Evacuation paths in historic city centres: a holistic methodology for assessing their seismic risk

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Abstract

During seismic emergencies in historical urban scenarios, evacuation paths can suffer significant damages and modifications due to both extrinsic (i.e.: building facing the path) and intrinsic (i.e.: pavements state, the presence of underground lifelines or hypogeum) vulnerabilities. Such damages and modifications can hinder the population's evacuation and the first responders' intervention, mainly because of paths' blockage or unavailability in emergency conditions. Paths' safety is additionally affected by populations' exposure conditions, also due to individuals' motion in the post-earthquake environment. Hence, an analysis of factors influencing the seismic risk of evacuation paths and a consequent evaluation of their safety during the emergency are thus desirable. This work aims to offer a preliminary and quick holistic method for seismic risk assessment and damage level estimation of possible evacuation paths. Firstly, data about safety influencing factors (i.e.: path use and exposure; geometric features; physical-structural features; extrinsic vulnerability; seismic hazard) are collected, associated to related weights and organized in risk indexes according to three calculation approaches. Then, according to real-world data, a correlation about path risk-damage levels is proposed with the additional purpose to evaluate the method capabilities in describing post-earthquake scenarios. Obtained results evidence that the proposed methodology could help safety designers in the seismic emergency planning of urban paths (i.e.: by

means of risk maps) by including the management of population's evacuation routes towards assembly points, the optimization of rescuers' activities and the promotion of different priorities of interventions on building heritage.

KEYWORDS: Earthquake emergency evacuation, Urban path network, Risk index evaluation, Safe paths, evacuation path network, urban path damages.

1 Introduction

Earthquakes in a historical urban fabric can lead to critical situations which affect the built environment and the exposed population during the event and the following post-event emergency phases because of built scenario modifications due to earthquake damages [1–3].

In fact, earthquake-induced modifications to urban fabric can influence the effective safety levels for population moving along evacuation paths and the related possibility to reach safe areas (e.g.: no possibility to reach assembly points because evacuation paths could be blocked by debris) in which individuals could receive the first responders' support [4–7]. Debris generation from building collapse could be added to street pavement cracks or land failure by provoking additional risks for citizens' evacuation and rescuers' access to the damaged scenario [8–11].

According to a general risk assessment approach [12–14], the evacuation path risk depends on the combination between:

- hazard, mainly in terms of soil category, morphology and topography, local amplification phenomena also related to the position of the historical urban fabric (e.g.: on the top of a hill) [15];

- vulnerability as a function of: intrinsic vulnerability, which relates to the elements composing the street itself, the related infrastructural elements (i.e.: street pavements, foundations, embankment, and lifelines) [16] and the interfering elements, such as underground structures) [9,17]; extrinsic vulnerability, which refers to the elements that do not directly belong to the path itself but can compromise or block it (i.e.: buildings that can collapse by blocking facing streets because of debris formation) due to the typical scenario of historic city centres (i.e.: narrow streets with high facing buildings; network complexity);
- possible exposure conditions (i.e.: high density of citizen, tourists' presence, mass-gathering events) [18,19].

From this point of view, the proposal of a holistic risk index concerning evacuation paths network elements can help safety planners to [2,18–23]:

- understand which factors are effectively able to affect safety conditions (before/during the emergency);
- design proactive risk-reduction strategies (i.e.: interventions on buildings);
- design evacuation plans (i.e.: safest path choice) leading to efficient rescue operations' management in historical scenarios.

Correlations between risk, event intensity and earthquake-induced damages could be able to offer additional data for emergency scenario characterization [24]. Such scenarios' predictions could be also included in models for emergency and evacuation simulation [25–28].

1.1 *Background on evacuation path risk analysis*

Methods for estimating the influence of extrinsic vulnerability have been largely debated, by proposing different methodologies for building vulnerability assessment [20,29–31]. Macroseismic methods seem to be more suitable for urban scale application because their application is based on easy-to-detect building parameters [32]. Taking advantages of these methods, previous works gave a quantification of produced debris on path network elements (i.e.: streets) by using correlations between building vulnerability, macroseismic intensity and geometrical aspects [22]. A quick methodology for assessing the seismic vulnerability of paths network by considering interferences with building heritage damages was also proposed [22].

On the contrary, few works inquired about intrinsic path vulnerability. Previous studies principally focused on paths' network capabilities evaluating earthquake-induced effects in terms of variations on possible traffic flows or social-economic consequences generated by one or more unusable paths [33]. Other approaches dealt with particular structural features (i.e.: technical provisions, structural project, soil compaction rather than liquefaction) of highway networks systems, by focusing their attention on typologies whose presence in historical urban fabrics is limited (i.e.: trenches, embankments, bridges) [10,34].

Other researches proposed to analyse the paths network by separately considering intrinsic and extrinsic vulnerabilities for each composing element [16]. The application of this methodology needs a detailed description of each path link, by including specific local surveys and related data collection processes that could not be quickly employed in a wide scale assessment. Similar methods adopt empirical and quick analysis criteria at the overall urban fabric scale, by trying to include hazard characterization in terms of soil features and response [20].

The intrinsic vulnerability features have been also associated with their seismic response through fragility curves [35,36]. These curves describe the possibility for buildings, streets and pipelines to reach a certain damage state in correspondence to specific earthquake severity values (e.g.: Peak Ground Acceleration - PGA). In this way, the extrinsic vulnerability could be combined to the analysis of intrinsic one by means of combinations of earthquake-induced effects. Since this approach associates an own fragility curve for each studied street element, it seems to be quite onerous for application to a wide-scale urban area. Moreover, it should be precisely calibrated for historical scenarios. Concerning such description of street damages due to earthquake effects, simplified methods based on discrete damage scale for paths elements (called "Road Damage Scale" - RDS) have been proposed [37]. Correlations between variables characterizing a seismic event (i.e.: magnitude, distance from the epicentre and hypocentre distance) and street damages were provided on real cases observations. Nevertheless, such an approach seems to overlook the path risk-affecting factors.

Other works related to emergency management issues have considered urban paths as a cooperating system, and have assessed their physical efficiency in order to guarantee the operability of the contingency plan [11].

Finally, the method for paths risk assessment developed by Task-4 of SAVE project activities [19] tried to give a preliminary comprehensive overview on the risk-affecting factors concerning the aforementioned emergency path-related issues. In general terms, this method (called "Cherubini's method" in the following) is aimed at evaluating the seismic risk of the whole historical centre by defining the risk of each composing urban paths elements (i.e.: streets; squares; crossroads). To this end, differently from previous studies, aspects involving paths structure and geometrical features are merged to the ones referring to paths conditions in terms of traffic and exposure (i.e.:

establishing if the path is an interconnection route or an access route, if it is travelled in one-way, and evaluating its average traffic flow). Such aspects are then combined according to a weighted approach to define the final path risk index. The Cherubini's method offers wide capabilities on how to collect and merge the risk-affecting factors and innovatively includes paths exposure issues, but it should be improved by including the local seismic hazard and the seismic effects on soil related to the infrastructures.

1.2 Work aim and main limitations

As underlined in Section 1.1, current methodologies seem to be affected by different lacks. Firstly, they seem to overlook aspects related to typical elements of urban fabric (i.e.: the presence of underground natural or artificial cavities that could influence the frequency spectrum of seismic waves [38]), local soil response to earthquake shaking (i.e.: liquefaction) and other risk sources affected by the presence of underground pipelines [39]. These conditions could cause damaging consequences in case of leakages or explosions triggered by high-severity earthquakes.

Secondly, they generally avoid jointly considering causes and features linked with the path network evaluation. Although some researches [10,19,20] offer reliable bases to this end, no one seems to involve the analysis of historical centre scenarios by including the effects of intrinsic damaging of streets.

Finally, methods to relate path risk and possible earthquake-induced damage state to safety planners supporting activities for wide-scale applications in urban paths systems are not currently available. Therefore, this paper firstly tries to develop a holistic methodology which considers all the risk-affecting factors to provide path risk indexes in historical city centres. Then, three different calculation approaches (and so three novel path risk indexes) to combine the risk-influencing factors are proposed and compared. Then, analyses on post-earthquake damage grades prevision are innovatively included by linking the developed path risk indexes to paths damage scale provided by previous works [37]. Real-world data are used to this aim. This holistic perspective allows preventively assessing the path safety, and then evaluating path preservation strategies in the aftermath of seismic events by considering the different aspects on which designers could intervene.

The classification of risk conditions of each element (and of each composing part) in the evacuation path network will help safety planners in choosing the better strategies to evacuate citizen and to direct rescuers' teams in emergency phase, as well as in evaluating the impact of different proactive strategies of emergency management and risk reduction interventions.

2 Phases and methods

2.1 Phases

The paper is organised in the following phases:

- Paths network schematization, to univocally define the requirements for the elements to be investigated (Section 2.2);
- Definition of paths risk-influencing factors according to the main parameters suggested by the whole literature review: path configuration; exposure (Section 2.3.1); geometrical features (Section 2.3.2); physical-structural features of infrastructural elements (i.e.: streets) (Section 2.3.3); extrinsic vulnerability (Section 2.3.4); seismic Hazard influence (Section 2.3.5);

- Definition of the novel holistic path risk assessment methodology based on the influencing factors, which is implemented by proposing three calculation approaches to calculate the risk index (modified Cherubini's method, Expert Judgement, Analytical Hierarchy Process) (Section 2.4);
- Application of the three developed risk indexes to a real-world sample in order to evaluate their capabilities and offer a preliminary validation, through the proposal of a risk index-damage state level correlation (Section 2.5).
- Application of the novel methodology through the calculation approach-risk index having the highest coefficient of determination R^2 to a representative case study to preliminarily demonstrate its capabilities, by also means of risk maps representation (Section 2.6).

Notations used in the following sections are resumed in Appendix A.

2.2 Path Network schematization

In order to evaluate the path network, this has to be divided into different composing elements univocally determined, called Links and Nodes according to the definitions given in **Table 1** [22,25]. A graphical example is offered by **Figure 1**. Different paths could be traced by connecting consecutive links and nodes, to evidence rescuers' and evacuees' routes within the urban fabric, and from/to specific emergency areas. Since the proposed methodology is based on the risk analysis of the composing elements, the overall evaluation of each path risk can be performed by summing the partial risk indexes.

Table 1 Street network schematization; Links definition, the subdivision between types of Nodes and related assessment tools.

Path elements	kind	Definition	Assessment tools	Identification code
Nodes	Control point	crossroads, significant plano-altimetric and structural variations (i.e.: pavement features, the presence of structural elements such as retaining walls, protection measurements or bridges and tunnels) along the path network [22]	Control points take the maximum risk index of links converged in it evaluated through **Table 2**	Numeric code
	Square[1]	Nodes that can be considered assembly points or rescuers' first-aid areas (e.g. wide open spaces, where people spontaneously gather and can safely wait for rescuers' arrival) [25]	See **Table 3**	Alpha-numeric code
Links	-	Connection between two different nodes. A path composed of segments with different features can be schematized as an ensemble of consecutive links, divided by nodes.	See **Table 2**	Alphabetic code

[1] A Square is a particular node where building facades projections do not entirely cover the square's area itself. Such condition allows Squares to hold people during the emergency. For this reason, Squares need an ad hoc earthquake evaluation.

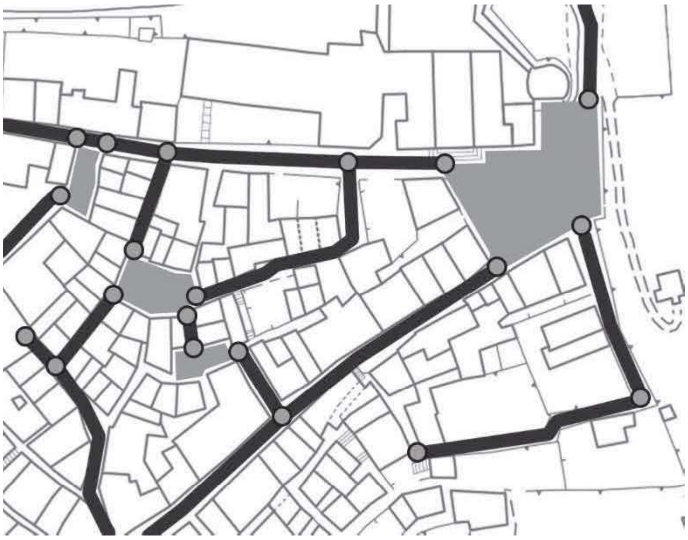

__Figure 1__ Example of a graphical representation of the path network scheme in a historical city centre map: Links (black segments) are delimited by Control Points (Nodes) placed in each plano-altimetric or structural variations (grey circles). Squares, defined according to __Table 1__, are highlighted by grey filled areas.

2.3 Risk-influencing factors definition for methodology definition

Starting from the literature discussion presented in Section 1, the proposed methodology tries to collect all the risk-influencing parameters in six influencing factors combined by topics and discussed in the following sub-sections. According to previous works [19,40,41], each parameter can be characterised by different conditions, called "alternatives" (between two and five), which are associated to a numeric value within the risk index, as described in Section 2.4. All the considered influencing factors are defined by considering both the single path network composing elements (intrinsic vulnerability and exposure conditions) and the elements that could directly compromise its state (extrinsic vulnerability and seismic hazard). According to general **Table 1** guidelines, the proposed methodology evaluates the factors influencing path risk by means of two similar Assessment Table: **Table 2** shows the one related to Links risk assessment; **Table 3** summarizes the one for Squares assessment.

In general terms, both **Table 2** and **Table 3** contain information about exposure, geometrical features and physical-structural features, subsoil conditions and vulnerability of facing buildings. The Squares Assessment Table (**Table 3**) includes specific parameters that are proposed in addition to the ones of Link Table or replace some of them because of specific Squares features. Parameters linked to specific street typologies (e.g.: bridges, viaducts and tunnels) are omitted in the current work proposal because they are rarely present in historic city centres.

Table 2 *Link Assessment Table: factors, parameters and associated alternatives are reported to evaluate the risk-influencing aspects of links within the urban path network. IDs for factors and parameters are assigned to connect this table with Table 4.*

ID	Factors	ID	Parameters	Alternatives
A	Path analysis	A.1	Link code	-
			1° Node code	-
			2° Node code	-
		A.2	State	Clear Partially obstructed Obstructed
B	Exposure	B.1	Street type	Interconnection Access
		B.2	Direction of travel	Single Double
		B.3	Carriageway	Separated Unique
		B.4	Path type	Urban Suburban
		B.5	Average Flow	Low Medium High
C	Geometric features	C.1	Length (m)	$0 < L \leq 0.33\ L_{max}$ $0.33\ L_{max} < L \leq 0.67\ L_{max}$ $0.67\ L_{max} < L \leq L_{max}$
		C.2	Width (m)	$0.67\ W_{max} < W \leq W_{max}$ $0.33\ W_{max} < W \leq 0.67\ W_{max}$ $0 < W \leq 0.33\ W_{max}$
D	Physical-structural features	D.1	Finishing surface	Asphalted Paved Rough
		D.2	Potential landslides	No landslide, retaining walls in both sides Landslide, retaining walls in one side Landslide, no retaining walls
		D.3	Underground elements	Low-risk pipes

				High-risk pipes Caves, cisterns or cavities
		D.4	Conservation state	High Medium Low
		D.5	Street Typology	Level link Hillside link, with retaining walls Hillside link, without retaining walls Tunnel Bridge and viaduct
E	Extrinsic vulnerability	E.1	V_{Nlink}	$0 < V_{Nlink} \leq 25\%$ $25\% < V_{Nlink} \leq 50\%$ $50\% < V_{Nlink} \leq 75\%$ $75\% < V_{Nlink} \leq 100\%$
F	Seismic hazard	F.1	Design ground acceleration (a_g)	$a_g \leq 0.05g$ $0.05g < a_g \leq 0.15g$ $0.15g < a_g \leq 0.25g$ $a_g > 0.25g$
		F.2	Ground type	A B C D E
		F.3	Topographic amplification factor	T1 T2 T3 T4

Table 3 *Squares Assessment Table: parameters and associated alternatives are reported only for factors B, C and D (and the related parameters) that are different from Links Assessment Table according to how defined in Section 2.3. The other factors (A, E and F) are the same as reported in Table 2*.

ID	Factors	ID	Parameters	Alternatives
B	Exposure	B.1	Usage	Wide crossroad Pedestrians' zone Parking area
		B.2	Presence of obstacles	Absence Presence
		B.3	Square type	Urban Suburban
		B.4	Average Flow	Low Medium High
C	Geometric features	C.1		$0.67\ A_{max} < A \leq A_{max}$ $0.33\ A_{max} < A \leq 0.67\ A_{max}$ $0 < A \leq 0.33\ A_{max}$

D	Physical-structural features	D.2	Potential landslides	No landslide, retaining walls in more than one sides Landslide, retaining walls in one side Landslide, no retaining walls
		D.5	Square Typology	Level Square Hillside Square with retaining walls Hillside Square without retaining walls

2.3.1 Path analysis and Exposure

The Link Assessment Table identifies the inspected street element through a code and their respective nodes; a preventive information about link accessibility is also given to investigate only usable paths in emergency conditions (**Table 2**, ID=A).

For both Links and Squares, the exposure factor (ID=B) is assessed in terms of path role and importance that it assumes within the urban fabric during the emergency.

In **Table 2**, ID=B concerns link exposure-affecting parameters from the point of view of functional analysis. Paths can represent an access route to the urban environment strategic in emergency phases or can constitute an interconnection among safe areas or strategic buildings [11]. Moreover, the link is considered an effective evacuation path in case of absence of barriers, traffic lane dividers, bollards or further obstacles that entirely limit the width of lanes or even prevent the access of rescuers/evacuees. Average flow refers to a semi-quantitative assessment of traffic along the path.

In **Table 3** ID=B parameters are modified so as to consider the specific features of squares and, first of all, their intended use: wide crossroad, characterized by multi-directional movement of both vehicles and pedestrians; pedestrian zone; parking area, characterized by possible available areas limitations due to parked vehicles. In addition, other square-specific parameters refer to the presence of architectural elements like street furniture, fences, low walls, trees which could be widespread in the square area and could interfere with pedestrians' motion/rescuers' access or emergency operations.

2.3.2 *Geometric features*

As reported in **Table 2** ID=C, the length of the street affects the travel time required to reach a destination, while its width can influence the evacuation flows because of interfering obstacles that could also limit the effective width of the path (i.e.: urban furniture; debris presence due to damaged buildings). The paths sample in the considered urban historical area is organized by following a related dimensional scale in terms of width *W* and length *L*. Longer and narrower paths in the sample are considered as more hazardous in respect to the others. For Squares, the considered geometrical parameter concerns the area extension (**Table 3,** ID=C).

2.3.3 *Physical-structural features*

The evaluated parameters in **Table 2** ID=D firstly concern street surface (asphalted, paved or rough), that could influence the streets' accessibility also related to its conservation state. Indeed street pavement typologies and their state of conservation could affect the evacuation process causing pedestrians accidents or injuries during the escape [42].

Potential slide down of soil and rocks on both sides of the path and the preventing measures (e.g.: retaining walls) are identified so as to include risks due to the blockage of the path to evacuees and rescuers' vehicles, causing problems and delays to the emergency mobility [15].

A specific parameter is added by this work to include the existence of caves, cisterns and natural or artificial underground structures that are typical of the historical urban environment [17]. These subsoil vulnerable elements could provoke instability leading to local street collapses. Furthermore, pipes placed at scarce depth could be considered as weak points for the street safety. Such lifelines are distinguished between [39,43,44]: low-risk lifelines such as electrical power or water supply systems with restrained pipes dimension; high-risk lifelines like gas and oil distribution networks. In this way, the study also evaluates the risk connected to pipelines of gas or water supply system that could lead to cascade effects (i.e.: dangerous gas leaks, fires, local soil destabilization).

2.3.4 Extrinsic vulnerability

In **Table 2**, ID=E innovatively takes advantage of the street vulnerability method [22] referred to aspects concerning extrinsic vulnerability assessment by inquiring the building heritage directly facing paths or squares. Thus, according to a related geometric approach for path blockage [4], if the width W_b of the urban space (street/square) facing the building b is higher than the building average height H_b [m], the building is considered as not interfering and hence it is not inquired [4,22]. Vulnerability Index V_{link} considers the interfering building and is a function of: building incidence I_b on the link defined as the ratio between building L_b and link L lengths, respectively ($I_b = L_b/L$); building vulnerability V_b expressed according to the macroseismic method to ensure quick application for historical city centre scale [32] (a probable scenario is given in **Figure 1**). For each link j, $V_{link,j}$ is calculated as shown in Equation (1) by considering the buildings on the link j:

$$\mathrm{V_{link,j}} = \sum_{b \in j} \mathrm{V_b} * \mathrm{b} \tag{1}$$

However, within buildings in the same scenario, link vulnerabilities must be normalized by the maximum $V_{link,j}$ obtainable in that scenario. According to [20,22], obtained $V^{N}{}_{link,j}$ are divided into four alternatives, as shown in **Table 2** section E.

2.3.5 Seismic hazard

Seismic hazard factors are innovatively introduced by this work on path risk assessment. The observation of real cases highlights how both base and local features of soil can be relevant for the paths' damaging, because of cracks or damages occurring on the ground and directly affecting the carriageway state [15]. Our methodology, taking advantages from Eurocode 8 [45], proposes to evaluate the seismic hazard basing on the design ground acceleration (a_g) [g] related to each seismic zones, the ground types and also, according to Italian building code, on the topographic amplification factors [46]. The adoption of the Eurocode 8-based criterion ensures a quick application even if low-detailed resources and no geotechnical documentation or local surveys on soil (such as microzoning studies) are available [47].

2.4 Risk Index definition

Three different calculation approaches are proposed to combine the risk-influencing factors described in Section 2.3 and then to obtain the final Risk Index $I_{R,j}$ for each link. In general terms, a holistic method can be operatively applied by considering a Multi-Criteria Decision Making process [48] in which the defined risk-influencing factors do not necessarily have the same relevance in the overall risk index.

***Table 4** Features of the three calculation approaches are reported with the aim to compare the introduced modification in respect to [19].*

	[19]	Modified Cherubini's approach	Expert judgement	Analytical Hierarchy Process
Modified parameters and factors	-	Added the parameter "Underground elements" in Physical-structural features factor		
	-	Added the factor "Extrinsic vulnerability" with a single parameter (V_{link})		
	-	Added the factor "Seismic hazard" with following parameters: "Design ground acceleration", "Ground type" and "Topographic amplification factor"		
Values	Cherubini's approach	Values are given following Cherubini's approach	Values are given by the Expert judgement	Given through Analytical Hierarchy Process

Weights	Cherubini's approach	approach	Weights are given by the Expert judgement	Two sets of weights are given for each factor and parameters through the Analytical Hierarchy Process
$I_{R,j}$ calculation approach	The weighted sums are firstly normalized on factors maximum obtainable value and then on related weight for each factor	The weighted sum is firstly normalized on factors maximum obtainable value and then on related weight for each factor	The index is obtained through the sum of Sp_{iK} values weighted on related Wc_K for each factor	The calculation is given by a first weighted sum on Wi_K for each parameter and then on Wc_K for each factor
$I_{R,j}$ formulation	$\sum_{K=1}^{5}\left[\frac{\left(\sum_i Sp_{iK}\right)}{\left(\sum_i Sp_{iK}^{MAX}\right)} * Wc_K\right]$	$\sum_{K=1}^{5}\left[\frac{\left(\sum_i Sp_{iK}\right)}{\left(\sum_i Sp_{iK}^{MAX}\right)} * Wc_K\right]$	$\sum_{k=1}^{5}\left(\sum_i Sp_{iK} * Wc_K\right)$	$\sum_{k=1}^{5}((\sum_i Sp_{iK} * \mathrm{Wi}_K) * Wc_K)$

2.4.1 Modified Cherubini's approach

The first calculation approach, based on Task-4 of SAVE project [19], tries to fill its lacks through some changes including influencing factors and parameters defined in previous Section 2.3 and highlighted in **Table 4**. Each factor containing influencing parameters is associated with a weight to establish a hierarchy of influence (values and weights are reported in **Table 5**). In this case, the final Risk Index $I_{R,j}$ is assessed through the Equation (2):

$$I_{R,j} = \sum_{K=1}^{5}\left[\frac{\left(\sum_i Sp_{iK}\right)}{\left(\sum_i Sp_{iK}^{MAX}\right)} * Wc_K\right] \quad (2)$$

where:

- Sp_{iK} is the value conferred to the *i*-th parameter of the *K*-th factor;
- Sp_{iK}^{MAX} is maximum attributable value to the *i*-th parameter of the *K*-th factor;
- Wc_K is the weight related to the *K*-th factor;

According to [19], Equation (3) permits to obtain the correspondent normalized index for each link ($I_{Rn,j}$):

$$I_{Rn,j} = \frac{I_R}{\sum_{k=1}^{5} Wc_K} \tag{3}$$

2.4.2 *Expert judgement*

The second approach establishes an alternative hierarchy among factors based on an expert judgement [49]. Different weights are associated to each factor and different values are associated to each alternative according to **Table 5** while considering the Expert Judgement approach, thus another formulation for Risk Index $I_{R,j}$ assessment is defined in Equation (4):

$$I_{R,j} = \sum_{k=1}^{5} \left(\sum_{i} Sp_{iK} * Wc_K \right) \tag{4}$$

According to the previous definition of Sp_{iK}, Sp^{MAX}_{iK} and Wc_K, Equation (5) normalizes the obtained Risk Index:

$$I_{Rn,j} = \frac{I_{R,j}}{\sum_{k=1}^{5} \left(\sum_{i} Sp^{MAX}_{iK} * Wc_K \right)} \tag{5}$$

2.4.3 Analytical Hierarchy Process

The third proposed way to reach the Risk Index $I_{R,j}$ can be supported by Analytical Hierarchy Process (AHP) developed by [41] and used with the same purpose in this field by [50]. This approach needs to introduce a second level of weights to each parameter (Wi_K) establishing an influence scale among them. The AHP considers that the sum of conferred weights must be equal to one both for factors and for each parameter. In this way, the generated Risk Index varies between zero and one and it does not require further normalization. The weight distributions (reported in **Table 5** in AHP section) are obtained through the open source tool AHP Online System[2] and the calculated Ratio of Consistency (lower than 10%) confirms the acceptability of the proposed weights. Equation (6) shows the proposed calculation of the Risk Index, that is gained by defining Wi_K as the weight related to the *i*-th parameter:

$$I_{R,j} = \sum_{k=1}^{5}((\sum_{i} Sp_{iK} * \mathrm{Wi}_K) * Wc_K) \tag{6}$$

Regardless of the chosen approach, $I_{R,j}$ and $I_{Rn,j}$ can be collected in tables and graphically represented on urban centre maps to directly recognise where most dangerous paths (links) are collocated and how the safe areas (squares) are connected between them.

Table 5 *Weights of factors (Wc_K), weights of parameters (Wi_K) and the related values (Sp_{iK}) are reported for the three different considered approaches: Modified Cherubini's approach, Expert judgement and the Analytical Hierarchy Process.*

		Modified Cherubini's approach		Expert judgement		Analytical Hierarchy Process (AHP)		
Factor ID	Parameter ID	Wc_K	Sp_{iK}	Wc_K	Sp_{iK}	Wc_K	Wi_K	Sp_{iK}
B	B.1	0.2	0.4	0.333	0.4	0.045	0.272	0.5

[2] AHP Online System available at: https://bpmsg.com/academic/ahp-hierarchy.php (last access: 2018/04/17).

			0.6		0.6			1
	B.2		0.6		0.6		0.272	0.5
			0.1		0.1			1
	B.3		0.2		0.2		0.036	1
			0.1		0.1			0.5
	B.4		0.6		0.6		0.272	1
			0.3		0.3			0.5
	B.5		0.1		0.1		0.147	0.33
			0.3		0.3			0.67
			0.5		0.5			1
C	C.1	0.40	0.1	0.667	0.1	0.067	0.667	0.33
			0.5		0.5			0.67
			1		1			1
	C.2		0.2		0.2		0.333	0.33
			0.4		0.4			0.67
			0.6		0.6			1
D	D.1	0.80	0.3	1.000	0	0.381	0.143	0.33
			0.55		0.3			0.67
			0.8		0.5			1
	D.2		0.1		0		0.429	0.33
			0.8		0.8			0.67
			1		1			1
	D.3		0.1		0.33		0.143	0.33
			0.6		0.67			0.67
			0.8		1			1
	D.4		0.3		0		0.143	0.33
			0.55		0.3			0.67
			0.8		0.5			1
	D.5		0.1		0		0.143	0
			0.4		0.4			0.25
			0.5		0.5			0.5
			0.6		0.6			0.75
			0.8		0.8			1
E	E.1	0.60	0.25	1.000	0.25	0.126	0.126	0.25
			0.5		0.5			0.5
			0.75		0.75			0.75
			1		1			1
F	F.1	1.00	0.25	1.000	0.25	0.381	0.400	0.25
			0.5		0.5			0.5
			0.75		0.75			0.75
			1		1			1
	F.2		0		0		0.400	0
			0.25		0.25			0.25
			0.625		0.625			0.5
			1		1			1
			0.75		0.75			0.75
	F.3		0		0		0.200	0
			0.25		0.25			0.5
			0.25		0.25			0.5
			0.5		0.5			1

2.5 *Risk Indexes application and comparison*

The three approaches on risk indexes assessment of path network (Modified Cherubini's approach, Expert Judgment and the AHP approach) are applied to a real-world sample to evaluate their capabilities and offer a preliminary validation of each one. To this aim, a risk index-damage state level correlation, based on damage levels given by [37], is also offered in order to demonstrate the reliability of the proposed calculation approaches through the comparison between assessed normalized Risk Index and damages suffered by links from real cases observation.

Figure 2 *Urban scenario damages in the Central Italy seismic sequence in 2016: A) street pavement cracking due to unstable slopes and landslides-induced effects (Intrinsic vulnerability); B) an aerial view of Amatrice (RI, Italy) main street, that is partially blocked by ruins formation provoked by buildings collapse; debris impeded rescuers' interventions (Extrinsic vulnerability). Video frames by Corpo Nazionale dei Vigili del Fuoco http://www.vigilfuoco.tv/ (last access 2018/04/17).*

Risk Assessment Tables are compiled for a paths sample[3] concerning Italian historical city centres struck by the 2016 Central Italy seismic sequence, the 2012 Emilia Romagna region (Italy) and the 2009 Aquila (Italy) earthquake. Most of the considered links are highly affected by street pavement modifications or paths' blockage due to unstable slopes, landslide or debris accumulations that contribute to urban scenario modifications as shown by the examples in **Figure 2**. For each link in the sample, $I_{R,j}$ and $I_{Rn,j}$ values are calculated following each proposed calculation approach. The damage level of each path is evaluated by comparing photographic documentation of links before and after the earthquake event, and by adopting the description of post-earthquake damages effects according to the Road Damage Scale (*RDS*) [37]. RDS can vary from 0 to 5 (integer scale). The adopted damage scale for paths considers damages due to landslides, unstable slopes and cracks to the street, debris presence along the street and presence of failed external elements that could impede partially or completely the path accessibility. Then, $I_{Rn,j} - RDS$ pairs are organized to evaluate the risk index capability in describing possible critical conditions in post-earthquake scenarios. The three proposed risk assessment approaches are considered validated if a higher risk index corresponds to a higher link damage level. According to general tri-linear trends in earthquake safety and damage assessment, by including *fragility curves* and studies on seismic vulnerability [8,32,35,51], a linear interpolation between $I_{Rn,j} - RDS$ pairs is then performed according to previous studies' approaches [37]. Finally, a comparison of produced regression lines is provided through the evaluation of coefficient of determination R^2 to define the more suitable calculation approach (based on data fitting effectiveness) among the considered ones.

[3] The database is uploaded as supporting file and also available at: https://goo.gl/yzHNTQ (last access: 2018/04/29)

2.6 Application to a case study

Among the three Risk Index calculation approaches, the one having the highest coefficient of determination R^2 is chosen to be applied on a case study referring to an Italian historical city centre, with the purpose to give a real application of the research. This case study (different from previously employed sample) is referred to a representative Italian historical centre: Offida (Italy). Offida's city centre has been affected by intense seismic activity over times[4], including the ones connected to the Central Italy seismic sequence in 2016-2017 (in this case, without reporting considerable damages). Paths network shows a medieval compact and irregular urban fabric due to the hilly site conformation, and it is mainly characterized by historical masonry buildings. Offida also owns particular risk features from a touristic point of view, and so for the exposure-related parameters, because of its significant cultural heritage (religious sites, a theatre hosting exhibitions during the whole year, museums, cultural events in both winter and summer seasons).

Although the methodology could be applied for all the outdoor public spaces in an urban centre, this work would like to focus on paths selected among the network according to the following criteria, so as to evidence the capabilities connected to safety planners application in intervention strategies definition and evacuation plan design:

- only links accessible by vehicles are considered;
- paths involved by the presence of facing masonry buildings are considered to focus literature-supported evacuations on extrinsic vulnerability;
- accessible squares are considered while private courtyards are excluded.

[4]Seismic activity of Offida (Italy): https://emidius.mi.ingv.it/DBMI11/query_place/ (last access on 2018/04/17).

Risk indices are assessed for each link and node.

In order to graphically evidence the riskiest paths within the urban fabric, a Seismic Risk Map is proposed. This can be a tool for supporting emergency management directly obtained from the proposed methodology application (regardless of the calculation approach). In addition, another map named Intervention Priority Map is defined to assign resources for risk-reduction strategies within the studied urban centre by means of an immediate graphic representation.

The Seismic Risk Map is obtained with the following steps:

- $I_{Rn,j}$ is calculated in according to Section 2.4.2 for each link;
- $I_{Rn,j}$ values are grouped in a scale composed by four sets also according to literature studies [20,40]: Low risk (0%-25%), Medium-Low risk (25%-50%), Medium-High risk (50%-75%), High risk (75%-100%);
- Each set corresponds to a different colour on the map.

The Intervention Priority Map follows the following rules:

- $I_{Rn,j}$ values are calculated as explained in Section 2.4.2;
- the maximum $I_{Rn,j}$ value is obtained for the studied sample and it is defined as $I_{max,\,S}$;
- Priority Intervention Indices I_{IP} are obtained according to the Equation (7) below:

$$I_{IP} = I_{Rn,j}/I_{max,\,S} \qquad (7)$$

- I_{IP} values are grouped in a scale composed by four sets: Low priority (0%-25%), Medium-Low priority (25%-50%), Medium-High priority (50%-75%), High priority (75%-100%) which are associated to different colours in the map.

3 Results

3.1 Comparisons between Risk Indexes and damage

Figure 3 shows the linear correlations between noticed damages and assessed Indices obtained for the three proposed approaches. Results show a lower risk index limit (about 20%) that corresponds to no damages for all the three approaches[5]. A Risk Index close to zero is not observed because, in the analysed cases, some risk-affecting parameters are always present (and different from zero), such as the local seismic hazard. At the same time, from RDS=4 to RDS=5 the trend is only traced because of the lack of real-world data, due to the currently analysed sample characterization.

The graphical comparison and the analytic results (regression equation for each approach) in **Table 6** underline that:

1) For all the three approaches, a trilinear trend is present. The sloped line is similar for each one. **Figure 3** graph B) displays a lower damages increase than the other graphs.

2) R^2 values are generally acceptable, even if the modified Cherubini's approach has the lowest R^2, and it graphically seems to assume a not strictly monotonous linear trend too. The Expert Judgement approach expresses the better regression model in respect to the other two approaches, according to its R^2 value.

3) The AHP-based approach is developed so as to follow an evaluating calculation approach previously applied in other studies (i.e.: [40,50]) that limits subjective interpretations about weights assignment. For these reasons, it seems to be the most rigorous approach. Anyway, appendix B data

[5] As reported by grey line in **Figure 3**, it is possible to identify a first segment that represents a step from zero to around 20% of I_{Rn} in case B) and around 24-30% of I_{Rn} and I_R in cases A) and C) also according to **Table 5**.

shows how differences between AHP and Expert Judgement approach predictions are really close one to each other, by confirming their similarities. Anyway, when considering a specific link, $I_{Rn,j}$ values from the three approaches (see Appendix B) are very similar (average percentage difference equal to 5%).

Table 6 Comparisons among proposed approaches in terms of trend lines equations. The table also shows data about the domain in terms of Risk Index, and the obtained R-squares for $I_{Rn,j}$- RDS pairs correlations.

Compared approaches	Equations	Domains	R^2
Modified Cherubini's approach	$\begin{cases} RDS = 0 \\ \text{RDS} = 10.13\, I_{Rn,j} - 2.24 \\ RDS = 5 \end{cases}$	$I_{Rn,j} < 24\%$ $24\% \leq I_{Rn,j} \leq 73\%$ $I_{Rn,j} > 73\%$	0.57
Expert judgement	$\begin{cases} RDS = 0 \\ \text{RDS} = 8.86\, I_{Rn,j} - 1.79 \\ RDS = 5 \end{cases}$	$I_{Rn,j} < 20\%$ $20\% \leq I_{Rn,j} \leq 77\%$ $I_{Rn,j} > 77\%$	0.78
Analytical Hierarchy process	$\begin{cases} RDS = 0 \\ \text{RDS} = 11.46\, I_{R,j} - 3.47 \\ RDS = 5 \end{cases}$	$I_{R,j} < 30\%$ $30\% \leq I_{R,j} \leq 74\%$ $I_{R,j} > 74\%$	0.74

Such results confirm the capabilities of the risk index by means of the related predictions of damages: the higher the $I_{Rn,j}$ the higher the RDS. A sufficient reliability of the proposed novel holistic method and a satisfied sensitivity of Links Assessment Tables is reached independently from the three approaches involved to elaborate the final $I_{Rn,j}$. The choice of a specific risk index, thus, only seems to affect the trustworthiness (in terms of confidence, according to the R^2 values) and the precision of estimations.

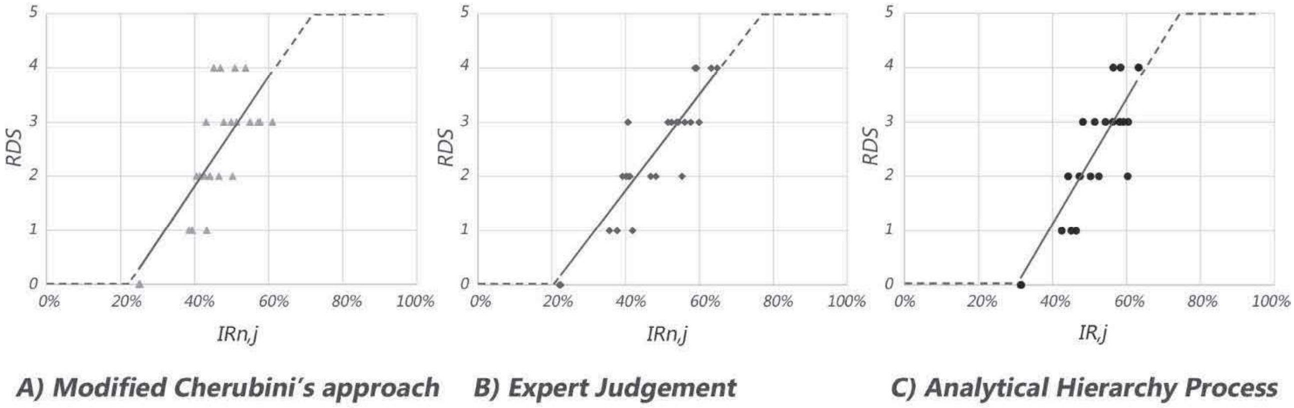

Figure 3 *Tri-linear correlation between analysed path risk indices ($I_{R,j}$ and $I_{R,j}$) and related street damages levels (RDS): A) Modified Cherubini's approach; B) expert judgment; C) Analytical Hierarchy process. Dashed lines predict expected trends in domains where data sample are not currently present. Equations for the three regression trends are offered by Table 5.*

3.2 A historical urban centre

The risk maps in **Figure 4** and **Figure 5** permit to graphically have under control the overall risk situation of the selected paths of Offida (AP), describing the evaluated scenario. Appendix C offers detailed numeric results. It is possible to recognize which parameters influence those values by focusing on links with higher risk. The analysis of the related tables and assigned values to parameters evidence that the case-study paths network is mainly characterized by a Medium-Low risk: this result highlights the homogeneity of the urban fabric. Some other dangerous situations are evaluated. As shown in **Figure 4**, the link "V" is located close to slope edges with possible landslides. Moreover, the risk index is influenced by exposure factors. In fact, the considered paths have an access role to the city centre and it is used as a one-way street. For these reasons, it results in Medium-High risk. Intervention Priority Map in **Figure 5** shows links "S" and "T" with a Medium-High priority level, located near areas with potential landslides. The same level is attributed to links "M" and "R", but they are developed on level ground. A high index is reached because of the presence of buildings with relevant seismic vulnerability. In addition, the specific situation of the segment “V” is remarked, which can represent an access street to the city centre.

Seismic Risk Map and Intervention Priority Map seem to be not so different in terms of outcoming results. Nevertheless, while the first allows comparing maps of different city centres thanks to its risk index absolute scale representation, the second permits to detect risk variation between paths of the same city centre, because of its different formulation (see Equation (7)).

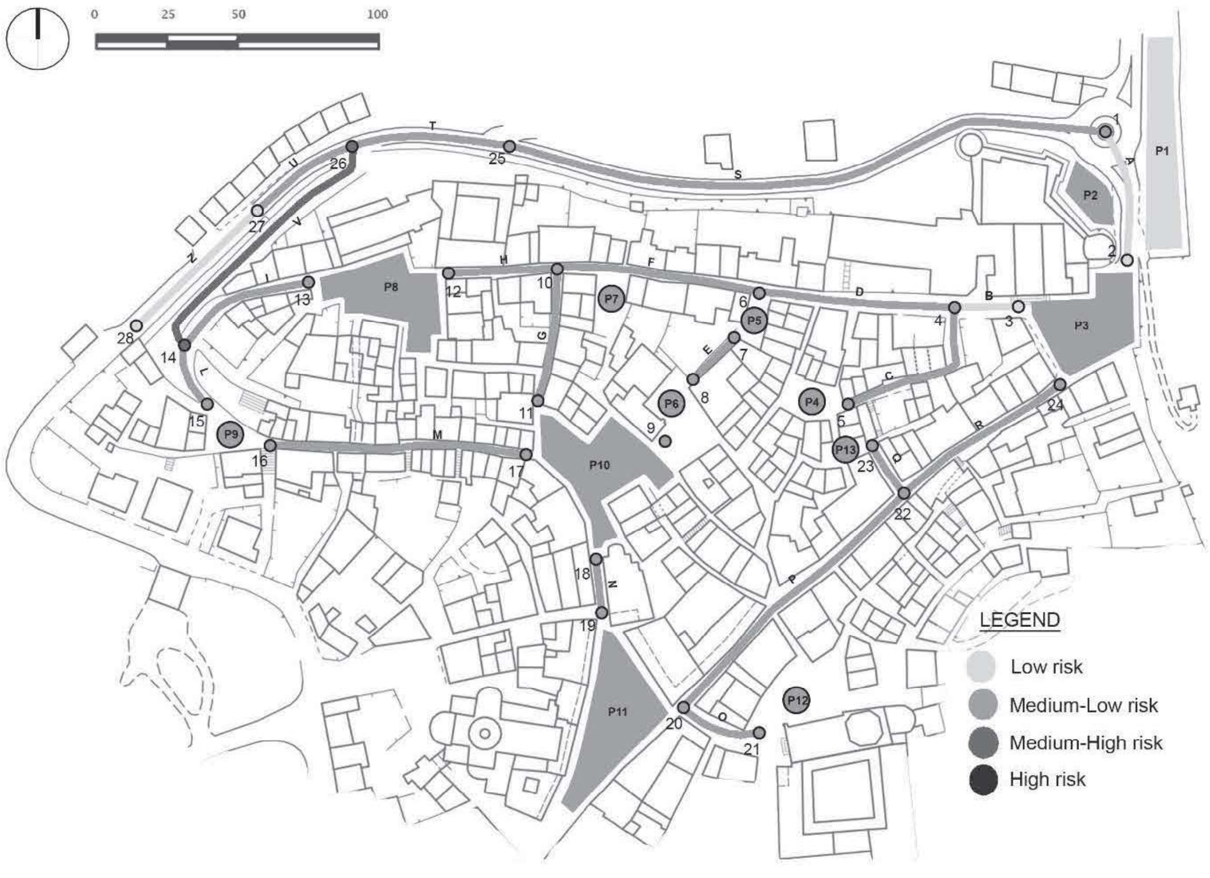

Figure 4 *Seismic Risk Map of the selected part of Offida (AP) paths network. Links are marked with letters, nodes with numbers and the wider filled areas are the squares considered in this case study application. According to Section 2.6 definition, such elements are*

associated with the four risk levels (represented to the four shades of grey). Squares identified by black circled are considered as not relevant in emergency management for their limited dimension.

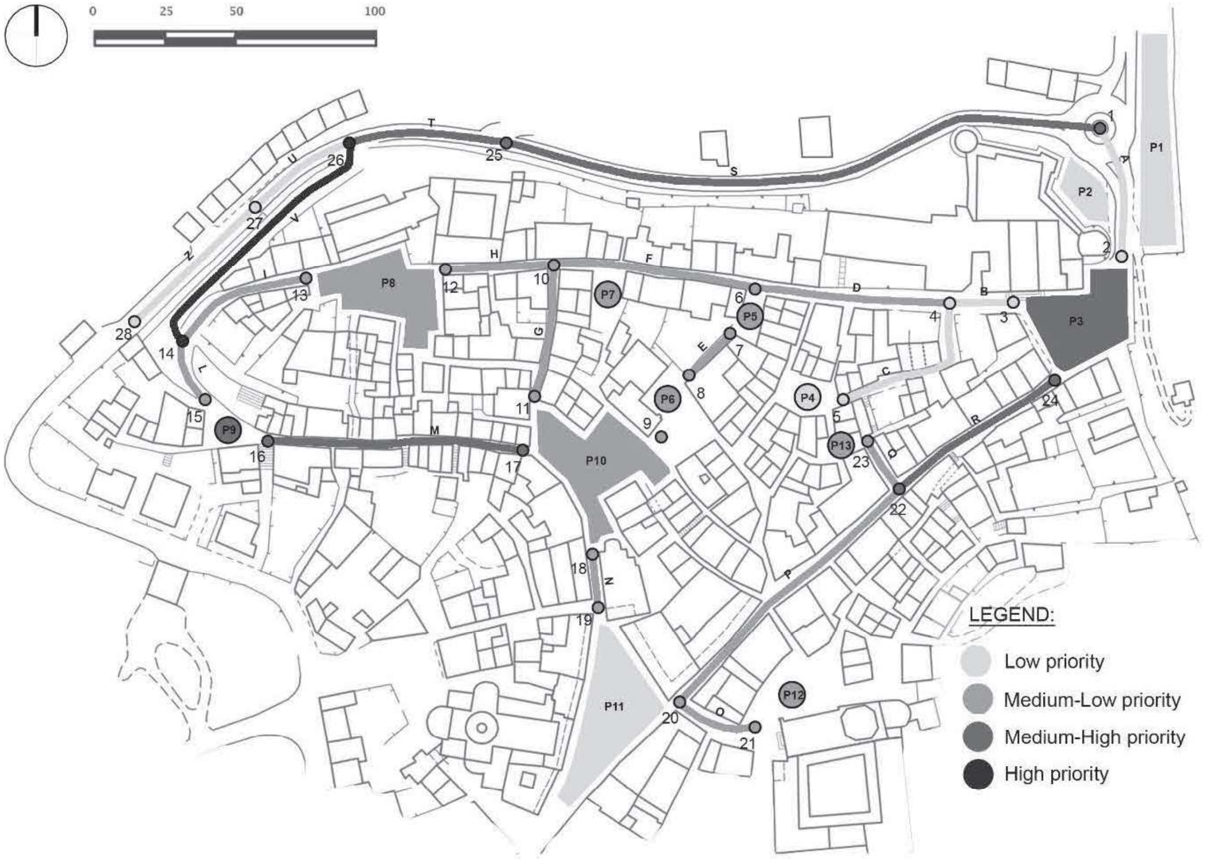

Figure 5 *Intervention Priority Map of a portion of Offida (AP) paths network. According to the same map description of Figure 4, and to Section 2.6 definition, the map priority rank is referred to the risk index normalized on the case study maximum risk value.*

3.3 Holistic methodology capabilities for future applications

The previous methodology for the seismic risk assessment of evacuation paths attempts to provide a new concept to consider all factors influencing the evacuation process. The proposed holistic methodology firstly allows defining a percentage value that gathers risk-affecting factors (i.e.: referring to the normalized risk indexes). Hence, the outcoming overall evaluation does not involve a separate layers description [20]. At the same time, the adoption of quick evaluation methods also guarantees to use it in a straightforward way by detecting wide urban historical areas. In particular, differently from other previous studies, it tries to combine path intrinsic and extrinsic vulnerability. In such a way, unlike previous works [22], this novel method can include obstructions and interruptions not only caused by ruins formation, but also by eventual structural failures, landslides or street pavement cracking. Besides, it can also give significant bases for the integration of exposure factor (inquired by means of quick path related features data collection) in such evaluations.

Secondly, vulnerability assessment, related to the path itself (intrinsic vulnerability), concerns frequent situations belonging to the urban environment, differently from other methodologies referred to particularly typologies of main streets [10,16]. In respect to previous researches, the proposed methodology application could be extended to typical elements present in path infrastructural elements like bridges, viaducts or tunnels that can be also placed outside the urban fabric.

Finally, this work considers important factors that could represent vulnerable elements in historical urban areas, according to the base reference method (i.e.: [19]). Anyway, in respect to such method, caves, cisterns or hypogeum hidden under street pavement or lifelines, pipes and culverts are effectively considered.

4 Conclusion and remarks

The risk assessment of evacuation paths in urban areas in case of earthquake emergencies is useful to evaluate the safety of an urban scenario and exposed population, especially during the evacuation process. Particular attention has to be paid to historical urban environment where pedestrians' evacuation can be hardly stressed or impeded by hazards due to the complex urban fabric, its composing elements and vulnerabilities, the earthquake effects on them (e.g.: ruins formation from buildings collapse along streets, ground failures or links interruptions due to their damage). To perform such safety evaluation at historical urban scale, rapid methods should be preferred because of the urban scale dimension, while a holistic method should be adopted since many factors (vulnerability, hazard, and exposure) contemporarily affect the safety levels during and in the post-earthquake scenario.

In this paper, a novel methodology for assessing the risk level of the evacuation paths in the seismic emergency has been proposed. Buildings collapse and intrinsic vulnerability of street typologies are now considered. The holistic risk assessment also involves different seismic hazard and exposure conditions. Then, each risk-affecting factor (and related parameter) is considered in a weighted manner according to three different approaches. A preliminary methodology validation was performed by applying it to a sample of paths placed in seismic damaged historical urban fabrics and a good agreement was found. The present work relates to a real-world sample (actually limited to significant Italian case studies) selected to apply the proposed methodology, the related calculation approaches and the evaluation of post-earthquake damage. Hence, future activities should enlarge the reference sample so as to increase the method robustness and to improve the risk-damages prediction criteria effectiveness. From this point of view, since the holistic methodology adopts quick characterization criteria due to the possible implementation at a wide urban scale, method’s verification needs to be supported by samples from several earthquakes databases.

Future researches could also develop a paths damages prediction algorithm towards simulating different scenarios for different macroseismic intensity inputs, so as to consider the effective earthquake severity in damages assessment.

Anyway, according to current results, this novel holistic methodology can be applied to have under control the overall risk situation of paths in historical centres and so to provide evaluation tools for scenario assessment and emergency planning. The damage prevision criterion could also support the development of pedestrians' evacuation simulators in urban outdoor environments. By focusing on debris formation, behavioural aspects and human motion speed, simulation models could take advantages from this study in aspects related to pedestrians' safer path choice and losses of street integrity/capability due to earthquakes. Besides, it could be a first criterion to evaluate and taking into account streets vulnerability and their damages in evacuation procedures.

During the evaluation of evacuation management strategies, results from its application could suggest which links should be excluded from selected paths because of their high-risk level, and which could be considered safer (according to a relative scenario sample-based scale).

The proposed seismic risk assessment methodology could be combined with simulation tools for analysing the evacuation process and the use of paths in historic city centres. In such way, results could also be useful to local authorities to suggest where directing risk-reduction interventions and resources following an order of intervention priority (e.g.: through a path risk maps of the historical urban fabric: Seismic Risk Map and Intervention Priority Map).

Acknowledgements

The authors wish to thank Eng. Teresa Caprini for her valuable help in data collection.

5 Appendix A

***Table 7** Notation table.*

Symbol	Measure	Description
R	-	Seismic risk, related to the number of people killed or injured, the damage to property and the impact on economic activity due to the occurrence of the disastrous event
V	-	Seismic vulnerability, related to the “weakness” of the element
H	-	Seismic hazard, related to the possibility of future seismic actions
E	-	Seismic exposure, related to the presence and the “value” of buildings and other objects and to the possible consequences on human life
a_g	m/s^2	Peak ground acceleration (PGA)
$I_{R,j}$	-	Street network Risk index for j-link
$I_{Rn,j}$	-	Normalized street network Risk index for j-link
Wi_k	-	Weigh related to the i-th parameter
Wc_k	-	Weigh related to the k-th factor
Sp_{ik}	-	Value conferred to the i-th parameter of the k-th factor
Sp_{ik}^{max}	-	Maximum attributable value to the i-th parameter of the k-th factor
V_b	-	Seismic vulnerability index of the considered building through the macroseismic method
b	-	Incidence of the building in the link, as the ratio between building and link lengths
L_b	m	Building length
$V_{link,j}$	-	Seismic vulnerability of the j-link
$V_{Nlink,j}$	-	Normalized seismic vulnerability of the j-link
RDS	-	Road Damage Scale [37]
Average Flow	Veic./h	Number of vehicles that travel across a section per unit time
L	m	Link length from node to node
L_{max}	m	Maximum link length in the analysed sample
W	m	Link width in terms of carriageway average extension
W_{max}	m	Maximum Link width in the analysed sample
A	m^2	Area of evaluated Square
A_{max}	m^2	Maximum Square area in the analysed sample

6 Appendix B

Table 8 *Method validation sample data. The assessed link is identified through to the relative ID by showing related: location and reference earthquake; evaluated risk index ($I_{R,j}$) and normalised index ($I_{Rn,j}$) according to the three approaches (in the AHP approach, such values are equal); Road Damage Levels (RDS).*

code	Location	Earthquake	Modified Cherubini's approach		Expert judgement		AHP	RDS
			$I_{R,j}$	$I_{Rn,j}$	$I_{R,j}$	$I_{Rn,j}$	$I_{R,j}$	
A	Arquata del Tronto (AP)	Central Italy 2016	1.22	41%	3.57	40%	44%	2
B	Pescara del Tronto (AP)	Central Italy 2016	1.65	55%	5.13	58%	58%	3
C	Norcia (PG)	Central Italy 2016	1.18	39%	3.36	38%	43%	1
D	Norcia (PG)	Central Italy 2016	1.30	43%	3.73	42%	46%	1
E	Norcia (PG)	Central Italy 2016	1.50	50%	4.79	54%	56%	3
F	Castelluccio di Norcia (PG)	Central Italy 2016	1.51	50%	4.92	55%	60%	2
G	Castelluccio di Norcia (PG)	Central Italy 2016	1.54	51%	4.99	56%	60%	3
H	Tra Valli Umbre (PG)	Central Italy 2016	1.53	51%	5.18	63%	63%	4
I	Forca Canapine (PG)	Central Italy 2016	1.61	54%	3.17	65%	63%	4
J	Amatrice (RI)	Central Italy 2016	1.16	39%	1.96	36%	45%	1
K	Offida (AP)	Central Italy 2016	0.75	25%	2.00	22%	32%	0
L	Tolentino (MC)	Central Italy 2016	0.76	25%	5.33	22%	31%	0
M	Accumoli (RI)	Central Italy 2016	1.72	57%	4.58	60%	59%	3
N	Amatrice (RI)	Central Italy 2016	1.73	58%	4.83	51%	54%	3
O	Amatrice (RI)	Central Italy 2016	1.83	61%	4.82	54%	58%	3
P	Onna (AQ)	Aquila (Italy) 2009	1.36	45%	4.29	59%	56%	4
Q	Onna (AQ)	Aquila (Italy) 2009	1.32	44%	4.29	48%	53%	2
R	Fossa (AQ)	Aquila (Italy) 2009	1.41	47%	4.86	59%	58%	4
S	Arischia (AQ)	Aquila (Italy) 2009	1.44	48%	4.66	52%	51%	3
T	San Felice sul Panaro (MO)	Emilia (Italy) 2012	1.28	43%	3.84	47%	44%	2
U	San Carlo (FE)	Emilia (Italy) 2012	1.24	41%	3.49	39%	47%	2
V	San Carlo (FE)	Emilia (Italy) 2012	1.29	43%	3.62	41%	48%	3
W	Mirabello (FE)	Emilia (Italy) 2012	1.33	44%	3.62	41%	47%	2
X	Sant'Agostino (FE)	Emilia (Italy) 2012	1.40	47%	3.66	41%	50%	2
Y	San Carlo (FE)	Emilia (Italy) 2012	1.29	43%	3.62	41%	48%	3

7 Appendix C

Table 9 *Case study application results from the historical centre of Offida (AP) Italy, by collecting obtained values from inquiring parameters according to Section 2 definition for each link and squares. For both paths network elements, the evaluated risk indices* ($I_{R,j}$) *and the normalised ones* ($I_{Rn,j}$) *are shown.*

ID case	A	B	C	D	E	F	$I_{R,j}$	$I_{Rn,j}$
Links								
A	Clear	0.47	0.20	0.73	0	1.25	2.65	29%
B	Clear	0.50	0.33	0.97	0.25	1.00	3.05	33%
C	Clear	0.43	0.33	0.97	0.50	1.00	3.24	35%
D	Clear	0.50	0.60	0.97	0.50	1.00	3.57	39%
E	Clear	0.60	0.47	1.27	0.50	1.00	3.84	42%
F	Clear	0.50	0.60	0.97	0.75	1.00	3.82	42%
G	Clear	0.60	0.33	1.27	0.50	1.00	3.70	40%
H	Clear	0.50	0.33	0.97	0.75	1.00	3.55	39%
I	Clear	0.50	0.33	1.57	0.50	1.00	3.90	42%
L	Clear	0.50	0.33	1.57	0.25	1.00	3.65	40%
M	Clear	0.50	0.73	1.47	0.50	1.00	4.20	46%
N	Clear	0.50	0.33	1.27	0.75	1.00	3.85	42%
O	Clear	0.60	0.20	1.27	0.50	1.00	3.57	39%
P	Clear	0.67	0.60	1.27	0.75	1.00	4.29	47%
Q	Clear	0.60	0.33	1.27	0.75	1.00	3.95	43%
R	Clear	0.67	0.33	1.27	0.75	1.00	4.02	44%
S	Clear	0.53	0.93	1.63	0.25	1.25	4.60	50%
T	Clear	0.53	0.33	1.93	0.25	1.25	4.30	47%
U	Clear	0.53	0.33	0.63	0.50	1.25	3.25	35%
V	Clear	0.73	0.60	2.47	0.25	1.25	5.30	58%
Z	Clear	0.53	0.33	0.33	0.25	1.25	2.70	29%
Squares								
P1	Clear	0.43	0.07	1.73	0	1.25	2.45	30%
P2	Clear	0.47	0.67	0.33	0.25	1.25	2.96	35%
P3	Clear	0.53	0.07	1.67	0.50	1.00	3.77	45%
P8	Clear	0.67	0.07	1.27	0.50	1.00	3.50	42%

P10	Clear	0.67	0.07	1.27	0.50	1.00	3.50	42%
P11	Clear	0.50	0.07	0.97	0.50	1.00	3.04	36%

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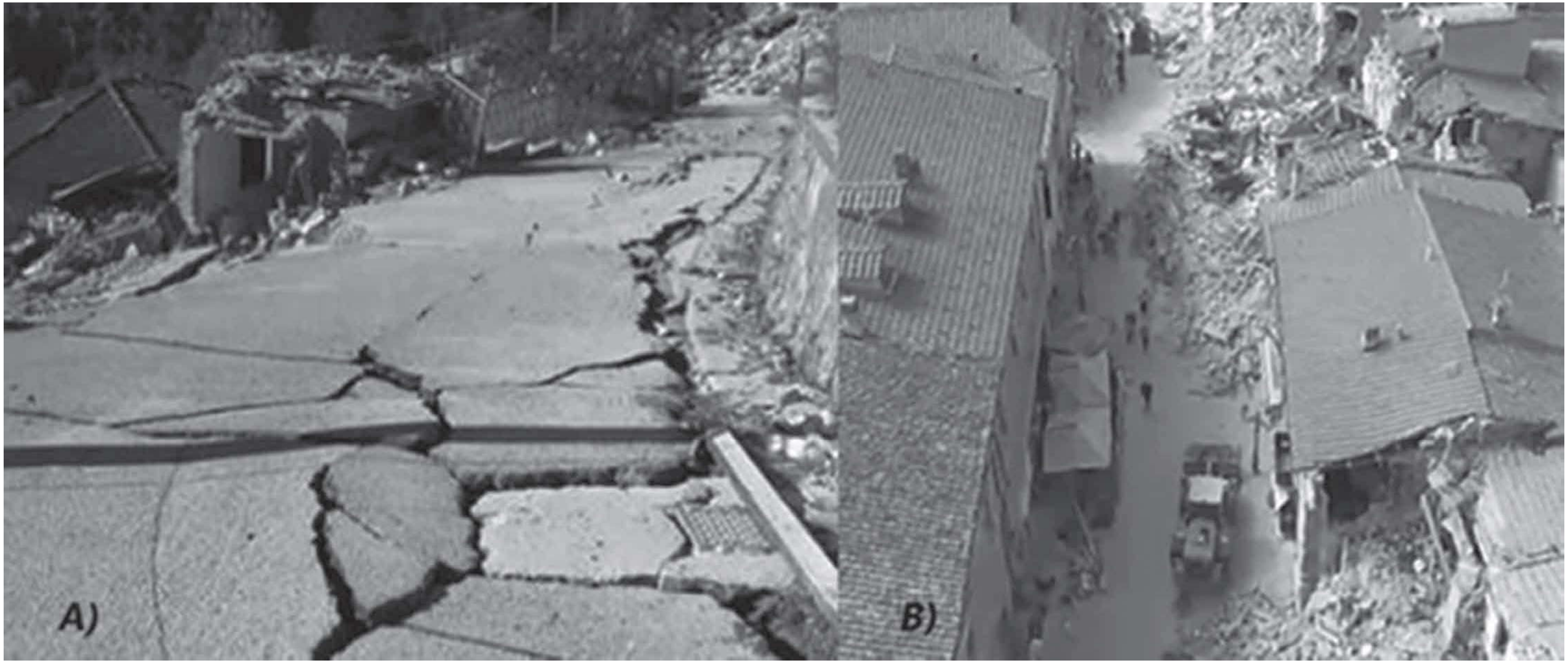
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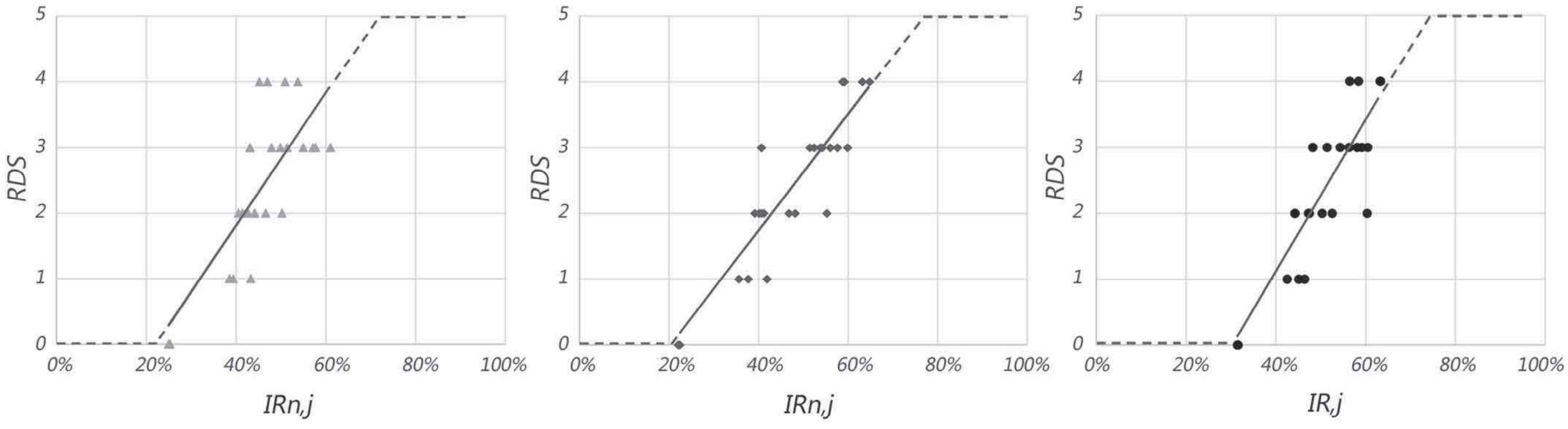
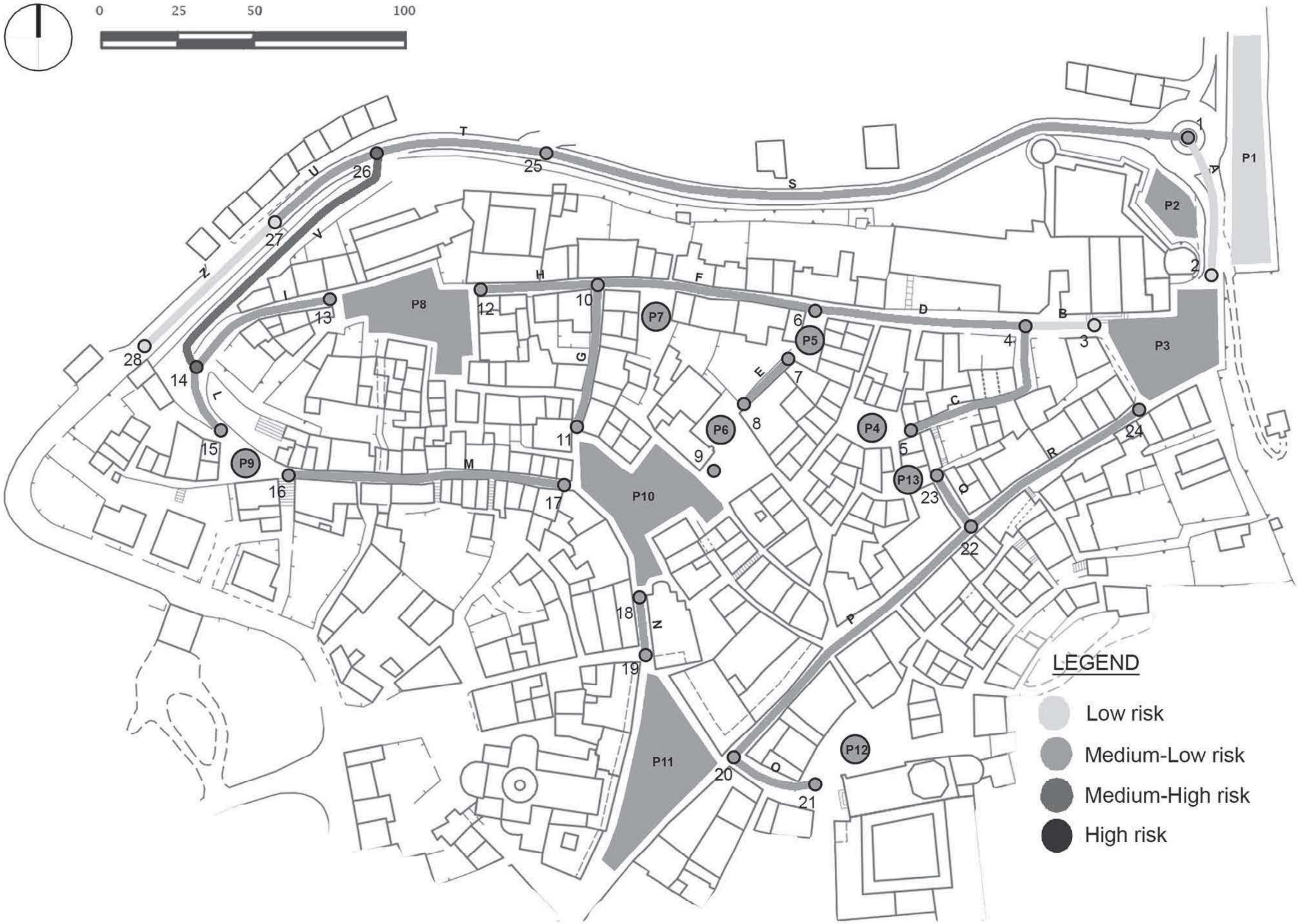


A) Modified Cherubini's approach B) Expert Judgement C) Analytical Hierarchy Process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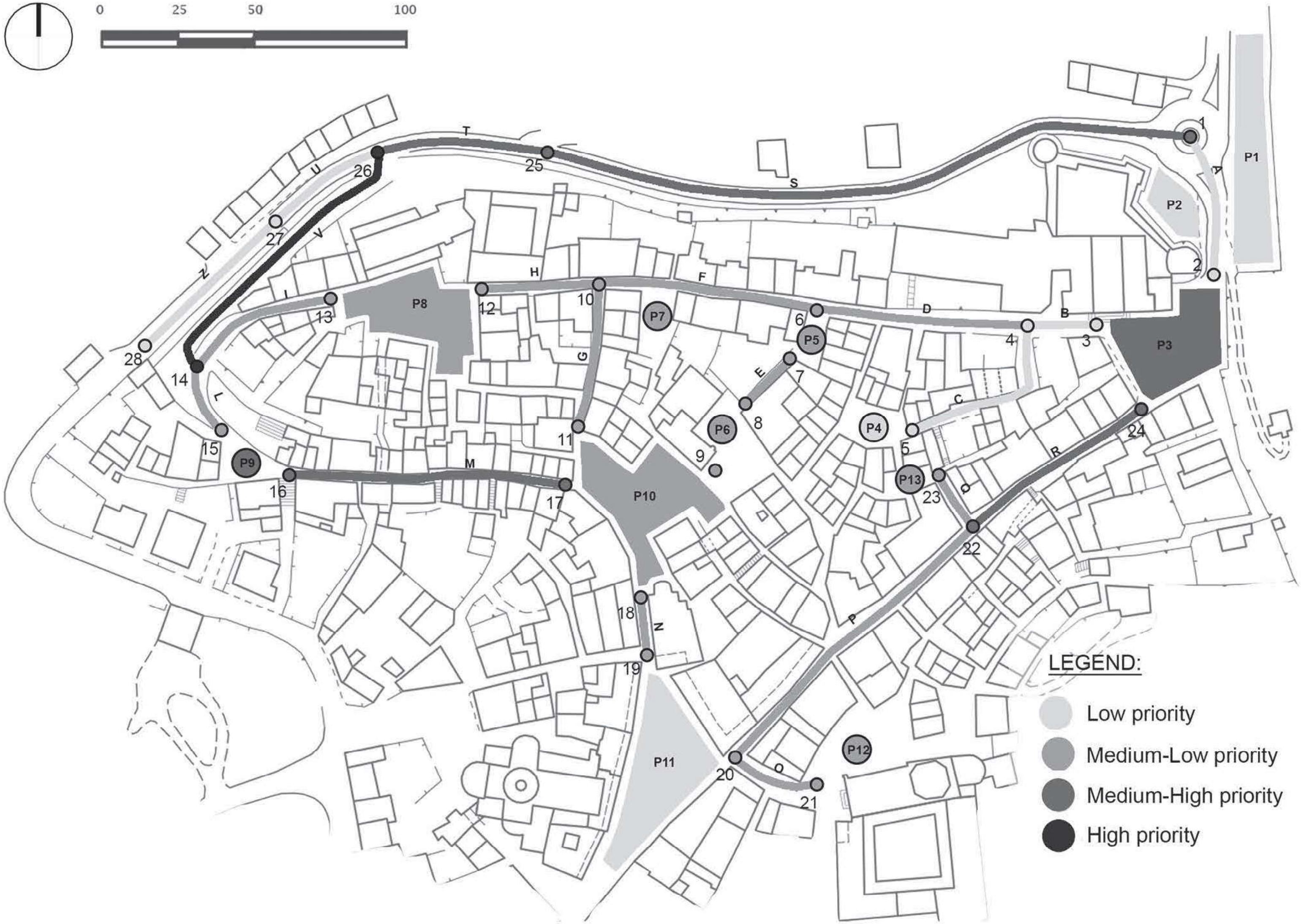
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LEGEND:
Low priority
Medium-Low priority
Medium-High priority
High priority