WP 4: Human factors simulation in BETs and definition of a related behavioral-based (B-based) resilience metric

T4.2 - Simulators application to selected BETs in their current state and by applying current SUOD/SLOD standards mitigation strategies. Interferences assessment between selected SUOD/SLOD through simulation-based approach, with possible overlap of effects and related amplifications. Definition of a set of KPIs for overall resilience evaluation of BE and criteria for their correlation.

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Abstract

Facing the safety assessment of the Built Environment (BE) means considering the inseparable relationship between the physical space and its users. Among the phases of the Disaster Life Cycle, that of evacuation represents the most critical one for user resilience in the risk-prone built environment, especially for SUdden-Onset Disasters (SUODs), as environmental conditions are changed within a short time after the disaster. The need of quantitative metrics to evaluate the disaster resilience and safety of users in BE open spaces is expressed through the definition of Key Performance Indicators (KPI).

This deliverable aims to define a system of KPIs for users' resilience and safety to SUOD, especially to seismic and terrorist risk. The elaborated KPIs have been then tested on idealized Built Environment Typologies (BET) identified by D3.2.1, to compare different risk scenarios, highlighting similarities and diversity, and to optimize the design of mitigation solutions. The results show the possibility of using the same KPIs to quantify the safety and resilience of users with respect to different behaviors due to different types of disasters,

constituting a necessary step towards an overall metric for resilience to SUODs in open spaces within the built environment.

Keywords

Resilient evaluation, SUOD, BET, KPIs, Behavioral-based simulations.

Approvals

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-	-	-	-	-

Summary

1. Introduction

The definition of key performance indicators (KPIs) for safety assessment, focused on the population perspective is a key issue in the risk assessments of the built environment, and several researches have addressed the topic (O'Brien et al. 2017; Zlateski et al. 2020).

There are numerous aspects to consider regarding the safety of users in open spaces and require quantitative metrics to be able to evaluate the adoption of different mitigation strategies in specific risk scenarios.

The fundamental aspects certainly include the conditions of movement of displaced persons (Dong et al. 2018), the identification of threats (Tai et al. 2010; Bernardini et al. 2016; Robat Mili et al. 2018), the evaluation of the best evacuation paths, and the morphological and construction characteristics of these paths.

Within this framework, the present deliverable aims to define and catalogue the most suitable KPIs for the multi-risk investigation of BETs, based on behavioral-based simulations.

2. Methodology

The methodology of this deliverable is based on two fundamental cores represented in **Errore. L'origine riferimento non è stata trovata.**:

1. Theoretical basis for KPI definition, is structured in 3 points:
   - the awareness that the KPIs will be defined on the basis of applicability for the purposes of simulation-based analyses and that they will have to flow into the simulations themselves, enriching the proposed model (D 4.1.1);
   - the definition through SMART approach: Specific, Measurable, Assignable, Realistic and Time related (Doran 1981; Thakur et al. 2020);
   - the analysis of the PIs evaluated in the previous steps of the research project related to the seismic risk conditions in BE prone to earthquake (D 1.2.1; Russo et al. 2021) and prone to terrorism risk (D 1.3.1);

2. Simulation of KPI in BET scenarios are then elaborated to compare the data in different configuration of idealized typology of Open Spaces and in different risk scenarios.

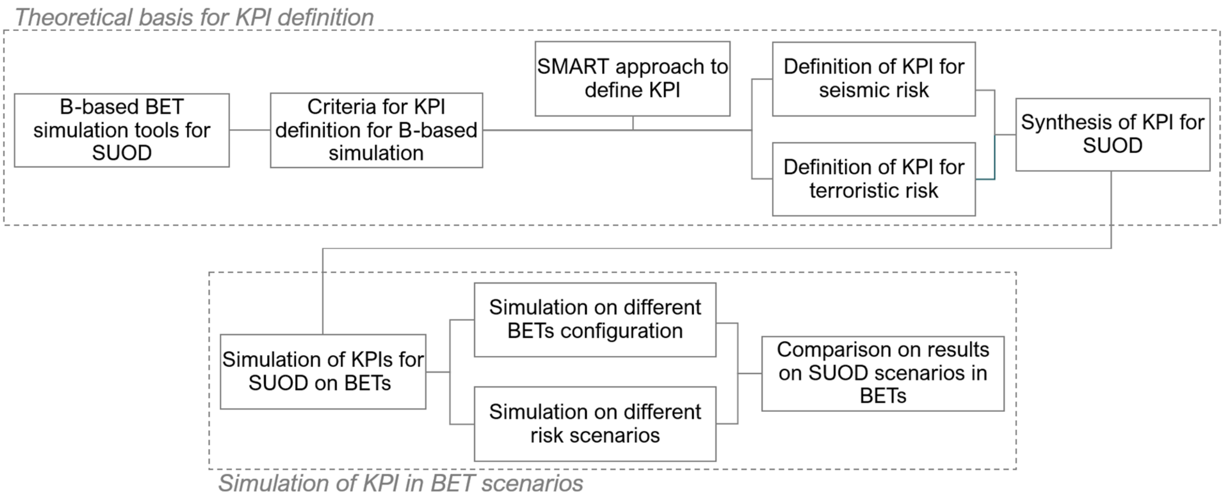

Figure 1 methodology scheme for definition of PI

2.1 Human factors simulation in BETs

The model of human simulation in BETs developed within the BE SECURE project assumed the role of support tool for stakeholders and related designer, for assessing the BE resilience and comparing the probable impact of solutions for risk-mitigation measures in the BE (Hissel et al. 2014; Bernardini and Ferreira 2020), as defined in D 5.2.1. To define possible KPI to be implemented into this process, it is essential to clarify which are the desired outputs from the simulation. The considered outputs to describe the disaster conditions in the BE(T), mainly focus on (Ronchi et al. 2013; van der Wal et al. 2021; Bernardini et al. 2021):

- **timing issues**, that are, for SUODs, evacuation times, starting from the evacuation curve representation;
- **interaction in the crowd** issues, that are related to the density and contacts that can also involve physical contact and falls, therefore additional risks, the number of users for each type of area (e.g. safe areas for SUODs), and the position and number of users in critical boundary conditions (e.g. overcrowding, interactions with debris and so on), thus collecting the individuals' trajectories from a general perspective (e.g. counter of the usage of each patch in the BE by users, together with their related timing);
- **behavioural** issue, by counting the number of users adopting each behaviour or involved in specific actions, also in reference to their location (e.g. number of people's fall over the simulation time and their position).

These elements will be fundamental in defining the KPIs, which in turn must be able to investigate these issues and provide prediction indications related to these aspects.

2.2 KPIs definition: the SMART approach

International Organization for Standardization (ISO) has defined different standards regarding KPI, namely ISO 22400 for manufacturing operations management, ISO 14031 for environmental performance evaluation and ISO 13053 for defining Six Sigma performance improvement methodology.

KPI are generally classified into leading and lagging KPI. Leading KPI measure activities, which has significant impact on future performances, whereas lagging indicator measures output of past events (Thakur et al. 2020). In this specific case, we are going to work with leading KPI.

Among numerous approaches, the one defined by Doran is surely one of the most suitable for application on multi-risk investigation of BE (Doran 1981). Doran proposed the SMART philosophy to compose the Management's goals and objectives by considering them as critical step in company's management process. The SMART represents:

- Specific - target a specific area for development;
- Measurable - quantify/indicator for improvement;
- Assignable - responsible personnel/team;
- Realistic - objectives that can be achieved with available resources;
- Time related - time frame for result to be achieved.

According to the specific area of research and the applicability to behavioural-based simulation of BE (see section 2.1), the SMART philosophy could be elaborated and adapted as follow:

- Specific - target a specific risk or risk-combination for BE;
- Measurable - quantify/indicator for improvement;

- Assignable - to one or more risk-prone element of the BE;
- Realistic - objectives of behavioural issues or involving in specific actions;
- Time related - for SUODs specific investigation, linked to evacuation times.

Therefore, an indicator must satisfy the aforementioned criteria in order to be eligible for KPI. The KPIs will be selected to be valid for Seismic risk, terrorist risk or both. The combination is not related to a temporal coexistence, but to an approach to SUOD risks in contrast to SLOD risks, specifying that the possibility that terrorist attack and earthquake occur at different times has been taken into consideration.

2.3 KPI simulation for BETs scenarios

The validity of the selected KPIs according to the method described in Section 2.2, has been tested through the application to a series of idealized BETs (D'Amico et al. 2021). For each BET identified were then defined three possible geometric configurations, with the aim of highlighting any critical issues derived from the presence or not of specific elements of urban furniture (bollards with chains and monument in the center of the square).
The proposed methodology combines the action of static KPIs and dynamic KPIs. The first focus on the geometric and morphological aspects of the space and how these influence user behaviors; while the last directly assess the behavioral aspects of users during a natural or anthropogenic type of emergence, through simulations. This classification is useful because it allows a double risk analysis and consequently on the possible strategies to be adopted.

3. Results and discussions

The following are the results of the actions taken in this work: the selection of PIs for literature [3.1], elaboration of new KPIs [3.2], final selection of KPIs [3.3], simulation of KPIs for BETs scenarios when the calculation for each KPI is analyzed [0], and finally the comparison of KPIs values for BETs scenarios [3.5].

3.1 Selection of KPIs

The analysis of PIs reached out a selection of to 30 items eligibility to KPIs for SUODs multirisk. The description of these PIs is reported below.

The Balance Index (**ID 1** in Table 1) by (Tumini et al. 2017) indicates the system of open spaces of a city and that is the network of streets, parks and squares that is activated after a disastrous SUOD event (earthquake or terrorist attack) for emerging activities (useful areas) in the city in the short and long term through the equation (1).

$$BI = {\sum A_{ub}}/{\sum A_b} \tag{1}$$

where A_{ub} is the unbuilt useful areas of the BET and A_b is the built areas of the BET.
The BI has been integrated and improved to include the effects of debris, then related to earthquake evacuation conditions (Zlateski et al. 2020), combining **ID 8** and **25** in Table 1 through the difference between the CSA (Codified Safe Areas) considered net of courtyards and other areas not accessible, and the area occupied by debris (A_{deb}) in the open space and along the links (2).

$$A_{eff} = CSA - A_{deb} \tag{2}$$

The pedestrian route directness (**ID 2** in Table 1) defines the ratio between the actual distance of a route in the urban space (D) and the geodetic (or straight-line) distance (d_l) between its origin and destination (3).

$$PR = {}^{D}/_{d_l} \tag{3}$$

In the event of an evacuation, this parameter can be used to define the capacity of an urban system to allow direct movement from the vulnerable position to the safety zone (León et al. 2019). The Road Resisitor Coefficient R_{RC} (**ID 3** in Table 1) measures the objective risk of the road network for the evacuation of pedestrians and is defined by equation (4).

$$R_{RC} = {}^{l_r}/_{w_r} \tag{4}$$

where l_r is the length of the evacuation road and w_r is the width of the evacuation road.
The larger the R_{RC} is, the more difficult it is to evacuate. It is easy for victims to evacuate on short wide roads, while on the contrary, congestion will occur and certain disasters, like the stampede (Zhang et al. 2015).
Tortuosity (**ID 4** in Table 1) is a risk index that expresses the difference between the minimum linear path length and the average evacuees' path length, highlighting the criticalities along the path and the microscopic interactions between the evacuees and the surrounding built environment (i.e. for pedestrians' and debris avoidance, for pedestrians' behaviors on the links) (Bernardini and Ferreira 2020).
Difference-in-path ratio (**ID 5** in Table 1) is the ratio of length between the effective and ideal escape routes and is calculated as the mean value of all evacuees arriving in the CSA. The higher ratio, the more tortuous is the path to reach CSA (Zlateski et al. 2020).
The temporary Secure Open Spaces (SOSs) (**ID 6** in Table 1) express the amount of open public areas that are useful for shelter and recovery (Tumini et al. 2017) calculated with equation (5).

$$SOSs = {}^{\sum SOS\ areas}/_{inhabitants} \tag{5}$$

Thus, in post-perturbation reconstruction, the quantity of open areas must remain in balance with built-up areas and population density to maintain or improve resilience. An SOS value at or above 4 mq per inhabitant indicates a good amount of useful open spaces after the disaster.
Cities subject to seismic events (and more generally to SUODs) must be equipped with an effective evacuation system, equipped with well-known, accessible and safer escape routes. In this regard the ERD (**ID 7** in Table 1), defines the distance of evacuation routes from the farthest (Tumini et al. 2017).
The Friction rate (**ID 9** in Table 1) considers the reduction in the speed of evacuation of evacuees caused by micro-vulnerabilities (for inappropriate use, inadequate maintenance and problems related to the design of evacuation routes) detected along the evacuation path, also allowing a comparison of them and to determine their relative degree of vulnerability (Álvarez et al. 2018). The quantification of the micro-vulnerabilities and the obstruction levels of the evacuation routes is defined through a proposed friction rate, defined as in the equations (6.1 - 6.2)

$$i\ [\%] = \frac{\sum_j S_{m_j} \times \alpha_j}{S_r} \times 100 \tag{6.1}$$

$$\alpha_j = 1 - SCV_j, \tag{6.2}$$

where S_m is the surface area of the micro-vulnerability associated with an evacuation route, S_r is the surface area of the analyzed evacuation route, and α is the speed reduction factor associated with each micro-vulnerability. Another parameter that can affect the evacuation speed is the walking speed variability (ID **12** in Table 1) that considers speed adjustment for the pedestrians in relation to factors including evacuee (Wang and Jia 2021). Simulation of the evacuation speed is essential in estimating the victim and, ultimately, the risk of evacuation. This parameter is computed (n.r.) and incorporated in the model to allow for more realistic evacuation simulation.

The Walkability Index (WI) (**ID 10** in Table 1) evaluates the percentage of streets and pedestrian walkways (Tumini et al. 2017) and calculate with the equation (7).

$$WI = \left({}^{l_w}\!/_{l_{tot.}} \right) \times 100 \tag{7}$$

where l_w is the length of walkways, $l_{tot.}$ Is the total streets length and multiplying the ratio by 100 gives a percentage value always between 0% and 100%.

In the context of a crisis due to rapid disasters, urban morphology strongly influences the evacuation times of users. The KPI Pedestrian speed conservation (**ID 11** in Table 1) considers morphological and geophysical aspects which affect this aspect, according to factors including land use and terrain slope. Particular attention should be paid to the design of the road network, concerning the width and length of routes and the volume of traffic (León and March 2014).

The Exposure Index (**ID 13** in Table 1) is defined in terms of human lives (number of persons) and assesses the spatio-temporal distribution of users depending on the hosted activities in both outdoor and indoor areas (i.e. facing buildings, because of the correlation between their intended use). The exposure was assessed following the innovative procedure proposed by (Bernabei et al. 2021) with the equation (8) where individual vulnerability aspects are taken into account considering three different age categories.

$$E = \sum_i U_{OD_i} \times x_{\%i} \times w_i \tag{8}$$

where U_{ODi} are the normalized user occupancy in the given time period, $X_{\%i}$ are the percentages of the related age group within the population of the OS in the HBE and w_i is the weighted percentages of the related age group.

The Population Density (**ID 14** in Table 1) that refers to the number of inhabitants per area:

$$PD = {}^{inhabitants}\!/_{area} \tag{9}$$

considering that a high Population Density (PD) means low system resilience. This parameter suggests that in a resilient city (Tumini et al. 2017).

The congestion degree in crowded roads (**ID 15** in Table 1) provides an estimate of the crowding condition along evacuation paths following a SUOD emergency in order to plan the most functional evacuation route (Kanno et al. 2016). This is influenced by geographical characteristics such as road width, possible degree of collapse of buildings and is calculated with equation (10).

$$Congestion_r = \sum \left({}^{occurrences\ of\ path}\!/_{number\ of\ path} \right) \tag{10}$$

The flow robustness (**ID 16** in Table 1) is measured by computing the flow robustness defined as:

$$FR = {}^{n_f}\!/_{n_{tot.}} \tag{11}$$

where n_f is the number of flows and $n_{tot.}$ is the total number of possible flows in a network.

A new flow strength value is calculated each time a node is removed from the system (either due to debris, destruction, etc). The obtained value is normalized with the total number of flows of the network, which is $n\ (n - 1)$, where n is the number of nodes in a network. A further method is to measure the effect of interruptions using indices (der Sarkissian et al. 2020). Mean connectivity (**ID 17** in Table 1) represents the number of alternative paths within the whole grid (Giuliani et al. 2020) and is the ratio between the connectivity values and the total number of segments in the set (12).

$$\bar{C} = \frac{1}{n}\sum_{i=1}^{n} C_{\theta,i} \qquad (12)$$

The values range from 1 to *n*, being *n* the total number of segments, and are high in case of a dense presence of alternative paths; $C_{\theta,i}$ is the measure of angular connectivity and is the sum of the total number of angle turns to a root segment *i*.
High values of the mean connectivity guarantee the presence of alternative paths in the grid; Instead, Frequency Index (**ID 18** in Table 1) represents the distribution level of the shortest paths in the grids.
The frequency index *v* is expressed by the ratio between the maximum actual choice $Ch_\theta(x)^{max}$ in the set of segments and the maximum value it could virtually reach v^{max} (13).

$$v = \frac{Ch_\theta(x)^{max}}{v^{max}} = \frac{Ch_\theta(x)^{max}}{{n^2}/{2} - {3n}/{2} + 1} \qquad (13)$$

The index is between 0 and 1, representing a vulnerable system when v tends toward 1 and resilient otherwise. It assumes that a resilient system has a diffuse presence of shortest paths all over the grid while a dense concentration through a small number of spatial elements determines a vulnerability condition (Giuliani et al. 2020).
The ERI (**ID 19** in Table 1) evaluates the number of evacuation routes. This evaluates the provision of secure evacuation routes in urban areas, calculated with the equation (14).

$$ERI = \left(\frac{\sum n.\,Evacuation\ Ruote}{\left({inhabitants}/{100}\right)}\right) \qquad (14)$$

Reasoning in these terms, it is necessary to think about the entire evacuation system so that it is as fast as possible (Tumini et al. 2017).
Similarly to the ID **15** in Table 1, the congestion degree in crowded areas (**ID 20** in Table 1) estimate the crowding condition in crowded areas (Kanno et al. 2016) and is calculated with the equation (15).

$$Congestion_A = \sum\left[\frac{people\ in\ crowded\ area}{(evacuation\ sites \times number\ of\ paths)}\right] \qquad (15)$$

The Connectivity Index (**ID 21** in Table 1) is defined as the relationship between the street links (i.e., street sections between intersections) and the street nodes (or intersections).

$$c_{index} = {s_{link}}/{s_{node}} \qquad (16)$$

The presence of nodes along the street links allows a faster and safer evacuation as they provide users with the opportunity to choose the best route and avoid roads blocked by debris (León et al. 2019).
The Evacuation time percentile (**ID 22** in Table 1) represents the time required to escape of the 95% of people who arrived in a safe zone. Social and environmental factors have an important influence on evacuation time. The correct design of the architectural spaces and the recognition of wrong behaviors and waste of time by users are essential elements in order to reduce the time of exit by increasing the level of safety of the building (D'Orazio et al. 2015). This PI value is calculated direct from model output.

The Crowd effects (**ID 23** in Table 1) and the Number of deaths/casualties (**ID 24** in Table 1) are a fundamental aspect in the design of evacuation plans (Li et al. 2015; Du et al. 2020). The first parameter considers the negative effects that can occur during an evacuation (e.g. the risk of falling, limited physical capabilities etc.), compounded by the increased number of people trying to leave a building within a short period of time. The second PI is a promising method for implementing more rational and quantitative estimates of earthquake fatalities. The estimate of the victims considers the evacuation time as the main variable, variable depending on the parameters of the building (n. of exits, obstacles, etc.) and the physical characteristics of the users (fragility, age, etc.). Either PIs are made directly from the model.
The Proximity Index (PI) (**ID 26** in Table 1) lend themselves to this purpose in that they emphasize the importance of the pedestrian staircase and evaluates the distribution of urban services (schools, health centers, sports facilities, etc.) as a function of the citizens who benefit from it (Tumini et al. 2017). This factor is calculated with the equation (17).

$$PI = \left({inhabitants\ near\ basic\ services}/{tot.\,inhabitants} \right) \times 100 \tag{17}$$

The Occupancy Index for the link (**ID 27** in Table 1) represents the debris area along the link in question and is calculated with the equation (18).

$$O_{link} = min\left(\frac{A_{debris,link} + N_{av,link} \times \left(1 + \%\sigma_{N_{av,link}}\right) \times dA_{ped,D}}{W_{link} \times L_{link}} ; 1 \right) \tag{18}$$

where $A_{debris,link}$ [m^2] is the area of debris along the considered link, $N_{av,link}$ is the number of evacuees using a certain *link* to reach a certain CSA, is $dA_{ped,D}$ [m^2] the average moving pedestrian's area (fixed at 0.25 m^2) in Level of Service D conditions, W_{link} is the width of the link and L_{link} is the lenght of the link.
This parameter is used to consider interference from debris and associated slowdowns in CSA pathway (Zlateski et al. 2020).
Safety Index for rescuers' access route (**ID 28** in Table 1) is the number of connections that make up the first aid attendant pathway. The index considers all the number of links that composes the rescuers' access path.

$$S_{link,SAA} = \left(\frac{A_{debris,link}}{A_{eff,link}/dA_{ped,D}} \right) \times \left(min\left(\frac{N_{av,link}}{A_{eff,link}/dA_{ped,D}} ; 1 \right) \right) \times \left(1 - \frac{pos_{link}}{n_{link,route}} \right) \tag{19}$$

where pos_{link} is the position of the considered link inside the rescuers' path can be evaluated by considering the number $n_{link,route}$ of links composing the access route. The overall value is 1.0 for the link closer to the SAA.
Where possible, more than one route of access should be identified (at least two alternatives, given what is noted above for the CSA). The preferred approach should be the shortest with minimal interference conditions (Zlateski et al. 2020).
The number of evacuees for SUODs (**ID 29** in Table 1) considers the percentage of people who can effectively participate in the evacuation compared to the total number of people involved in the event. Earthquake-related experience and education can prevent injuries and self-identification and self-help play key roles in emergency and medical rescue responses (Kang et al. 2017).
The mean flow rate at the exit (**ID 30** in Table 1) is simply defined as the number of people passing through the door per second and is calculated as the number of participants divided by the total evacuation time (i.e. the time between the first and the last participant passing through the door) direct from model

outputs. The flow rate is one of the most used to evaluate the efficiency of the evacuation, in fact it is an important value used in building regulations (Feliciani et al. 2020).

Below is a complete analysis of the indicators deriving from the previous steps of the research, in relation to the SUODs, i.e. the seismic and terrorist risk (D 1.2.1, D 1.2.2, D 1.2.3, D 1.3.1, D 1.3.2).

Table 1. Analysis of indicators deriving from D121, D122, D123, D131, and D132 reports

ID	Name	Reference	Formula	Unit of measure	S	M	A	R	T	eligibility for mutlirisk KPI
1	BI: Balance index	(Tumini et al. 2017)	$BI = {\sum A_{ub}}/{\sum A_b}$	[m²/m²]	X	X	X	X	X	**X**
2	Pedestrian route directness	(León et al. 2019)	n.r.	[m/m]	X	X		X	X	
3	R_{RC}: Road resistor coefficient	(Zhang et al. 2015)	$R_{RC} = {l_r}/{w_r}$	[m/m]	X	X	X	X	X	**X**
4	Tortuosity	(Bernardini and Ferreira 2020)	n.r.	[m/m]	X	X		X	X	
5	difference-in-path ratio	(Zlateski et al. 2020)	n.r.	[m/m]	X	X		X	X	
6	temporary secure Oss	(Tumini et al. 2017)	$SOSs = {\sum SOS\ areas}/{inhabitants}$	[m²/inh]	X	X	X	X	X	**X**
7	ERD: evacuation route distances	(Tumini et al. 2017)	n.r.	[m]	X	X		X		
8	effective areas surface	(Zlateski et al. 2020)	$A_{eff} = CSA - A_{deb}$	[m²]	X	X	X	X	X	**X**
9	Friction rate	(Álvarez et al. 2018)	$i = \frac{\sum_j S_{m_j} * \alpha_j}{S_r} \times 100$ $\alpha_j = 1 - SCV_j$	[%, m²/m²]	X	X	X	X	X	**X**
10	WI: Walkability index	(Tumini et al. 2017)	$WI = \left({l_w}/{l_{tot.}}\right) \times 100$	[%, m/m]		X		X	X	
11	Pedestrian speed conservation	(León and March 2014)	n.r.	[%]	X	X	X	X	X	**X**
12	Walking speed variability	(Wang et al. 2021)	n.r.	[m/s]	X			X	X	
13	Exposure index	(Bernabei et al. 2021)	$E = \sum_i U_{OD_i} \times x_{\%i} \times w_i$	[%]	X	X	X	X	X	**X**
14	Population density	(Tumini et al. 2017)	$PD = {inhabitants}/{area}$	[inh/ha]	X	X	X		X	
15	Congestion degree in crowded roads	(Kanno et al. 2016)	$Congestion_r = \sum \left(\frac{occurrences\ of\ path}{number\ of\ path}\right)$		X	X		X	X	
16	Flow robustness	(Der Sarkissian et al. 2020)	$FR = {n_f}/{n_{tot.}}$		X	X		X	X	
17	Mean connectivity	(Giuliani et al. 2020)	$\bar{C} = \frac{1}{n}\sum_{i=1}^{n} C_{\theta,i}$		X	X		X	X	
18	Frequency index	(Giuliani et al. 2020)	$v = \frac{Ch_\theta(x)^{max}}{v^{max}} = \frac{Ch_\theta(x)^{max}}{n^2/2 - 3n/2 + 1}$		X	X		X	X	

19	ERI: Evacuation route index	(Tumini et al. 2017)	$ERI = \left(\frac{\sum n.\,Evacuation\ Ruote}{\left(inhabitants/_{100}\right)}\right)$	[n°/inh]	X	X		X	X	
20	Congestion degree in crowded areas	(Kanno et al. 2016)	$Congestion_A = \sum\left[\frac{people\ in\ crowded\ area}{evacuation\ site \times number\ of\ path}\right]$		X	X		X	X	
21	Connectivity index	(León et al. 2019)	$c_{index} = {}^{S_{link}}/_{S_{node}}$		X	X	X		X	
22	Evacuation time percentile, i.e. 95th	(D'Orazio et al. 2015)	direct from model outputs	[s]	X	X	X	X	X	**X**
23	Crowd effects, i.e. number of physical contacts and falls	(Du et al. 2020)	direct from model outputs	[number of items]	X	X	X	X	X	**X**
24	Number of deaths / casualties	(Li et al. 2015)	direct from model outputs	[persons, %]	X	X	X	X	X	**X**
25	Effective codified safe area CSA surface	(Zlateski et al. 2020)	See ID 8	[m²]		x		x	x	
26	Proximity index (PI)	(Tumini et al. 2017)	$PI = \left(\frac{inhab.\,near\ basic\ serices}{tot.\ inhab.}\right) \times 100$	[%]	x	X		X	X	
27	Occupancy index for the link	(Zlateski et al. 2020)	$O_{link} = min\left(\frac{A_{debris,link} + N_{av,link} * \left(1 + \%\sigma_{N_{av,link}}\right) * dA_{ped,D}}{W_{link} * L_{link}}; 1\right)$	[0-1]		X		X	X	
28	Safety index for rescuers' access to the link of a defined access route (Slink, SAA)	(Zlateski et al. 2020)	$S_{link,SAA} = \left(\frac{A_{debris,link}}{A_{eff,link}/dA_{ped,D}}\right) * \left(min\left(\frac{N_{av,link}}{A_{eff,link}/dA_{ped,D}}; 1\right)\right) * \left(1 - \frac{pos_{link}}{n_{link,route}}\right)$	[0-1]	X	X		X	X	
29	Number of evacuees for SUOD (considering SAP, self-aid percentage)	(Kang et al. 2017)	direct from model outputs	[#]		X			X	
30	Mean flow rate at the exit	(Feliciani et al, 2020)	direct from model outputs	[persons /s]	X	X	X	X	X	**X**

3.2 New KPIs developed

Starting from PIs derived from literature, some of them have been modified to be applied to the specificity of SUOD emergencies in OS. The new elaborated KPIs have been described below.

The balance index BI by (Tumini et al. 2017) has been adapted to include the effects of debris, thus relating to *earthquake evacuation conditions* (Zlateski et al. 2020), and thus it improves and combines **IDs 1, 8** and **25** in Table 1 using a ration form in (20).

$$BI = {}^{\sum A_{deb}}/_{\sum A_{tot}} \tag{20}$$

where A_{deb} represents the area of the square occupied by debris and A_{tot} is the entire surface of the square. It considers that the safe areas are only the ones placed outdoor (i.e. within the AS or LS or BET), and that

debris affects the quantity of such safe areas in case of evacuation. Higher this BI of debris (**ID 31** in Table 1), higher the safety level for evacuees. Anyway, free-from-debris areas should be highest as possible and, in any case, able to host all the evacuees, i.e. in non critical crowding conditions (that is, crowding index lesser than 3pp/m^2) (Zlateski et al. 2020). The BI of debris varies from 0 (maximum safety conditions) to 1 (minimum safety condition).
The number of evacuees for SUODs (**ID 32** in **Errore. L'origine riferimento non è stata trovata.**) integrates and improves **ID 29** in Table 1, since if considers the ratio between all the people who can effectively succeed in the evacuation, and the original (pre-SUOD) number of exposed people. It is oriented towards earthquake evacuation since it considers effects of debris and terrorist act effects on the exposed inhabitants (those placed in indoor and outdoor who can be ideally sensible to the SUOD, at the starting time t0 of the event). This value varies from 0 (worst conditions, since all the people were not able to participate in the evacuation) and 100% (best conditions).
The obstacle friction rate (**ID 33** in **Errore. L'origine riferimento non è stata trovata.**) improves **ID 9** in Table 1 and relates to **ID 17** in Table 1. To solve the question concerning the validity of the Alvarez friction rate for narrow environments (streets), the following equations (21.1-21.2) has been defined.

$$i\ [\%] = \frac{\sum_j (L_o \times \alpha_j)}{\sum_t L_{evt}} \times 100 \qquad (21.1)$$

$$\alpha_j = 1 - SCV_j, \qquad (21.2)$$

where L_o is the sum of the width of the obstacles, L_{evt} is the sum of the width of the evacuation flows and SCV in the Speed Conservation Value, that varies from 0% (block) to 50% (possibility to jump). In this way, linear obstacles can also be considered (benches, balustrades, chains, etc.).

The obstacle protection rate (ID 34 in **Errore. L'origine riferimento non è stata trovata.**) is a completely new KPI, valid for terrorist act only, since it considers the distance [m] between the user and a protective obstacle in respect to its distance [m] from the attackers. This KPI takes in consideration that the probability of survival to shooting attacks is increased staying out of shooters’ sight, and this aspect is lectured during emergency trainings (Zhu et al. 2020). The concept of limiting the terrorist’s sight can be applied also in other armed assaults (i.e., cold steel) and car-bombing attack. Thus, it evaluates the level of protection that an obstacle can provide to a user against a terroristic attack, working as a shelter where user can hide. According to European experience in educating citizen, some urban furniture within the built environment can work as passive system of protection during the attack (see D131), like for example cars, trees, monuments, benches, flowerpots.
For this purpose, the equation (22) was defined.

$$\frac{\sum_j (Ss_j \times ps_j)}{St \times pt} \qquad (22)$$

where S_{sj} is the safe surface, defined distinctly by attack type: Attack by gunman - defined by the attack hide cone, having the attacker as its vertex and determined by the shadow area generated by the j-th effective encumbrance and/or frontier; Gunman attack - defined as a surface complementary to that obtained by drawing tangents from the attacker's point of origin to the first obstructions, effective with respect to the attack, and to the frontier, with respect to the direction of movement of the attacker defined as linear. P_{sj} represents the number of people present in the j-th safe surface, evaluated on the basis of the user density (pp/m^2) of the areas (m^2) included in the safe surface. St is the total area bounded by the border and crossings. Pt is the total number of people present in the BET/square.

Table 2. New KPI developed

ID	Name	Reference	Formula	Unit of measure	S	M	A	R	T	eligibility for mutlirisk KPI
31	BI: Balance index of debris	adapted from (Tumini et al. 2017)	$BI = {\sum A_{deb}}/{\sum A_{tot}}$	[m^2/m^2]	X	X	X	X	X	**X**
32	Number of Evacuees for SUOD	elaborated from (Kang et al. 2017)	direct from model outputs	[%]	X	X	X	X	X	**X**
33	Obstacle friction rate	adapted from (Álvarez et al. 2018)	$\frac{\sum_j (L_o \times \alpha_j)}{\sum_t L_{evt}} \times 100$ $\alpha_j = 1 - SCV_j$	[%]	X	X	X	X	X	**X**
34	Obstacle protection rate	New	$\frac{\sum_j (Ss_j \times ps_j)}{St \times pt}$	[m/m]	X	X	X	X	X	**X**

3.3 Final selection of KPIs

Here we present the final selection of KPIs for SUODs according to the exposed method. The selected KPIs are valid for seismic risk, terrorist risk or both. The combination is not related to a temporal coexistence, but to an approach to SUOD risks in contrast to SLOD risks, specifying that the possibility that terrorist attack and earthquake occur at the same times has been not taken into consideration.

The KPI ID K1 is valid only for earthquake, IDs K11 and K12 are valid only for terrorism analysis. This suggests a double key of reading, from the top priority to the seismic risk, from the bottom to the terrorist risk. The KPIs with ID from K1 to K4 are geometric indicator, this not directly measure user behaviour, but the effects that the built environment (and how it responds to SUODs events) has on them. The KPIs with ID K5 and K6 and K12 are static-behavioral KPIs, they study user behavior but they are not dependent on a simulation.

Some of the KPIs can directly relate to the results of the B-based evacuation simulations, as shown by **Errore. L'origine riferimento non è stata trovata.**, i.e. new IDs K7, K8, K9, K10, K11.

Table 3. Final selection of KPI

ID	Name	Reference	Formula	Unit of measure	Data from B-based simulation	Seismic	Terrorist	SUOD combination
K1	BI: Balance index of debris	adapted from (Tumini et al. 2017)	$BI = {\sum A_{deb}}/{\sum A_{tot}}$	[m²/m²]		x		
K2	R_{RC}: Road resistor coefficient	(Zhang et al. 2015)	$R_{RC} = {l_r}/{w_r}$	[m/m]		x	x	x
K3	Pedestrian speed conservation	(León and March 2014)	$v_f = Vi \times \theta_{\%,cons} \times St_{\%,cons}$ $v_{loss} = 1 - (v_f/v_i)$	[%]		x	x	x
K4	Obstacle friction rate	adapted from (Álvarez et al. 2018)	$\frac{\sum_j (L_o \times \alpha_j)}{\sum_t L_{evt}} \times 100$ $\alpha_j = 1 - SCV_j$	[%]		x	x	x
K5	Temporary secure Oss	(Tumini et al. 2017)	$SOSs = \frac{\sum SOS\ areas}{inhabitants}$	[m²/inh]		x	x	x
K6	Exposure index	(Bernabei et al. 2021)	$E = \sum_i U_{OD_i} * x_{\%i} * w_i$	[%]		x	x	x
K7	Evacuation time percentile, i.e. 95th	(D'Orazio et al. 2015)	From simulation	[s]	x	x	x	x
K8	Crowd effects, i.e. number of physical contacts and falls	(Du et al. 2020)	From simulation	[number of items]	x	x	x	x
K9	Mean flow rate at the exit	(Feliciani et al, 2020)	From simulation	[number of persons/ s]	x	x	x	x
K10	Number of Evacuees for SUOD from surrounding buildings in the Oss	elaborated from (Kang et al. 2017)	From simulation	[%]	x	x	x	
K11	Number of deaths / casualties	(Li et al. 2015)	From simulation	[persons, %]	x		x	
K12	Obstacle protection rate	New	$\frac{\sum_j (Ss_j \times ps_j)}{St \times pt}$	[m/m]			x	

The method for calculating these KPIs either comes directly from the literature or has been specially modified to be adapted to the objectives of this paper, as described below in detail.
The BI (K1 in Table 3) defines the actual post-earthquake emergency usable surface through the ratio exposed in equation (23).

$$BI = {A_{deb}}/{A_{tot}} \tag{23}$$

where A_{deb} is the area occupied by debris and A_{tot} is the total area of BET. This ratio derives from a reworking of the original formula of (Zlateski et al. 2020).

The R_{RC} (K2 in Table 3) is a purely geometric indicator and has been calculated for each access road to the BET as described in Section 2.1 through the ratio of Length (L) and Width (W) of the road. To obtain a unique index for the square, the R_{RC} values of all access roads are mediated through the equation (24).

$$R_{RC}tot. = \sum R_{RC} / n.\,street \quad (24)$$

where, R_{RC} is the road resistor coefficient calculated for each road and n. street is the number of access roads to the square.

The Pedestrian speed conservation (K3 in Table 3) was estimated considering the slope of the ground, the width of the roads and the volume of traffic according to the guidelines of (León and March 2014). The traffic volume has been estimated considering the width of the roads of the Bets through the D.M. 05/11/2001 in reference to the Italian territory. The speed loss is calculated for each road (v_{loss}) (25.2) and for the entire square (V_{loss}) (25.3), averaging the values obtained.

$$v_f = v_i \times \theta_{\%,cons} \times St_{\%,cons} \quad (25.1)$$

$$v_{loss} = 1 - (v_f / v_i) \quad (25.2)$$

$$V_{loss} = \sum v_{loss} / n.\,street \quad (25.3)$$

where v_i is the Initial walking speed, assumed to be 1.4 m/s considering a pedestrian density value ≤0.8 pp/mq (free walking), v_f is the final velocity. This estimate is derived from the percentage conservation of speed versus road slope ($\theta_{\%,cons}$) and traffic level ($St_{\%,cos}$).

The Obstacle friction rate (K4 in Table 3) assesses the increase in evacuation difficulty due to the presence of obstacles (both areal and linear), as described in Section 3.2. The indicator, designed mainly to assess terrorist scenarios, has been adapted to study seismic risk scenarios, using the same equation adapted from (Álvarez et al. 2018). The total width of the evacuation flows (L_{evt}) was defined considering respectively the escape from the square (terrorist attack) and the shelter in the center of the square (earthquake).

The provision of safe evacuation areas - SOSs (K5 in Table 3) in cities is estimated through the equation given in Section 3.1. The impact derived from the presence of special buildings was included thanks to an integration of the original equation (26).

$$SOS = \frac{\sum_i A_i + A_{SB}}{\sum_i (A_i \times UO_{od}) + (A_{SB} \times UO_{SB})} \quad (26)$$

where A_{SB} is the special building surface and UO_{SB} is the density of users for special buildings. Thus, in post-perturbation reconstruction, the quantity of open areas must remain in balance with built-up areas and population density to maintain or improve resilience.

The Exposure index (K6 in Table 3) has been adapted from (Bernabei et al. 2021) described in Section2.1, with the aim of evaluating evaluates the number of people in the BET both inside the buildings and in the square area, as described above. In the seismic scenario, to this amount must also be added the percentage of users who take refuge in the square, coming from other parts of the city; This percentage is called FSUP and is equal to 45% of the users of the square calculated previously. While, for terrorist scenarios, only users in outdoor spaces are considered at risk; all those who are inside the buildings surrounding the square are considered safe. In particular, the assessment process involves the application of the following equations.

$$E_{max}[pp] = (UO_{od} \times A_{ext} \times (1 + FSUp)) + (A_{sb} \times UO_{id,sb}) \quad (27.1)$$

$$E_E[pp] = (UO_{od} \times A_{ext} \times OI_{pp}) + (UO_{od} \times A_{detr} \times OO_{pp}) + (UO_{od} \times A_{ext} \times FSUp) - (UO_{od} \times A_{free} \times OO_{pp}) \pm (A_{sb} \times UO_{id,sb}) \quad (27.2)$$

$$E_T[pp] = (UO_{od} \times A_{ext} \times OO_{pp}) + (A_{sb} \times UO_{id,sb}) \quad (27.3)$$

$$E = \frac{E_E(E_T)}{E_{max}} \quad (27.4)$$

where, E_{max} is the maximum exposure value, against which exposure is normalized for seismic risk (E_E) and terrorist attack risk (E_T), using the equation (27.4).
ID K7 (Table 3) can be compared to the exposure timing effects to SLODs (compare to D4.2.3 - Section 3).
ID K8 (Table 3) focuses on the probability that crowding conditions could lead people to being exposed to physical contacts, and so additional injuries. Either IDs K7 and K8 are valid for both earthquake and terrorist acts analysis, since they describe the evacuation process.
ID K9 (Table 3) can be both applied to terrorist act and earthquake evacuation simulation and assess the rapidity of the evacuation process. Anyway, the value could be ideally calculated in average terms for all the evacuation time length, or a given percentile in the number of arrived evacuees. The value could be also calculated as normalized flow, that is in respect to the permeability of the scenario (i.e. for terrorist act evacuation, where the permeability is equal to the overall egress widths, that is summing all the used and available roads widths).
The KPI called R_{evac} (K10 in Table 3), considers the number of people who arrived in a safe area, in respect to the number of people participating in the evacuation, according to Equation 30.

$$Revac = 1 - \frac{number\ of\ evacuees\ arrived\ in\ a\ safe\ area}{number\ of\ participating\ evacuees} \quad (30)$$

Thus, the denominator of this ration also includes the effects of possible casualties on the whole evacuation process. The value can be calculated considering the number of arrived people in respect of the initial participants to the evacuation process, thus avoiding to consider people who are not affected by the process (e.g. people placed indoor in case of a terrorist act).
ID K11 (Table 3) can integrate the analysis in case of terrorist act since deaths/casualties are simulated through the model of D 4.1.1. Results of ID K11 can be compared with the probability of health problems in SLODs, being effects of the disaster occurrence in a direct manner. This has been normalized by the number of people participating in the evacuation. By this way, this value is based on the effective number of exposed people who take parts in the evacuation (i.e. outdoor ones for terrorist acts; all the outdoor and indoor users in case of earthquake), and excludes those who are unable to participate in the evacuation, thus assuming the impact of TSAP or SAP values in the final casualties phenomena. The value could be also calculated as in the following equation (31).

$$CR = \begin{cases} \dfrac{number\ of\ casualties}{number\ of\ outdoor\ users \times (1 - TSAP)}\ for\ terrorist\ act \\ \dfrac{number\ of\ casalties}{total\ number\ of\ users \times (1 - SAP)}\ for\ earthquake \end{cases} \quad (31)$$

3.4 Simulation of KPIs for BETs scenarios

The first simulation of values of KPIs is tested on the idealized BETs scenarios (D'Amico et al. 2021).
Each BET considered has been analyzed through the elaboration of 3 different configuration of the space, as most representative of cases in historical towns: C_1 - with the presence of bollards with chains, C_2 - with

the presence of a monument, C_3 – with the presence of both bollards with chains and a monument, as reported in Figure 2 with the example of BET1A (the only exception is BET5 that has two configurations: the base one and the one with the presence of a monument - Figure 3); and 5 scenarios has been investigated in relation to the SUOD risk: S_b – base scenario without specific risk, SE_1 - earthquake scenario with two road exit occluded, SE_2 – earthquake scenario with all road exit occluded, ST_1 – terrorist act scenario with hand weapon or gun, ST_2 - terrorist act scenario with autocar). The configuration of spaces derives from D 4.1.1, while the scenarios derived from D 1.2.5 for earthquake risk and from D 1.3.3 for terrorist act risk.

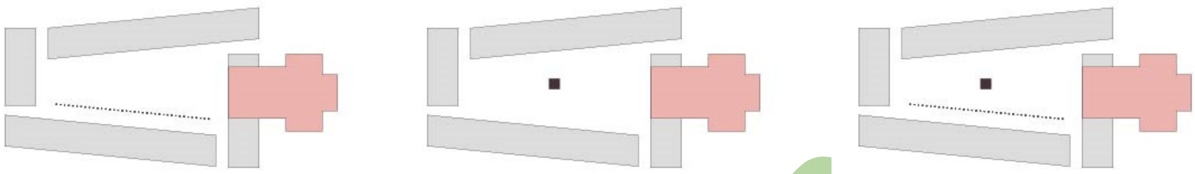

Figure 2. Configurations of BET1A: C1 - with the presence of bollards with chains, C2 - with the presence of a monument, C3 – with the presence of both bollards with chains and a monument.

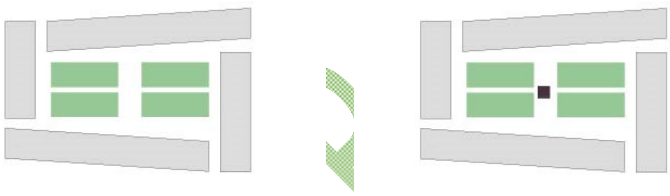

Figure 3. Configurations of BET5: C1 - base, C2 - with the presence of a monument.

KPI 1 - Balance Index of debris (BI): The BI of debris ideally varies from 0 (maximum safety conditions) to 1 (minimum safety condition). The scenarios ST1 and ST2 have not been computed in terms of BI because it has been assumed that this type of risk does not produce debris.

Table 4. Final value of KPI 1

		Sb	SE_1	SE_2	ST_1	ST_2
BET 1A	C_1					
	C_2	0.00	0.05	0.43	-	-
	C_3					
BET 1B	C_1					
	C_2	0.00	0.05	0.43	-	-
	C_3					
BET 2A	C_1			0.52		
	C_2	0.00	0.04	0.53	-	-
	C_3			0.53		
BET 2B	C_1			0.52		
	C_2	0.00	0.04	0.53	-	-
	C_3			0.53		
BET 3	C_1					
	C_2	0.00	0.13	0.39	-	-
	C_3					
BET 4A	C_1					
	C_2	0.00	0.28	1.00	-	-
	C_3					
BET 4B	C_1		0.30			
	C_2	0.00	0.30	1.00	-	-
	C_3		0.31			
BET 4C	C_1		0.30	0.30		
	C_2	0.00	0.30	0.30	-	-
	C_3		0.31	0.31		
BET 5	C_1	0.00	0.09	0.55		
	C_2			0.56	-	-

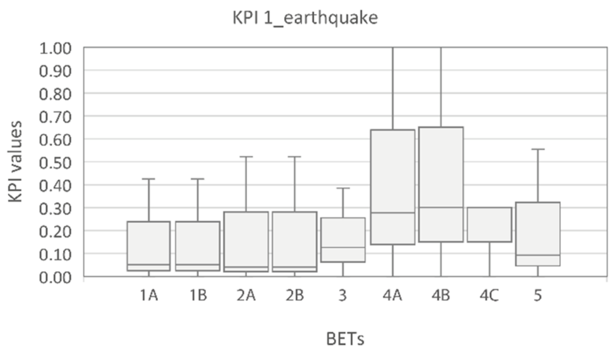

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Figure 4. Summary graphs of KPI 1 values in the three risk scenarios for the most complex BET configuration

KPI 2 - Road resistor coefficient (R_{RC}): The length is set at 1m to have a final index always variable between 0 (easy and fluid evacuation) to 1 (difficult evacuation/ congested road). The following table (Table 5) shows the unit values for each BET calculated by averaging the R_{RC} of each road. For scenarios SE1 and SE2, the maximum value (i.e. 1) of R_{RC} has been assigned to roads blocked by debris.

Table 5. Final values of KPI 2

		Sb	SE_1	SE_2	ST_1	ST_2
BET 1A	C_1, C_2, C_3	0.17	0.58	1.00	0.17	0.17
BET 1B	C_1, C_2, C_3	0.17	0.58	1.00	0.17	0.17
BET 2A	C_1, C_2, C_3	0.19	0.60	1.00	0.19	0.19
BET 2B	C_1, C_2, C_3	0.19	0.60	1.00	0.19	0.19
BET 3	C_1, C_2, C_3	0.19	0.58	1.00	0.19	0.19
BET 4A	C_1, C_2, C_3	0.18	0.52	1.00	0.18	0.18
BET 4B	C_1, C_2, C_3	0.18	0.52	1.00	0.18	0.18
BET 4C	C_1, C_2, C_3	0.18	0.52	1.00	0.18	0.18
BET 5	C_1, C_2	0.17	0.58	1.00	0.17	0.17

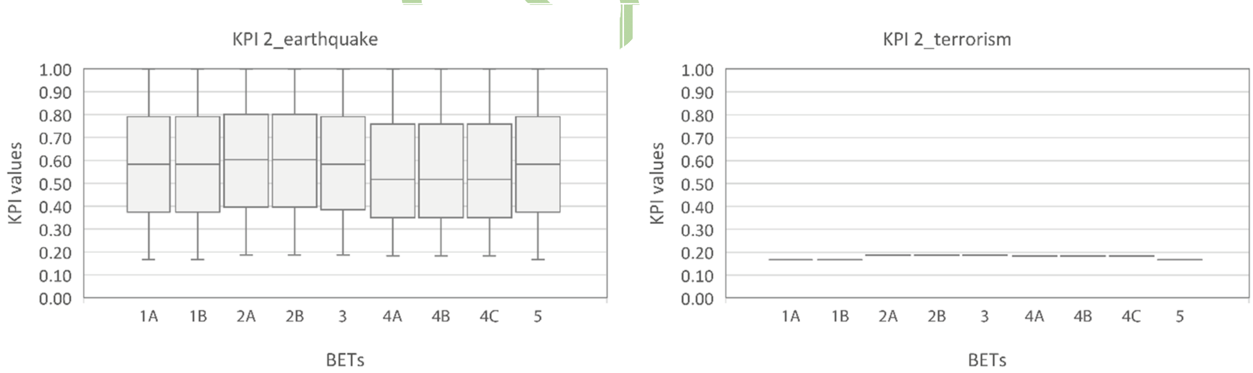

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Figure 5. Summary graphs of KPI 2 values in the three risk scenarios for the most complex BET configuration

KPI 3 - Pedestrian speed conservation: The following table (Table 6) shows the rate of speed loss for each BETs, which is independent of the risk scenario and the presence of special buildings. The final values are presented in terms of percentage speed loss, so they range between 0% and 100%.

Table 6. Final values of KPI 3

		Sb	SE_1	SE_2	ST_1	ST_2
BET 1A	C_1					
	C_2			0.40		
	C_3					
BET 1B	C_1					
	C_2			0.33		
	C_3					
BET 2A	C_1					
	C_2			0.34		
	C_3					
BET 2B	C_1					
	C_2			0.34		
	C_3					
BET 3	C_1					
	C_2			0.34		
	C_3					
BET 4A	C_1					
	C_2			0.33		
	C_3					
BET 4B	C_1					
	C_2			0.33		
	C_3					
BET 4C	C_1					
	C_2			0.33		
	C_3					
BET 5	C_1			0.33		
	C_2					

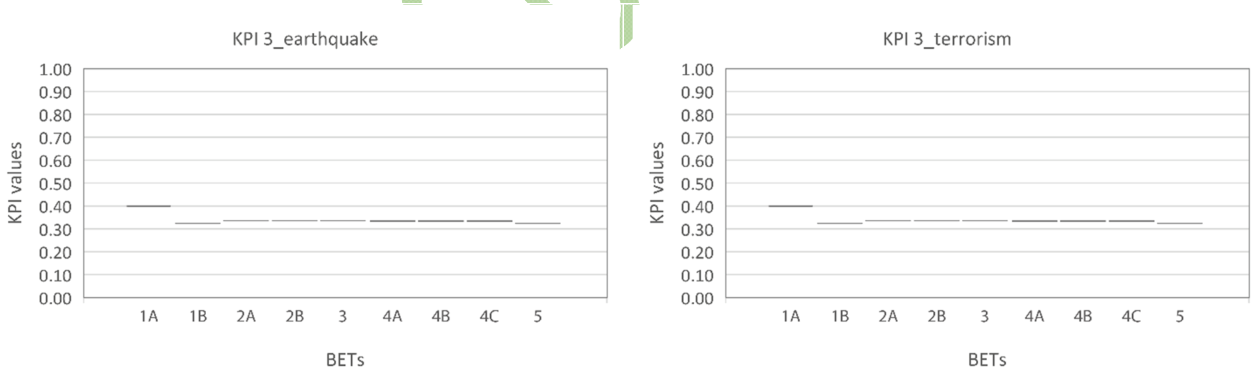

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Figure 6. Summary graphs of KPI 3 values in the three risk scenarios for the most complex BET configuration

KPI 4 - Obstacle friction rate: The final value, according to the rating scale of other KPIs, varies from 0 (minimum risk) to 1 (maximum risk).

Table 7. Final values of KPI 4

		Sb	SE1	SE2	ST1	ST2
BET 1A	C_1	0.32	0.38	0.81	0.40	0.40
	C_2	0.13	0.20	0.62	0.25	0.25
	C_3	0.32	0.38	0.81	0.34	0.34
BET 1B	C_1	0.32	0.38	0.81	0.40	0.40
	C_2	0.13	0.20	0.62	0.25	0.25
	C_3	0.32	0.38	0.81	0.34	0.34
BET 2A	C_1	0.29	0.36	0.95	0.34	0.34
	C_2	0.10	0.17	0.76	0.22	0.22
	C_3	0.29	0.36	0.95	0.32	0.32
BET 2B	C_1	0.29	0.36	0.95	0.34	0.34
	C_2	0.10	0.17	0.76	0.22	0.22
	C_3	0.29	0.36	0.95	0.32	0.32
BET 3	C_1	0.29	0.40	0.67	0.31	0.31
	C_2	0.15	0.27	0.54	0.17	0.17
	C_3	0.29	0.40	0.67	0.25	0.25
BET 4A	C_1	0.25	0.50	1.00	0.27	0.27
	C_2	0.10	0.36	1.00	0.18	0.18
	C_3	0.25	0.50	1.00	0.27	0.27
BET 4B	C_1	0.25	0.53	1.00	0.27	0.27
	C_2	0.10	0.38	1.00	0.18	0.18
	C_3	0.25	0.53	1.00	0.27	0.27
BET 4C	C_1	0.25	0.53	1.00	0.27	0.27
	C_2	0.10	0.38	1.00	0.18	0.18
	C_3	0.25	0.53	1.00	0.27	0.27
BET 5	C_1	0.27	0.37	0.92	0.30	0.30
	C_2	0.27	0.37	0.92	0.23	0.23

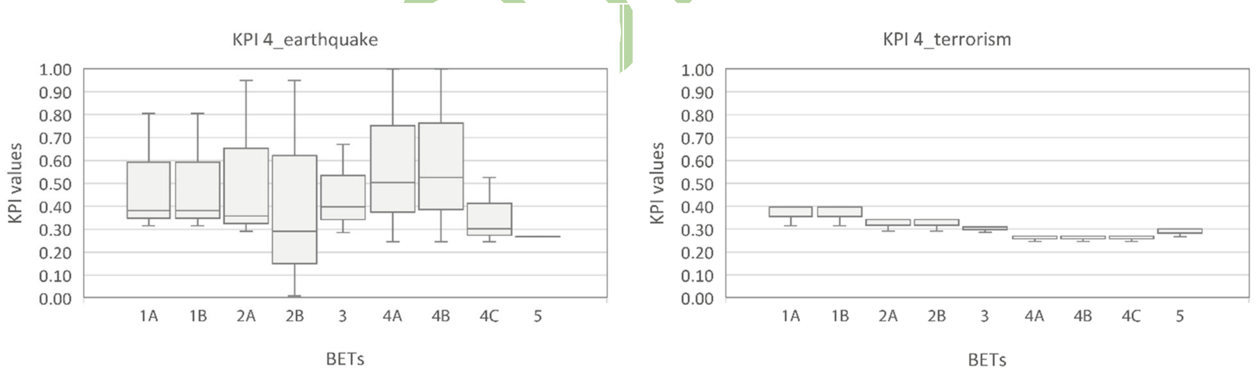

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Figure 7. Summary graphs of KPI 4 values in the three risk scenarios for the most complex BET configuration

KPI 5 - Temporary secure (SOSs): An SOS value at or above 4 mq per inhabitant indicates a good amount of useful open spaces after the disaster. In any case, the collection areas for 1 mq per inhabitant may also be used for short-term emergency management (Tumini et al. 2017; Aman and Aytac 2022). The values are normalized with respect to these limit values, so the final SOSs varies between 0 (per SOS<1 mq per inhabitant) and 1 (per SOS≥4 mq per inhabitant).

Table 8. Final values of KPI 5

		Sb	SE$_1$	SE$_2$	ST$_1$	ST$_2$
BET 1A	C$_1$			0.80		
	C$_2$	0.41	0.46	0.81	1.00	0.76
	C$_3$			0.81		
BET 1B	C$_1$			0.46		
	C$_2$	0.00	0.00	0.47	1.00	0.17
	C$_3$			0.48		
BET 2A	C$_1$	0.51	0.54	0.94		
	C$_2$	0.52	0.55	0.95	1.00	0.74
	C$_3$	0.52	0.55	0.95		
BET 2B	C$_1$			0.61		
	C$_2$	0.00	0.00	0.63	1.00	0.35
	C$_3$			0.63		
BET 3	C$_1$		0.01	0.40		
	C$_2$	0.00	0.02	0.41	1.00	0.47
	C$_3$		0.02	0.41		
BET 4A	C$_1$			1.00		
	C$_2$	0.96	1.00	1.00	1.00	1.00
	C$_3$			1.00		
BET 4B	C$_1$			1.00		
	C$_2$	0.96	1.00	1.00	1.00	1.00
	C$_3$			1.00		
BET 4C	C$_1$		0.28	0.28		
	C$_2$	0.00	0.29	0.29	0.97	0.00
	C$_3$		0.30	0.30		
BET 5	C$_1$	0.00	0.00	0.66	1.00	1.00
	C$_2$			0.67		

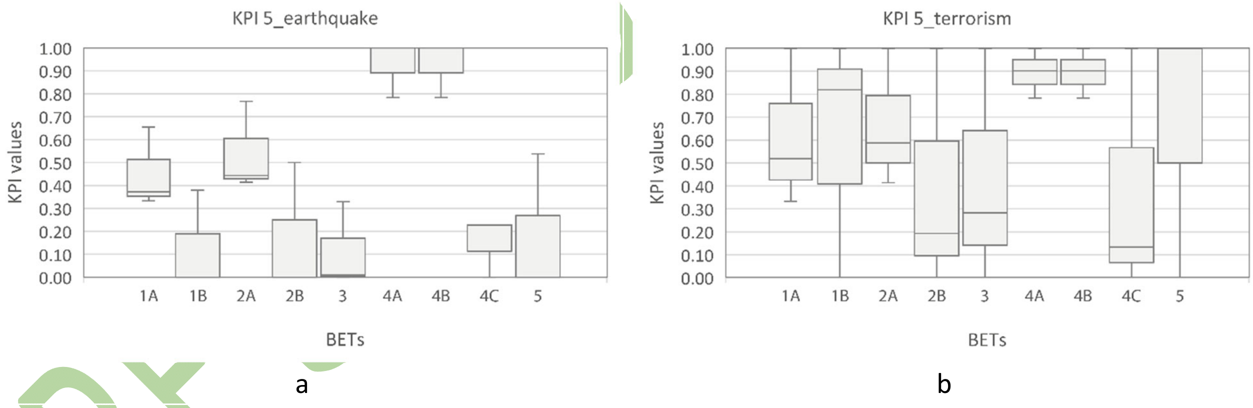

Figure 8. Summary graphs of KPI 5 values in the three risk scenarios for the most complex BET configuration

KPI 6 - Exposure Index: The worst possible scenario (E_{max}), is one in which no user is safe. On this way, the values always variable between 0 (minimum exposure) and 1 (maximum exposure).

Table 9. Final values of KPI 6

		Sb	SE_1	SE_2	ST_1	ST_2
BET 1A	C_1					
	C_2	0.43	0.63	0.65	0.21	0.2
	C_3					
BET 1B	C_1					
	C_2	0.35	0.52	0.55	0.06	0.06
	C_3					
BET 2A	C_1					
	C_2	0.45	0.65	0.67	0.24	0.24
	C_3					
BET 2B	C_1					
	C_2	0.35	0.52	0.55	0.06	0.06
	C_3					
BET 3	C_1					
	C_2	0.35	0.52	0.54	0.06	0.06
	C_3					
BET 4A	C_1			0.80	0.42	0.42
	C_2	0.54	0.79	0.81	0.43	0.43
	C_3			0.81	0.43	0.43
BET 4B	C_1			0.80	0.42	0.42
	C_2	0.54	0.79	0.81	0.43	0.43
	C_3			0.81	0.43	0.43
BET 4C	C_1					
	C_2	0.35	0.54	0.54	0.06	0.06
	C_3					
BET 5	C_1	0.35	0.52	0.55	0.06	0.06
	C_2			0.56		

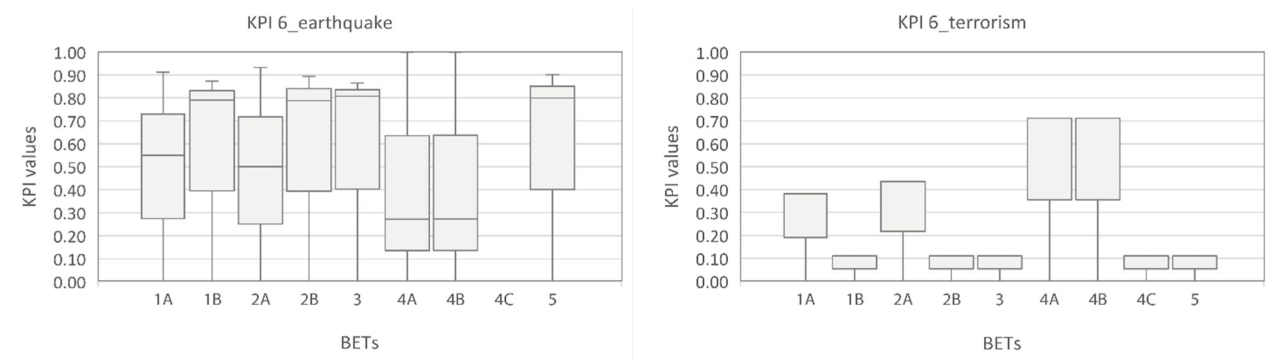

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Figure 9. Summary graphs of KPI 6 values in the three risk scenarios for the most complex BET configuration

KPI 7 - Evacuation time percentile (95th): To ensure a variation range from 0 to 1, that is from minimum to maximum risk, the Evacuation time at the 95th percentile T95 [s] has been normalized by the maximum simulation time, that is equal to 600s for each scenarios. The evacuation time directly increases with risk, since it expresses that people can still remain in risky conditions (i.e. inside the square in case of terrorist act; still moving and not reaching the central part of the square for earthquake evacuation).

Table 10. Final values of KPI 7

		SbE	SE_1	SE_2	SbT	ST_1	ST_2
BET 1A	C_1	0.32	0.48	0.81		0.09	0.08
	C_2	0.39	0.48	0.86	0.06	0.09	0.07
	C_3	0.35	0.49	0.86		0.08	0.07
BET 1B	C_1	0.17	0.40	0.83		0.06	
	C_2	0.15	0.42	0.82	0.06	0.07	0.07
	C_3	0.17	0.32	0.82		0.06	
BET 2A	C_1	0.26	0.31	0.66	0.1	0.12	0.09
	C_2	0.22	0.37	0.70	0.08	0.09	0.07
	C_3	0.26	0.36	0.48	0.06	0.07	0.06
BET 2B	C_1	0.26	0.25	0.33	0.06	0.06	0.06
	C_2	0.20	0.20	0.62	0.07	0.07	0.07
	C_3	0.26	0.27	0.33	0.06	0.06	0.06
BET 3	C_1	0.13	0.17	0.70	0.05	0.06	0.06
	C_2	0.12	0.14	0.31	0.05	0.05	0.05
	C_3	0.14	0.19	0.69	0.06	0.07	0.07
BET 4A	C_1	0.04				0.06	0.06
	C_2	0.03	0.04	0.06	0.05	0.05	0.06
	C_3	0.03				0.05	0.05
BET 4B	C_1	0.04				0.06	0.06
	C_2	0.03	0.04	0.06	0.05	0.05	0.06
	C_3	0.03				0.05	0.05
BET 4C	C_1	0.09	0.09	0.12		0.02	0.02
	C_2	0.09	0.10	0.16	0.02	0.02	0.02
	C_3	0.01	0.10	0.13		0.02	0.02
BET 5	C_1	0.06	0.04	0.08	0.09	0.10	0.09
	C_2	0.05	0.05	0.10	0.08	0.10	0.09

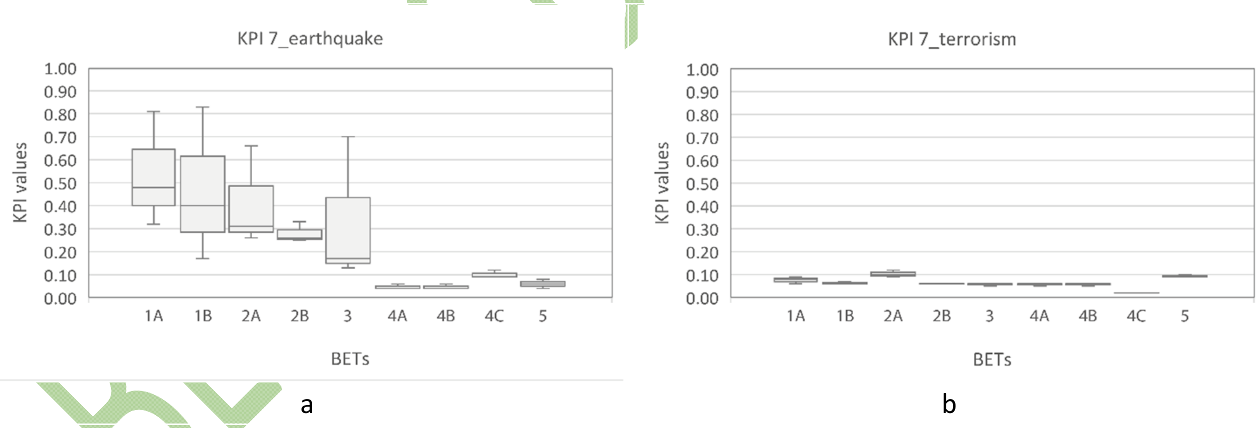

Figure 10. Summary graphs of KPI 7 values in the three risk scenarios for the most complex BET configuration

KPI 8 - Crowd effects (number of physical contacts and falls): Crowd effects has been calculated according to the number of physical contacts between evacuees potentially leading to users' falls PCF [number of events] divided by the 95th percentile of evacuation time T95 [s]. Then the following equation (28) has been used to normalize the value between 0 (as minimum risk because no users' collisions) and 1 (the maximum probability of physical contacts leading to falls is reached).

$$R_{PCF} = \frac{PCF_{sim}/\,T95}{PCF_{id,ev}} \tag{28}$$

where $PCF_{id,ev}$ [number of events/s] is equal to the 5% of the whole number of simulated pedestrians, thus considering that, per second, all these people can collide.

Table 11. Final values of KPI 8

		SbE	SE_1	SE_2	SbT	ST_1	ST_2
BET 1A	C_1				0.19	0.36	0.16
	C_2	0.04	0.03	0.01	0.31	0.31	0.29
	C_3				0.18	0.35	0.28
BET 1B	C_1	0.10					
	C_2	0.11	0.05	0.01	0.00	0.00	0.00
	C_3	0.09					
BET 2A	C_1	0.05	0.07	0.02	0.40	0.45	0.28
	C_2	0.06	0.06	0.02	0.26	0.29	0.20
	C_3	0.05	0.07	0.06	0.23	0.24	0.13
BET 2B	C_1	0.06	0.12	0.05			
	C_2	0.07	0.12	0.02	0.00	0.00	0.00
	C_3	0.07	0.10	0.05			
BET 3	C_1	0.14	0.11	0.01	0.00		
	C_2	0.18	0.13	0.03	0.01	0.00	0.00
	C_3	0.13	0.11	0.01	0.00		
BET 4A	C_1	0.14	0.10	0.07	0.23	0.49	0.29
	C_2	0.13	0.12	0.08	0.21	0.26	0.28
	C_3	0.22	0.13	0.06	0.20	0.24	0.33
BET 4B	C_1	0.14	0.10	0.07	0.24	0.58	0.27
	C_2	0.13	0.12	0.08	0.24	0.26	0.28
	C_3	0.22	0.13	0.06	0.22	0.24	0.20
BET 4C	C_1	0.13	0.10	0.07			0.04
	C_2	0.11	0.10	0.05	0.00	0.00	0.04
	C_3	0.11	0.10	0.07			0.00
BET 5	C_1	0.00	0.00	0.00	0.01	0.01	0.00
	C_2				0.00		0.01

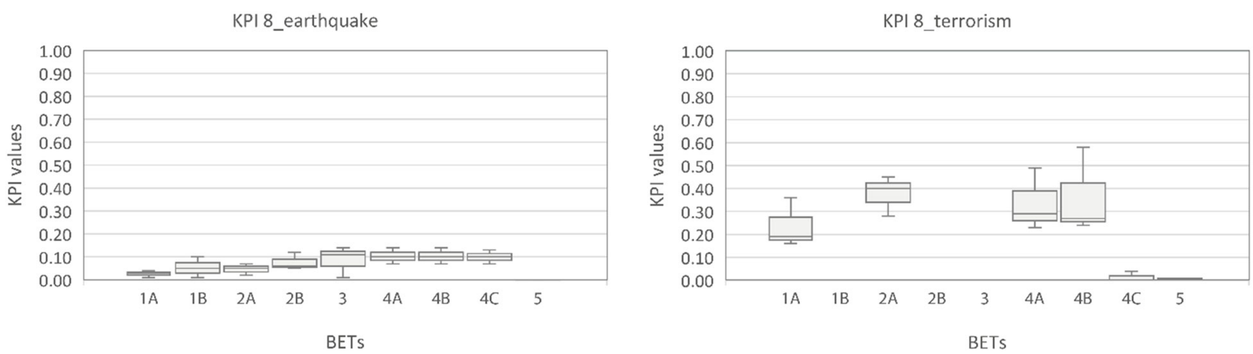

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Figure 11. Summary graphs of KPI 8 values in the three risk scenarios for the most complex BET configuration

KPI 9 - Mean flow rate at the exit: The mean flow rate at the 95th percentile of evacuees F95 [pp/s] is manipulated to obtain a normalized value ranging from 0 to 1 (maximum risk), by using the reciprocal value to 1 since the flows decrease while risk is increasing. The following equation (29) provides the final value of the normalized specific mean flow rate FN95 used as KPI 9.

$$FN95 = 1 - \frac{F95/\sum_i Wi}{F_{id,ev,max}} \tag{29}$$

where Wi is the width of each street reaching the square [m], so as to evaluate specific flows starting from F95, while $F_{id,ev,max}$ [pp/s/m] is the maximum specific flow according to previous works on experimental conditions[1]. Considering terrorist act, the users' flows effectively cross the streets linked with the square. Considering earthquake, the equation assumes, in a simplified manner, that the most important flows are those entering the square by using the streets.

Table 12. Final values of KPI 9

		SbE	SE_1	SE_2	SbT	ST_1	ST_2
BET 1A	C_1	0.82	0.88	0.93	0.48	0.65	0.74
	C_2	0.85	0.89	0.94	0.47	0.64	0.73
	C_3	0.83	0.89	0.94	0.47	0.63	0.73
BET 1B	C_1	0.66	0.85		0.88	0.89	
	C_2	0.60	0.86	0.93	0.89	0.91	0.90
	C_3	0.67	0.86		0.88	0.89	
BET 2A	C_1	0.82	0.85	0.93	0.67	0.76	0.75
	C_2	0.80	0.87	0.93	0.58	0.70	0.75
	C_3	0.82	0.87	0.90	0.50	0.60	0.67
BET 2B	C_1	0.82	0.81	0.86	0.91	0.91	0.91
	C_2	0.77	0.76	0.93	0.92	0.93	0.92
	C_3	0.82	0.83	0.86	0.91	0.91	0.91
BET 3	C_1	0.53	0.66	0.91	0.86	0.89	0.90
	C_2	0.49	0.58	0.81	0.85	0.87	0.87
	C_3	0.57	0.69	0.92	0.87	0.89	0.90
BET 4A	C_1	0.15	0.18	0.48	0.41	0.46	0.63
	C_2	0.04	0.18	0.51	0.36	0.44	0.59
	C_3	0.10	0.17	0.52	0.30	0.42	0.55
BET 4B	C_1	0.15	0.18	0.48	0.39	0.49	0.63
	C_2	0.04	0.18	0.51	0.35	0.44	0.56
	C_3	0.10	0.17	0.52	0.29	0.44	0.57
BET 4C	C_1		0.80	0.84	0.87		0.91
	C_2	0.80	0.80	0.88	0.88	0.90	0.91
	C_3		0.81	0.85	0.88		0.90
BET 5	C_1	0.84	0.76	0.87	0.90	0.92	0.92
	C_2	0.86	0.90	0.94	0.89	0.92	0.91

[1] https://etrr.springeropen.com/articles/10.1007/s12544-017-0264-6

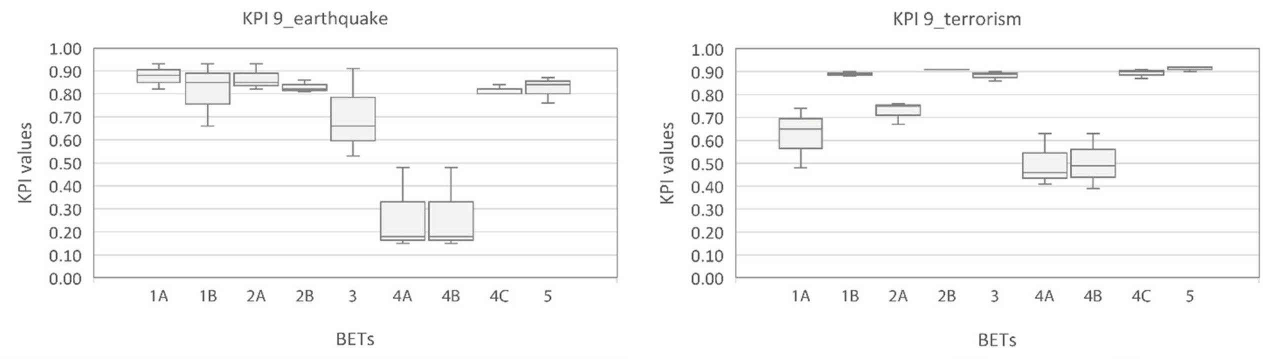

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Figure 12. Summary graphs of KPI 9 values in the three risk scenarios for the most complex BET configuration

KPI 10 - Number of evacuees for SUODs from surrounding buildings in the OSs: The values of this KPI are already normalized in output to the simulation.

Table 13. Final values of KPI 10

		SbE	SE_1	SE_2	SbT	ST_1	ST_2
	C_1	0.01	0.02	0.07		0.07	
BET 1A	C_2	0.02	0.05	0.11	0.00	0.04	0.38
	C_3	0.01	0.03	0.13		0.06	
	C_1		0.01	0.05			0.06
BET 1B	C_2	0.01	0.02	0.04	0.01	0.01	0.10
	C_3		0.01	0.06			0.03
	C_1	0.00	0.01	0.01		0.11	0.28
BET 2A	C_2	0.00	0.00	0.01	0.00	0.19	0.33
	C_3	0.01	0.00	0.00		0.16	0.33
	C_1	0.00	0.01	0.02		0.01	0.04
BET 2B	C_2	0.01	0.00	0.01	0.01	0.02	0.06
	C_3	0.01	0.01	0.01		0.02	0.05
	C_1					0.02	0.05
BET 3	C_2	0.00	0.00	0.00	0.01	0.01	0.03
	C_3					0.02	0.03
	C_1					0.05	0.22
BET 4A	C_2	0.00	0.01	0.01	0.00	0.05	0.24
	C_3					0.07	0.26
	C_1					0.10	0.22
BET 4B	C_2	0.00	0.01	0.01	0.00	0.06	0.26
	C_3					0.10	0.28
	C_1		0.01			0.07	0.12
BET 4C	C_2	0.01	0.00	0.01	0.02	0.05	0.10
	C_3		0.00			0.12	0.12
BET 5	C_1	0.86	0.87	0.79	0.01	0.02	0.17
	C_2	0.91	0.92	0.88	0.01	0.01	0.09

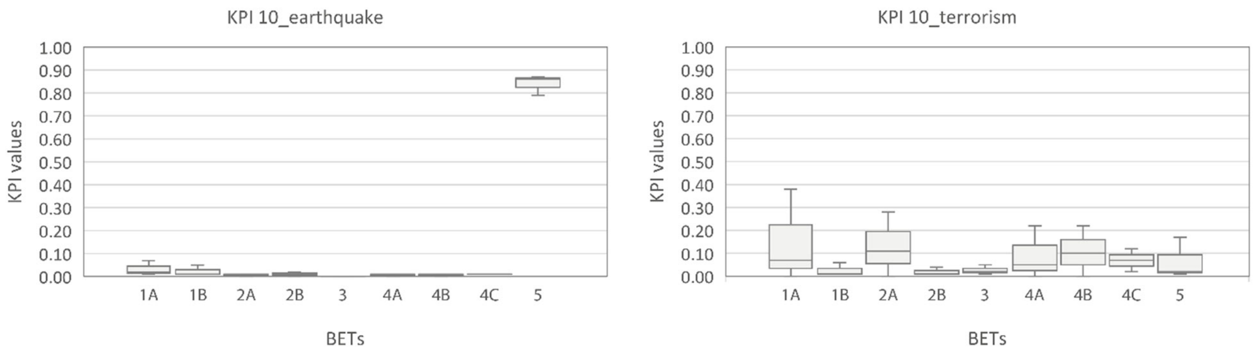

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Figure 13. Summary graphs of KPI 10 values in the three risk scenarios for the most complex BET configuration

KPI 11 - Number of deaths/casualties: As shown in Table 14, no casualties are considered for earthquake, since no people is involved in fatal damages during the simulation time.

Table 14. Final values of KPI 11

		SbE	SE_1	SE_2	SbT	ST_1	ST_2
BET 1A	C_1					0.18	0.78
	C_2	0.00	0.00	0.00	0.00	0.05	0.77
	C_3					0.11	0.80
BET 1B	C_1						0.12
	C_2	0.00	0.00	0.00	0.00	0.00	0.11
	C_3						0.05
BET 2A	C_1					0.15	0.53
	C_2	0.00	0.00	0.00	0.00	0.31	0.66
	C_3					0.32	0.58
BET 2B	C_1					0.00	0.10
	C_2	0.00	0.00	0.00	0.00	0.06	0.15
	C_3					0.04	0.08
BET 3	C_1						0.21
	C_2	0.00	0.00	0.00	0.00	0.03	0.04
	C_3						0.05
BET 4A	C_1					0.14	0.49
	C_2	0.00	0.00	0.00	0.00	0.10	0.47
	C_3					0.14	0.51
BET 4B	C_1					0.14	0.46
	C_2	0.00	0.00	0.00	0.00	0.14	0.51
	C_3					0.30	0.56
BET 4C	C_1					0.20	0.20
	C_2	0.00	0.00	0.00	0.00	0.05	0.10
	C_3					0.34	0.20
BET 5	C_1	0.00	0.00	0.00	0.00	0.03	0.31
	C_2				0.00	0.01	0.20

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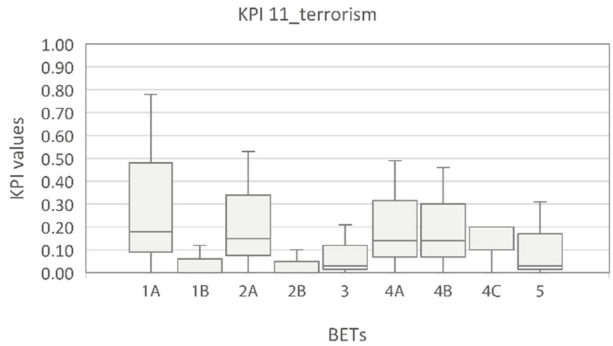

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Figure 14. Summary graphs of KPI 11 values in the three risk scenarios for the most complex BET configuration

KPI 12 - Obstacle protection rate: The point of attachment in the idealized BET, occurs where the density of crowding is greatest. Particularly at dehors, where the presence of a commercial activity or special building (e.g. a church) was considered.
To ensure a variation range from 0 to 1, that is from minimum to maximum risk, the complementary of the value obtained from the formula described in Section 3.2 was made.

Table 15. final values of KPI 12

		Sb	SE_1	SE_2	ST_1	ST_2
BET 1A	C_1	0.00	-	-	1.00	0.85
	C_2	0.00	-	-	1.00	0.94
	C_3	0.00	-	-	1.00	0.86
BET 1B	C_1	0.00	-	-	1.00	0.98
	C_2	0.00	-	-	0.98	0.79
	C_3	0.00	-	-	0.98	0.53
BET 2A	C_1	0.00	-	-	1.00	0.86
	C_2	0.00	-	-	0.99	0.96
	C_3	0.00	-	-	0.99	0.86
BET 2B	C_1	0.00	-	-	1.00	0.55
	C_2	0.00	-	-	0.97	0.72
	C_3	0.00	-	-	0.97	0.67
BET 3	C_1	0.00	-	-	1.00	0.60
	C_2	0.00	-	-	0.99	0.70
	C_3	0.00	-	-	0.99	0.60
BET 4A	C_1	0.00	-	-	1.00	0.50
	C_2	0.00	-	-	0.99	0.61
	C_3	0.00	-	-	0.99	0.52
BET 4B	C_1	0.00	-	-	1.00	0.50
	C_2	0.00	-	-	0.99	0.61
	C_3	0.00	-	-	0.99	0.52
BET 4C	C_1	0.00	-	-	1.00	0.44
	C_2	0.00	-	-	0.94	0.76
	C_3	0.00	-	-	0.94	0.44
BET 5	C_1	0.00	-	-	1.00	1.00
	C_2	0.00	-	-	0.98	0.99

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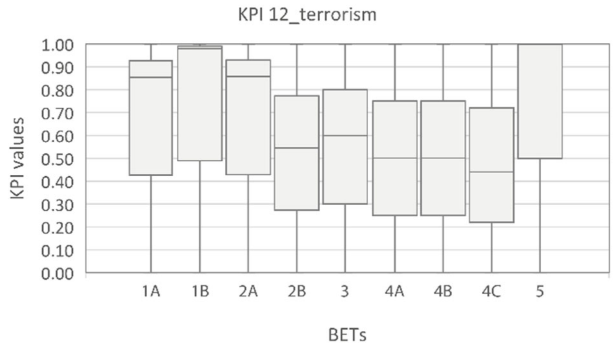

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Figure 15. Summary graphs of KPI 12 values in the three risk scenarios for the most complex BET configuration

3.5 Comparison of KPIs values for BETs scenarios

Finally, the application of KPIs to idealized BETs makes it possible to assess SUOD risk and compare results for different scenarios. However, it is their idealized nature that also determines their main limitations. Another aspect to keep in mind is the different approach used in assessing the two types of risk. Earthquake is a natural hazard, and the expected damage is directly proportional to the vulnerability of the built environment and by the presence or absence of people. In the application to the BETs, the seismic hazard of the built environment was estimated, referring to the Italian territory (highly seismic) and setting a return period (RP) of 475-years. The 475-year return period (or 10 percent probability of exceedance in 50 years) event is the most common standard used in the industry for assessing seismic risk, and it is also the basis for most building codes for seismic design. That RP allowed the determination of two damage scenarios, SE1 and SE2 respectively described in Section 3.4. Terrorism, on the other hand, is an anthropogenic risk, determined by the initiative of a person or group of people. In this case, two types of attacks have been defined, one by gunfire and that is derived from the action of a man personally attacking a crowd; the other is a vehicle attack and that is the action of a vehicle that enters the BET/square and crashes into a target, running over those it encounters along its trajectory. It is clear from these definitions that the assessment of KPIs must consider different aspects if one or the other risk is involved, which will be set out in detail for each.

The **KPI 1** (Balance Index of debris) is a geometric indicator, used to evaluate earthquake scenarios. The main limitation is to be found in the way the amount of debris in the BETs is estimated. As you can see in the Figure 4, the most critical BET are the smaller ones and where buildings face structurally vulnerable to the earthquake (4A and 4B), in fact in these cases the debris can take up all the space.
Like the **KPI 1**, also **KPI 2** and **KPI3** are a geometric indicators, but in this case they are applicable to both seismic and terrorist risk. The R_{RC} (**KPI 2**) for the earthquake measure the road obstruction in function of the debris generated by the collapse of buildings and as can be seen from the graph in Figure 5.a varies significantly with the magnitude of the event. As far as terrorism is concerned, it cannot be determined whether roads are usable since there is no object or debris obstructing their passage. Whether or not a road can be used depends mainly on the subjective reaction of users following the attack; in fact, even the results (Figure 5.a) show no difference between the baseline and risk scenarios. And then, the **KPI 3** (Pedestrian Speed conservation) investigates environmental boundary conditions that can make it more difficult to manage human flows. According to the literature (León and March 2014) this KPI considers the slope of the roads and the level of traffic. The results for BET are similar because they were taken all flat

(except the 1A which has a slight slope) and since no data on traffic and the importance of roads are known, the level of traffic was also considered homogeneous.
Similarly, the **KPI 4** (Obstacle Friction Rate) is a geometric KPI, designed to assess the effects of terrorism has also been adapted to describe the seismic risk. The OFR index define the negative influence of the presence of obstacles in an OS for user evacuation process, both on the run from the attack and on the way to the safe place. It showed that the use of continuous linear development mitigation measures (bollards with chains), while limiting the probability of vehicle attack, constitutes an obstacle to user evacuation. The presence of monuments or dehors do not constitute a major encumbrance except when placed near escape routes/access roads or in OS constrictions, as they decrease the flow capacity.
Since the geometric distribution of the BET is the same, the ST1 and ST2 scenarios are identical; in fact, from the point of view of the OFR the risk remains the same whether it is armed attack or truck. In addition, the presence of debris (SE1 and SE2) represents an additional obstacle that is added to those already present, in fact the OFR values for the earthquake are significantly higher at the same starting conditions. In fact, as can be seen from the graphs in Figure 7, the BETs that are most critical with respect to OFR are those with limited size (BET 4) particularly for earthquake, for which debris provides a large impact in terms of OFR, coming to occupy the entire OS area. Trapezoidal-shaped BETs (BET 2) also present critical issues, particularly when user flows are concentrated in the narrow part.
KPI 5 and **KPI 6** are two static-behavioural indicator. Firstly, for **KPI 5** (Temporary Secure Open Spaces) is important to emphasize what is meant by Temporary Secure Open Spaces. For the earthquake the OSs is the surface of the BET/square not occupied by debris after the shock, while for terrorism we mean the portion of surface behind an obstacle, which can provide a temporary shelter in case of attack. This definition is not sufficient to fully represent the complexity of the real scenario, but it is still a valid tool that allows you to assess the risk of an OS and the possibility of adopting mitigation policies. From the results in Figure 8, it can see that the presence of a Special Building determines rather high values for this KPI already from the base scenario. The presence of the Special Building means the presence of a greater number of people in the BET/square and for the same OSs this means an increase in risk. BET 4A and 4B (with Special Building) are definitely the most at risk because of their small size, which further decreases for risk scenarios, also reaching negative values (no availability of safe surface) for the ST2. Instead, **KPI 6** (Exposure Index) is an indicator that provides a quantitative estimate of the users exposed in a BET/Square in relation to the risk conditions. The results obtained for seismic risk scenarios (Figure 9a) are generally worse than those of terrorist risk (Figure 9a) for the same BET. This condition is primarily to be found in the number of users potentially involved in the event. For the earthquake are outdoor users and especially indoor ones to be exposed, while for terrorism were considered terrorist attacks on sensitive plates outside, so the users involved are only those outdoors.
Instead, to assess the actual behavior of users during the earthquake or terrorist attack, we analyze the results of **KPIs 7** to **11** from the simulations.
In general terms for **KPI 7** (Evacuation time percentile), BETs without the special buildings shows median TN95 values lower than the ones with the special buildings, except for the BET 4. In BET 4A (and 4B) most of the people are placed in front of the square, thus easily reaching the centre of the BET itself. On the contrary, in BET4C, TN95 is higher since most of the users come from the linked streets and are slowed down while entering the BET, especially in critical damage conditions. Figure 10 shows an example of the TN95 for the different BETs, considering the earthquake (Figure 10.a) and terrorism (Figure 10.b) conditions, by pointing out how wider BETs are generally riskier than the smaller ones, essentially because the evacuation timing is both affected by the path lengths inside the square, and by possible crowding

effects. Figure 11 resumes the values of **KPI 8** (crowd effects) for earthquake (Figure 11.a) and terrorism (Figure 11.b), in the different BETs. As expected, higher values occur for smaller BETs, since users interacts in smaller outdoor spaces and so they increase the possibility of physical contacts while moving.

The Mean flow rate at the exit (**KPI 9**) describes the evacuation process and in particular quantifies the flows of users crossing the BET/square. Figure 12.a traces the KPI boxplot for the different BETs, for earthquake conditions. It is worth noticing that BET 4A and B, which have the most compact layout and smaller dimensions, are essentially characterized by lower risk conditions due to FN95, since most of the users are generated in from of the special building, and they could easily reach the centre of the square (compare with TN95). The BET4A and B conditions are quite scattered, being minimum values related to minimum damage conditions. As can be seen from the values in Table 12 the risk increases with heavier damage conditions (SE2>SE1), while the internal layout (C1, C2, C3) leads to similar values of the parameters for both earthquakes and terrorist acts. Figure 12.b focuses on terrorist acts, by shown that riskiest conditions are related to dynamic attacks, as expected, since people should also adapt their paths and flows to the attackers.

KPI 10 defines the number of people actually participating in the evacuation relative to the total number of users involved in the event. Figure 13.a shows that, for earthquake, BETs have similar risks except for BET5. Herein, risk is higher since most of the people are unable to find a final safe position since they cannot access the green areas, and they still move to reach the centre of the square while they are limited by the presence of other individuals still arrived near the central area.

Concerning **KPI 11**, which defines the Number of deaths/casualties, as expected, the presence of dynamics in attack conditions increases the Number of deaths/casualties, since the attackers chase the users where they are placed. This result is thus observed in all the scenario. As expected, the riskiest BETs are those hosting the higher number of users, thus the ones with the special building, since the attack happens where most of the crowd is densely focused. According to its definition, KPI 11 does not relate to earthquake evacuation, since it does not consider possible casualties over time due to seismic damages.

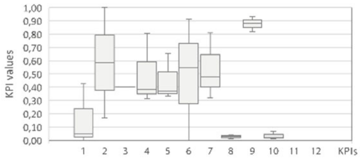
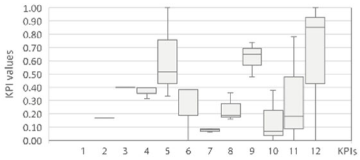
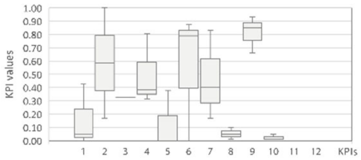
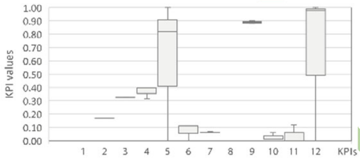
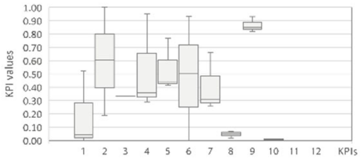
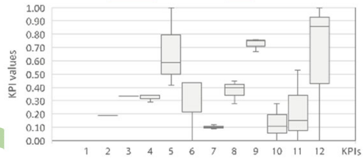
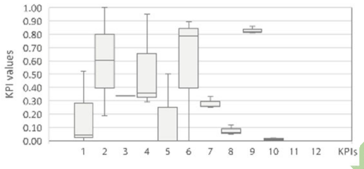
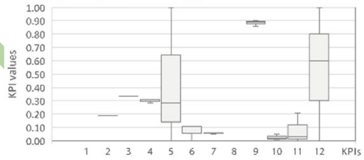
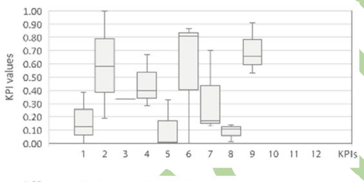
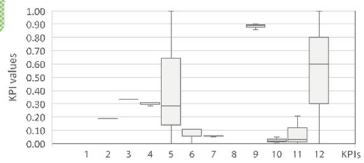
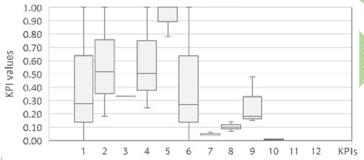
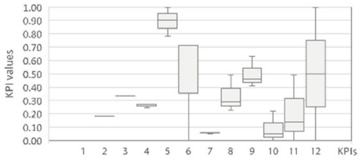
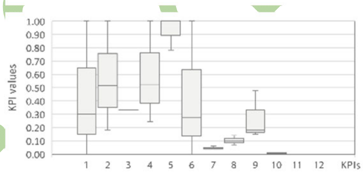
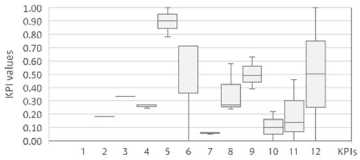
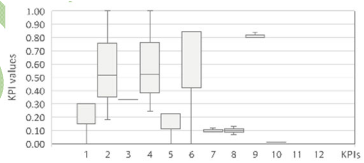
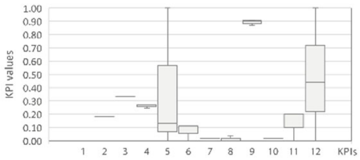
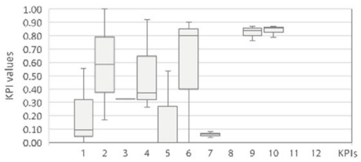
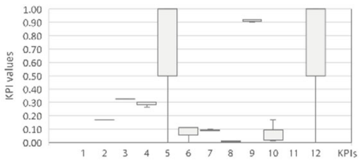
The **KPI 12** (Obstacle Protection rate) values turn out to be very high (high risk) because the extent of the protection area turns out to be very small compared to the total area of the square. This is compounded by a distribution of encumbrances that is effective at attack, whether armed (ST1) or by vehicle (ST2) with respect to the morphology of the squares. For example, the central location of the monument together with the side attachment point (dehors or special building) defines the ideal shielding condition. However, as a general rule and under non-ideal conditions such as BET, single obstacle with limited surface area (e.g. punctual ones such monuments) does not provide sufficient protection to the user from the attacker. These have major relevance in protection when they are considered as system (more punctual elements) in the case of ST1, or in a systemic way with other elements (borders of squares, bollards) for ST2 attacks.

It is clear from the results that the different physical and morphological configuration of the BETs emphasizes some KPIs rather than others, highlighting which aspects need to be acted upon to mitigate risks. There is no one KPI that stands out uniquely above all others, but each BET is characterized by one or more KPIs, except for KPIs that characterize only one risk. For example, KPI 12 (Obstacle protection rate) turns out to be very characterizing for terrorism risk, for all BETs and particularly for the larger ones, since the safe area that an element can provide is still limited compared to the area of the BET.

Comparing the BETs (Table 16), it can be seen that the results obtained for earthquake risk tend to be more concordant and homogeneous with each other, while for terrorism risk they are much more varied and uneven.

Larger BETs (1, 2, 3, and 5) and particularly those in which there is a special building (A), are generally characterized by large numbers of people, potentially exposed to risk (see KPI 6 in Table 16). When a potentially damaging event occurs, the first action one takes is to find a haven away from the sources of danger, which for earthquake generally coincides with the centre of the BET/plaza (away from the dangers of collapse), while for terrorism it means hiding from the bomber's view. The risk in this case is directly proportional to the distance users must travel to get to safety (see KPI 9 in **Errore. L'origine riferimento non è stata trovata.**). The very availability of safe areas (KPI 4 in Table 16), which is sometimes reduced or absent because of debris (for earthquake) or because the shielding provided by furnishings (e.g., monuments) is insufficient (terrorism), can also be a risk factor, especially in smaller BETs (4). While not among the highest KPIs in any of the BETs, it is worth noting the impact of user density, which can lead to increased falls and slowdowns during escape (KPI 8 in Table 16), particularly for terrorism, in smaller BETs and with the presence of the special building. Similar is the situation for KPI 10 (Table 16**Errore. L'origine riferimento non è stata trovata.**), which describes the evacuation process; the exception is BET 5, where this value for seismic risk appears to be the most characterizing among the KPIs due to the hindrance to reach the centre of the BET (safe place).
These results are very important because demonstrates the importance of using a system of indicators, which considers different aspects of risk.

Table 16. Summary graphs of KPIs for each BET, comparing earthquake risk and terrorist risk

BETs	Earthquake	Terrorism
1A		
1B		
2A		
2B		
3		
4A		
4B		
4C		
5		

The results just discussed highlight the criticality of certain spatial configurations and risk scenarios and may suggest a range of strategies to mitigate and/or reduce hazards to users. Such solutions can be physical or educational.
For geometric KPIs, the main solutions involve changing the configuration of the square or going to act on the elements that characterize it and the buildings that surround it. For seismic risk, it is very important to know the architectural vulnerability of buildings and if necessary to secure them to prevent or limit collapse in the event of an earthquake, which in addition to generating rubble that obstructs escape routes and limits the safe area, can cause numerous casualties. On the other hand, for terrorism one solution could be to restrict vehicle access to the plaza (ST2) through the installation of fixed or mobile bollards on access routes. While for armed attack (ST1) indirect control check points may have chilling effect. Obviously, the geometric features of square are independent to this kind of attack (ST1), that, on the contrary, is mostly related to the physical openness of the public open areas (absence of obstacles) and, consequentially, to the visual openness of perpetrators. The most effective solution turns out to be in both cases, to provide as a mitigation measure a series of obstacles, arranged discontinuously in space. Placement of blocks at exits can also be useful in evacuation management (for both seismic and terrorist risk) have a positive effect on evacuation flows, allowing an orderly departure (Shiwakoti et al. 2019) and to direct users to the safest and most easily accessible areas for rescue. In this way, the safe areas can be expanded, allowing users to choose the shelter closest to them. Looking then at the KPIs results on BET 5, it appears that the absence of stakes (shatterproof) reduces the general level of safety.
The results obtained in the different geometric configurations of BETs (C1, C2, C3) suggest that the presence of chained posts can be a limitation, turning into a dangerous obstacle during escape. For the same purpose can be used, as mentioned above, point elements such as planters or bollards without chains. Finally, for behavioural KPIs and in general to increase user safety, it is important to support a broad awareness and education campaign aimed at improving knowledge and reduction of exposure and the creation of risk awareness to foster the preparedness of communities (Giuliani et al. 2022). On the other hand, the potential mitigative effect of obstacles in reducing fatalities may pass through the education of users suggesting their protection by means of hiding compared to their position within the square (far or near the protective elements); this according to major European guidelines in educating people during violent acts (Cantatore et al. 2022).

4. Conclusion

The results obtained have demonstrated the validity of the methodological approach based on the use of synthetic indicators (KPIs) to assess SUODs risks in an open space. Although using the same indicators it was necessary to follow two different approaches for the two types of SUODs selected as different are the reactions to the danger. As for the earthquake, the greatest risks are near the buildings due to the possible collapse and accumulation of debris; the flow of people is then directed towards the centre of the square in search of a refuge. For terrorism the reaction is exactly the opposite, the square is the place of attack, so people try to escape to the outside.
The application to BETs allowed for the testing of a wide range of scenarios, while the application to real cases allows for the evaluation of the effectiveness of the method in more articulated spaces and more complex situations such as the presence of several special buildings, the presence of commercial activities on the ground floor of buildings (with dehors facing the public space), etc. The behaviour and interactions between users and with the surrounding environment are strongly related to density, which in turn depends on the use made of the square. The behaviour and interactions between users and with the

surrounding environment are strongly related to density, which in turn depends on the typical use made of the square. This aspect is very relevant if we consider the application to real scenarios, so the presence of certain activities (e.g., shops, trusted stores, clinics etc.) can determinate the presence of a specific target of users, factor to be considered in the definition of risk.
The main future integration to this method is to obtain a unit risk index, assigning a weight to each selected parameter (KPIs) using a multi-criteria decision analysis methodology commonly called Analytic Hierarchy Process (AHP). In accordance with what emerged in this work, two separate metrics will be developed for each SUOD, one for the earthquake and one for terrorism. This differentiation is even more important at this stage as a single KPI may have a different relevance based on the risk analysed; further emphasizing the great versatility of KPIs, in adapting to multiple scenarios.

5. Abbreviations

AS - Areal Spaces

BE - Built Environment

BET - Built Environmental Typology

BIM - Building Information Model

GIS - Geographic Information System

LS - Linear Spaces

OS - Open Spaces

SLOD - Slow-onset disaster

SUOD - Sudden-onset disasters

6. References

Álvarez G, Quiroz M, León J, Cienfuegos R (2018) Identification and classification of urban micro-vulnerabilities in tsunami evacuation routes for the city of Iquique, Chile. Natural Hazards and Earth System Sciences 18:2027–2039. https://doi.org/10.5194/nhess-18-2027-2018

Aman DD, Aytac G (2022) Multi-criteria decision making for city-scale infrastructure of post-earthquake assembly areas: Case study of Istanbul. International Journal of Disaster Risk Reduction 67:102668. https://doi.org/10.1016/j.ijdrr.2021.102668

BE S2ECURE project D 4.1.1 | Selected SLOD/SUOD simulation tool for BETs delivered (2022)

BE S2ECURE project D 1.2.1 | Matrix of seismic risk conditions in BE prone to earthquake (2020a)

BE S2ECURE project D 1.3.1 | Matrix of terrorism risk conditions in BE (2020b)

BE S2ECURE project D 1.2.2 | Factors influencing buildings/aggregates, surrounding outdoor BE, modifications during the event (2020c)

BE S2ECURE project D 1.2.3 | Factors influencing outdoor BE seismic risk and its modification (2020d)

BE S2ECURE project D 1.3.2 | Current BE terrorism risk management and reduction strategies (2020e)

Bernabei L, Mochi G, Bernardini G, Quagliarini E (2021) Seismic risk of Open Spaces in Historic Built Environments: A matrix-based approach for emergency management and disaster response. International Journal of Disaster Risk Reduction 65:102552. https://doi.org/10.1016/j.ijdrr.2021.102552

Bernardini G, D'Orazio M, Quagliarini E (2016) Towards a "behavioural design" approach for seismic risk reduction strategies of buildings and their environment. Saf Sci 86:273–294. https://doi.org/10.1016/j.ssci.2016.03.010

Bernardini G, Ferreira TM (2020) Simulating to evaluate, manage and improve erthquake resilience in historical city centers: application to an emergency simulation-based method to the historic centre of coimbra. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLIV-M-1–2020:651–657. https://doi.org/10.5194/isprs-archives-XLIV-M-1-2020-651-2020

Bernardini G, Romano G, Soldini L, Quagliarini E (2021) How urban layout and pedestrian evacuation behaviours can influence flood risk assessment in riverine historic built environments. Sustain Cities Soc 70:102876. https://doi.org/10.1016/j.scs.2021.102876

Cantatore E, Quagliarini E, Fatiguso F (2022) European Cities Prone to Terrorist Threats: Phenomenological Analysis of Historical Events towards Risk Matrices and an Early Parameterization of Urban Built Environment Outdoor Areas. Sustainability 14:. https://doi.org/10.3390/su141912301

D'Amico A, Russo M, Angelosanti M, et al (2021) Built Environment Typologies Prone to Risk: A Cluster Analysis of Open Spaces in Italian Cities. Sustainability 13:9457. https://doi.org/10.3390/su13169457

Der Sarkissian R, Abdallah C, Zaninetti J-M, Najem S (2020) Modelling intra-dependencies to assess road network resilience to natural hazards. Natural Hazards 103:121–137. https://doi.org/10.1007/s11069-020-03962-5

Dong B, Yan D, Li Z, et al (2018) Modeling occupancy and behavior for better building design and operation—A critical review. Build Simul 11:899–921. https://doi.org/10.1007/s12273-018-0452-x

Doran GT (1981) There's a S.M.A.R.T. way to write managements's goals and objectives. Management Review., 70(11). 35–36

Giuliani F, de Falco A, Cutini V (2020) The role of urban configuration during disasters. A scenario-based methodology for the post-earthquake emergency management of Italian historic centres. Saf Sci 127:104700. https://doi.org/10.1016/j.ssci.2020.104700

Giuliani F, de Falco A, Cutini V (2022) Rethinking earthquake-related vulnerabilities of historic centres in Italy: Insights from the Tuscan area. J Cult Herit 54:79–93. https://doi.org/10.1016/j.culher.2022.01.004

Hissel F, Morel G, Pescaroli G, et al (2014) Early warning and mass evacuation in coastal cities. Coastal Engineering 87:193–204. https://doi.org/10.1016/j.coastaleng.2013.11.015

Kanno M, Ehara Y, Hirota M, et al (2016) Visualizing High-Risk Paths using Geo-tagged Social Data for Disaster Mitigation. In: Proceedings of the 9th ACM SIGSPATIAL Workshop on Location-based Social Networks. ACM, New York, NY, USA, pp 1–8

León J, March A (2014) Urban morphology as a tool for supporting tsunami rapid resilience: A case study of Talcahuano, Chile. Habitat Int 43:250–262. https://doi.org/10.1016/j.habitatint.2014.04.006

León J, Mokrani C, Catalán P, et al (2019) The Role of Built Environment's Physical Urban Form in Supporting Rapid Tsunami Evacuations: Using Computer-Based Models and Real-World Data as Examination Tools. Front Built Environ 4:. https://doi.org/10.3389/fbuil.2018.00089

O'Brien W, Gaetani I, Carlucci S, et al (2017) On occupant-centric building performance metrics. Build Environ 122:373–385. https://doi.org/10.1016/j.buildenv.2017.06.028

Robat Mili R, Amini Hosseini K, Izadkhah YO (2018) Developing a holistic model for earthquake risk assessment and disaster management interventions in urban fabrics. International Journal of Disaster Risk Reduction 27:355–365. https://doi.org/10.1016/j.ijdrr.2017.10.022

Ronchi E, Kuligowski E, Reneke P, et al (2013) The Process of Verification and Validation of Building Fire Evacuation Models

Russo M, Angelosanti M, Bernardini G, et al (2021) Factors Influencing the Intrinsic Seismic Risk of Open Spaces in Existing Built Environments: A Systematic Review. Sustainability 14:42. https://doi.org/10.3390/su14010042

Shiwakoti N, Shi X, Ye Z (2019) A review on the performance of an obstacle near an exit on pedestrian crowd evacuation. Saf Sci 113:54–67

Tai C-A, Lee Y-L, Lin C-Y (2010) Urban Disaster Prevention Shelter Location and Evacuation Behavior Analysis. Journal of Asian Architecture and Building Engineering 9:215–220. https://doi.org/10.3130/jaabe.9.215

Thakur A, Beck R, Mostaghim S, Grosmann D (2020) Survey into predictive key performance indicator analysis from data mining perspective. In: 2020 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA). IEEE, pp 476–483

Tumini I, Villagra-Islas P, Herrmann-Lunecke G (2017) Evaluating reconstruction effects on urban resilience: a comparison between two Chilean tsunami-prone cities. Natural Hazards 85:1363–1392. https://doi.org/10.1007/s11069-016-2630-4

Van der Wal CN, Formolo D, Robinson MA, Gwynne S (2021) Examining Evacuee Response to Emergency Communications with Agent-Based Simulations. Sustainability 13:4623. https://doi.org/10.3390/su13094623

Wang Z, Jia G (2021) A novel agent-based model for tsunami evacuation simulation and risk assessment. Natural Hazards 105:2045–2071. https://doi.org/10.1007/s11069-020-04389-8

Zhang N, Huang H, Su B, Zhao J (2015) Analysis of dynamic road risk for pedestrian evacuation. Physica A: Statistical Mechanics and its Applications 430:171–183. https://doi.org/10.1016/j.physa.2015.02.082

Zhu R, Lucas GM, Becerik-Gerber B, Southers EG (2020) Building preparedness in response to active shooter incidents: Results of focus group interviews. International Journal of Disaster Risk Reduction 48:101617. https://doi.org/10.1016/j.ijdrr.2020.101617

Zlateski A, Lucesoli M, Bernardini G, Ferreira TM (2020) Integrating human behaviour and building vulnerability for the assessment and mitigation of seismic risk in historic centres: Proposal of a holistic human-centred simulation-based approach. International Journal of Disaster Risk Reduction 43:101392. https://doi.org/10.1016/j.ijdrr.2019.101392

7. Appendix

7.1 PIs and descriptor

Eligible PIs analyzed according to risk descriptors.

Risk type				Descriptors			IDs													
S	T	H	P	Description	Descriptor	[u.m.]	1	3	6	8	9	11	13	15	20	22	23	24	28	31
X	X			**Section 1: Main type**																
X	X			Morphology	Main class (compact/elongated/very elongated)															
X		X	X		Canyon aspect ratio	m/m												S		
		X	X		Proximity of sidewalk to traffic	m														
X	X	X	X	Dimension of OS	Area	m^2	X		X	X	X								X	
X		X			Width	m		X				X							X	
X		X	X	Hmax built front	H max	m														
X		X	X		Average building height	m												S		
X		X		**Section 2: Characteristics of geometry and space**																
X		X		**Frontier**																
X				Structural types	% of SA	m/m*100												S		
X					Length of the built front	m														
X					Number of SU															
X					Length of SU	m														
X					Height of SU front	m														
X					Number of storeys															
X	X			Access	Number														X	
X	X	X	X		Width	m													X	
		X	X		Position/orientation (azimuth)															
	X				Presence of mitigation/control systems														X	
X	X			Special buildings	Presence								X							
X	X				Number								X							
X	X				Length of SB front	m														
X					Height	m														
X					Area	m^2							X					X		
X					Height of gable															
X	X			Town walls	Presence															
X	X				Linear extension	m														
X					Position															
X					Width or depth	m														

	X				Area	m^2			
X	X	X	X	Porches	Presence				
X	X				Linear extension	m			
X		X	X		Positon				
X		X	X		Width or depth				
X	X				Area				
X	X	X	X	Green area	Presence		X		
X	X	X	X		Crowding potential				
		X	X		Position (related to LS or AS)				
	X	X	X		Density	m^2 (veg)/ m^2 (green area)			
	X				Area	m^2	X		
X	X	X	X	Water	Presence				
X	X	X			Crowding potential				
	X				Extension of water content	m			
	X	X			Water body area	m^2			
		X			Water body volume	m^3			
X	X	X	X	Quote/difference slope	Slope	m/m*100			
X	**X**			**Content**					
X	X			Special Buildings	Number				
X	X				Height	m			
	X	X	X		Area	m^2			
X					Length	m			
X					Width	m			
X					Height of gable	m			
X	X			Quote difference/slope	Slope	m/m*100		X	X
X	X			Monuments (i.e. obelisk, statues, Fontaine etc.)	Presence of fountaine				
X	X				Presence of monuments				
X	X				Number				
	X	X			Area	m^2			
X	X	X	X	Green area	Presence		X		
X	X	X	X		Crowding potential				
	X	X	X		Extension (area)	m^2	X		
		X	X		Greenery adsorption capacity	mass/time o mass/area (e.g. mg/s or g/ m^2)			
		X	X		Tree crown diameter	m			
X		X	X	Water	Crowding potential				

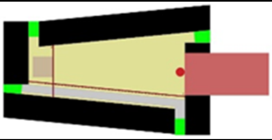
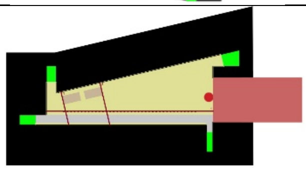
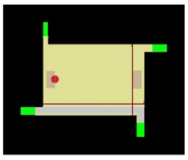
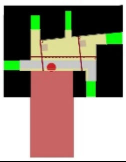
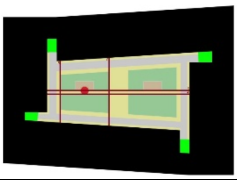
X	**X**			**Section 3: Constructive characteristics**							
X	**X**			**Frontier**							
X				Homogeneity of built environment	Last intervention period						S
X					Stte of conservation						S
X					Wall disconnection in plan						S
X					Wall disconnection in elevation						S
X		X		Homogeneity of constructive techniques	Homogeneous/ not homogeneous						S
X					Masonry quality						S
X					Wall thickness	m					S
X					Roof types						S
X					% openings	m^2/m^2*100			S		
X					No-structural protruding and decorative elements						
X					Anti-seismic devices						S
		X			Facade finishing albedo	-					
		X	X		Facade finishing current roughness	-					
		X			Facade heat capacity	J/ kg K					
			X		Facade pollutant deposition capacity	mass/time o mass/area (e.g. mg/s or g/m^2)					
	X			Fixed obstacles	n. of mitigation system				X	X	X
	X				Mitigation systems						
	X			Temporary obstacles	n. of mitigation system				X	X	X
	X				Mitigation systems						
X	**X**			**Content**							
		X		Pavement type	Pavement finishing albedo	-					
X				Pavement condition	Classes of conditions		X	X			
		X	X		Pavement finishing current roughness	-					
X	**X**			**Section 4: Characteristics of use**							

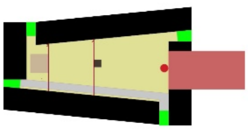
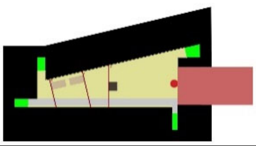
		X	X	Crowding	People presents	person (pp)			X	X	X	X	X	
X	X	X	X		Crowding potential	pp/ m²		X			X	X	X	
X	X				Tourism attraction	arrivals /inhabitants [pp/pp]							X	
		X	X		Exposure duration	hrs							X	
	X			Special uses of OS	Sensitive targets attraction to OS								X	
X	X	X	X	Strategic building / Special uses of building facing OS	Presence of special buildings or special uses			X						
X	X	X	X		Crowding potential			X			X	X	X	
	X				Symbolism level									
X		X	X		Presence of Schools			X						
X		X	X		Presence of Hospitals			X						
	X	X	X		Sensitive targets attraction to building use			X					X	
X	X			Accessibility for vehicle	Incidence of accessibility to vehicles to total accesses	m/m *100								X
		X	X		Traffic intensity	Vehicle /km								X
	X				Level of accessibility									X
X	X			Accessibility for pedestrian	Incidence of accessibility to pedestrian to total accesses	m/m *100								X
	X	X	X	Vehicles (parking)	Parking area location		X							X
X	X			Sights	Presence of sight									X
	X				Symbolism level								T	X
	X			Sensitive targets	Presence of Sensitive target (people as hard target)								T	
X		X	X		Presence of Sensitive target (elders/frail/gender/youngsters)						X	X	X	
X		X	X		% presence of Sensitive target (elders/frail/gender/youngsters)	%					X	X	X	
	X				Symbolism level								T	
X	**X**			**Section 5: Environmental characteristics**										
X				Seismic intensity	Ground motion severity								S	
X					Seismic microzonation								S	
		X		Climate classification [DPR 412/1993]	Climate zone									
		X	X	Climate conditions	Wind/breeze speed	m/s								
X		X	X		Air temperature	°C								
		X	X		Solar Irradiation	W/ m²								

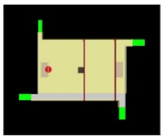
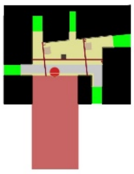
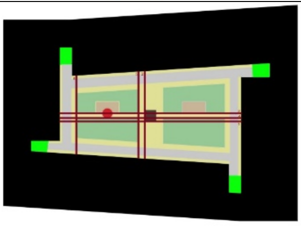
		X		Pollutant concentration	AQI	
	X	X	Multi-hazard potential	Pollution sources presence Boolean		
X			Ground type	classes of types		S
	X	X		Ground roughness	-	
	X			Ground albedo	-	
	X			Ground heat capacity	J/ kg K	

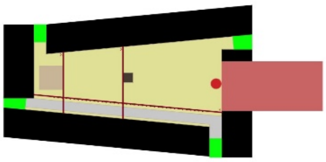
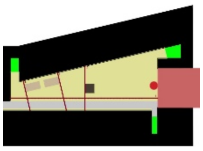
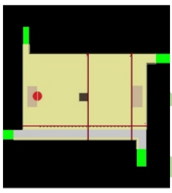
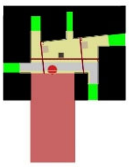
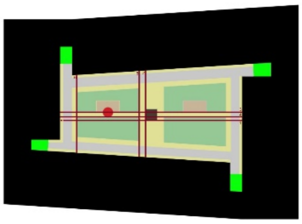
7.2 Support material of Section 3.4 Simulation of KPI for BETs scenario

KPI 4 - Obstacle friction rate (OFR) analysis for each different configuration of the space (C1, C2, C3) for terrorist risk scenario (ST1, ST2).

	C1	Obstacles	Lo	Levt	SCV	OFR	
	BET 1A, 1B (ST1, ST2)	Bollards with chains	74.5	93.43	0.50	39.87	**0.396**
		Dehor	12.0	30.81	0.00	39.95	
	BET 2A, 2B (ST1, ST2)	Bollards with chains	74.5	94.00	0.50	39.63	**0.342**
		Dehor 1	5.0	24.72	0.00	20.23	
		Dehor 2	5.0	19.46	0.00	25.69	
	BET 3 (ST1, ST2)	Bollards with chains	50.5	70.00	0.50	36.07	**0.313**
		Dehor	12.0	49.00	0.00	24.49	
	BET 4A, 4B, 4C (ST1, ST2)	Bollards with chains	24.5	38.00	0.50	32.24	**0.267**
		Dehor 1	4.0	20.03	0.00	19.97	
		Dehor 2	4.0	17.70	0.00	22.60	
	BET 5 (ST1, ST2)	Dehor	24.0	93.00	0.00	25.81	**0.295**
		Green area	64.06	93.00	0.50	34.44	
			26.62	44.20	0.50	30.11	
			20.88	40.08	0.50	26.05	

	C2	Obstacles	Lo	Levt	SCV	OFR	
	BET 1A, 1B (ST1, ST2)	Monument	5.0	36.52	0.00	13.69	**0.253**
		Dehor	12.0	30.81	0.00	38.95	
	BET 2A, 2B (ST1, ST2)	Monument	6.0	28.5	0.00	21.31	**0.221**
		Dehor 1	5.0	24.72	0.00	20.23	
		Dehor 2	5.0	19.46	0.00	25.69	
		Monument	5.0	49.00	0.00	10.20	**0.173**

	BET 3 (ST1, ST2)	Dehor	12.0	49.00	0.00	24.49	
	BET 4A, 4B, 4C (ST1, ST2)	Monument	5.0	38.00	0.00	13.16	0.185
		Dehor 1	4.0	20.03	0.00	19.97	
		Dehor 2	4.0	17.70	0.00	22.60	
	BET 5 (ST1, ST2)	Monument	6.0	93.00	0.00	6.45	0.225
		Monument	6.0	44.63	0.00	13.44	
		Dehor	24.0	93.00	0.00	25.81	
		Green area	64.06	93.00	0.50	34.44	
			26.62	44.20	0.50	30.11	
			20.88	40.08	0.50	26.05	

	C3	Obstacles	Lo	Levt	SCV	OFR	
	BET 1A, 1B (ST1, ST2)	Bollards with chins	74.5	93.43	0.50	39.87	0.337
		Monument	5.0	36.52	0.00	13.69	
		Dehor	12.0	30.81	0.00	38.95	
	BET 2A, 2B (ST1, ST2)	Bollards with chains	74.5	94.00	0.50	39.63	0.320
		Monument	6.0	28.15	0.00	21.31	
		Dehor 1	5.0	24.72	0.00	20.23	
		Dehor 2	5.0	19.46	0.00	25.69	
	BET 3 (ST1, ST2)	Bollards with chains	50.5	70.00	0.50	36.07	0.251
		Monument	5.0	49.00	0.00	10.20	
		Dehor	12.0	49.00	0.00	24.49	
	BET 4A, 4B, 4C (ST1, ST2)	Bollards with chais	24.5	38.00	0.50	32.24	0.267
		Dehor 1	4.0	20.03	0.00	19.97	
		Dehor 2	4.0	17.70	0.00	22.60	
	BET 5 (ST1, ST2)	Monument	6.0	93.00	0.00	6.45	0.225
		Monument	6.0	44.63	0.00	13.44	
		Dehor	24.0	93.00	0.00	25.81	
		Green area	64.06	93.00	0.50	34.44	
			26.62	44.20	0.50	30.11	
			20.88	40.08	0.50	26.05	

KPI 12 - Obstacle protection rate (OPR): Scheme of safe areas considered for terrorist attacks (ST1: armed attack and ST2: vehicle attack) and for earthquake (SE1: earthquake scenario with two road exit obcluded and SE2: earthquake scenario with all road exit obcluded) for each different configuration of the space (C1, C2, C3).

Table 17. Scheme of safe areas (green areas in the scheme) for terrorist attacks in C1 configuration (with the presence of bollards with chains)

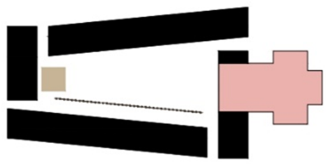
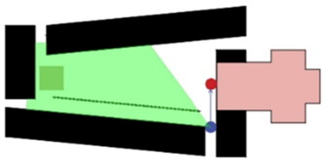
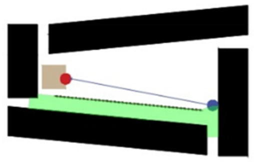
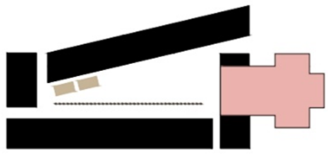
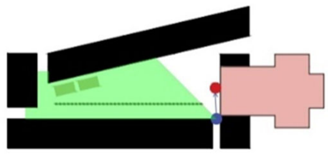
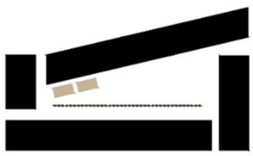
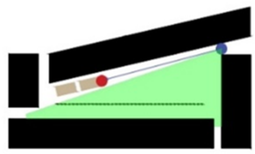
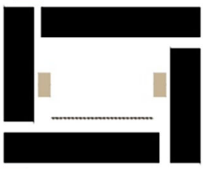
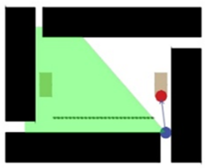
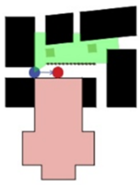
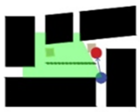
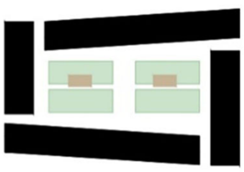
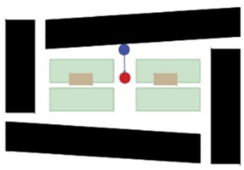
BETs	ST1	ST2
BET 1A		
BET 1B		
BET 2A		
BET 2B		
BET 3		
BET 4A/4B		
BET 4C		
BET 5		

Table 18. Scheme of safe areas (green areas in the scheme) for terrorist attacks in C2 configuration (with the presence of monuments)

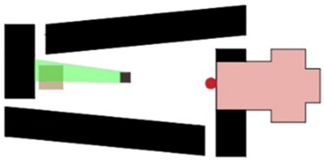
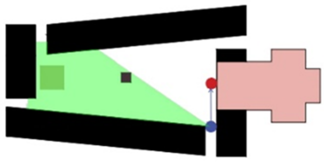
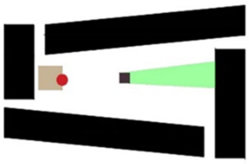
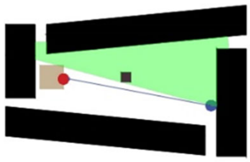
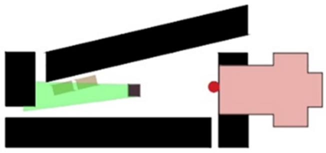
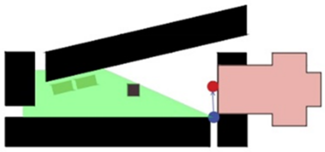
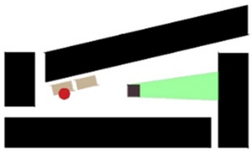
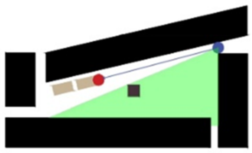
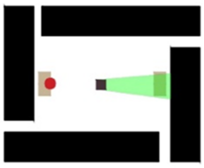
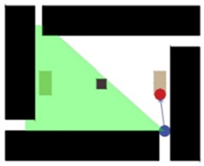
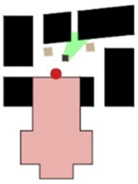
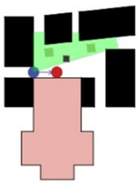
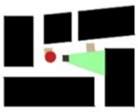
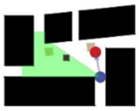
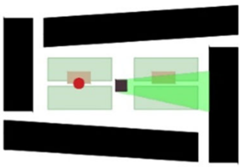
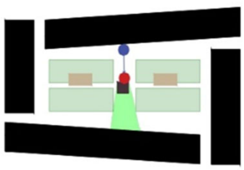
BETs	ST1	ST2
BET 1A		
BET 1B		
BET 2A		
BET 2B		
BET 3		
BET 4A/4B		
BET 4C		
BET 5		

Table 19. Scheme of safe areas for terrorist attacks (green areas in the scheme) in C3 configuration (with the presence of both bollards with chains and monuments)

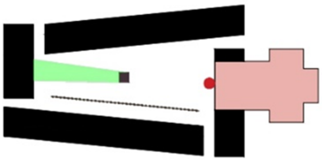
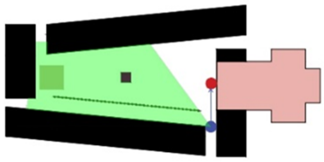
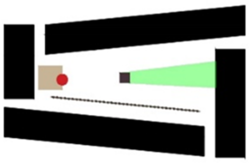
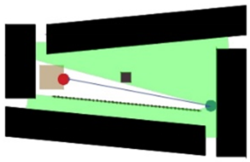
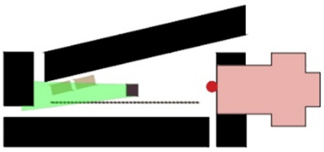
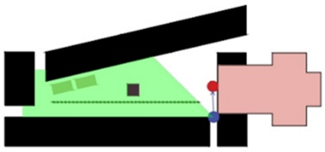
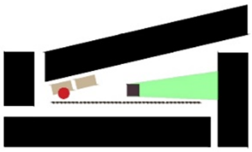
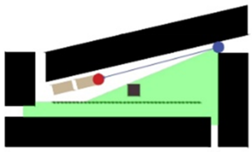
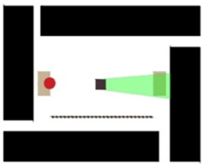
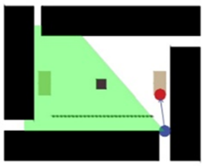
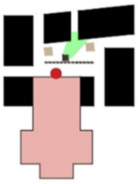
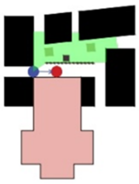
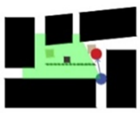
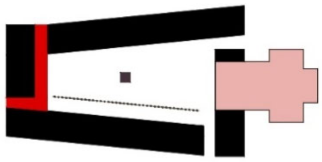
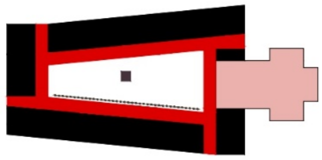
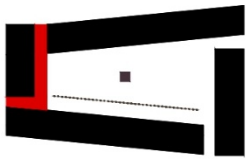
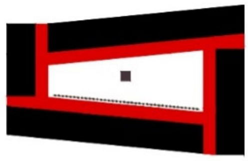
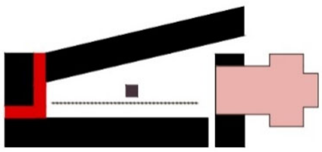
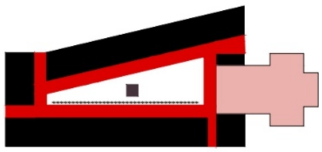
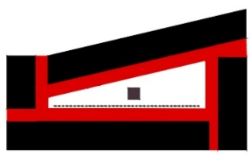
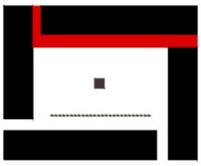
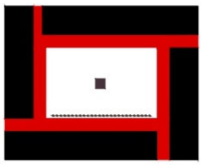
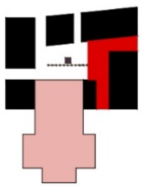
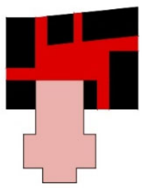
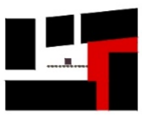
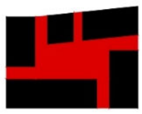
BETs	ST1	ST2
BET 1A		
BET 1B		
BET 2A		
BET 2B		
BET 3		
BET 4A/4B		
BET 4C		
BET 5	-	-

Table 20. Scheme of safe areas for earthquake in C3 configuration (with the presence of both bollards with chains and monuments). The safe area is the area of the square free from rubble (red areas in the scheme), in the C1 and C2 configurations the scenario is the same unless the monumeno (C1) and the stakes (C2)

BETs	ST1	ST2
BET 1A		
BET 1B		
BET 2A		
BET 2B		
BET 3		
BET 4A/4B		
BET 4C		
BET 5 (C2)