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

As discussed in the previous deliverables, SUOD and SLOD events affect the built environment. For this reason, a consistent part of this project has been focusing on the definition and selection of mitigation strategies to tackle down these phenomena. In fact, BETs resilience-improving solutions have already been introduced and analysed in D2.2.4 and also in D5.1.1 and D 5.2.1. Thanks to a literature review it has been possible to identify, collect, categorize and analyse several mitigation strategies (D5.1.1). All of them have been divided into three main groups of strategies: morphological factors, physical-material and construction factors and dedicated systems aimed at supporting proper users' behaviours and managers' strategies. The study and the analysis of existing strategies showed that not all mitigation measures act in the same way, and some are more effective in one context than in another. For this reason, this document focuses on presenting which of the strategies are generally most effective regardless of the specific context. Starting from the collection of all mitigation measures defined in D5.1.1 and comprising the simulation-based analysis of strategies effectiveness shown in D5.2.1, this report investigates the most suitable strategies according to different criteria: safety, functionality, application impact and feasibility, impacts on the users. The application on idealised archetypes (BETs) allows to identify the best strategies in a specific context. The BET application offers direction on which strategy to favour based on the BE's specific features. This analysis want to define strategies that ought to be encouraged for their effectiveness, easy integration and the benefits that can be obtained, also taking into account the local characteristics that are essential for good mitigation performance.

Keywords

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

Approvals

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0.3	20.11.2022	Congruence check with D5.2.1 and results update	Gabriele Bernardini	UNIVPM
1.0	01.09.2023	Proofreading	Gabriele Bernardini, Gessica Sparvoli	UNIVPM

Summary

1. Introduction

Scientific research into mitigation strategies for SLOD and SUOD phenomena is increasing, underlining the emerging recognition by scientists, planning authorities and government agencies of the impact of urban design and planning on these phenomena. The BE S2ECURe project's advanced analytical and simulation tools can offer significant aid in identifying the optimal mitigation measures for single hazards and multi-hazard combinations. This approach enables the assessment of the potential effects of relevant strategies in a typological and timely way, which is advantageous in terms of time and resources.
The indicators for SLOD, SUOD and their combinations can provide quantitative assessments of mitigation strategies. These assessments can be complemented by evaluations of the feasibility of implementing solutions in the BETs and their impact, even after making adjustments to the salient BET parameters. By doing so, the validity of the analysis can be extended beyond the simulated sample (D'Amico et al. 2021).
This deliverable synthesizes two levels of analysis previously discussed in D5.1.1 and D5.2.1 in order to identify the best strategies. The first level involves semi-quantitative analysis of implementation levels and potential impact, as defined by the criteria outlined in D5.1.1 (Blanco Cadena et al. 2023). It should be noted that this analysis was based on the strategies employed rather than the BET analysed. The second issue pertains to the results of the simulations shown in D5.2.1 and their connection to the feasibility of implementing the proposed solutions in the BETs.
The analysis focuses on individual BETs rather than the entire set of ideal cases, as each condition has unique characteristics that limit the effectiveness of multi-risk combinations and strategies (D5.2.1). It should be noted that the strategies presented in this report provide only a brief overview of possible solutions, which should be further explored in individual case studies based on their distinctive features (Quagliarini et al. 2023).

2. Evaluation of current strategies

As already seen in D1.2.5, D1.3.1, D 2.2.4, and D 5.1.1 along with the available knowledge and technologies, a great variety of mitigation solutions already exist both for SUODs and SLODs phenomena. The strategies selected for this work are resumed in Table 1 according to D 5.1.1 and the application for simulations in D 5.2.1.

The effectiveness of each strategy is closely linked to the context in which it is implemented, i.e. the results obtained in D 5.2.1, where the strategies were simulated and their impact was assessment from a quantitative and objective perspective. Obviously, the most reliable solution is the actual experimentation of each strategy, but the application to the BETs was the quickest and simplest way to outline in general terms the aspects and parameters most relevant to the effectiveness of the strategy.

For this reason, the validation through simulations has been combined with qualitative analysis in terms of implementation level and potential impact. Simulations have the potential of predicting real results, but at the same time require also more information to set the model. This document aims at defining the best strategies through this double evaluation, uniting both qualitative analysis and simulations.

Table 1. Mitigation measures

Code	Strategy	Strategy with impact on both SLODs and SUODs	Validation through simulations
SL.A.1	Trees	✓	✓

SL.A.2	Shrubs and hedges		✓
SL.A.3	Green barriers	✓	✓
SL.A.4	Seasonal shadings		✓
SL.A.5	New BE morphology (form, layout, orientation)	✓	✓*
SU.A.6	BETs simulations for preventive evacuation plans		
SU.A.7	Redundancy of evacuation routes		
SL.B.1	Urban surface and roughness / cool pavement		✓
SL.B.2	Permeable pavers		✓
SL.B.3	Permeable grass pavers		✓
SL.B.4	City trees		
SU.B.5	Protection of strategic lifelines and infrastructures		
SU.B.6	Increase available free areas and define «safe» areas		
SU.B.7	Permeable grass pavers		✓
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	✓	✓
SU.B.9	Set up/install warning systems		
SU.B.10	Set up Remote/in situ Control systems		
SL.B.11	Cool facade	✓	✓
SL.B.12	Reflective roof / cool roof	✓	✓
SL.B.13	Green walls	✓	✓
SL.B.14	Green roofs	✓	✓
SL.B.15	Photocatalytic materials	✓	
SL.B.16	algal pbr		
SU.B.17	Preventive vulnerability assessment studies		
SU.B.18	Elimination of superfetations	✓	
SU.B.19	Masonry wall quality increase		
SU.B.20	Replacement of pushing roof typology	✓	
SU.B.21	Maintenance		
SU.B.22	Using perimeter-based solutions just outside the building (barriers or buffer zones)	✓	✓**
SL.C.1	Public transportation		
SL.C.2	Shared mobility		
SL/SU.C.3	Controlled/limited traffic zones	✓	
SL.C.4	Electric and hybrid mobility		
SL.C.5	Soft mobility		
SU.C.6	Pedestrian only areas	✓	
SL/SU.C.7	Behavioural simulations		
SU.C.8	Evacuation training		
SU.C.9	Support vulnerable people		
SL/SU.C.10	Risk education and dissemination activities		
SL.C.11	Energy efficiency education and dissemination activities		
SL.C.12	Waste management - to avoid production of pollutants - education and dissemination activities		
SU.C.13	Change building's function	✓	
SU.C.14	Reduce crowding indexes	✓	
SU.C.15	Modify utilization time	✓	

* It could be possible to validate through simulation, but not in the context of this research because HBE is already defined

** This strategy is not implementable in ENVI-met because it doesn't change the microclimate (B-based solution)

2.1 Qualitative analysis

In order to analyse the strategies which must be evaluated through simulation, a preliminary qualitative analysis has been done in D5.1.1 and is here reported. The analysis considers two parameters (implementation level and potential impact) and assigns to each of them a score based on the ranges defined in Table 3 of D5.1.1.

The selection of strategies relies on their scores and whether they can be simulated using the BES2ECURe project's software. Simulation analysis was conducted only on strategies that could be simulated, in view of the assigned parameter ranges.

The last column of the following tables illustrates the feasibility of implementation in the simulation software.

2.1.1 Implementation level

As reported in D5.1.1, the implementation level identifies how easily the specific mitigation measure can be implemented in the BE and is evaluated by means of "1", "2" and "3" if the measure is respectively *rarely implemented (difficult to implement)*, *often implemented (average difficulty of implementation)* or *very often implemented (easy to implement)*.

The evaluation of this parameter takes into account not only how many times the mitigation strategy has been implemented in a BE, but also the difficulty of implementing it especially in HBE due to local regulations. In addition, since several strategies are related to the buildings, their implementation is bound to the will of the owners. The score collected by each strategy is reported in Table 2.

Table 2. Implementation level score

Code	Strategy	Implementation level	Validation through simulation
SL.A.1	Trees	3	✓
SL.A.2	Shrubs and hedges	3	✓
SL.A.3	Green barriers	1	
SL.A.4	Seasonal shadings	2	✓
SU.A.6	BETs simulations for preventive evacuation plans	3	
SU.A.7	Redundancy of evacuation routes	3	
SL.B.1	Urban surface and roughness / cool pavement	1	✓
SL.B.2	Permeable pavers	2	✓
SL.B.3	Permeable grass pavers	2	✓
SU.B.5	Protection of strategic lifelines and infrastructures	2	
SU.B.6	Increase available free areas and define «safe» areas	2	
SU.B.7	Install evacuation instruction signs	3	✓
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	3	✓
SU.B.9	Set up/install warning systems	3	
SU.B.10	Set up Remote/in situ Control systems	3	
SL.B.11	Cool facade	1	✓
SL.B.12	Reflective roof / cool roof	2	✓
SL.B.13	Green walls	1	✓
SL.B.14	Green roofs	2	✓
SU.B.17	Preventive vulnerability assessment studies	3	
SU.B.18	Elimination of superfetations	1	
SU.B.19	Masonry wall quality increase	2	
SU.B.20	Replacement of pushing roof typology	2	
SU.B.21	Maintenance	3	
SU.B.22	Using perimeter-based solutions just outside the building (barriers or buffer zones)	2	
SL/SU.C.3	Controlled/limited traffic zones	1	

SU.C.6	Pedestrian only areas	2
SL/SU.C.7	Behavioural simulations	3
SU.C.8	Evacuation training	3
SU.C.9	Support vulnerable people	2
SL/SU.C.10	Risk education and dissemination activities	3
SU.C.13	Change building's function	2
SU.C.14	Reduce crowding indexes	2
SU.C.15	Modify utilization time	2

2.1.2 Potential impact

As reported in D5.1.1, the impact of the mitigation varies from case to case due to the very complex nature of SLODs and SUODs phenomena. The qualitative scale adopted for the evaluation of the general mitigation potential is based on a range between 1 (*negligible*) and 5 (*very high*), passing through 2 (*low*), 3 (*medium*) and 4 (*high*).

The potential impact represents a generic and qualitative parameter due to the fact that each specific area needs a calculation which consider the specific context to evaluate more precisely the effect of the mitigation measure.

The score collected by each strategy due to its potential impact is reported in Table 3.

Table 3. Potential impact score

Code	Strategy	Potential impact					Validation through simulation
		H	P	S	T	Total score	
SL.A.1	Trees	5	4	1	5	15	✓
SL.A.2	Shrubs and hedges	4	5	1	1	11	✓
SL.A.3	Green barriers	4	5	1	5	15	
SL.A.4	Seasonal shadings	3	1	1	1	6	✓
SU.A.6	BETs simulations for preventive evacuation plans	1	1	4	4	10	
SU.A.7	Redundancy of evacuation routes	1	1	4	4	10	
SL.B.1	Urban surface and roughness / cool pavement	5	1	1	1	8	✓
SL.B.2	Permeable pavers	5	1	1	1	8	✓
SL.B.3	Permeable grass pavers	5	5	1	1	12	✓
SU.B.5	Protection of strategic lifelines and infrastructures	1	1	4	4	10	
SU.B.6	Increase available free areas and define «safe» areas	1	1	4	4	10	
SU.B.7	Install evacuation instruction signs	1	1	4	4	10	✓
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	3	1	1	5	10	✓
SU.B.9	Set up/install warning systems	1	1	1	4	7	
SU.B.10	Set up Remote/in situ Control systems	1	1	1	4	7	
SL.B.11	Cool facade	5	1	3	1	10	✓
SL.B.12	Reflective roof / cool roof	3	1	3	1	8	✓
SL.B.13	Green walls	3	4	3	1	11	✓
SL.B.14	Green roofs	5	3	3	1	12	✓
SU.B.17	Preventive vulnerability assessment studies	1	1	5	1	8	
SU.B.18	Elimination of superfetations	3	1	4	1	9	
SU.B.19	Masonry wall quality increase	1	1	5	1	12	
SU.B.20	Replacement of pushing roof typology	5	1	5	1	12	
SU.B.21	Maintenance	1	1	4	1	7	
SU.B.22	Using perimeter-based solutions just outside the building (barriers or buffer zones)	5	1	4	5	15	
SL/SU.C.3	Controlled/limited traffic zones	2	5	1	3	11	

SU.C.6	Pedestrian only areas	2	5	1	4	12
SL/SU.C.7	Behavioural simulations	1	1	4	4	10
SU.C.8	Evacuation training	1	1	4	4	10
SU.C.9	Support vulnerable people	1	1	4	4	10
SL/SU.C.10	Risk education and dissemination activities	1	1	4	4	10
SU.C.13	Change building's function	4	4	4	4	16
SU.C.14	Reduce crowding indexes	4	4	4	4	16
SU.C.15	Modify utilization time	4	4	4	4	16

Based on the analysed parameters (implementation level and potential impact), Table 4 below resumes the total score achieved by each strategy in the qualitative analysis.

Table 4. Qualitative analysis total score

Code	Strategy	Implementation level	Potential impact	Total score	Validation through simulation
SL.A.1	Trees	3	15	18	✓
SL.A.2	Shrubs and hedges	3	11	14	✓
SL.A.3	Green barriers	1	15	16	
SL.A.4	Seasonal shadings	2	6	8	✓
SU.A.6	BETs simulations for preventive evacuation plans	3	10	13	
SU.A.7	Redundancy of evacuation routes	3	10	13	
SL.B.1	Urban surface and roughness / cool pavement	1	8	9	✓
SL.B.2	Permeable pavers	2	8	10	✓
SL.B.3	Permeable grass pavers	2	12	14	✓
SU.B.5	Protection of strategic lifelines and infrastructures	2	10	12	
SU.B.6	Increase available free areas and define «safe» areas	2	10	12	
SU.B.7	Install evacuation instruction signs	3	10	13	✓
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	3	10	13	✓
SU.B.9	Set up/install warning systems	3	7	10	
SU.B.10	Set up Remote/in situ Control systems	3	7	10	
SL.B.11	Cool facade	1	10	11	✓
SL.B.12	Reflective roof / cool roof	2	8	10	✓
SL.B.13	Green walls	1	11	12	✓
SL.B.14	Green roofs	2	12	14	✓
SU.B.17	Preventive vulnerability assessment studies	3	8	11	
SU.B.18	Elimination of superfetations	1	9	10	
SU.B.19	Masonry wall quality increase	2	12	14	
SU.B.20	Replacement of pushing roof typology	2	12	14	
SU.B.21	Maintenance	3	7	10	
SU.B.22	Using perimeter-based solutions just outside the building (barriers or buffer zones)	2	15	17	
SL/SU.C.3	Controlled/limited traffic zones	1	11	13	
SU.C.6	Pedestrian only areas	2	12	14	
SL/SU.C.7	Behavioural simulations	3	10	13	
SU.C.8	Evacuation training	3	10	13	
SU.C.9	Support vulnerable people	2	10	12	
SL/SU.C.10	Risk education and dissemination activities	3	10	13	
SU.C.13	Change building's function	2	16	18	
SU.C.14	Reduce crowding indexes	2	16	18	
SU.C.15	Modify utilization time	2	16	18	

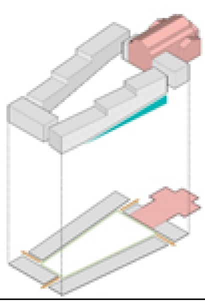
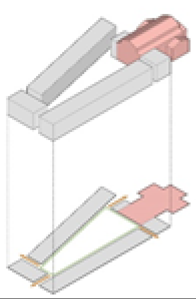
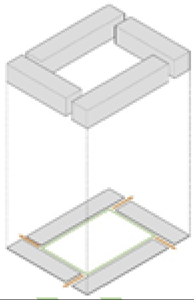
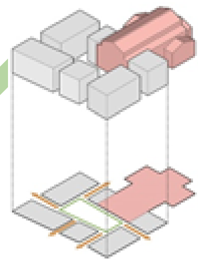
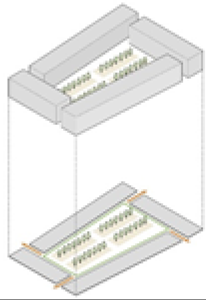
2.2 Simulation-based results on BETs

The results of the qualitative analysis, combined with the possibility to simulate a strategy, led to the selection of the mitigation measures to implement in the simulation software in order to compare BETs resilience before and after applying the strategy. The complete results of the BET applications are reported in D5.2.1, but a short overview of the process here follows.

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.

At this stage, although the defined BETs are 9, the variations of a single BET are not taken into account, since the little differences between cases A, B and C make no difference in this analysis. Thus, the simulated BETs are only 5, focusing the attention on those that are more prone to risks in view of their features (compare also Section 2 of D5.2.1).

Table 5. Selected BETs for the evaluation of resilience-improving solutions

1A	2A	3	4A	5
				

Several studies 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.

For this reason, in this phase a personalised solution is defined for each BET to provide an example of good practice, which can be emulated by designers. The purpose of these simulation is to prove the validity of the methodology more than providing a precise numerical result.

According to D5.1.1 and to the simulations conducted in D5.2.1, it is feasible to obtain risk reduction data for individual SLOD/SUOD risks and for the multi-risk combination by specifying the final vector.
The matrices depicted in Figure 1 exhibit the percentage alteration in risk relative to the initial state for both heatwave and air pollution risk, according to D5.2.1 outcomes of risk metrics. The colour scale is calibrated after considering all strategies and all BETs, from the least effective (in red) to the most effective (in dark green). This visual representation provides a comprehensive overview of the entire sample while ensuring objectivity and clarity. When attempting to counteract heatwaves, the most effective measures involve implementing greenery. Trees (SL.A.1), hedges (SL.A.2), and green pavements (SL.B.3) have proven particularly beneficial, especially for smaller BETs. Regarding air pollution, it is evident that BET 3 benefits from all tested mitigation strategies, achieving the maximum improvement through the use of cool pavement (SL.B.1) and cool facade (SL.B.11). These are typically constructed with low-roughness materials

that do not retain pollutant particles. Additionally, green facades (SL.B.13) absorb pollutants efficiently due to their large surface area.

	Heatwaves					Air Pollution				
	1A	2A	3	4A	5	1A	2A	3	4A	5
SL.A.1	-8,67%	-6,44%	-6,18%	-5,91%	-9,46%	0,00%	8,46%	-26,42%	-3,40%	10,69%
SL.A.2	-4,34%	-3,70%	-2,66%	-3,98%	-2,13%	0,00%	8,46%	-26,42%	-3,40%	0,00%
SL.A.4	-1,98%	-2,46%	-2,14%	0,00%	0,00%	0,00%	-3,98%	-26,42%	0,00%	0,00%
SL.B.1	9,46%	7,68%	9,25%	0,00%	0,00%	0,00%	-12,44%	-36,48%	0,00%	0,00%
SL.B.2	0,21%	0,39%	0,08%	0,00%	0,00%	0,00%	-3,98%	-26,42%	0,00%	0,00%
SL.B.3	-8,26%	-7,92%	-7,66%	-11,90%	-7,02%	0,00%	0,00%	-26,42%	-7,23%	0,00%
SU.B.8	-2,90%	-2,46%	-1,63%	0,00%	0,00%	0,00%	-3,98%	-26,42%	0,00%	0,00%
SL.B.11	3,75%	4,77%	3,15%	0,00%	0,00%	0,00%	-8,46%	-36,48%	0,00%	0,00%
SL.B.12	-0,30%	-0,22%	-0,82%	0,00%	0,00%	0,00%	-8,46%	-26,42%	0,00%	0,00%
SL.B.13	1,03%	2,31%	2,17%	2,77%	2,13%	0,00%	-8,46%	-36,48%	-7,23%	0,00%
SL.B.14	-0,54%	-0,58%	-0,61%	0,78%	-3,46%	0,00%	-8,46%	-26,42%	-11,06%	0,00%

Figure 1. Matrices of percentage variation for the single SLOD indicator, for the mitigation strategies (for code) analysed by simulation. The colour gradient goes from the least effective solution (red) to the most effective solution (deep green), calibrating the scale with respect to all solutions and all BETs.

Applying the same logic as shown for SLOD, Figure 2 illustrates the effects of mitigation strategies on earthquake and terrorist attacks as relevant SUODs in the project. While there are merely two SUOD-specific approaches, an assessment of the impact of all SLOD strategies that significantly influence both the initial distribution and movement of users was carried out. From the matrices illustrated in Figure 5, it is evident that the mitigation strategies that yield the most significant benefits regarding earthquakes and terrorism are those associated with the placement of static or movable barriers (SU.B.8). If correctly positioned in the BET to aid the evacuation process, the crowd can be directed towards the most effective escape routes. This can be achieved by separating driveways from pedestrian areas, circumventing the most crowded outdoor areas - such as those located in front of the special building - from others, and, in the event of a terrorist attack, creating riparian obstacles for potential attackers. Trees (SL.A.1), hedgerows (SL.A.2), and seasonal shading (SL.A.4) have a limited impact on the movement process directly but can greatly alter the position of individuals prior to an emergency. They promote a more evenly distributed presence of users in the square, reducing the effects of local overcrowding. This minimizes the risk of critical crowd movements such as higher densities, slower speeds and physical contact among people. Additionally, this decreases the direct impact of attackers in the event of an attack. The multi-hazard vector modules (see D4.2.4) were calculated for the post-attack scenarios as done in the previous section.

	Earthquake					Terrorism				
	1A	2A	3	4A	5	1A	2A	3	4A	5
SL.A.1	-4,86%	-2,82%	0,00%	0,00%	-15,51%	-12,64%	-9,03%	3,10%	-10,76%	-12,97%
SL.A.2	-1,43%	-0,41%	0,26%	0,00%	0,00%	-18,82%	-9,74%	3,10%	-10,76%	-15,23%
SL.A.4	0,00%	-3,18%	0,00%	0,00%	0,00%	-15,52%	-13,10%	2,30%	-10,76%	-15,23%
SL.B.1	0,00%	0,00%	0,00%	0,00%	0,00%	-12,03%	-2,78%	2,30%	-10,76%	-15,23%
SU.B.7	0,00%	0,00%	0,00%	0,00%	0,00%	-1,73%	-5,49%	2,30%	3,68%	-15,23%
SU.B.8	-2,14%	0,04%	0,37%	1,39%	0,00%	-20,04%	-8,13%	0,64%	-23,29%	-15,23%

Figure 2. Matrices of percentage variation for the single SUOD indicator, for the mitigation strategies (for code) analysed by simulation. The colour gradient goes from the least effective solution (red) to the most effective solution (deep green), calibrating the scale with respect to all solutions and all BETs.

Figure 3 presents the multi-risk mitigation matrix, expressed as a percentage change compared to the pre-retrofit scenario, and thus it adopts the multirisk vector modules analysis. It is evident that many of the mitigation strategies are generally effective in most BETs, despite some strategies not having a positive effect for a single risk. Change values of less than 0% indicate that the post-intervention multi-risk does not vary. It should be noted that certain strategies do not always produce clear benefits for SLODs and SUODs, as well as for multi-risk situations. This outcome highlights the utility of simulating evaluations to verify the effectiveness of these strategies, which may still be associated with potential advantages in general, without regard for the specific characteristics of BETs. In detail, the efficiency of mitigating strategies is specifically impeded by their limited (or rather deteriorating) impact on heatwaves, as illustrated in Figure 1. However, the outcomes may fluctuate based on the descriptive BETs' parameters and user behaviours, necessitating further validation of the depicted scenario under various parameter-based circumstances to extend its sustained validity.

	1A	2A	3	4A	5
SL.A.1	-7,83%	-5,18%	-0,61%	-3,11%	-13,85%
SL.A.2	-7,04%	-3,62%	0,30%	-2,94%	-3,92%
SL.A.4	-4,94%	-5,98%	0,08%	-2,57%	-3,56%
SL.B.1	-2,09%	0,29%	2,73%	-2,57%	-3,56%
SL.B.2	0,03%	0,05%	0,02%	0,00%	0,00%
SL.B.3	-1,21%	-1,08%	-1,70%	-1,03%	-1,12%
SU.B.7	-0,54%	-1,64%	0,56%	0,93%	-3,56%
SU.B.8	-7,54%	-2,73%	-0,02%	-4,29%	-3,56%
SL.B.11	0,58%	0,69%	0,72%	0,00%	0,00%
SL.B.12	-0,05%	-0,03%	-0,19%	0,00%	0,00%
SL.B.13	0,16%	0,33%	0,50%	0,26%	0,35%
SL.B.14	-0,08%	-0,08%	-0,14%	0,07%	-0,56%

Figure 3. Matrices of percentage variation for multi-risk vectors, for strategies (for code) analysed by simulation. The colour gradient goes from the least effective solution (red) to the most effective solution (deep green), calibrating the scale with respect to all solutions and all BETs.

Based on the simulation results showed in Figure 1, Figure 2 and Figure 3, has been developed a scoring method for implementing the simulation results with the qualitative analysis discussed in Section 2.1. In particular, this study defines three distinct categories based on the following values. Assigning a value of 1 considers a stable multi-risk vector or a moderate increase in risk. A slight decrease in the level of multi-risk expressed by the vector (within the limit of the 75th percentile between the solutions, i.e. about 1%) is assigned a value of 2. Finally, if the multi-risk level is significantly decreased (with a change beyond the 75th percentile limit), the value 3 is assigned. The impacts of the simulated mitigation strategies for each BET are summarised in Table 6, according to the scoring methodology just defined.

Table 6. Quantitative analysis of the effectiveness of the strategies (per code) from a multi-risk perspective: representation in classes of multi-risk reduction compared to the percentage change values in Figure 6, from lowest (1) to highest (3) reduction class.

	1A	2A	3	4A	5
SL.A.1	3	3	3	3	3
SL.A.2	3	2	1	3	3
SL.A.4	2	3	1	2	3
SL.B.1	2	1	1	2	3
SL.B.2	1	1	1	2	1
SL.B.3	2	2	3	2	2
SU.B.7	2	2	1	1	2
SU.B.8	3	2	1	3	3
SL.B.11	1	1	1	2	1
SL.B.12	1	1	2	2	1
SL.B.13	1	1	1	1	1
SL.B.14	1	1	2	1	2

3. Selection of best mitigation strategies for SLODs, SUODs and in combination

From the assessment made in Section 2 it is possible to establish the most suitable mitigation measure to be implemented in BETs.

Based on the qualitative analysis and on the simulation results, tables below summarise the total score achieved by each simulated strategy summing up the two validation methods, for global best strategies and for single BET best strategies.

Table 7. Global best strategies through combined analysis of Implementation level, Potential impact and Simulation results based on the analysis in Table 6. Final column shows the total score as sum of other columns.

Code	Strategy	Implementation level	Potential impact	Simulation	Total score
SL.A.1	Trees	3	15	15	33
SL.A.2	Shrubs and hedges	3	11	12	26
SL.A.4	Seasonal shadings	2	6	11	19
SL.B.1	Urban surface and roughness/*cool pavement*	1	9	9	19
SL.B.2	Permeable pavers	2	10	6	18
SL.B.3	Permeable green pavers	2	14	11	27
SU.B.7	Install evacuation instruction signs	3	13	8	24
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	3	13	12	28

SL.B.11	Cool facade	1	11	6	18
SL.B.12	Refflective roof/*cool roof*	2	10	7	19
SL.B.13	Green facade	1	12	5	6
SL.B.14	Green roof	2	14	7	9

Table 8. Best strategies for single BET. The column of single BET shows the total score defined through the combination of Implementation level, Potential impact and single Simulation results from the analysis in Table 6.

Code	Strategy	Total score for single BET				
		1A	2A	3	4A	5
SL.A.1	Trees	21	21	21	21	21
SL.A.2	Shrubs and hedges	17	16	15	17	17
SL.A.4	Seasonal shadings	10	11	9	10	11
SL.B.1	Urban surface and roughness/*cool pavement*	12	11	11	12	13
SL.B.2	Permeable pavers	13	13	13	14	13
SL.B.3	Permeable green pavers	18	18	19	18	18
SU.B.7	Install evacuation instruction signs	18	18	17	17	18
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	19	18	17	19	19
SL.B.11	Cool facade	13	13	13	14	13
SL.B.12	Refflective roof/*cool roof*	13	13	14	14	13
SL.B.13	Green facade	14	14	14	14	14
SL.B.14	Green roof	17	17	18	17	18

The last column of Table 7 presents the total score obtained as the sum of Implementation level, Potential Impact and Simulation scores. Table 8, in contrast, shows the best strategies for each BET in absolute values by adding up the outcomes of each strategy for the specific BETs. In Table 7 and Table 8, the strategies with the highest sum have the potential to be the most effective. These tables respectively highlight the best strategies at a global level (regardless of the BET being employed) and at the level of the individual BET. Typically, the best strategies include the implementation of green infrastructures. In this regard, the outcomes concur with the partial simulation findings (refer to Figure 3 and Table 6), connecting the optimal resolutions with those related to tree implementation, and secondarily, with fixed or mobile barriers and obstacles when integrated with green elements. Table 9 presents and orders the mitigation strategies from most effective to least effective in general and for each BET considered according to the scores obtained from the combination of the qualitative and quantitative analyses presented in Tables Table 7 and Table 8.

Table 9. Summary of mitigation strategies ordered from most effective (best strategies) to least effective.

Global best strategies		Best strategies for single BETs									
		1A		2A		3A		4A		5	
SL.A.1	33	SL.A.1	21	SL.A.1	21	SL.A.1	21	SL.A.1	21	SL.A.1	21
SU.B.8	28	SU.B.8	19	SL.B.3	18	SL.B.3	19	SU.B.8	19	SU.B.8	19
SL.B.3	27	SU.B.7	18	SU.B.7	18	SL.B.14	18	SL.B.3	18	SL.B.3	18
SL.A.2	26	SL.B.3	18	SU.B.8	18	SU.B.7	17	SL.A.2	17	SU.B.7	18
SU.B.7	24	SL.B.14	17	SL.B.14	17	SU.B.8	17	SU.B.7	17	SL.B.14	18
SL.B.14	23	SL.A.2	17	SL.A.2	16	SL.A.2	15	SL.B.14	17	SL.A.2	17
SL.A.4	19	SL.B.13	14	SL.B.13	14	SL.B.12	14	SL.B.2	14	SL.B.13	14
SL.B.1	19	SL.B.2	13	SL.B.2	13	SL.B.13	14	SL.B.11	14	SL.B.1	13
SL.B.12	19	SL.B.12	13	SL.B.11	13	SL.B.2	13	SL.B.12	14	SL.B.2	13

SL.B.2	18	SL.B.11	13	SL.B.12	13	SL.B.11	13	SL.B.13	14	SL.B.11	13
SL.B.11	18	SL.B.1	12	SL.A.4	11	SL.B.1	11	SL.B.1	12	SL.B.12	13
SL.B.13	18	SL.A.4	10	SL.B.1	11	SL.A.4	9	SL.A.4	10	SL.A.4	11

However, it is worth noting that determining the best strategies for BET offers more comprehensive and relevant information to the BE. Such information can serve as a model of good practice that planners can emulate, since it helps to estimate the effects (from the simulation) related to the typological characteristics of the outdoor built environment under study. In this way, it is feasible to establish a basic hierarchical arrangement of the best strategies in common situations. Afterward, these solutions can be put into practice in realistic scenarios that come close to simulated ones.

4. Conclusions and remarks

The aim of this paper is to provide an overview of the most common mitigation measures for both SLODs and SUODs in BE. The classification of mitigation measures is complex because each specific effect is influenced by a number of factors which together define the best strategies. Firstly, there is a significant difference in the impact of the same strategy for SLODs and SUODs. In the first case, the physical properties of the strategies are very important, i.e. their capacity to "absorb" heat or polluting particles, and this is a characteristic linked above all to the type of intervention; in fact, the most effective strategies for SLODs are all those that provide for the use of green materials or the use of materials that have the same effects due to their composition and nature (SL.B.1, SL.B.2, SL.B.11, SL.B.12). On the other hand, it is very important for SUODs to make the space more functional, so that evacuation processes are intuitive and easy. This aspect is closely linked to the nature of SUODs, which are sudden events in which a very important and difficult to predict aspect comes into play, namely people's behaviour.

Trying to simplify the space is crucial in order to limit the possibility of users making wrong choices in a moment of panic, which could potentially cost them their lives. A.3, SU. Therefore, the most effective strategies for Safety Use Occupancy Devices (SUODs) involve not only strictly behavioural techniques (SU. B.7), but also those that divide and organise the space (SL. B.8), which encourage the use of green elements (such as planters).

Flexibility regarding the elements employed to counter SUODs led to the emergence of "green" strategies, notably the planting of new trees (SL. A.1), green pavements (SL. B.3) and hedges (SL. A.2). These strategies were identified as the best from a multi-risk perspective. In particular, trees (SL. A.1) emerge as the most effective strategies both in general and for individual BETs, owing to their adaptability and diversity. Altering the quantity, type, and dimensions of trees makes this strategy effortlessly adjustable to any spatial configuration.

Finally, from a multirisk perspective, the BETs application points out that trees (SL.A.1) is always the best strategy, in view of the SLOD mitigation but also to the effects on initial users' distribution in SUODs (limiting negative interactions in the evacuation process). Nevertheless, although their implementation level and potential impact is good, the application of trees could be not allowed in specific contexts, e.g. historical ones, due to preservation issues. Then, the introduction of obstacles and urban furniture in the open space can be an effective solution (SU.B.8) in case they are integrated with greeneries, since they can collect users' evacuation flows and limit direct effects of SUODs in terrorist acts risks, does not generally imply an increase of risk for earthquake, and can (limitedly) contribute to the increase of both SLODs conditions. In this sense, SU.B.8 is very interesting for the implementation level too, since it can require limited interactions with the BE, and could be easily implemented also in historical scenarios.

The results obtained can serve as a starting point and guide to improve the built environment (BE). Nonetheless, it is crucial to test these strategies on specific case studies to verify their applicability and feasibility, considering landscape and other constraints. It is also vital to validate if there is actual adherence between the research results of this chapter (that feed into inventories of generalised best strategies) and the investigation outcomes linked to non-ideal built environments characteristics. Such issues will be faced in the case study applications, i.e. D6.2.3.

5. References

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