WP 5 - Strategies for improving/designing resilience of BETs

T5.2 Evaluation of BETs resilience-improving solutions through simulation and in terms of safety/functionality/application impacts and feasibility

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Abstract

Built Environment Typologies - BET (D3.2.1) are a useful abstraction of real case studies that can support resilience assessment and design phases in rapidly identifying the potential general criticalities of the built environment and its users to single and multi-risks. Typologies of resilience-improvement strategies can be recognized for each of them, depending on their main composing features, but a validation of their effectiveness on the BE(T) and its users is needed through holistic and simulation-based methods including the human behaviours in case of emergencies. This deliverable compares the resilience levels of BETs before and after the application of the different strategies and their combinations as defined in D5.1.1. The comparison is performed by applying the agent-based simulation model developed in D4.1.1, and then comparing KPIs and metrics on BETs resilience. In particular, simulations results concerning BET scenarios before the selected strategies application are based on D4.2.1 activities and reorganized according to D4.2.2 and D4.2.3 KPIs and then D4.2.4 B-based metrics. Simulation of retrofitted BET similarly organizes the outputs according to the same rationale. Results demonstrate differences in KPI-to-KPI values increasing resilience, and in the overall comparison by the metrics, which also depends on the selected strategies and implementation levels. From this point of view, the comparison results can be also used to trace trends in resilience improvement depending on the BET and on the implementation level and constitute a first basis for the selection of best strategies as in D5.2.2. At the same time, the BET-based assessment can supply local administrations and safety designers with preliminary and quick-to-apply tools for evaluating the effectiveness of strategies in their context, providing bases for D6.2.5. Then, they could move towards the application of the methods in view of their BE specificities, as better pointed out by D6.2.3 activities.

Keywords

Slow-Onset Disasters; Built environment; Pollution; Urban Heat Island; Sudden-Onset Disasters; Earthquake; Terrorism; mitigation techniques

Approvals

Role	Name	Partner	Date
Coordinator	Enrico Quagliarini	UNIVPM	-
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Revision versions

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0.1	22.10.2021	Deliverable structure and main content	Martha Caramia	POLIMI
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0.3	10.09.2022	Results update based on additional simulations	Gabriele Bernardini	UNIVPM
1.0	04.08.2023	Additional Review according to the (multi)risk metrics and related update of the results, and final language control/text editing	Gabriele Bernardini, Gessica Spavoli	UNIVPM

Summary

1. Introduction

It is difficult to find an "optimal strategy" for simultaneous mitigation of SLOD and SUOD risks. The classification of mitigation measures is complex because of the influence of several parameters, including behavioural ones. Therefore, it must be considered that the effectiveness of measures applied to a specific urban context may not always be suitable for other contexts and vice-versa, and it is therefore necessary to consider each case individually, to exclude those solutions that are not suitable and rather choose among those that are compatible.

To this end, the solution portfolio provides relevant information on effective and tailored strategies to improve the resilience and adaptation of the built environment to hazards from a multi-hazard perspective and is a useful tool for practitioners, policymakers, and city administrations to intervene. The purpose of this paper is to apply mitigation strategies to BETs and identify the parameters of the built environment most influential in implementing resilience.

1.1 Definition of SLODs and SUODs phenomena mitigation

Nowadays, the most common SLODs present in cities are the Urban heat island (UHI) and the Air pollution (AP).

Urban heat island effect is a commonly used term to describe the tendency of urban areas to experience higher outdoor air temperature levels compared to their contiguous rural periphery (Landsberg 1981). It is a fact that this phenomenon is related to the characteristics of the urban landscape, including building density, size and orientation, open space configuration and the use of heat absorbing construction materials, irrespective of global warming trends (Asimakopoulos et al. 2011) (Gartland 2008). Unthoughtful design, including intensive development leading to a massive loss of vegetation and pervious surface cover, might increase the UHI intensity, causing discomfort of city users and increase energy consumption from cooling energy demand in buildings. For this reason, informed actions, better known as “adaptation” and “mitigation measures” are spreading. “Adaptation” denotes short-term adjustments of human behaviour and systems in a way that provides partial and temporary relief from the effects of overheating. Adaptation measures do not operate on the urban microclimate, but rather on the human system and therefore have only a limited and local effect on thermal comfort. This research project focuses more on the mitigation measures: these are week-conceived, comprehensive, and collective actions, involving both governmental bodies and affected stakeholders that are aimed at the transformation of the urban microclimate through modifications of the physical environment.

The second SLOD analysed in this work is Air pollution. Air pollution is one of the largest health risk problems according to World Health Organization, with many cities suffering from poor air quality. The most harmful pollution for citizens includes nitrogen oxides, fine secondary particulate matter and ozone. These are all associated with negative health outcomes with both direct and indirect effects. In fact, according to the WHO, ambient air pollution contributed to 7% of all deaths worldwide (European commission 2016). Today air pollution in the majority of big cities is dominated by emissions from transport. This is a complicate matter, because different compounds react mutually in the atmosphere, before they start to have impacts, either in the cities or further afield (Mcdonald 2012). On average, traffic is the biggest source of air pollution, responsible for one quarter of particulate matter in the air (Degrauewe et al. 2019). For this reason, the European commission has introduced common limit values for exhaust emission to limit pollution, but still more mitigation measures need and can be implemented in cities to reduce air pollution or at least to absorb the pollutants already present in the air.

Urban Heat Island

- Shaded areas
- Canyon H/W
- Albedo coefficient
- Soil permeability
- Wind speed

Air Pollution

- evapotranspiration
- pollutant absoption
- traffic
- street canyon ventilation
- building emissions
- Wind speed

Figure 1. SLODs parameters to work on

Meanwhile, the SUODs considered to have the greatest impact on the safety of the built environment and people are the Earthquake and the Terrorist attack.

Earthquake risk is strongly related to the characteristics of the urban landscape, including the density of buildings, the construction techniques and building materials used, and the configuration and size of open spaces. Our historic centres are dense with fragile buildings, which could be severely damaged or even collapse involving the users who populate the square. For this reason, in addition to damage control solutions on buildings that are already widespread, mitigation actions targeting the open spaces of the built environment are becoming more common. The goal is to educate users by defining a resilient space that facilitates emergency management and limits errors to reduce the risk of casualties.

The last SUOD analysed is terrorism, an anthropogenic hazard determined by the unpredictable action of an individual or group of individuals. This event can result in great damage to places but more importantly involve numerous human lives, since generally the choice of the location of the attack falls where there is a crowd, at important socio-cultural points of attraction. This is a complicated issue since it is very difficult to predict and where the goal of the attackers is generally precisely to generate panic and casualties. The most effective mitigation solutions now result to be those aimed at eliminating or limiting the entrance of the bombers or providing temporary shelter for the victims during the attack, with sufficiently large and sturdy furniture elements.

These solutions can also aid in assessing individual vulnerability and exposure as part of risk management, with the objective of facilitating proper evacuation during a disaster and mitigating casualties through the manipulation of user behaviour or numbers.

Seismic risk

- morpho-typology
- dimensions of OS
- OS balance
- slope/different slope protections measures
- monuments
- fixed and temporary obstacles
- special building
- vehicles
- accessibility for vehicles and for pedestrians
- crowding
- seismic intensity
- ground type
- life line utilities
- OS interconnections
- undergroung cavities

Terrorism risk

- morphology
- fixed and temporary obstacles
- special uses and special buildings
- crowding

Figure 2. SUODs parameters to work on

Mitigation measures are a myriad of intervention measures that vary in scale and magnitude, as well as their implementation potential and compatibility with the local conditions.

The study carried out in the previous deliverables allowed to identify mitigation measures and classify them according to three main groups of strategies: (i) morphological factors, (ii) physical-material and construction factors and (iii) dedicated systems aimed at supporting proper users' behaviours and managers' strategies. However, since the purpose of this paperwork is to define the best and most applicable BETs resilience-improving solutions, it was considered appropriate not to consider the third group of strategies (dedicated systems aimed at supporting proper users' behaviours and managers' strategies) since their implementation is strictly related to human behaviour, political actions of governmental and local authorities and the context of application.

2. Methods: selected strategies and their impact assessment

The results of the qualitative analysis, combined with the possibility to simulate a strategy carried out in D 5.1.1, led to the selection of the mitigation measures to implement in the simulation software to compare BETs resilience before (compare with D4.2.4) and after (in this report) applying the strategy. In fact, the most appropriate mitigation strategies have been selected for each BET in relation to the SLOD and SUOD risk and to the possible multi-hazard SLOD+SUOD combinations and the frequency with which these situations occur (see also table 4 and Table 5 in D5.1.1).

For this reason, this deliverable analysed the impact that the previously highlighted strategies can have on all types of emergencies relevant to open spaces as shown in Table 1~~Table 1~~.

In particular, the table filters the strategies by listing the main ones that, among those indicated in D511, can be modelled with the representation tools and analyses with the simulation tools used for the analyses in this deliverable. Subjective evaluations are excluded to ensure objectivity. It is apparent from the analysis that certain strategies can impact multiple phenomena simultaneously, despite being designed solely for one. Such strategies can therefore be conveniently considered when there is a combination of several risks, whether stemming from SLOD events, SUOD events or both simultaneously.

Table 1. Summary analysis of mitigation strategies based on the category according to the mitigation strategies described in D511: Level of implementation, from rarely implemented (+) to very often implemented (+++); Potential impact, categorised as negligible or with possibility of aggravation under certain operating conditions in grey, limited in yellow, medium in light green or high in dark green) compared to SLOD (H=heat flood, P=air pollution) and SUOD (E=earthquake; T=terrorist attack); Impact on users in terms of evacuation movement; Simulatability, between those that can be fully simulated according to D4.1.1 tools (x) and partially simulated since they are related just to some secondary scenario inputs (p).

Code	Strategy	Implementation level	Potential impact				Effect on users	Simulability
			SLOD		SUOD			
			H	P	E	T		
SL.A.1	Trees	+++					x	x
SL.A.2	Shrubs and hedges	+++					x	x
SL.A.4	Seasonal shadings	++					x	x
SL.B.1	Urban surface and roughness / cool pavement	+						x
SL.B.2	Permeable pavers	++						x
SL.B.3	Permeable grass pavers	++						x
SU.B.7	Permeable grass pavers	+++			a	a	x	x
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	+++	b			a	x	x
SL.B.11	Cool facade	+			c			x
SL.B.12	Reflective roof / cool roof	++			c			x
SL.B.13	Green walls	+			c			x
SL.B.14	Green roofs	++			c			x
SU.B.18	Elimination of superfetations (d)	+	d					p
SU.B.19	Masonry wall quality increase (d)	++						p
SU.B.20	Replacement of pushing roof typology (d)	++	d					p
SU.B.21	Maintenance (d)	+++						p

a = planning through the concepts of SL/SU.C.7 + SU.A.6
b = effective strategy if combined with the inclusion of meaningful green elements
c = effective strategy when combined with one or more strategies between SU.B.18, 19, 20, 21
d = effective strategy when combined with one or more strategies between SL.B.11, 12, 13, 14

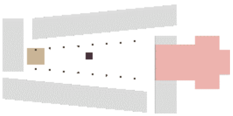
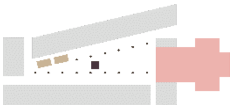
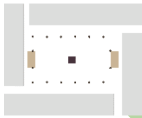
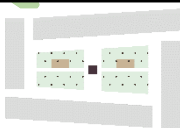
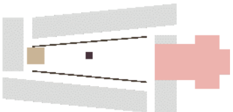
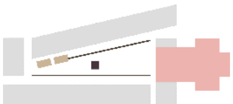
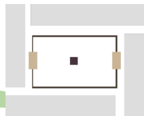
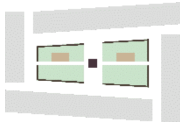
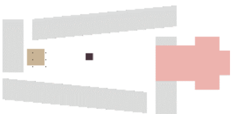
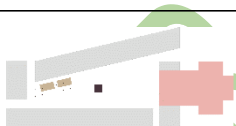
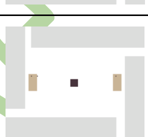
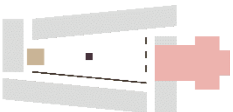
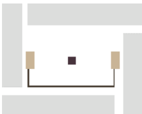
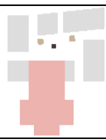
The final analysed solutions included:

- for only SLOD: SL.A.1 - Trees, SL.A.2 - Shrubs and hedges; SL.A.4 - Seasonal shadings; SL.B.1 - Urban surface and roughness/cool pavement; SL.B.2 - Permeable pavers; SL.B.3 - Permeable grass pavers; SL.B.11 - Cool facade; SL.B.12 - Reflective roof/cool roof; SL.B.13 - Green walls; SL.B.14 - Green roofs;
- for only SUOD: SU.B.7 - Install instruction signs for evacuation and safe areas; SU.B.8 - Install mobile or fixed barriers, dissuaders, or furniture.

To evaluate the application impact of mitigation strategies it is necessary to test their effectiveness and express it through data. For this purpose, the BETs form has been identified as the perfect testing area on which experiment, according to the specific case, the necessary and available strategies. Several studies (Shan et al. 2007; Hwang et al. 2011; Al-Dabbous and Kumar 2014; Abhijith and Gokhale 2015;

Van Ryswyk et al. 2019) encountered in literature define an incremental simulation approach in which green strategies are gradually implemented in the simulated built environment. Since the archetypes derived from WP3 are derived from real cases, simulation results cannot be considered as universal. In fact, each archetype is simulated with site location related climate data and background pollution concentrations. Some of the selected strategies involve a change in the layout of the BET as they involve the replacement or implementation of street furniture elements (e.g., trees, planters, roadblocks etc.) and are shown graphically in Table 2~~Table 2~~. The BETs with the Special Building are obviously more susceptible to risk due to the presence of a higher number of people in it. In fact, along with BETs 3 and 5, BETs 1A, 2A and 4A (4B) have been selected to test mitigation strategies.

Table 2. Summary diagrams of selected mitigation strategies for the analysed BETs. There are shown the strategies involving geometric/distributional change in BETs.

Mitigation strategies	BETs 1A	2A	3	4A/AB	5
SL.A.1					
SL.A.2					
SL.A.4				-	-
SL.B.8					-

Simulation strategies are tested first for SLOD risks and then for SUOD risks, using the user distribution maps resulting from the heatwave analysis as input for the SUOD analyses. The strategies are not tested for all BETs, since the investigations conducted show that these are not relevant for the specific BE. A complete overview of the scenario selection is also reported in summary of simulations.xlsx.

3. Results

3.1 Final KPI metrics of mitigation strategies

Figure 3~~Figure 3~~ shows the effects of mitigation strategies for UTCI on selected BETs. Specifically, the pre-intervention scenarios (grey bars) are compared with the various post-intervention scenarios (coloured symbols). It is clearly seen that the solutions that result in the greatest risk reduction are definitely SL.B.3 (up to 11.9%) and SL.A.1 (up to 9.5%). Although less impactful, solutions SL.A.2, SL.A.4, and SL.B.8 also led to improvements, with UTCI reduction for all BETs ranging between 0.0% and 4.3%.

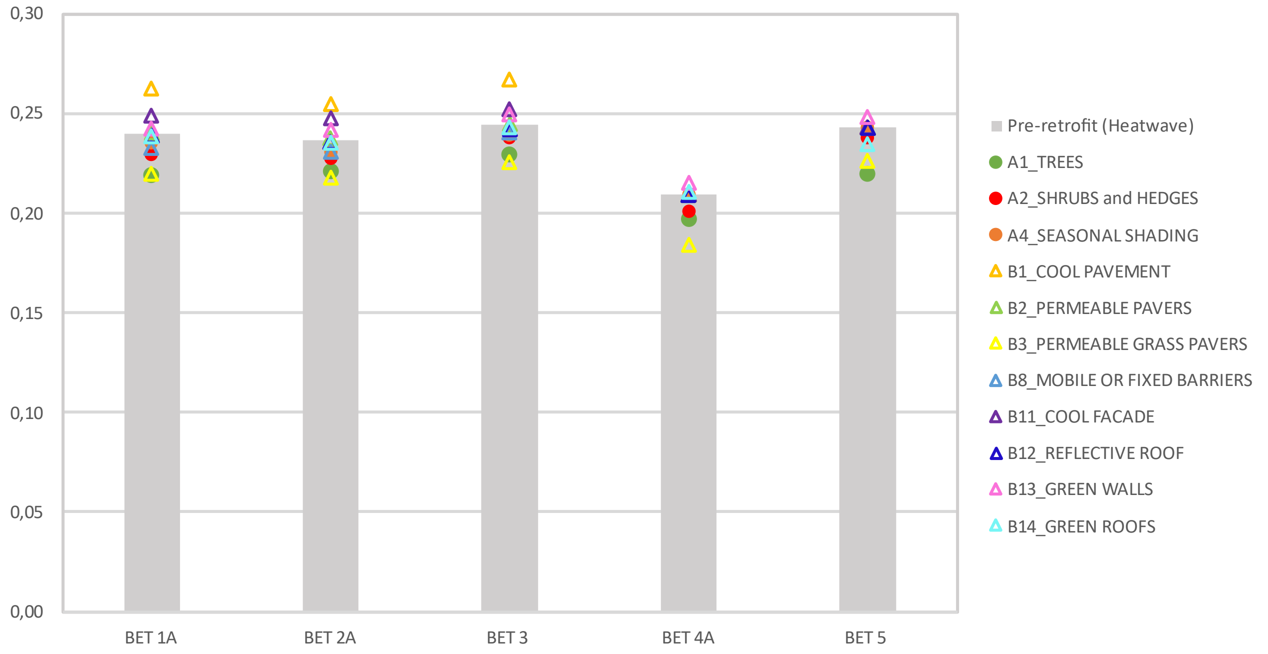


Figure 3. Comparison graph between the UTCI risk scenario under normal conditions (grey bars) and the retrofit scenarios (coloured symbols)

Figure 4~~Figure 4~~ instead, shows the effects of the same mitigation strategies just observed for UTCI, for AQI on selected BETs. In this case, mitigation strategies are not being tested on all BETs, but only for those best suited to respond to the selected strategies. The tested mitigation strategies all result effective in countering the risk of AQI, with mitigations reaching 35% in BET 3. Only in the case of BET 2A and 5 for strategies SL.A.1 and SL.A.2 are there slight aggravations from the starting condition. With the exception of BET 3 the changes result to be minimal since the starting conditions also have a very small order of magnitude. In general, as found in D 4.2.3 and D 4.2.4, the risk for AQI given the conditions examined does not pose significant health risks.

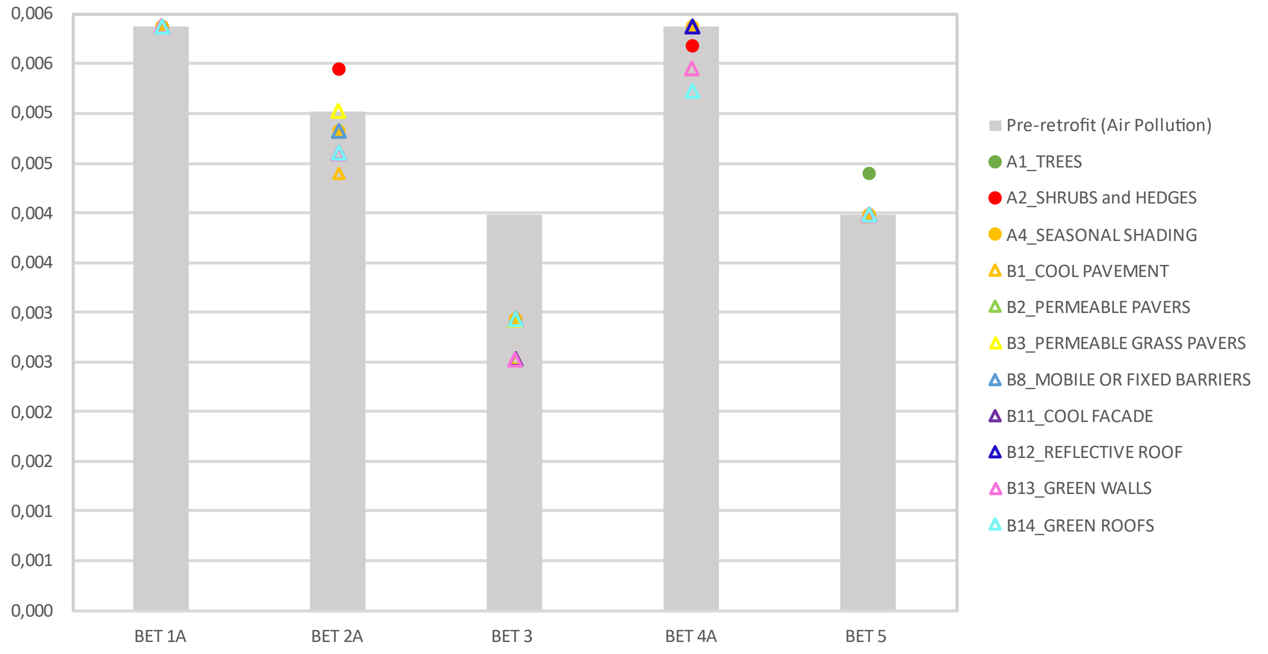


Figure 4. Comparison graph between the AQI risk scenario under normal conditions (grey bars) and the retrofit scenarios (coloured symbols)

Finally, combining the two metrics for mitigation strategies for UTCI and AQI leads to the overall SLODs metric in Figure 5~~Figure 5~~. This result confirms the trend already observed for the two risks individually. This outcome confirms the trend already observed for each risk separately, and it can be concluded that the most effective solutions for mitigating the combined SLODs are SL. A.1, SL. B.8, with a similar percentage improvement to UTCI of around 9%.

The mitigation strategies just described as most effective for SLOD risk, coincide with the solutions tested for SUOD risk, except for SL.B.7 specific to rapid-onset disasters, as they relate to the implementation of evacuation directions.

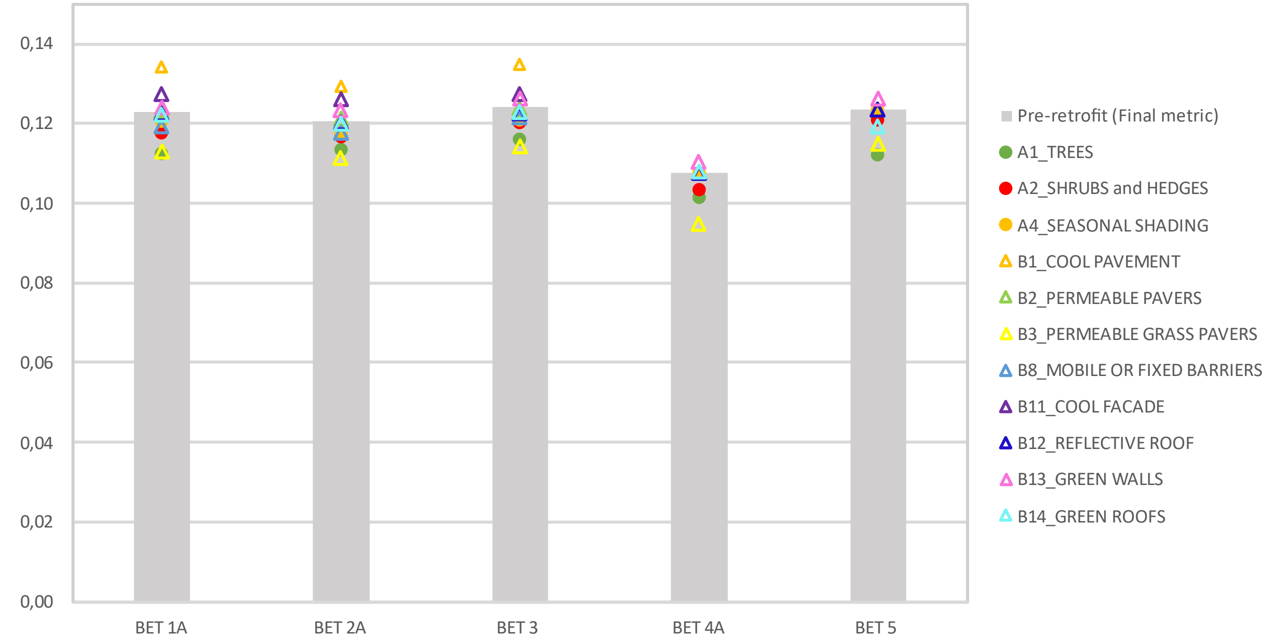


Figure 5. Comparison graph between the SLOD metric risk scenario under normal conditions (grey bars) and the retrofit scenarios (coloured symbols)

The figures below show the final KPI metrics (D 4.2.2; D 4.2.3; D 4.2.4) for the selected mitigation strategies for earthquake risk and terrorist risk. Through comparison with the pre-retrofit scenarios, the impact of each mitigation strategy in the BETs is evaluated for increasing risk conditions (Sb - base scenario without specific risk/false alarm, SE1 - earthquake scenario with two road exits occluded, SE2 - earthquake scenario with all road exit occluded, ST1 - terrorist armed attack scenario).
In general, for seismic risk, the tested mitigation strategies determined a risk reduction in almost all scenarios. The greatest impact is for strategy SL.A.1 (Figure 6~~Figure 6~~), where there is a risk reduction reaching 24%. Strategy SL.A.4 (Figure 8~~Figure 8~~), tested only for BET 2A appears to be equally effective, with a percentage reduction in this case ranging between 2% and 3.5%.
The SL.B.8 strategy (Figure 11~~Figure 11~~) represents a special case, with risk reductions of up to 7.5% for the largest BETs, but also a slight increase of 5.5% in risk for BET 4. This trend is determined by the type of action implemented, the placement of barriers represents an additional obstacle in the evacuation process, especially in smaller BETs, while in larger BETs it is irrelevant.
For terrorist risk, the situation is more varied. In this case, five mitigation strategies are tested against the baseline risk scenario (false alarm) and against the ST1 risk (armed attack).
The strong heterogeneity found in the risk analysis through KPIs (D 4.2.2) is also reflected in this stage of mitigation strategy analysis. Looking at the results of the final metrics, no clearly defined behaviour can be found for any of the strategies. The SL.B.8 strategy (Figure 11~~Figure 11~~) has shown to have beneficial outcomes in most BETs. Exceptional results arise in BET 4 with a risk reduction of 14.5%. Conversely, for BET 2A, the implementation of barriers leads to an increase in risk by up to 8.6%. The SL. B.7 strategy (Figure 10~~Figure 10~~) appears to be most controversial, as it gives the best results with a 44.5% risk reduction for BET 2A, but also leads to a large increase in risk (over 50%) for BET 1A.

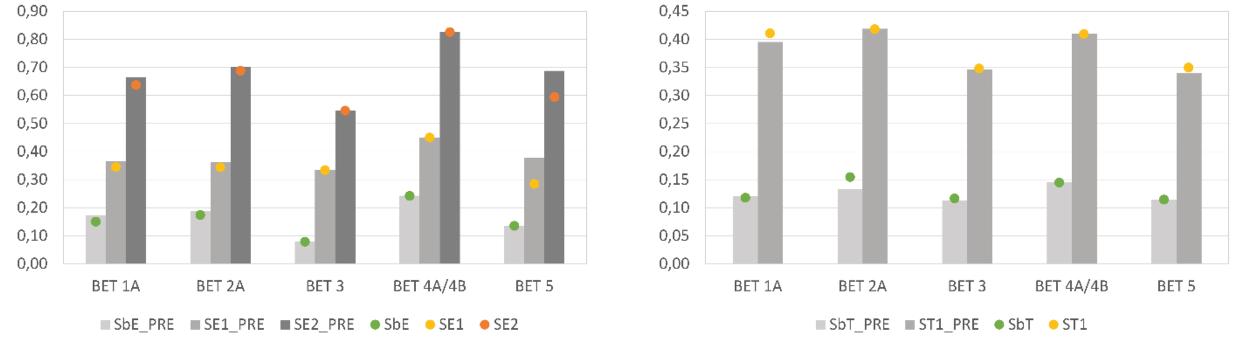


Figure 6. Graphs comparing the risk scenario in normal conditions (grey bars) and that with the implementation of the mitigation strategy SL.A.1 (green, yellow and orange dots) related to the Earthquake and Terrorism scenarios for each BETs considered.

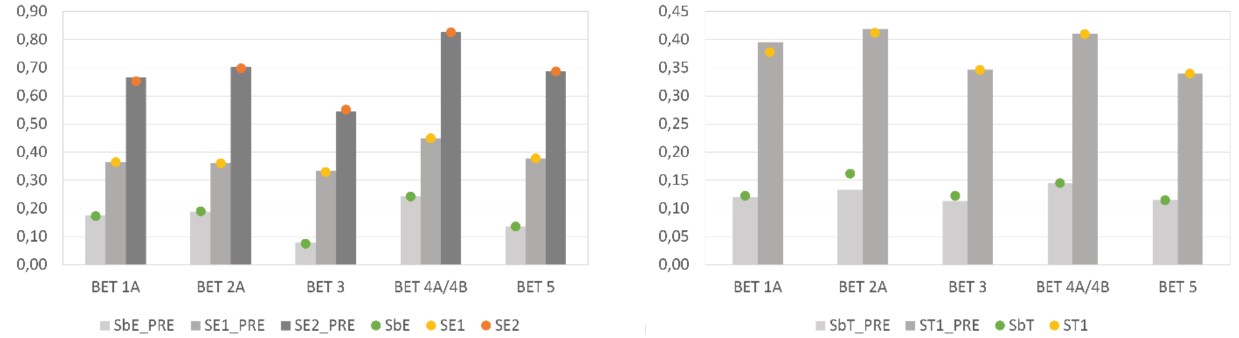


Figure 7. Graphs comparing the risk scenario in normal conditions (grey bars) and that with the implementation of the mitigation strategy SL.A.2 (green, yellow and orange dots) related to the Earthquake and Terrorism scenarios for each BETs considered.

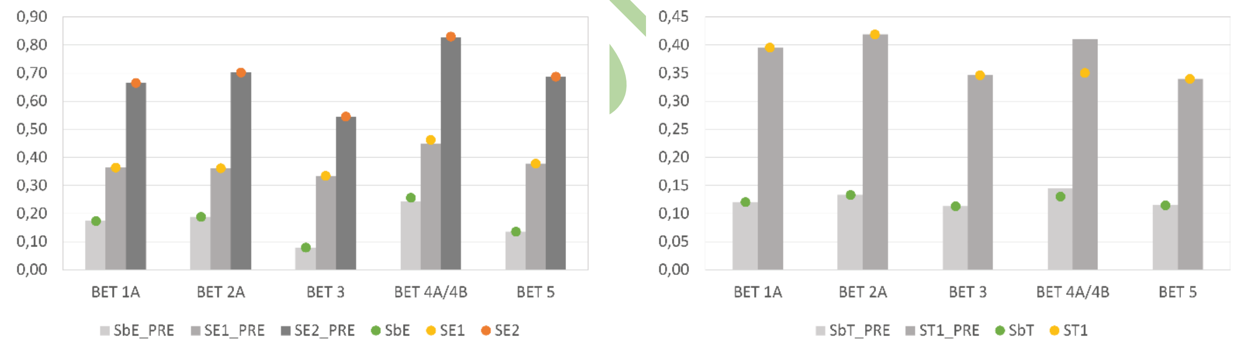


Figure 8. Graphs comparing the risk scenario in normal conditions (grey bars) and that with the implementation of the mitigation strategy SL.A.4 (green, yellow and orange dots) related to the Earthquake and Terrorism scenarios for each BETs considered.

Figure 9. Graph comparing the risk scenario in normal conditions (grey bars) and that with the implementation of the mitigation strategy SL.B.1 (green, yellow and orange dots) related to the Terrorism scenarios for each BETs considered.

Figure 10. Graph comparing the risk scenario in normal conditions (grey bars) and that with the implementation of the mitigation strategy SL.B.7 (green, yellow and orange dots) related to the Terrorism scenarios for each BETs considered.

Figure 11. Graphs comparing the risk scenario in normal conditions (grey bars) and that with the implementation of the mitigation strategy SL.B.8 (green, yellow and orange dots) related to the Earthquake and Terrorism scenarios for each BETs considered.

The heterogeneity of the results just seen for the final metric of retrofit strategies for terrorism does not provide the best understanding of the effectiveness of the proposed solutions. The metric is the result of the weighted combination of KPIs seen in D 4.2.2, each analysing a specific aspect of risk. Not all mitigation solutions influence the indicators in the same way, so it is necessary to analyse them individually to recognize the impact of the proposed solutions.
First, it is necessary to mention that the static KPIs K1, K2, K3, K6 (Table 3 in D 4.2.2) are not affected by the proposed mitigation solutions. All others are shown in Table 3~~Table 3~~.
For each KPI, the effect determined by the mitigation intervention is expressed in percentage terms, compared with the pre-retrofit condition (0%) for each BETs. Thus, it is possible to recognize the most

effective strategy, for earthquake and terrorism, and if the same trend is obtained for all KPIs. For seismic risk, the analysis of individual KPIs confirms what has been observed for the metric. Most BETs are negatively affected by the SL.B.8 strategy, designed mainly for terrorist attacks, due to the placement of barriers/obstacles within the square. This effect is caused by the fact that these elements become obstacles during escape and reduce the usable area of the square.

For terrorism risk the analysis is more complex.

Table 3. Graphs comparing mitigation solutions tested for individual KPIs for each BET. Mitigation effects are expressed as percentages compared with the pre-retrofit condition (0%)

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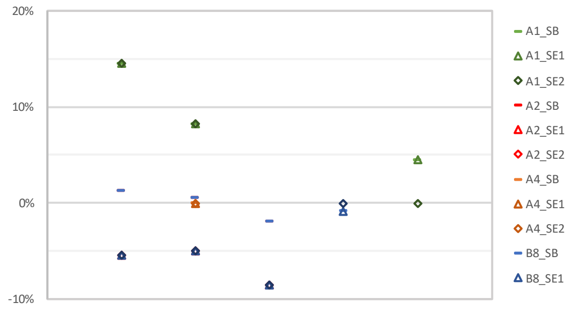
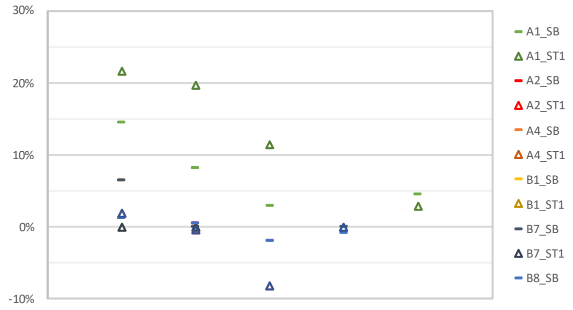
<tr><td>K4</td><td>
</td><td>
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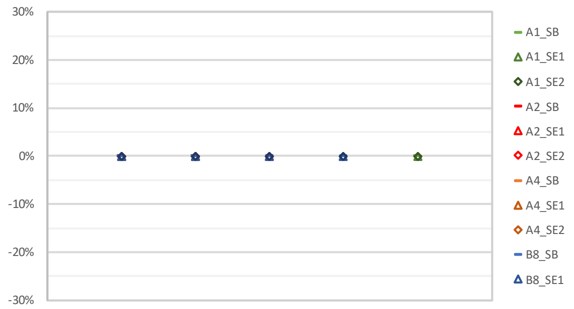
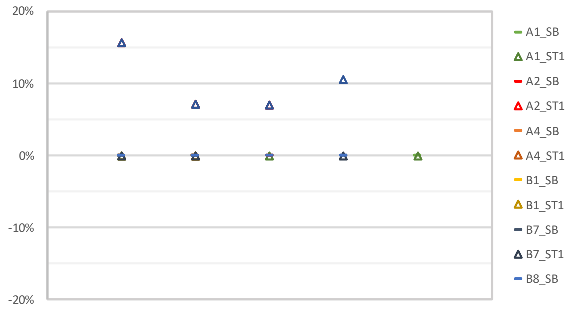
<tr><td>K5</td><td>
</td><td>
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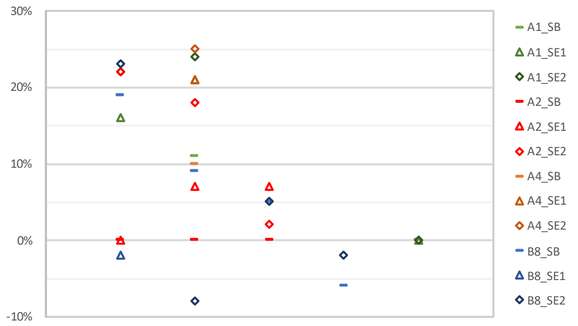
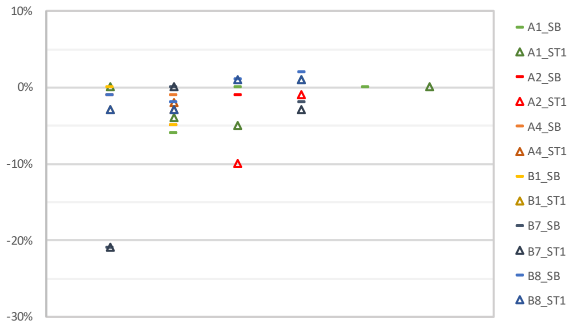
<tr><td>K7</td><td>
</td><td>
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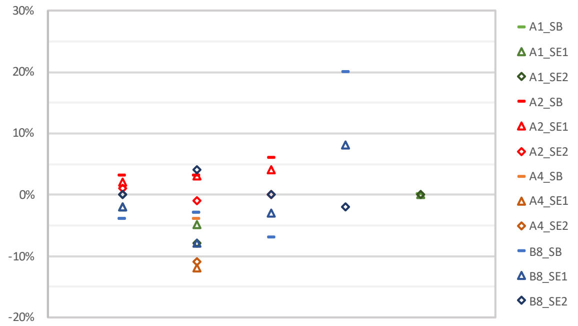

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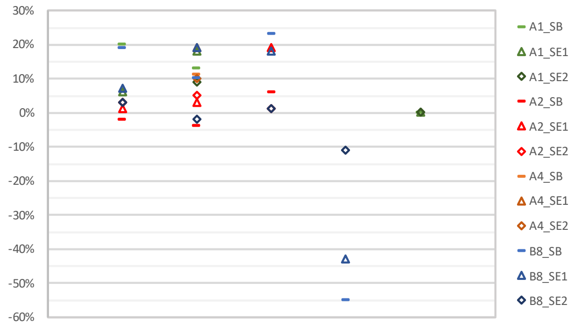

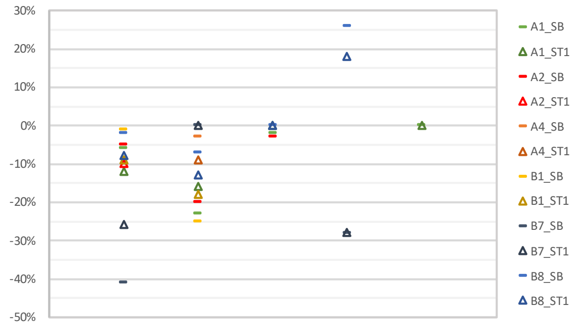

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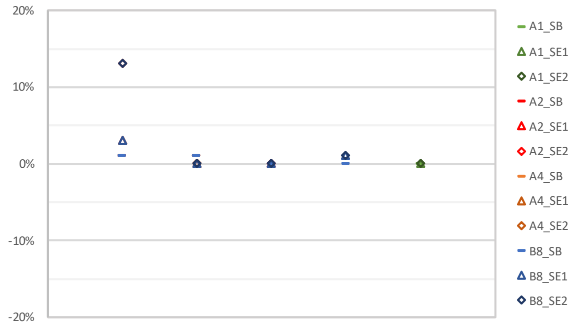

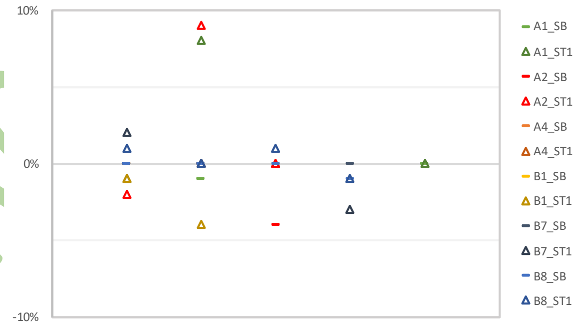

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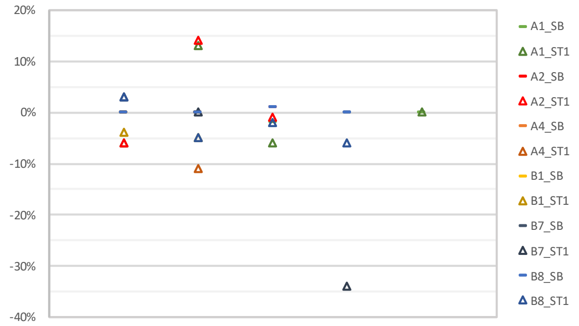

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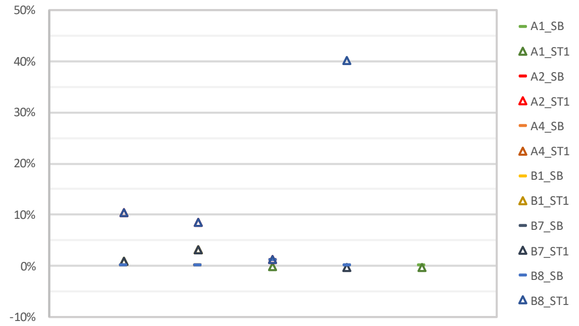

3.2 Final vectors of mitigation strategies

Finally, the four-dimensional vector defined in D4.2.4 is used to facilitate the comparison of mitigation solutions for BETs in the multi-risk scenario. The vector module is shown in Equation 1~~Equation 1~~ (also compare Section 2.4 in D4.2.4).

Equation 1

$$SL_{TOT} = \sqrt{\frac{SE^2 + ST^2 + SH^2 + SP^2}{4}}$$

Each BET is characterized by a single value, which represents the risk mitigation of specific strategy with respect to the multi-risk SLOD+SUOD combination. The matrix in Figure 12~~Figure 12~~ expresses the results of the analysis for each proposed simulation. The colour scale highlights with different shades of red (from light to intense red) the BETs for which a mitigation strategy is not resulting in an improvement in initial risk conditions, but instead in a worsening.

PRE	**0,308**	**0,315**	**0,256**	**0,345**	**0,300**
	1A	2A	3	4A	5
SL.A.1	0,284	0,298	0,254	0,335	0,258
SL.A.2	0,286	0,303	0,257	0,335	0,288
SL.A.4	0,293	0,296	0,256	0,336	0,289
SL.B.1	0,301	0,316	0,263	0,336	0,289
SL.B.2	0,308	0,315	0,256	0,345	0,300
SL.B.3	0,304	0,311	0,252	0,342	0,297
SL.B.7	0,306	0,310	0,257	0,349	0,289
SL.B.8	0,285	0,306	0,256	0,331	0,289
SL.B.11	0,310	0,317	0,258	0,345	0,300
SL.B.12	0,308	0,315	0,255	0,345	0,300
SL.B.13	0,308	0,316	0,257	0,346	0,301
SL.B.14	0,308	0,314	0,256	0,346	0,298

Figure 12. Matrix of multi-risk vectors for proposed mitigation strategies. The gradient represents the effectiveness of the strategies with respect to the initial risk conditions (first row of "PRE" values). White: risk mitigation - Red (based on intensity): from ineffective mitigation to worsening risk.

It is clear from the matrix in Figure 12~~Figure 12~~ that in most cases the mitigation strategies are found to be effective, save for some exceptions already presented in the previous section (Section 3.1). The ineffectiveness of mitigation strategies is particularly related to the limited effects on SLOD risk for heat waves, as shown in Figure 13~~Figure 13~~ reporting the effects of strategies for individual hazards. Strategy SL.B.13 (green walls) has pejorative effects on all BETs. In Figure 13, the green cell with the "-" represents a reduction in risk for the mitigation strategy, while the white cell marked with "+" represents an increase in risk caused by the mitigation strategy. As shown by comparing the results of the multi-hazard matrix and the single-hazard matrix, heat wave risk has the greatest impact in determining the effectiveness of mitigation strategies. In fact, the in the way the SUOD risk simulations are defined, heat wave risk has a significant impact in determining the initial location of people inside the BET.

	SL.A.1						**SL.B.7**				
S	-	-	-	-	-	S	-	-	-	-	-

T	-	-	+	-	-	T	-	-	+	+	-
H	-	-	-	-	-	H	-	-	-	-	-
P	-	+	-	-	+	P	-	-	-	-	-
	SL.A.2						**SL.B.8**				
S	-	-	+	-	-	S	-	+	+	+	-
T	-	-	+	-	-	T	-	-	+	-	-
H	-	-	-	-	-	H	-	-	-	-	-
P	-	+	-	-	-	P	-	-	-	-	-
	SL.A.4						**SL.B.11**				
S	-	-	-	-	-	S	-	-	-	-	-
T	-	-	+	-	-	T	-	-	-	-	-
H	-	-	-	-	-	H	+	+	+	-	-
P	-	-	-	-	-	P	-	-	-	-	-
	SL.B.1						**SL.B.12**				
S	-	-	-	-	-	S	-	-	-	-	-
T	-	-	+	-	-	T	-	-	-	-	-
H	+	+	+	-	-	H	-	-	-	-	-
P	-	-	-	-	-	P	-	-	-	-	-
	SL.B.2						**SL.B.13**				
S	-	-	-	-	-	S	-	-	-	-	-
T	-	-	-	-	-	T	-	-	-	-	-
H	+	+	+	-	-	H	+	+	+	+	+
P	-	-	-	-	-	P	-	-	-	-	-
	SL.B.3						**SL.B.14**				
S	-	-	-	-	-	S	-	-	-	-	-
T	-	-	-	-	-	T	-	-	-	-	-
H	-	-	-	-	-	H	-	-	-	+	-
P	-	-	-	-	-	P	-	-	-	-	-

Figure 13. Matrix of single-risk vectors for proposed mitigation strategies. The green cell with the "-" represents a reduction in risk for the mitigation strategy, while the white one "+" represents an increase in risk caused by the mitigation strategy.
S-Earthquake risk, T-Terrorism risk, H-Heatwaves risk, P-Air Pollution risk.

4. Conclusions and remarks

The aim of this paper is to provide an overview of the most effective measures to address SLOD and SUOD risks in BE, as single risks and in multi-hazard combinations, although the analysis cannot be considered fully comprehensive due to the limited number of strategies and case studies examined. The proposed evaluation methodology defines guidelines for testing pre-intervention conditions and strategies, and also provides typological evidence of the positive impact of mitigation solutions. The strategies tested are among the most common and notable in the national and international panorama, and can also have a direct impact from a behavioural perspective, not only from a built environment perspective.

The most relevant aspect concerns the management of space, limiting its use in smaller BETs and trying to organise it better in larger BETs. Smaller open spaces are generally less affected by SLOD hazards, as their small size and built frontages protect them from excessive heat and from pollutant sources due to lower traffic volumes, while they are particularly sensitive to SUOD hazards, and in particular to earthquakes, due to the debris that can cover the entire surface.

The effectiveness of mitigation strategies in this scenario relies on limiting the introduction of obstacles like hedges or roadblocks, which decrease the available space and hinder the movement of crowds. However, larger BETs have the opposite effect, especially for SLOD events, where the objective of mitigation measures is to introduce elements that can increase the shaded area and filter the air, such as trees and hedges. At the same time, it is essential for SUODs that mitigation strategies outline a secure location and provide clear guidance for the evacuation process.

Overall, the findings indicate that the most successful approaches are those that incorporate the integration of greenery, a component already present in many suggested strategies. This is especially significant considering the growing importance assigned to this matter, particularly in the context of tackling environmental hazards of which SLODs are a part.

However, it is also important to consider the distinctive features of a real-world environment, beyond BETs. In actual situations, certain strategies may not be possible due to specific site limitations, high expenses, feasibility, or regulatory problems linked to deployment.

Given the comparison results of this report, the next step concerns the full definition of best strategies (D5.2.2) to combine not only quantitative simulation-based results, but also semi-quantitative and expert-judgement based issues on their applicability and potential impact in extended BETs conditions.

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BE S2ECURE project D 4.2.3 | SLOD KPIs for determining B-based resilience of BETs

BE S2ECURE project D 4.2.4 | B-based (multi-risks) resilience metric for BE

(2023) BE S2ECURE project D 4.2.2 | SUOD: B-based KPIs per determinare la resilienza delle BETs

BE S2ECURE project D 3.2.1 | Basic BETs configuration and typical combinations