MOON: a New Overlay Network Architecture for Mobility and QoS Support

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MODELLING INTERDEPENDENCIES AMONG CRITICAL INFRASTRUCTURES AT URBAN SCALE

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ABSTRACT

Modern urban areas are transforming into sophisticated systems integrating both structures and infrastructures. This interconnection significantly increases the risk of disasters, which involves typical urban areas at different levels with structural, social, psychological and economic consequences. Therefore, improving emergency preparedness and mitigating possible disaster-induced losses of populous modern cities is becoming crucial.

Critical infrastructure, e.g. the transportation, electric and water networks, can be damaged due to inherent fragility with respect to the initiating external hazard (e.g. earthquake). Buildings collapse after strong earthquakes is the typical source of malfunctioning for connected critical infrastructures. In this work, the effect of debris after structural collapse or extensive damages on related networks is studied. A new formula to evaluate the debris affected area as function of the geometric characteristics of the masonry buildings is proposed. This strategy can be implemented in a virtual city model that is recognized useful for decision makers to quantify the performance of critical infrastructures following a disaster and to plan better resilience strategies in order to limit losses and downtime.

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Modelling Interdependencies Among Critical Infrastructures at Urban Scale

G.P. Cimellaro[1], M. Domaneschi[2], G. Scutiero [3] and S. Mahin[4]

ABSTRACT

Modern urban areas are transforming into sophisticated systems integrating both structures and infrastructures. This interconnection significantly increases the risk of disasters, which involves typical urban areas at different levels with structural, social, psychological and economic consequences. Therefore, improving emergency preparedness and mitigating possible disaster-induced losses of populous modern cities is becoming crucial.

Buildings collapse after strong earthquakes is the typical source of malfunctioning for connected critical infrastructures. In this work, the effect of debris after structural collapse or extensive damages on related networks is studied. A new formula to evaluate the debris affected area as function of the geometric characteristics of the masonry buildings is proposed. It can be implemented in a virtual city model to quantify the performance of critical infrastructures following a disaster and to plan better resilience strategies.

Introduction

In the last decades, the growing number of people in the modern urban areas increased the networks and infrastructures connectivity. It is both physical and functional and increase as new technologies are developed. The degree of such interdependencies appears to be escalating and the outcomes of this process are difficult to predict.

In literature a number of definitions on interdependencies among lifelines infrastructures and networks can be found (Cimellaro 2016). Dependency can be defined as unidirectional connection between two infrastructures, through which the state of one infrastructure is correlated to the state of the other. However, a bidirectional relationship between two infrastructures can also be defined when state of each one affects the state of the other one. As a result, the functioning in one infrastructure is function of the second infrastructure if the two are interdependent. Information on the interdependency degree allows to design resilient community for ensuring sustainability and withstanding to disastrous events.

For resilience assessment of urban communities against disasters as strong ground motion, computer-based simulations have become the most feasible and efficient methodology for scientific research and engineering application (Lu & Guan 2017). This paper deal with the assessment of the effect of debris after structural collapse or extensive damages on critical infrastructures, as the transportation network. A new formula to evaluate the debris affected area as function of the geometric characteristics of the buildings is proposed. It allows to estimate this area by the development of collapse scenarios of buildings. The research has been focused on masonry structures that represents a wide part of the European buildings in both the most important cultural cities but also in the general small towns and traditional villages.

The proposed formulation can be implemented in the virtual city models that are recognized useful for decision makers to quantify the performance of critical infrastructures following a disaster and to plan better resilience strategies in order to limit losses and downtime.

Methodology

The proposed methodology consists in the correlation between geometric parameters of masonry buildings and the debris area. The Applied Elements Method (AEM) based software is used as analysis tool. The AEM adopts the concept of discrete cracking and numerically reproduces the structural collapse passing through all stages from the application of loads in elastic stage to the crack initiation and propagation in tension-weak materials, reinforcement yielding, element separation, element collision (contact). The possible analysis domain of AEM method in comparison to finite element method (FEM) method is shown in Figure 1. AEM presents some positive aspects with respect to the FEM that is generally accurate and reliable for analysis of continuum structures but the onset of element separation is difficult and contact modeling of debris collision is time consuming.

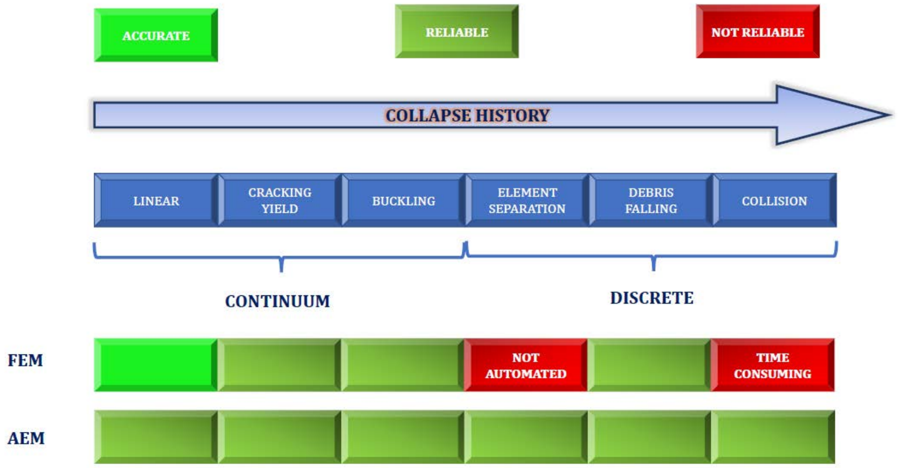
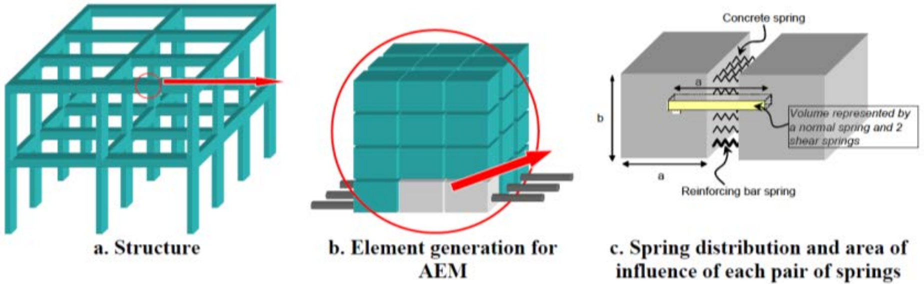


Figure 1. Analysis domain of AEM compared to FEM.

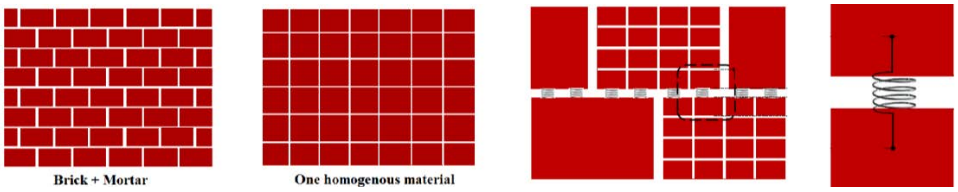


a. Structure

b. Element generation for AEM

c. Spring distribution and area of influence of each pair of springs

Figure 2. AEM elements detail.



(b)

Figure 3. Simulating masonry with AEM.

Therefore, the structure is modeled as an assembly of small elements as shown in Figure 2. The elements are assumed to be connected by one normal and two shear springs located at contact points that are distributed on the elements edges.

Using AEM method, the brick can be simulated in different ways, as in its real configuration or as homogenous material (Figure 3). The real configuration includes the individual bricks in a staggered pattern connected by interface springs with mortar by material properties. The brick itself can be divided into sub-elements to allow the cracks to develop inside an individual brick. Since it is not practical to model the mortar as separate elements, the thickness of mortar is not included in the real configuration approach. On the other hand, the continuum simulation, or the macro simulation, represents the brick wall as one homogenous material with averaged material properties for the mortar and the adjacent brick elements. The reinforcing steel bars are modeled by springs that represent their material properties, their location and their dimension (Applied Science International 2017).

Case study and methodology validation

A case study conducted on a shaking table by Iroshi Himai et al. (2015) on masonry buildings subjected to earthquake is considered to evaluate the accuracy of a simulation by AEM method. Specimens were built and dynamically tested with fourteen input motions on a seismic simulator at National Research Institute for Earth Science and Disaster Prevention (NIED) on February 23-24, 2011. Some results are shown in Figure 4 in terms of damages at different PGA levels and displacement time historyat the top of the building in Figure 5. Additional details of the study are reported in (Scutiero et al. 2018).

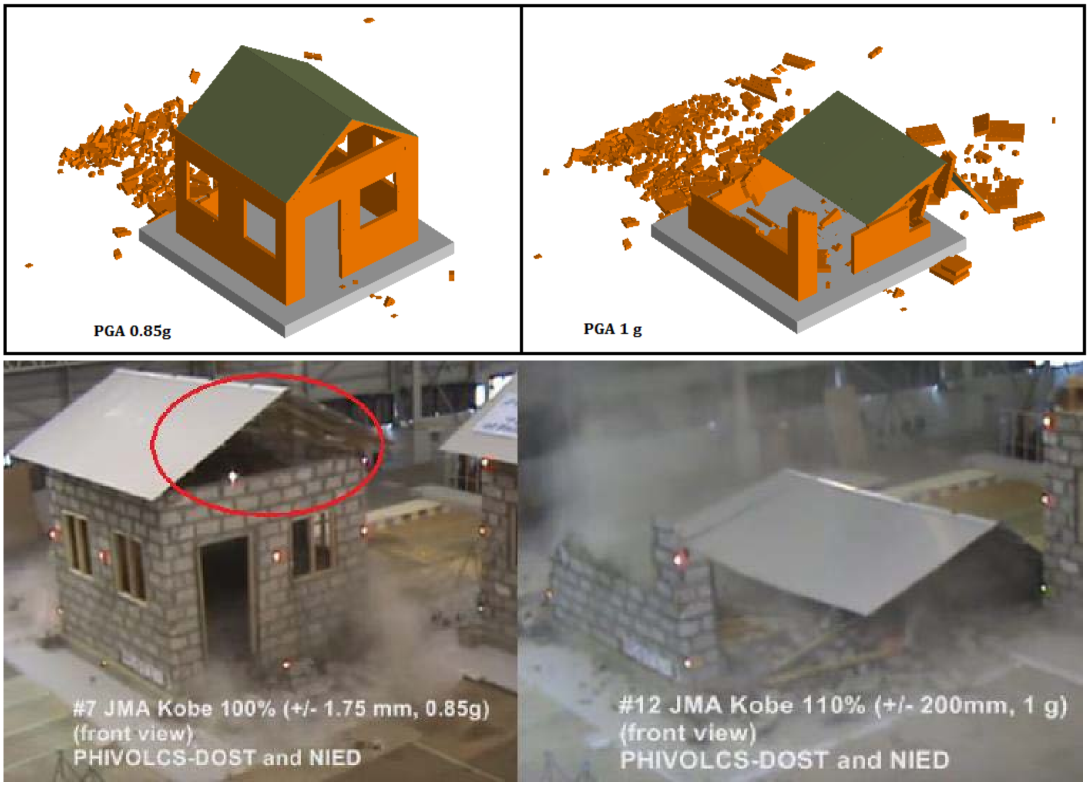


Figure 4. Comparison between AEM and laboratory outcomes at different PGA (0.85-1.0g).

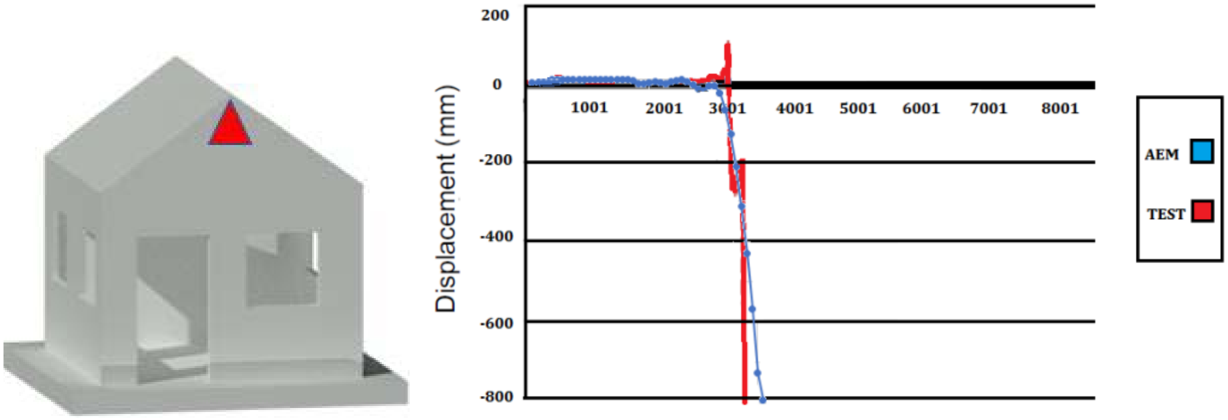


Figure 5. Displacement time histories in AEM and laboratory test.

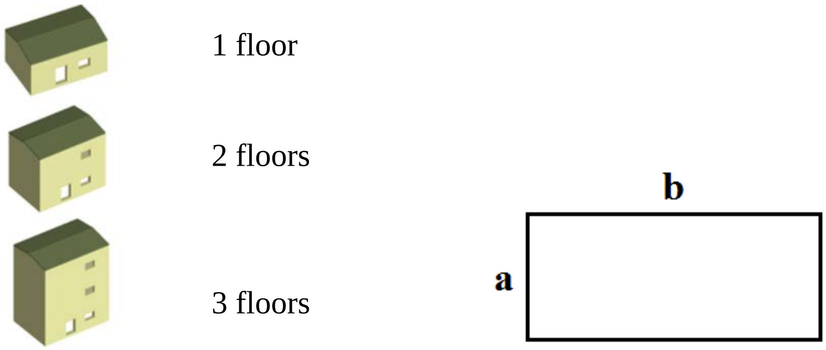


Figure 6. Group characteristics and general footprint.

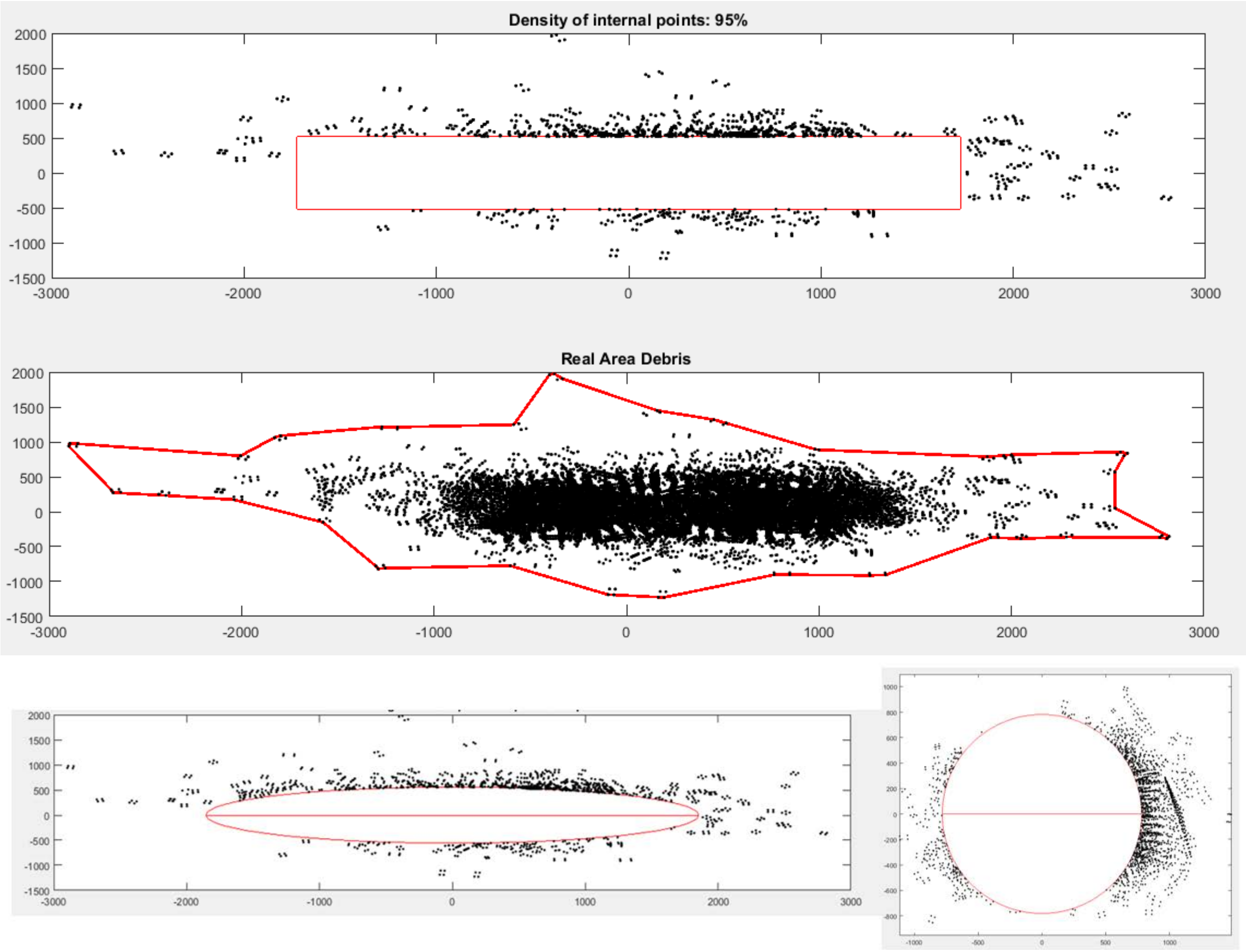
Table 1. Analyzed groups.

Group	Ratio	a[m]	b[m]	Area [m2]
1	0.2	4	20	80
2	0.3	4.9	16.3	79.9
3	0.4	5.7	14.1	80.4
4	0.5	6.3	12.6	79.4
5	0.6	6.9	11.5	79.4
6	0.7	7.5	10.7	80.3
7	0.8	8	10	80
8	0.9	8.5	9.4	79.9
9	1	8.9	8.9	79.2
10	0.2	8	40	320.0
11	0.3	9.8	32.6	319.5
12	0.4	11.4	28.2	321.5
13	0.5	12.6	25.2	317.5
14	0.6	13.8	23	317.4
15	0.7	15	21.4	321.0
16	0.8	16	20	320.0
17	0.9	17	18.8	319.6
18	1	17.8	17.8	316.8
19	0.2	12	60	720.0
20	0.3	14.7	48.9	718.8
21	0.4	17.1	42.3	723.3
22	0.5	18.9	37.8	714.4
23	0.6	20.7	34.5	714.2
24	0.7	22.5	32.1	722.3
25	0.8	24	30	720.0
26	0.9	25.5	28.2	719.1
27	1	26.7	26.7	712.9

Debris area assessment

Numerical simulations consider 27 types of buildings groups. Each group consists in three types of building: 1, 2 and 3 floors. Figure 6 summarizes the group characteristics and the general footprint, while Table 1 reports the details of the analyzed groups. By nonlinear dynamic analyses the buildings progressive collapse is simulated using a central Italy 24/08/2016 earthquake record. The mechanical parameters are calibrated based on the current Italian regulation on existing masonry (NTC 2008) like homogenous material. To amplify the area of debris, the lowest mechanical parameters for masonry are used. Figure 7 depicts a collapse as the result of the AEM simulation.

Figure 7. Example of AEM simulation.


Density of internal points: 95%

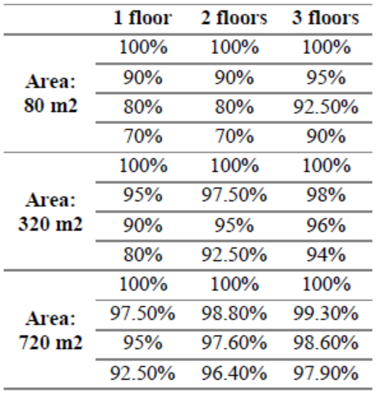
Real Area Debris

Figure 8. Rectangular (a), polyline (b), elliptic (c) and circular area (d) for surrounding debris.

The AEM output file can be exported and the coordinates of the debris amount can be saved in a text file. This last can be easily processed for further evaluations: a rectangular area with a percentage of internal points can be defined through a scale factor (Figure 8a) and another one containing all the debris can also be identifies through a polyline (Figure 8b). Other two geometries (elliptic and circular) are considered and compared with rectangular shape. The ellipse axes and the circle radius are scaled with the same principle as the rectangle (Figure 8c and 8d).

Different cases of percentage of inside points (debris) as function of the building's area are considered (Table 2).

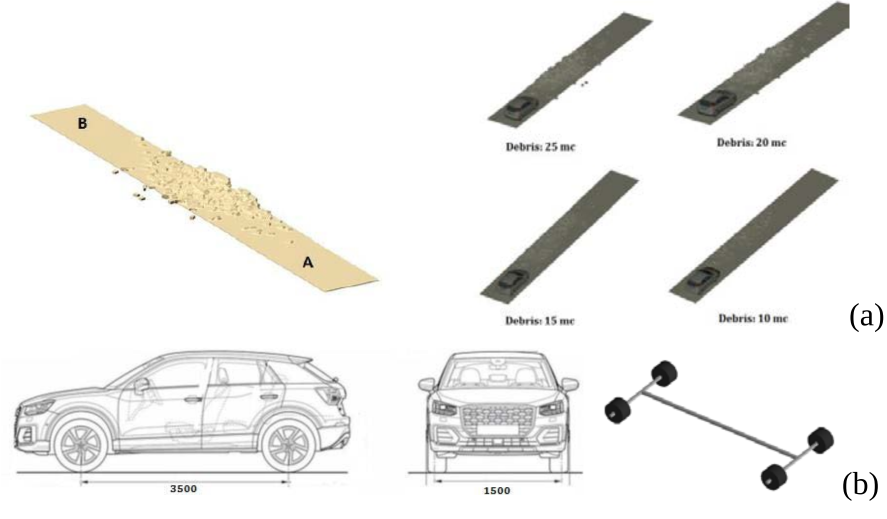
Table 2. Analyzed percentage of inside debris.

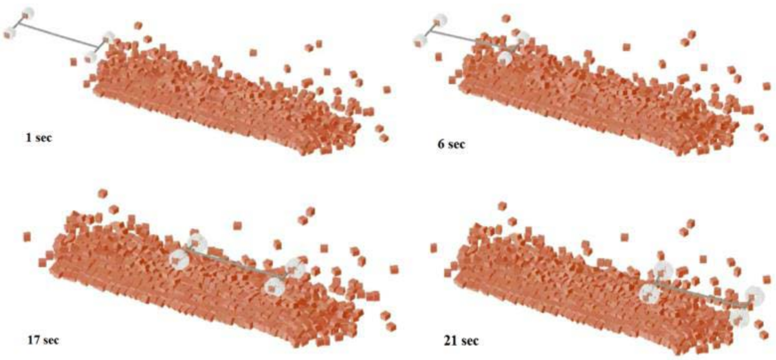


	1 floor	2 floors	3 floors
Area: 80 m2	100%	100%	100%
	90%	90%	95%
	80%	80%	92.50%
	70%	70%	90%
Area: 320 m2	100%	100%	100%
	95%	97.50%	98%
	90%	95%	96%
	80%	92.50%	94%
Area: 720 m2	100%	100%	100%
	97.50%	98.80%	99.30%
	95%	97.60%	98.60%
	92.50%	96.40%	97.90%

Simulation of road interruption

In order to evaluate the amount of debris that can be able to interrupt a standard road an AEM simulation is performed and the volume limit for passing a vehicle is calculated. The test is passed if the vehicle starting from point A can reach point B on a standard road. Four scenarios with different debris volumes are simulated: 25 m^3, 20 m^3, 15 m^3, 10 m^3 (Figure 9). The 20 mc volume results the critical one. Additional details can be found in (Scutiero et al. 2018).





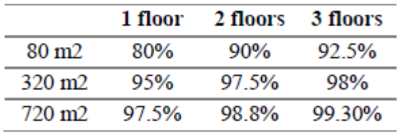
(c)

Figure 9. Car passage on different debris volumes (a), AEM car model (b) and simulation (c).

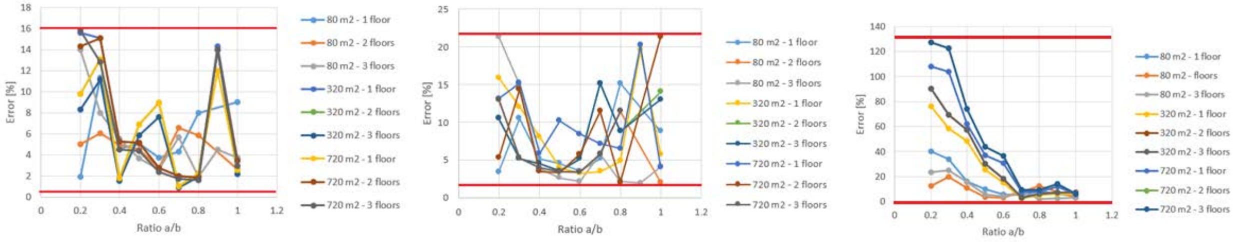
Results

Table 3 reports the best (lowest) values of the combination “debris volume passed by car test that correspond to a neglected debris volume between 11 and 14 m^3. It can be shown that as the volume of the building grows, the outer area with less debris is less extensive. Rectangular geometry has been selected as the best performer with respect to circular and ellipse area. For the circle the error (measured area with respect to the real one) is higher for low ratios, but decreases for unitary ratios. Figure 10 summarizes the results and compares the different options.

Table 3. Analyzed percentage of inside debris.



	1 floor	2 floors	3 floors
80 m2	80%	90%	92.5%
320 m2	95%	97.5%	98%
720 m2	97.5%	98.8%	99.30%



Rectangle **Ellipse** **Circle**

Figure 10. Error vs ratio a/b.

The data have been interpolated through a plan as shown in Figure 11. Two residuals tests have been performed to verify the reliability of the model and details can be found in (Scutiero et al. 2018).

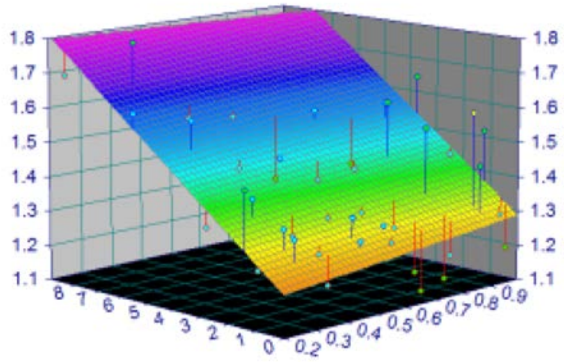


Figure 11. Data interpolation.

The formula for obtaining rectangular shape scale factor is given by:

$$scale\ factor = 1.202 + 0.0864 \cdot \left(\frac{a}{b}\right) + 0.0659 \cdot \left(\frac{Area_{footprint}}{Volume_{building}} \cdot \frac{h^2_{building}}{a}\right) \tag{1}$$

Where the volume represents the occupied volume by building's material and it is roughly equal to:

$$Volume_{building} = Area_{footprint} \cdot h \cdot 0.27 \tag{2}$$

Additional details can be found in (Scutiero et al. 2018).

Conclusions

In earthquake affected areas debris due to damage occurrence plays a crucial role on related infrastructures as transportation network. Indeed, as cascading consequence of debris accumulation, the road network can be interrupted with evident effect on the emergency management after the disastrous event. The proposed formulation is able to provide and assessment of debris generation after a seismic event and can predict whether a road is inaccessible to emergency procedures.

This approach is oriented to numerical implementation in more general procedures as the development of virtual city models for community resilience evaluation, emergency and waste management planning that is triggered immediately after a seismic event. Furthermore, it can provide rapid removal and relocation of debris in order to facilitate the rescue of victims.

Acknowledgments

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