also to others realities.

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